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SO MANY STANDARDS, SO LITTLE TIME:
A HISTORY AND ANALYSIS OF FOUR DIGITAL VIDEO STANDARDS

BY

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DISSERTATION

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ABSTRACT

This dissertation focuses on standards for digital video - the social aspects of their design and the sociotechnical forces that drive their development and adoption. This work is a history and analysis of how the MXF, JPEG 2000, FFV1 and Matroska standards have been adopted and/or adapted by libraries and archives of different sizes. Well-funded institutions often have the resources to develop tailor-made specifications for the digitization of their analog video objects. Digital video standards and specifications of this kind are often derived from the needs of the cinema production and television broadcast realms in the United States and may be unsuitable for smaller memory institutions that are resource-poor and/or lack staff with the knowledge to implement these technologies. This research seeks to provide insight into how moving image preservation professionals work with - and sometimes against - broadcast and film production industries in order to produce and/or implement standards governing video formats and encodings. This dissertation describes the transition of four digital video standards from niches to widespread use in libraries and archives. It also examines the effects these standards produce on cultural heritage video preservation by interviewing people who implement the standards as well as people who develop them.

For Karin

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

There are no universally agreed-upon evergreen target video standards for high-quality

video digitization. Professionals in memory institutions often have difficulty deciding which

digital format(s) will best serve to capture the information encoded on their decaying analog

video materials. This dissertation explores the development cultures for digital video standards

and their adoption in libraries and archives. This work contributes to larger conversations about

how the video digitization and preservation realm develops, adopts and adapts encoding and

file container standards. Understanding how and why digital video standards are developed and

adopted can help to fill a gap in audiovisual preservation research and will be an important part

of the race to digitize analog video materials that are susceptible to loss because of the physical

degradation of their carriers and the obsolescence of their playback technology.

This dissertation focuses on standards for digital moving image encodings and containers - the

social aspects of their design, the technical choices that drive their development and the

decision-making processes of large and small cultural heritage repositories when picking an

encoding/container combination for digitizing their legacy video materials. It is a history, but it

is also an analysis of the sociotechnical factors that allowed for the movement of four digital

video standards from niches in television broadcast, cinema production and online piracy into

widespread adoption in libraries and archives. This research contributes to our understanding

of how audiovisual standards are developed, how they work and how they are implemented in

the library/archives world. My work also contributes to a growing body of work related to video

digitization in the world of cultural heritage. My work makes these contributions by providing a history of four twenty-first century video standards in the words of the people who developed and/or are using them.

The differences in design and adoption between open-source and proprietary moving image encodings and multimedia containers offer rich grounds for exploration and inquiry. This dissertation seeks to provide insight into how moving image preservation professionals work with - and sometimes against - broadcast and film production paradigms in order to produce standards governing video digitization in the memory realm. This work is also an examination of some of the effects of the standards they produce on cultural heritage video preservation.

This dissertation comes at a time when there is a seismic shift in video digitization and preservation. This shift is characterized by a growing preference among preservation professionals for open-source tools and standards that do not come directly from the broadcast and cinema realms. When I worked for the Library of Congress from early 2010 to late 2012, the Library was at the forefront of development of video digitization best practices, using film and television industry standards like MXF (the Material eXchange Format) and JPEG 2000. (The latter is not explicitly a cinema or industry developed standard, but it has found broad adoption in those realms since 2010.) In fact, the Library's specification for using MXF and JPEG 2000 in their video digitization work - a document once called AS-AP, for Application Specification for Archiving and Preservation - is my model for industry-influenced standards development in my research. AS-AP is now, since at least 2016, referred to as AS-07 by the Library of Congress.[1]

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[1] http://www.digitizationguidelines.gov/guidelines/MXF_app_spec.html. Accessed on April 5, 2019.

In my time at the Library of Congress I found that many smaller institutions were looking to the Library for input on which standards they should adopt. In the years since I left the Library, more institutions, large and small, have been adopting and adapting open-source standards - standards that are, for the most part, unfettered by industry participation - for their work. This preference for open-source technologies has grown significantly since I started this research in 2014 and continues unabated. A major force in this shift has been the standardization of FFV1, a high-quality losslessly compressed video encoding, and Matroska, a multimedia file format, by a working group within the Internet Engineering Task Force, or IETF. This working group is an example of open-source standards development and adaptation.

This dissertation is largely driven by interviews with people who implement these industry-adopted and/or open-source standards as well as some of the people who have developed them. In this way my work contributes to the larger, ongoing conversation about which digital encodings and containers are most suitable for high quality video digitization in different contexts. It also serves as a report on this shift in preference from industry to open-source technologies in the video preservation realm in the United States and parts of Europe.

1.2 STATEMENT OF PROBLEM

A key constraint in the preservation of analog video recordings is time, or the lack of it. Videotape degrades rapidly, playback machines break down and no analog video players are currently being supported by their developers, meaning these formats have become obsolete. As one luminary in the audiovisual preservation realm put it, "analog magnetic recordings are the poster children for the problems of format volatility" (Fleischhauer, 2003, page 96). A

commonly-cited figure for the viable lifespan of analog videotape is around fifteen to twenty

years from now (Casey, 2015). The only uncertainty in video preservation is not *if* irreplaceable

moving image recordings will be lost but *how many* will be lost. The only means by which the

information encoded on these vulnerable tapes can be preserved long-term is by digitization -

the creation of digital video surrogates for the analog originals. Preservationists must choose

from a wealth of standards for the encodings and file formats that form the digital objects they

create through their digitization workflows.

Much of the development of standards for master-quality moving image encodings and

containers in the United States and Europe is driven by Hollywood and the American and British

broadcast industries. In recent years, the Library of Congress has chosen MXF (a container

format developed by the Society of Motion Picture and Television Engineers) and JPEG 2000 (or

J2K - a losslessly-compressed image encoding) for the digitization of their video materials.[2]

(Lossless compression refers to any encoding scheme that allows a digital file to be made

smaller in size with no permanent loss of quality.[3]) Many other national-level cultural heritage

institutions - nonprofit and for-profit - have begun implementing this combination for use as

preservation master files.

Large institutions like the Library of Congress often have enough influence and funding

to work with big industries and standards-making bodies to develop tailor-made specifications

for their digitization work. The Library's AS-07 document, while appropriate for larger

institutions, is often unsuitable for smaller repositories (universities, colleges, local heritage

institutions and so on) because the technical complexity inherent in MXF and J2K files and the

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[2] http://www.digitizationguidelines.gov/guidelines/MXF_app_spec.html. Accessed on January 8, 2019.
[3] https://techterms.com/definition/lossless. Accessed on May 20, 2019.

hardware and software needed to produce them lead to high costs of implementation. For this reason, conformance to this specification is effectively out of the reach of many memory institutions. This lack of access is, in fact, one of the chief reasons for the IETF working group's efforts with respect to Matroska and FFV1. The divide between those who can implement AS-07 in their digitization initiatives versus those who cannot afford it can be seen as a disparity of access and of power.

The Library of Congress' work on their standard relies heavily on input from the Advanced Media Workflow Association, or AMWA, a standards-making body comprised mostly of American television broadcast professionals.[4] The Society of Motion Picture and Television Engineers (SMPTE), a body mostly made up of American film industry professionals, developed the MXF container.[5] Since the interests of the American television broadcast and Hollywood industries are so woven into the Library of Congress' work on their video digitization standard, it is reasonable to believe that decoding, encoding, transcoding and playback tools will be plentiful for the foreseeable future for this encoding/format combination.[6] The sustainability of the video materials in smaller, more modestly funded institutions is harder to predict. Will their materials be as sustainable over the long term as those produced at larger institutions with broad resources like the Library of Congress? Smaller institutions likely cannot direct the amounts of staffing, technology, budgets or technical knowledge of a Library of Congress to the long-term stewardship of their time-based content. Some smaller memory institutions have been looking at alternatives to MXF and/or JPEG 2000 but there has been a widespread and

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[4] http://www.amwa.tv/about.shtml. Accessed on January 8, 2019.
[5] https://www.smpte.org/. Accessed on January 8, 2019.
[6] For ease of sentence construction I have used the term "American" to refer to the United States throughout this dissertation unless otherwise noted.

entrenched belief in the world of audiovisual preservation that, because the Library of Congress

has shown preference for MXF/J2K, this is the best approach for all memory institutions,

regardless of their size and profile.[7] I believe that this perception may be slowing the adoption

of open-source video-digitization technologies in much of the library/archives world. More

importantly, it is slowing the digitization of video in many memory institutions because they are

either unable to perform high-quality digitization in-house or they are taking a 'wait and see'

attitude towards the emergence of a well-adopted standard. The fragility of analog video

carriers, coupled with the slow adoption of digitization standards, could mean that a great deal

of moving image content is irretrievably lost as the profession decides on what, if any,

'evergreen' video digitization standards emerge. It is not hyperbole to assert that the clock is

ever-more-rapidly ticking with respect to the viable lifespans of analog video objects.

1.3 THE CHANGING LANDSCAPE OF AUDIOVISUAL PRESERVATION

Since 2015, there has been an effort to create a completely open-source video

digitization standard for cultural memory institutions using the Matroska container and the

experimental new FFV1 lossless video encoding. This initiative evolved out of the PREFORMA

(PREservation FORMAts for culture information/e-archives) open source software project.[8] The

standardization is taking place under the auspices of the Internet Engineering Task Force. The

working group within the IETF that is tasked with developing this specification is called CELLAR

(Codec Encoding for LossLess Archiving and Realtime Transmission) and, according to the

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[7] In 2011, I put together a proposal for a presentation about FFV1, Matroska and other 'alternative' encodings for preservation at the annual conference of the Association of Moving Image Archivists. The proposal was declined because, according to one reviewer, "everyone is going to be using the Library of Congress' specification."
[8] http://www.preforma-project.eu/mediaconch.html. Accessed on January 8, 2019.

website for their email communication list, the group's purpose is to "work to formalize

specifications of the Matroska media container, FFV1 codec, and FLAC codec, based on existing

work from the respective communities."[9] The goal of this group is the development of

standards for high-quality, losslessly-compressed video digitization that produces files of similar

quality to the Library of Congress' MXF/J2K specification but without the same kinds of industry

influence and the high costs of implementation of AS-07. My research is driven by interviews

with people involved in developing and/or adopting MXF, JPEG 2000 (as manifested, in some

cases, as AS-07), Matroska and FFV1.

The Library of Congress has a strong relationship with the American broadcast industry

and, in fact, a great deal of the material being digitized by the Library to the AS-07 specification

comes from American television as well as the Hollywood cinema production realm. The Library

collects a great deal of American broadcast television, which is comprised of signals that include

more than just moving picture information. One of the reasons the Library chose the MXF

container is because of its ability to contain closed captioning information along with video and

audio essences. A chief purpose of the AS-07 specification is to ensure the uniformity of

outputs from the Library of Congress' video digitization workflow. Another important purpose

of AS-07 is to describe the Library's video files with enough precision that vendors can develop

hardware and software that can create and decode those files. AS-07 acts as a standard for

interchange between these technologies. The CELLAR project also holds the interoperability of

files and software as one of the goals for its standards. Much of the Library of Congress' work

on AS-07 happened in face-to-face meetings with engineers at the Library's Packard Campus of

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[9] https://www.ietf.org/mailman/listinfo/cellar. Accessed on January 8, 2019.

the National Audio-Visual Conservation Center and in meetings of the Federal Agencies

Digitization Guidelines Initiative's Audio-Visual Working Group. Because much of the work in

developing the Matroska/FFV1 standard happens over the Internet via synchronous online

meetings, message boards and email lists, my research involved some participation in and

monitoring of these communications channels.

One example of standards development in the audiovisual preservation realm is the

MXF file container. American television broadcasters developed the MXF format in the 1990s

during the early stages of the transition from physical-media-based to digital-file-based

production workflows. These engineers realized that losing assets from poor asset management

practices becomes much easier in the file-based realm. For this reason, they developed MXF in

order to package digital assets with metadata to make them findable and self-describing. The

Library of Congress, in the mid-2000s, determined MXF to be a suitable container for their

digital assets as well, and for similar reasons (FADGI, 2010). Following the model of social

informatics, the present work looks at what factors - beyond the standards' technical

affordances - guided the Library's adoption, implementation and adaptation of the MXF

specification. It also looks at what factors have led to adoption of Matroska and FFV1 in other

institutions.

Over the past few years the Library of Congress has heavily promoted its specification

for the use of MXF and JPEG 2000 for their video digitization. Other memory institutions around

the world have closely watched the Library's work on this specification to see if it can be

adapted to their own needs. The implementation and spread of technologies like standards can

be very heavily influenced by the amount and kinds of resources that different actors can bring

to bear upon their promotion. For example, the Library of Congress has a larger voice in the audiovisual preservation profession than the City of Vancouver Archives does. In studying the audiovisual standards for MXF/J2K and Matroska/FFV1, I found it necessary to consider what these specifications mean to different users. I found that there are group identities forming around the choice of the Library's specification and the CELLAR standards. There are users who have chosen MXF and/or JPEG 2000 in order to align with Hollywood and television broadcasters - this is clearly one of the reasons for the Library of Congress' AS-07 document. There are also users who have decided *not* to use AS-07 because of its strong links to these industries. There are many users of the CELLAR standards who have decided to consciously align their institutions with the open-source community instead of the proprietary standards developers for pragmatic as well as idealistic reasons. While many CELLAR standards adopters and contributors are not just looking for low-cost solutions that work for them, they are also contributing to a zeitgeist in the preservation realm that is characterized by an increase in the adoption of free open-source tools developed by and for memory professionals. As this dissertation will explore, this paradigm shift has included a feeling of increased agency among many of these professionals as they no longer feel beholden to closed/proprietary "hand me down" standards and technologies derived from the cinema and broadcast realms.

CHAPTER 2: LITERATURE REVIEW

This section discusses the theoretical perspectives that guide this research. It also gives an overview of some of the major historical and theoretical works related to the preservation of analog and digital time-based media. This literature review describes the larger issues in the information science realm with which this dissertation is in dialogue.

2.1 SOCIAL INFORMATICS

My work falls under the subset of information sciences known as social informatics because it explores the social factors that lead to the development and adoption of video standards. MXF, JPEG 2000, FFV1 and Matroska have all found places in libraries and archives for reasons beyond their technical affordances. They have moved from their niches into libraries and archives at least partially because of social factors like the influence of their developers and users as well as the ideological stances of their adopters. Social informatics (SI) is a discipline that analyzes the social aspects and effects of computerization (Kling, 2007). Social informatics draws liberally from computer science, sociology and human-computer interaction (HCI). Where HCI tends to study how people interact with computers at the individual, psychological level, social informatics tends to focus on how computerization works on the organizational or cultural level (Bishop and Star, 1996). Another focus for SI is on how information communication technologies develop and change over time, how they affect the people who use them and how these technologies, in turn, are affected by those users.

A chief emphasis of SI scholarship is to challenge the notion of technological

determinism and to show that it has little analytical utility in terms of understanding how

technologies evolve and how societies respond to them (Kling, 2007). Determinism is the view,

shared by much of popular tech media like *Wired* magazine, that technologies influence

societies more than societies influence them and that technologies have enough agency to

change the society around them. Technologically deterministic models usually assume that

users are rational actors who tend to make the most informed decisions about which

technologies to adopt (Meyer, 2014). Deterministic arguments give very little insight into why

people adopt technologies because these arguments tend to presume that technologies evolve

following their own logic, irrespective of how users adapt them (MacKenzie and Wajcman,

1999). SI perspectives question that assumption and work to expose the cultural, ethical,

political, racial, social, gender and economic forces that also influence the adoption and

development of technologies. Choices of technologies can be constrained by any of these

factors, which can make the very idea of 'rational actors' analytically invalid. SI views

technologies as networks in themselves, with internal dynamics and dependencies on the

environments around them even though they may look and act like black boxes (Kling, 2000).

Social informatics scholars tend to argue that technologies and the cultures that they influence

both work, sometimes in concert and sometimes not, to co-evolve. In other words, developers,

users and technologies all influence each other. Social informatics does not just look at how

people have changed computers. It also looks at how computers change people.

Social informatics scholars have studied the dramatic technological changes related to

information communication technologies for a couple of decades. One technological

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development studied by SI is the rapid influx of desktop computers into office workplaces in the late twentieth century. The standard deterministic view of the time was that increased access to computerized processing power would make workers much more efficient. SI researchers, among others, found that in many cases the reverse was true - that continual software and hardware upgrades, changes and their related learning curves increased worker stress, consumed a great deal of work time and created the 'productivity paradox' of decreased worker output as computer use increased (Bishop and Star). In his analysis of the rise of the World Wide Web in the United States in the 1990s, Rob Kling dispelled similar deterministic claims about the liberating effects of the 'information superhighway' by showing that there were still many households unable to easily access the Internet (Kling, 2000). This 'digital divide,' which remains a problem today, shows that there are economic, race, social and gender factors which trouble the notion that the Internet tide raises all boats.

Another important tenet of social informatics is the idea that the 'best' technologies do not always survive in the marketplace. In fact, there can be considerable disagreement over what a 'best' technology is and who defines what is best. Concepts such as 'best' are often negotiated over time by various actors - such as developers, users and salespeople - related to the technologies and are highly affected by power dynamics and influence. Social informatics can give windows into these dynamics and how they influence the design of information technologies.

2.2 TECHNOLOGIES, POLITICS AND THE SOCIAL CONSTRUCTION OF TECHNOLOGY

One theoretical perspective within SI is the Social Construction Of Technology, or SCOT, which studies the developmental processes that cause technologies to morph and evolve over time as their developers and users interact with them. Applying a SCOT lens to information technologies shows their development from an evolutionary perspective, as a result of variation and selection and not as a smooth, orderly progression (Pinch and Bijker). SCOT is particularly effective at showing how the 'best' technologies (from their designers' perspectives) do not always win out in the marketplace or in the workplace. Because SCOT (and SI broadly) focuses not just on technologies themselves but also on the social and economic factors influencing their development and adoption, this analytical perspective can show why some technologies fail and why others succeed beyond a simple economic ('this technology was cheaper') or technocentric ('this technology was technically superior') perspective. In one example of a SCOT analysis, Wiebe Bijker and Trevor Pinch analyze the history and evolution of the bicycle from the large, ungainly 'penny-farthing' design to the smaller, geared design seen today (Ibid.). Their analysis does not just focus on the functionality of the bicycle designs themselves but also on the social milieus of the time that fueled the adoption of the more modern bike. One of these factors, for example, is the perception of the newer design as being more fitting for women, who were expected to be modest while cycling in skirts. In this case the Victorian framing of gender was a direct influence on how the modern bicycle was marketed and adopted. SCOT analyses take a constructivist approach and argue that human interactions shape technology over time.

Some sub-disciplines of SI, like SCOT, posit that technologies have interpretive flexibility - that the meanings of technologies can be quite different for different people and that those differences can be strongly influenced by social factors. These meanings can change as technologies move from niches into ubiquity. In the words of Audley Genus and Anne-Marie Cole, "niches can act as spaces for experimentation protected from market selection pressures, or to enable social networks supporting radical innovations to be built up" (Genus and Coles, 2008, page 1438). Jonathan Sterne draws from SCOT theories in his studies of the MP3 and how its meaning changed over time for different users (Sterne, 2012). The MP3 was designed largely by corporate interests to encode audio tracks for digitized films. However, with the rise of file sharing sites like Napster, the format moved from niche to regime because of piracy - arguably a regime that is at odds with the corporate/capitalist realm (Denegri-Knott, 2004).

Langdon Winner argued that technologies do not enter the world as neutral, apolitical objects. They are, instead, encoded with the biases, beliefs and politics of the people who create them (Winner, 1980). Winner gives as one controversial example of this phenomenon the overpasses designed by Robert Moses in New York City in the twentieth century. According to Winner, Moses designed many overpasses in that city to be tall enough to permit cars to pass under them while being low enough to prohibit the passage of buses. At the time buses in New York City were used mostly by the poor and by people of color - two often-overlapping populations in the United States that historically had minimal access to certain parts of the city. To Winner, this design was encoded with racism because it effectively prohibited the passage of these populations into the more affluent, white parts of the city. Winner's example depicts the apparently neutral technology of the overpass as, in actuality, containing a very particular bias

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and a very particular vision of what parts of New York should look like. In this way these overpasses are a technology that replicates a social order while also influencing it.

Technologies change the contexts in which they are embedded, but they are not infinitely malleable. Technologies enter social and political regimes loaded with their designers' assumptions about users and situations (Akrich, 1992). In fact, designers of technologies tend to envision a particular kind of user and encode that vision into the final product (Woolgar, 1990). Because of these presumptions, there is often a narrow array of contexts in which technologies can be made to work. Langdon Winner argues that there are often very limited political and social arrangements in which technologies can successfully function (Winner). He gives as an example the atomic bomb, a technology that by its design requires certain clearly delineated hierarchies and bureaucratic systems for it to function as a weapon, deterrent and a tool of empire. Jonathan Sterne argues that the lack of strong copyright protection in the MP3 specification reflects the MPEG's vision of consumers using the MP3 not for encoding and sharing music widely in the online environment but for more passively consuming physical media that they purchased in brick-and-mortar stores (Sterne).

In many cases it is possible to perform a kind of deconstructive reverse engineering on technologies in order to peer into the cultures and politics of the people who developed them. Technologies do not just describe their creators. They also come loaded with expectations about how their users will interact with these artifacts and what constraints and liberties users will be afforded in these interactions.

2.3 STANDARDS AND VIDEO DIGITIZATION

The term 'standard,' as Kai Jakobs says, can be devilishly hard to define. Jakobs writes that while there is no universally-accepted definition of what a standard *is*, there are two important elements that standards tend to *share*: they are each designed by some kind of recognized body and they are usually established by consensus (Jakobs, 2003). Carl Cargill, writing about standards from a business/economics perspective, says that one of the key goals to standards development is to help create a market wherein a standard solution is preferable to nonstandard solutions (Cargill, 1989). In other words, standards tend to be developed with the goal of insinuating themselves into existing markets or completely changing them in favor of those standards.

One of the things that make standards so powerful is their ability to travel through time and space. This is, in fact, one of the goals of digital file standards - to allow users to conform their files in such a way to ensure that playback hardware and software will decode them. John Law refers to standards as one kind of 'immutable mobile,' or a technological actor that can transcend spatial and temporal limits (Law, 1992). Standards are, of course, a kind of encoded power in themselves - they say, essentially, that *this thing* can only be considered *this kind of thing* if it adheres to this specification. Cargill notes that standards are usually compromises made by a community in order to serve various needs, biases and power relationships. In looking at standards designed to be free and open versus those designed to be closed and/or proprietary, making these needs, biases and power visible is critical to understanding the adoption and success/failure of these standards.

Standardization can be seen as "a process of constructing uniformities across time and space, through the generation of agreed-upon rules" (Timmermans and Epstein, 2010, page 71). These 'uniformities' can be critical for the smooth, error-free exchange of data between users and systems. Information communications technologies usually work best when they are defined by standards because this helps to ensure their interoperability (de Vries, 2003). Standards are usually designed to allow for some kind of interchange between other technologies. These standards are, therefore, considered *coordinative* standards because "frequently aim at interoperability and compatibility of technology with the effect that transaction costs are reduced and positive externalities are generated." (Werle, 2001, page 8).

There is a 'sweet spot' in standards development wherein enough actors are enrolled in the process to develop a highly interoperable standard but not so many actors are involved that the standard fails to achieve closure and stability (Hanseth, et al., 2006). Sterne's work on the MP3 is very illustrative here as well. Sterne describes the culture of the MPEG (the Motion Picture Experts Group - the standards-making body that developed the MP3) as one of mostly for-profit organizations working together (and, at times, at cross purposes) in order to anticipate the transition to digital moving image distribution (Sterne). The MP3 is a standard that is used in broadcast, home consumption and information technology. Therefore, unsurprisingly, broadcast, IT and electronics companies were all involved in its development and they inscribed their (occasionally competing) values into the format by making it a highly efficient computer format specification that can encode audio at moderate quality and low file size. Many digital standards draw upon all of these disciplines to describe digital video

encodings and containers. In the words of Dylan Mulvin and Jonathan Sterne, working backwards from a published standard by interrogating its limits "can uncover the epistemic and aesthetic politics of the engineering imaginary" (Mulvin and Sterne, 2016, page 24).

2.4 THE POLITICAL ECONOMY OF MOVING IMAGE PRESERVATION

In the early twentieth century, motion picture film preservation in the United States was mostly a state-funded endeavor that was later tied to copyright submission. Caroline Frick argues that because Hollywood productions featured prominently in this early film preservation milieu, the American film preservation endeavor has, over the course of the twentieth century, established the narrative that these privately produced motion pictures are synonymous with American film heritage (Frick, 2011). This narrative continues to be promulgated by the Library of Congress because the Library focuses much of its resources on the preservation of Hollywood and American broadcast television productions.

For more than a century, photochemical film production, exhibition and preservation was critical to American moving image heritage. Today, image capture has roundly shifted from the photochemical to the digital. Traditional motion picture preservation workflows and best practices focused on the physical object - the film or videotape - stored in stable climates on shelves. The change from chemical to digital image capture has brought with it a deluge of digital moving image recordings, afforded by the cheaper costs of video production (Van House and Churchill, 2008). Benign neglect - the passive preservation of physical carriers by stabilizing storage climates and containers over time - is a model that is insufficient for the needs of the file-based, digital environment. Proactive digital asset management is critical because files can

be very easily lost due to technological failures like hard drive crashes or user error like accidental erasure of data. Today's motion picture film workflows look radically different from the analog world: file management, metadata harvest and generation, fixity checking, migrating formats and encodings - the trappings of the digital IT infrastructures that dominate production and preservation of the twenty-first century moving image. In order to preserve digital material, modern archives have become very high-tech environments (Holdsworth, 2008). Moving image archivists must transition from being stewards of physical objects to maintaining digital objects and the infrastructures in which they are embedded (Gracy, 2007). This technological change has caused the moving image preservation realm to radically reformulate what preservation means. Furthermore, the profession has had to redefine the work and the identity of the moving image archivist as well.

One of the earliest book-length discussions of moving image preservation in the United States focused on the sociotechnical milieu of the photochemical. Anthony Slide's *Nitrate Won't Wait* was a landmark book about the dangers of the benign neglect of motion picture film, particularly the earliest cellulose nitrate films (Slide, 1992). Slide's work was an important step toward opening up the world of film preservation to a wider audience. While photochemical film preservation is still very important, the needs of analog videotape must be addressed because of its fragility and the growing obsolescence of video formats and playback equipment. For this reason, digitization has become the accepted long-term preservation strategy for this kind of material, which has further propelled the shift from the analog to the digital in the moving image preservation realm (Wright, 2012). Concepts of fidelity to the

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analog originals and of what constitutes high quality with respect to the digital surrogates have become central to the modern, file-based digital moving image preservation realm.

Most of the professional and academic discussion of moving image preservation focuses on the technologies involved in the transition from the analog to the digital. For example, in the past decade the major Hollywood film production studios have invested considerable resources in studying the effects of the transition from the photochemical to the digital on their industry (The Science and Technology Council of the Academy of Motion Picture Arts and Sciences, 2007). One of the key findings of this report is that as costs of digital production and post-production continue to drop, the need for digital file management becomes ever more critical. This finding is echoed by a recent report, funded by the Library of Congress, called *Preserving Digital Public Television Final Report* (Rubin, 2010). This report emphasizes the need for standardized digital video wrappers (like MXF) that encapsulate metadata along with video and audio information and that encourage ease of exchange and preservation of video files. This report had considerable influence from the departments in the Library of Congress that were working on AS-07.

There are, as yet, very few scholarly works about the effects of the transition from the analog to the digital on the *meanings* of preservation, quality and sustainability in the moving image realm. In the photochemical preservation world, the concept of sustainability hinged on the preservation of the physical object - the plastic/emulsion film object in a can on a shelf. Much of the work of moving image preservation professionals and developers of related standards, software and hardware depends upon an ongoing negotiation of just what quality and sustainability mean in the file-based audiovisual realm. In my nearly two decades in the

audiovisual production and preservation world, I have seen these conversations play out more in professional email lists and conferences than in academic journals or book-length treatises. These conversations often consist of ongoing series of attempts by archivists, librarians, production professionals and engineers to enroll each other in different notions of quality and sustainability with respect to the moving image. These notions often overlap but they can also be in conflict with one another.

One important work about the transition from celluloid to digital is Giovanna Fossati's work on the transition in the early twentieth century from traditional film preservation workflows to the file-based, digital environment (Fossati, 2009). In this book Fossati discusses how this ongoing technological change affects how film archivists see themselves, their work and the meaning of the moving image broadly. There is, as yet, no similar book-length discussion of the transition from analog to digital *video* preservation, although Jonathan Sterne is working on a book that may be applying his format theory lens to modern video technology.[10]

Technological shifts such as the transition from analog to digital image capture have largely been driven by the American cinema and broadcast production industries. These shifts can manifest as new tools for the creation and playback of moving image materials. These tools must be adopted by libraries and archives in order for them to do the work of preserving moving image media. In the case of photochemical film and analog video, libraries and archives had to use tools of moving image preservation and playback developed, built and marketed by large production and distribution companies like Sony, Panasonic and JVC. Now, in the era of

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[10] https://blogs.loc.gov/thesignal/2014/04/the-meaning-of-the-mp3-format-an-interview-with-jonathan-sterne/. Accessed on January 8, 2019.

digital media production, there are playback and transcoding tools created by large companies like Apple but there are also many tools created by and for the open-source and freeware communities. There are also more institutions developing their own tools as well as extensions of existing software tools for their local practice. Media preservation tools in libraries and archives today often do not have as much of a hand-me-down quality as in years past. Some tools and standards developed by and for the production industries are being adopted in the memory realms and some are not. The line between producers and consumers of media production and playback technologies has become blurred as more memory institutions adopt, adopt and create their own tools, specifications and standards.

For this reason, a useful theoretical lens for understanding this ongoing change is political economy because this perspective can flesh out the relationships within a market in a deeper, more nuanced fashion than the traditional economic binary of 'producers' and 'consumers.' In the case of digitization standards, the producer/consumer distinction gets muddied because of the combined influence of the production sector (producers of standards and content) and the archival sector (producers and consumers of both standards and content) in their development, adoption and use. Vincent Mosco argues that traditional economic analysis "tends to ignore the relationship of power to wealth and thereby neglects the power of institutions to control markets" (Mosco, Chapter 2). As Mosco says, political economy is "the study of *the social relations, particularly the power relations, that mutually constitute the production, distribution and consumption of resources*" (Ibid. emphasis his). Technical standards, like almost any product, can be influenced by these kinds of power relations within their development communities and by the access of their developers to particular technical

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and professional resources. Power and influence can play out in the adoption of standards as well. In the words of Stefan Timmermans and Steven Epstein, "standards are in principle voluntary, but they can become *de jure* mandatory" (Timmermans and Epstein, page 80).

As standards are used by more institutions and by institutions of high prominence, other libraries and archives may adopt them either out of necessity (these are the standards everyone is using) or out of desire to emulate other users (these are the standards everyone is using). This can lead to a kind of path dependence for standards, which is, as Mark Mason describes, a situation wherein a system develops a kind of momentum that maintains and sustains it (Mason, 2008). Deference to existing standards can be further problematic when communities rigidly adhere to them without question. Standards can come to "function as an alternative to expert authority - a way of embedding authority in rules and systems rather than in credentialed professionals" (Timmermans and Epstein, page 71). As I will show with Matroska and FFV1, there can be considerable resistance in a community to new standards that diverge from accepted practice. At the same time, some users may adopt new technologies at least partially *because* they are new.

2.5 ARCHIVES, PRESERVATION AND DIGITIZATION

The challenges and high costs of digital preservation are common topics of the professional literature of libraries and archives. Preservation of digital moving images and infrastructure can incur great cost in terms of time, effort and funding. Relying solely on technological solutions for the needs of preserving digital motion pictures is insufficient. For example, investing resources primarily in the development of 'forever media' for digital storage

is problematic because of how quickly storage media designs change over time (Bradley, 2007). There are so many hardware, software and standards dependencies involved in digital preservation that the endeavor can be very challenging. Ensuring the sustainability of digital information - including digital moving images - requires not just technological solutions but public and private economic commitments to preservation as well (Blue Ribbon Task Force, 2010). Creating and maintaining funding streams for preservation is a critical component in doing the highly complicated work of keeping digital information accessible. Public-private partnerships to create digitization standards like AS-07 are critical to the larger digital preservation endeavor.

The preservation of digital video is most successful when it is a holistic, infrastructure-level endeavor, taking into account not just the digital object itself, but the hardware, software, staffing and standards needed to decode and play out that object (Bradley). As the proliferation of digital information continues, the need for planning for preservation becomes more urgent (Smith, 2007). Developing best practices and standards that anticipate the needs of memory institutions is critical to responding to this growing need and is a core recommendation of a recent national-level digital preservation report (National Digital Stewardship Alliance, 2015).

CHAPTER 3: METHODS

This dissertation is, essentially, a history of the development of MXF, JPEG 2000, Matroska and FFV1 and their adoption in the library and archives realms. The purpose of the research has not been to develop an overarching theory regarding which forms of encoding (open-source or industry-influenced) are more appropriate for cultural heritage preservation, broadly speaking. Staffing, collecting mandates and other attributes of local practice still dictate what standards are appropriate for an institution. Is an open-source tool better for a repository than a standard developed by and/or for broadcast or cinema realms? It could very well be that open-source and closed/proprietary standards are *both* conditionally appropriate, depending on circumstances like repository funding and infrastructure. Furthermore, the distinction between the two is troubled by the fact that open-source tools like those being developed by CELLAR often have industry influence as well.

3.1 RESEARCH QUESTIONS THEN AND NOW

When I embarked upon the data gathering for this dissertation, I wanted to research how power and influence dynamics affect two different high-quality digital video standards development paradigms. I wanted to use the CELLAR standards as a model of collaboration by non-profit entities and the SMPTE standards as a model of for-profit standards-making. However, as I started the research and the interviews, it became immediately apparent that there has been considerable representation by for-profit and nonprofit entities in both CELLAR's and SMPTE's work. Furthermore, the distinction between nonprofit and for-profit, in

terms of the standards themselves, appeared to serve no useful purpose in my analysis since they are used by both for-profit and nonprofit actors. There was still the question of how the different groups - CELLAR, SMPTE and the Library of Congress - influence the adoption of the standards and specifications that they develop and promote. As the interviews progressed, I found my interviewees were talking quite a bit about the factors that influence their choice of video encoding and container standard for high-quality master video files.

I contacted several CELLAR and SMPTE participants for interviews. Many CELLAR participants were happy to be interviewed but few of the SMPTE standards-makers responded to my emails requesting interviews. I was able to piece together histories of how the four standards were developed but, because SMPTE and ISO participants were not available for interviews, I decided to shift the focus of my work from comparing and contrasting how the standards bodies operate to how and why preservation professionals are adapting and adopting FFV1, Matroska, MXF and/or JPEG 2000 in their preservation work. I also constructed histories of these formats in order to describe their moves from certain niches like piracy and the American entertainment industries to libraries and archives.

Over the course of my interviews and research I found that my research question was this:

How have the FFV1, Matroska, MXF and JPEG 2000 standards evolved to fit the needs of the audiovisual preservation realm and why are some libraries and archives choosing to adapt or adopt them?

3.2 THEORETICAL PERSPECTIVES IN THIS DISSERTATION

There are several theoretical perspectives I have brought to bear on my research question, which can best be understood as a social informatics question. Social informatics interrogates the social aspects of information technologies - the factors that influence their adoption (Kling, 2007). In a similar vein, my work looks at some institutions that have adopted (and/or have chosen NOT to adopt) the Library of Congress' specification document and which have chosen the similar open-source Matroska/FFV1 combination and why. What are the sociotechnical factors that drive the choice of one specification over the other? These questions of how and why the standards, their designers and their users interact and intersect are, essentially, social informatics questions.

The development of moving image encodings and containers is an ongoing collaborative effort between preservation professionals in both the for-profit and nonprofit realms. Because audiovisual preservation is such an emergent field, these actors have had to adapt and respond to changes in technology, funding priorities and evolving best practices in order to develop responses to the needs of the audiovisual production and preservation professions. The standards they have developed need to be fluid and adaptable. SCOT (Social Construction Of Technology) research and theory, which posits that both technical and social factors influence the ongoing development, adoption and refinement of technologies, is a useful lens to use for analyzing the adoption and evolution of these standards (Pinch and Bijker, 1987).

My work is also strongly influenced by Jonathan Sterne's recent book-length discussion of the development of the MP3 as both a technical specification and a sociocultural paradigm. In this book, Sterne argues for something he calls "format theory," which is an application of

SCOT to the world of digital format evolution and development (Sterne). Sterne's format theory

is an articulation of SCOT that focuses on the political, social and economic forces that lead to

the development, adoption and adaptation of formats like the MP3. For example, he looks

closely at how the MP3 format, as we understand it today, is an amalgam of the broadcast,

software development and Internet dissemination (often via piracy) realms. In this research I

have found it useful to think of the development and adoption of JPEG 2000, MXF, Matroska

and FFV1 as being influenced by those same domains. Part of the reason for this view is the fact

that 'broadcast' in 2019 means more than terrestrial/over-the-air distribution of content. Now

broadcasters and universities use the Internet as a means of content dissemination, which

means video encoding and container standards must take into account Internet and Web

infrastructure. Contemporary time-based media distribution - be it by archives, television/radio

broadcasters or cinema producers - represents a convergence of terrestrial broadcast models

and Internet playout and/or downloading. The dissemination and implementation of Matroska,

like the MP3, also has been influenced by online piracy.

Sterne's work with the MP3 also represents a deep dive into how the MP3 encodes

information. I believe that looking closely at the way the video formats work - how they both

constrain and guide digitization efforts in similar and different ways - is critical to understanding

not only how they are developed but also why they are (and why they are not) adopted in

preservation work.

Following the work of Vincent Mosco in his analysis of the political economy of

communication, this dissertation looks at these disparities in influence and resources in order

to factor them into the different levels of adoption of MXF/J2K and Matroska/FFV1 (Mosco,

2009). I also draw from Carl Cargill's work about how standards succeed in the marketplace (Cargill). This research is also influenced by Ole Hanseth's work on the power dynamics that play out in standards-making bodies and how those dynamics influence the resultant standards (Hanseth).

3.3 ETHICAL CONSIDERATIONS

I believe that professionals working in audiovisual preservation rarely have the ability to take time to reflect on issues related to the power dynamics in the development of the standards that they employ. As an academic, I now have the time and resources to explore these issues and, in so doing, hold up a mirror to this community, within which I have long been embedded. I believe this is a way that my research, including the interviews and site visits I employed, can serve the audiovisual preservation and production communities within which I have been situated for almost twenty years.

I believe it is important for a researcher to accept that they have a perspective and make their biases known. For example, as a digital preservation practitioner, I believe that FFV1 and Matroska, because of their openness and the growing array of freeware tools for their encoding and decoding, are probably more useful tools for most institutions, particularly those with minimal resources, than JPEG 2000 and MXF. The latter two standards are, as will be seen later in this document, difficult for many institutions with more resource constraints than the Library of Congress to use. While I do not make any claims of what standards are better or worse for audiovisual preservation, almost two decades of film and video production, digitization and preservation have informed my thinking about these standards. Furthermore, I

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have developed a sense of which standards for which I would advocate in my work as practitioner and, to some extent, as a teacher.

The fact that I have been a part of the audiovisual community for so long, and that I have been an active participant in the development of AS-07, has been very useful for this research. It has allowed me to have conversations with my interviewees that I believe may have been hard for other researchers. For one thing, I am familiar enough with video digitization to understand most of the jargon and video encoding principles mentioned by my interviewees. I also believe that my status as a fairly well-known member of this profession helped me receive responses to my requests for interviews. However, I believe that the fact that I am not a SMPTE member and have never been an active participant in their standards-making work was a factor in my failure to get interviews from members of that organization. Nevertheless, my familiarity with many of my interviewees seemed to help the conversations flow smoothly.

When I embarked upon my research I decided it would be best not to anonymize my interviewees. I made this decision for two reasons. First, I knew that at least part of this work would be a history of the various standards under scrutiny. I believe this history is far more useful for the audiovisual preservation community if the interviewees were named since so many of them have been active participants in the development and/or adoption of these technologies. Second, the world of audiovisual preservation is so small and close-knit that it seemed likely that the audience for this work would almost certainly know who at least some of these interviewees were, even if they were anonymized. For this reason, the consent form that I required each interviewee to sign prior to our conversations gave them the option of being anonymous or of having their names included in this work. Every interviewee chose **not** to be

anonymous. I should also note that several of these interviewees were friends and/or colleagues of mine prior to our interviews.

3.4 DATA GATHERING

Interviews with the people who design these standards have been critical to understanding why audiovisual preservation professionals are using - or choosing not to use - MXF, Matroska, JPEG 2000 and/or FFV1. Understanding the people who create standards is necessary to having a deep understanding of the standards documents they create. These interviews, coupled with a detailed review of publications by standards developers and users, have helped me to understand the development and adoption of the standards I have been analyzing.

One of the key research strategies in the social sciences is the interview. Interviews are an opportunity to spend time with people and learn about their experiences in their own words. Many social scientists view the interview as a collaboration in which the interviewer and the respondent are both active participants in a meaning-making situation (Holstein and Gubrium, 1995). Critical to this view is the notion that interviewees are not simply vessels for information and that the interview is not just a mission to search for and mine that information. Interviews are instead shared endeavors and interviewees are co-constructors of knowledge along with the researchers. The interview is a stage upon which information is conveyed and meaning is constructed (Kvale, 1996). This ethic of co-constructed meaning-making informed my interview process. As I spoke with my interviewees I made sure that they had the space to respond to the questions without much of my interjection or clarification. The interviews were

mostly driven by the questions I generated in advance but follow up questions and conversation made each interview distinct from the others.[11] One-on-one interviews ranged in length from roughly half an hour to ninety minutes, based on how talkative the interviewee was and where the follow up questions, if any, took us.

Over the course of the fall of 2017, the winter of 2017/2018 and the spring of 2018, I conducted interviews with twenty-six people. Because most of my interviewees were not within easy driving distance of Urbana, most of these interviews played out over Skype. I also conducted on-site interviews of people implementing these standards in their video digitization work at the Library of Congress, Scenesavers and Indiana University. I used a tool called Call Recorder to record the Skype interviews and export them as MP3 audio files for ease of transcription.[12] Unfortunately, I had some problems with the recordings for some of the interviews so I had to rely on the notes I took during those interviews rather than verbatim transcriptions for some of the interviewees' comments in this dissertation. The audio recordings from the interviews came to approximately 18.5 hours total. Interviewees did not see the questions before our interviews with two exceptions: Kate Murray insisted on seeing the questions prior to our interview and Ian Henderson told me he was too busy to schedule a synchronous interview, so I sent him the questions and he answered them over email. Murray's interview had minimal conversation beyond the printed interview questions, leading me to speculate that this may be because she came prepared with her responses. Henderson's interview, because it was by email, allowed for no synchronous follow up questions (and I did not ask for any clarification of any questions later). His interview was very useful and was very

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[11] See Appendices C and D for lists of questions asked in my interviews.

[12] https://www.ecamm.com/mac/callrecorder/. Accessed on May 22, 2019.

information-rich, but was not the kind of spontaneous, co-constructed meaning-making venture that the other, synchronous interviews were. The interviews I conducted at Indiana University and Scenesavers were in-person group interviews. These were particularly useful because there was a great deal of cross-talk between the interviewees, which yielded more information than I would have gotten one-on-one. For example, at Indiana University I had project managers as well as technicians in the room and I found that the managers answered the policy questions while the technicians, for the most part, fielded the technical questions. When it came to discussions of challenges in workflows, both of these groups of people were able to pick up on each other's comments and describe how the social and the technical aspects of the work contributed to the challenges of video digitization. Had I interviewed engineers and policy people separately I could have pieced these things together myself, but in a group interview the participants painted this picture together, spontaneously. Furthermore, the interviewees, because they have worked together so long, had a shared familiarity with the issues they face that allowed them to quickly understand what each other was talking about, and I believe that had I interviewed them separately, I would not have known the follow up questions to ask to find out more about these issues. It is worth noting, however, that having policy people (the supervisors) and the engineers (the staff) in an interview together could mean a lack of comfort on the part of one population in speaking openly about challenges they have had with the other population. It is possible that one-on-one interviews could make participants more comfortable responding to those kinds of questions. Because I did not believe my questions would probe interpersonal relationships or personnel issues, I did not see any compelling reason to refrain from conducting these group interviews.

Interviews comprise the bulk of the data for this dissertation, but I have also used

information from publications by the interviewees throughout my research. The audiovisual

preservation community tends to generate a great deal of documentation about their work:

promotional articles, conference publications, public-facing workflows and best practices.

Federal Agencies Digital Guidelines Initiative (FADGI) contributors like Carl Fleischhauer and

James Snyder have each written articles that were useful for my research. On the CELLAR side,

Ashley Blewer and Dave Rice wrote a very useful article about FFV1, Matroska and the history

of the CELLAR working group. I have also used local-practice documentation produced by Mike

Casey at Indiana University and Josh Yocum at Northwestern University. In the case of Indiana

University, I read Casey's article prior to our interview and asked follow up questions directly

related to issues raised in that article. In the case of the Yocum interview, Josh gave me his

documentation after we talked. I also drew from histories of MXF and JPEG 2000 written by

people involved in their development. These histories are *The MXF Book by* Bruce Devlin and

JPEG 2000: Image Compression Fundamentals, Standards and Practice by David Taubman and

Michael W. Marcellin. The writers of these histories did not respond to my requests for

interviews. I also contacted Michael Niedermayer, the creator of the FFV1 encoding, to request

an interview but he did not respond. I was able to piece together a history of the encoding from

other interviews I conducted and some of the published materials I found during my research.

The CELLAR working group is committed to transparency and its work has taken place

out in the open, using online message boards and email list conversations. I monitored both of

these resources and attended a CELLAR working group meeting via a synchronous Internet

conferencing tool in order to understand these communities and how their participants operate.

Prior to being a doctoral student, I spent nearly three years working for the Library of Congress on early drafts of the AS-07 specification. (The AS-07 working group continued work on the specification without my input after I left the Library.) This work on AS-07 is not a part of the research project that makes up this dissertation. My background with the Library, coupled with nearly two decades of experience in the audiovisual production and preservation realms has afforded me access to some working documents and I believe it helped me secure interviews with Kate Murray and James Snyder as well as a visit to the Library's preservation facility in Culpeper, Virginia.

I chose some interviewees like Mike Casey, Kate Murray and James Snyder because I knew about their work in standards-making and/or adoption prior to undertaking my research. In order to find other interviewees, I posted a call for participants to the email lists of the CELLAR working group and of the Association of Moving Image Archivists. I also did some snowball recruiting, as can be seen in my interview questions in this document's appendices. I asked my interviewees if there were other people they would recommend I interview, and I got some of my interviews from this method. Some of the interviewees have been involved in the CELLAR or AS-07 work. Others are implementing some combination of FFV1, Matroska, MXF or JPEG 2000. Some of the interviewees have worked on the development of these standards and are also implementers of them. The list below shows the interviewees' professional roles that are most pertinent to this research. None of my interviewees chose to be anonymized in this dissertation.

CELLAR Developers

- Ashley Blewer, audiovisual preservation expert and CELLAR participant

- David Rice, archivist at the City University of New York and CELLAR participant

- Steve Lhomme, developer of the Matroska container, CELLAR participant and contributor to the VideoLAN project[13]

- Reto Kromer, audiovisual preservation expert and CELLAR participant

- Brecht Declercq, audiovisual specialist at the Flemish Archives and CELLAR participant

AS-07 Developers

- James Snyder, video engineer at the Library of Congress and AS-07 contributor

- Kate Murray, leader of the Audiovisual Working Group of the Federal Agencies Digital Guidelines Initiative at the Library of Congress and a principal author of AS-07

Standards Implementers

- Erik Dix, audiovisual specialist in the Notre Dame University Archives and FFV1 user

- Nick Krabbenhoeft, Digital Preservation Manager at the New York Public Library and FFV1 and Matroska user

- Marion Jaks, video archivist at the Austrian Mediathek and FFV1 user

- Kieran O'Leary, Data and Digital Systems Manager at the Irish Film Archive and Matroska and FFV1 user

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[13] https://www.videolan.org/videolan/. Accessed on May 9, 2019.

- Josh Yocum, Digitization Assistant at Northwestern University Library and Matroska and FFV1 user; he also tested AS-07

- Ian Henderson, Digital Audio and Video Preservation Specialist at The National Archives of the United Kingdom and FFV1 and Matroska user; he also tested JPEG 2000 and MXF

- Evelyn McLellan, president of Artefactual, the company that produced the popular Archivematica open-source digital preservation system that uses Matroska and FFV1

- Benjamin Turkus, media preservation specialist at the New York Public Library and Matroska and FFV1 user

- Hermann Lewetz, audiovisual preservation and digitization specialist at the Austrian Mediathek, the first user of FFV1 for high-quality video preservation in an archives

- Jean-Christophe Kummer, CEO of NOA GmbH, CELLAR participant and FFV1 and Matroska user; he also consults archives and recommends the CELLAR standards

- Peter Bubestinger, CEO of AudioVisual Research & Development - for Long-Term Preservation, Matroska and FFV1 user and CELLAR contributor

- Lars Gaustad, Head of the Film Section of the National Library of Norway, Matroska and FFV1 user; he also tested MXF and JPEG 2000

- Jim Schupert, video engineer and video preservation specialist at Scenesavers, Matroska and FFV1 user; Scenesavers also has tried to create AS-07 files and has used MXF and JPEG 2000

- Jim Bird, President of Post Production Services at Scenesavers, Matroska and FFV1 user; Scenesavers also has tried to create AS-07 files and has used MXF and JPEG 2000 (I interviewed Bird and Schupert together at Scenesavers.)

- Mike Casey - Director of Technology for the Media Digitization and Preservation

  Initiative at Indiana University and Matroska and FFV1 user; his team also tested AS-07.

  This interview was a group interview including these specialists:

    - Brian Wheeler - Senior System Engineer

    - Jon Dunn - Library Technician

    - Rob Mobley - Video Preservation Engineer

    - Andrew DaPuzo - Director of Operations for Memnon at Indiana University

Some of the interviews took place in person. I chose to interview the following people in

person at their places of work. I chose to interview them in person because I wanted to have

the opportunity to see their workflows and capture technologies in person.

- James Snyder at the Library of Congress' Packard Campus for Audiovisual Preservation

  in Culpeper, Virginia in April 2018

- Jim Bird and Jim Schupert at Scenesavers in Cincinnati, Ohio in March 2018

- Mike Casey and other staff members working for the Media Digitization and

  Preservation Initiative at Indiana University in Bloomington, Indiana in March 2018

I drew the questions that I asked my interview subjects from my initial research

questions. One of the key concepts I explored in my interviews related to what factors inform

preservation professionals' decisions of which standard(s) to choose for their video digitization

and preservation work. I also explored whether these preservation professionals and specialists

had different ideas of what "quality" meant with respect to video digitization. I asked the following question of standards users:

- What are the measures and/or signifiers for 'quality' do you and your institution apply to the digital files that result from this/these standards?

What I found was that nearly all of the interviewees considered quality as a mathematically-informed metric: the size of a file (in bytes), the number of lines of resolution and the kind of brightness and color information encoded in the file told them whether it could be considered high-quality. By the time I finished interview data gathering, I decided that this question did not yield anything particularly pertinent to the question of why and how users choose between the standards, since the users seemed to view JPEG 2000 and FFV1 as fairly comparable in terms of image quality.

For standards implementers, the following questions were most useful in getting a sense of the sociotechnical factors that led to their adoption of (or their choice not to adopt) MXF, JPEG 2000, Matroska and FFV1. These are the questions that interviewees tended to spend the most time answering. They are also the questions that most informed the political economy aspect of my research because the answers often pointed to the power dynamics that influenced their standards choices within their particular institution and/or in the larger audiovisual preservation world. The questions were:

- What kinds of technical factors have informed which of which standard(s) to choose for your video digitization and preservation work?
- What kinds of social dynamics within your organizations have informed this choice?

- What kinds of dynamics, if any, in the larger audiovisual preservation profession have informed this choice? Are you conforming to any professional best practices by making the choices you've made?

For the interviewees working on the CELLAR or AS-07 development work, the following questions were particularly useful in exploring the evolution of the standards from their prior niches (piracy, television broadcast, cinema production) into the realm of libraries and archives. The interviewees often got very technical with respect to how the standards work and the changes needed to help them work in the memory realm. Their responses were very useful for helping me to show the social construction of these technologies. They also helped me to see that in some cases the standards were acting as boundary objects, as I will discuss more in the next subsection. The questions were:

- Tell me about the standards. Who are they for and what do they do?
- What are the strengths of the standards? Why would someone choose to use them?
- What do you think are the limitations to that standard?
- What sort of trade-offs or compromises did you have to make in the design of the standard?
- How do the members of the group evaluate the positives and negatives of these compromises?
- Can you describe some challenges you've encountered in your work on this standard?
- Why would you consider those to be challenges?
- How has the larger audiovisual preservation/engineering community interacted with

your group?

I also observed and participated in the No Time To Wait 2 conference in Vienna, Austria in November 2017. This conference, which was attended by many CELLAR participants, was an opportunity to observe a number of American and European open-source video standards developers and evangelists interact and discuss their work. This conference was also a key opportunity to make contacts that would lead to interviews for my research. Two notable contacts I made here were Steve Lhomme, inventor of the Matroska format and Hermann Lewetz of the Austrian Mediathek, who was the first adopter of the FFV1 encoding for media preservation work. Observing the conference also gave me the opportunity to see how members of the CELLAR community interact and discuss their work between them. I found it useful to see how enthused Matroska and FFV1 adopters are about the standards. This helped to illuminate the prominence of 'open source ideology' in some of the adopters' decision making with respect to the standards. This conference also gave me some valuable historical information. For example, the fact that FFV1 was initially created as a lark by early FFmpeg developers came to me from one of the conference sessions.

3.5 ANALYTICAL METHODS

I spent the fall of 2017 and the spring of 2018 conducting interviews. There were three reasons I believed I could conclude my interviews and begin writing this dissertation. First, I believed I had reached a saturation point with the interviews because my interviewees were, for the most part, responding to questions in the same ways. I believed that I was no longer

collecting new data from my interviews. Second, I had gathered enough information from my interviews and from the various publications I had read about the standards to piece together histories of each standard. Finally, I was getting no more responses to my requests for interviews, either from messages sent to email lists or from directly emailing potential subjects.

Because my work functions less like ethnography and more like a history of the standards, I did not code the interview data. After transcription of the interviews was complete, I read through them and indexed them in order to pull out comments that were useful in building the histories I was writing. I also looked for interviewees' comments about the reasons for adopting or for *not* adopting the various standards. Interviews with engineers and specialists involved in the development of these standards also explicated the factors and reasoning involved in the designs of the standards. Understanding the intentions of these designers has also been critical to understanding the technological affordances of the standards that allowed them to be used and adapted for libraries and archives.

Over the course of my research I have drawn from many kinds of published documentation. Archivists, engineers and other moving image specialists tend to generate many kinds of documentation related to their standards-making efforts. These professionals often write and/or contribute to blogs, professional email list correspondence, conference presentations, guidance documents and articles. I found them to be rich sources of information about the motivations and reasoning of standards developers and adopters. These documents also helped me to fill in gaps in the histories of the standards. This was especially useful for MXF and JPEG 2000 because I was not able to interview many of those standards' developers. The

publications by Carl Fleischhauer were particularly useful for getting information about the foundations of the AS-07 specification before I began working on it at the Library of Congress.

I believe histories are useful not only with respect to what they tell us about the past, but also to what they tell us about the present. Because the audiovisual preservation community is still actively developing best practices for video digitization, I think it is useful to draw from scholarly works to illuminate some of the forces at work in the development and adoption of these standards. To that end, I have brought to bear upon this history the theories developed by the social construction of technology and political economy scholars and works that I have cited above. This socio-technical framework has been a critical lens through which to view the data I have gathered from my research and interviews. A major goal of my work is *not* to simply assess the results of these people's work. Rather, I am looking to form an understanding of the forces - beyond just the engineers' abilities and preferences - that influence the development of these technologies. Likewise, it is important to analyze the factors related to the adoption and implementation of these standards as well. This analysis has been greatly informed by my discussions with archivists and digitization vendors who use - and adapt - these specifications. The next section of this dissertation contains a history of the standards that I have generated from my research and interviews. No such history of these four standards - told by their developers and their users - existed prior to this dissertation.

CHAPTER 4: HISTORY

In order to proceed with a discussion of these video standards and the negotiations surrounding their meaning and use, it is critical to describe the histories of MXF, JPEG 2000, Matroska and FFV1. Following are brief histories of these technologies, informed largely by interviews with and/or publications written by the people who developed and/or use them. These histories describe the development of the standards, the reasons for their development and how they moved from their niches (broadcast television, cinema, piracy) to widespread use in libraries and archives outside those niches. In this section I also show how the needs of media preservation in the digital realm required new technologies that were quite different from the needs of the analog video era. These histories also provide evidence for the lack of a clear-cut distinction between for-profit and nonprofit influences in video standards development. Furthermore, this section depicts the nonlinear adoption and adaptation of the standards as they moved from their niches into libraries and archives, which is a core tenet of one of the theoretical underpinnings of this dissertation: the social construction of technology.

4.1 A BRIEF HISTORY OF MXF AND JPEG 2000

According to Bruce Devlin, one of the developers of MXF, "the Material eXchange Format (MXF) is an open file format, targeted at the interchange of audio-visual material with associated data and metadata" (Devlin, 2002, page 1). In the 1990s, the American broadcast industry was beginning to move from a magnetic tape-based paradigm to media-independent digital asset management infrastructures (Rubin). MXF was designed to encourage

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the interoperability of files within production environments, ensuring ease of use between file

servers, audiovisual recording equipment and editing tools (Ibid.). This means MXF is an

example of a coordinative standard which, as Raymund Werle says, is "needed to facilitate the

interoperation of components of networks and the provision of services in technically

heterogeneous environments" (Werle, 2001, page 38). A chief purpose of MXF is to ensure that

a media file is self-describing - that it carries bundled within itself the metadata a user may

need in order to properly understand or decode the file's information. Libraries and archives

outside the broadcast realm share the need to ensure that digital assets that can move about

freely in IT environments without the encumbrance of sidecar metadata files that run the risk of

being separated from the main information payloads.

    MXF was, at least initially, designed primarily for the broadcast realm and not for the

world of cinema. Furthermore, the for-profit and nonprofit distinction becomes hazy when

speaking of the genesis of MXF. As a colleague noted in an email conversation with me:

> MXF was developed (so far as I know) for broadcasting, and Bruce [Devlin] was working
>
> for a company (Snell & Wilcox, as was) [sp] that sold equipment to broadcasting. So that
>
> part is 'for profit'. But the major broadcasters in Europe are 'public service broadcasters',
>
> many (as with the BBC) supported by the public (payment of a licence fee), not taking
>
> advertising and not specifically profit-oriented.[14]

    MXF was born out of a forum within the Moving Picture Experts Group called Pro-MPEG.

In the late 1990s this group was testing various digital formats for interoperability within

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[14] Richard Wright, personal email communication, October 30, 2018.

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production environments. At the time it was becoming very clear that production environments were soon going to be fully-realized digital production, post-production and dissemination infrastructures. The needs of broadcasters would not be served by any existing, 'off the shelf' format. Existing audiovisual file formats were not able to handle the needs of high-quality and high-throughput production systems. For example, the AVI (Audio Video Interleaved) video container format, while ubiquitous, was very poor at containing video timecode information in a predictable, standardized way (Wright). Concurrently, Avid, the producers of the nonlinear editing suite of the same name, which is used throughout Hollywood and television broadcast, was working on a tool they were calling AAF, the Advanced Authoring Format, which they were designing for very similar ends (Devlin, 2006). Representatives from Avid joined the Pro-MPEG group's discussions and told the group that what they were intending to do - to create a file format that would be useful to a broad array of producers, software manufacturers, broadcasters and hardware producers - was unlikely to move along in any efficient way. After months of analysis and negotiation between members, the Pro-MPEG forum realized that there was little likelihood of getting production hardware and software designers and manufacturers to agree enough to develop a new encoding standard. However, the forum came to realize that there could be agreement and appropriate buy-in for a format for the interchange of files between systems and software (Ibid.). Thus, the Pro-MPEG group and the AAF group began to work together to draw up the initial specifications for MXF in 1999. However, the group ultimately decided to use the Society of Motion Picture and Television Engineers (SMPTE) to standardize the MXF format because it has a more formalized, due process structure (Ibid.).

Some of the major contributors to the development of MXF were the BBC, Grass Valley, Panasonic, Sony, Pinnacle and Omneon. Panasonic was particularly invested in MXF because of their interest in a file container that could encapsulate the various digital objects produced when their cameras captured video essences and associated data to their new P2 solid-state capture card technology. This investment by Panasonic in MXF is an example of a very common phenomenon in standards-making: that of for-profit industries trying to influence standardization in order to gain or maintain market share for their products (de Vries). As my research illustrates, the power that the SMPTE name has, with respect to trust in particular standards, is substantial in the broadcast and film production realms. I will return to the cachet of the SMPTE standards in my analysis sections below.

JPEG 2000 is a still image encoding that takes its name from the Joint Photographic Experts Group, the working group within the International Standards Organization that developed and wrote the standard. JPEG 2000 is a successor to the original JPEG image encoding and the intention of this newer standard was to "minimize the number of bits required to represent the original image samples without any loss of information" (Taubman, 2000, page 5). One of the principal powers of JPEG 2000, and the one that differentiates it from its predecessor, is that images encoded as J2K can be decoded at any level of image quality up to and including its highest. This allows JPEG 2000 to be highly useful as a still image encoding in digital libraries because it allows for image scans that can scale in quality in proportion to a user's Internet connection bandwidth. The original JPEG standardization work began in the 1980s, with a draft international standard released in 1991. Of the standards under discussion in this dissertation, only the original JPEG existed before the World Wide Web. The high image-

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quality-to-file-size ratio of JPEG files made it very amenable to dissemination on early, dial-up

Web connections, which helped the format to achieve ubiquity.

In the late 1990s, photochemical image capture was still the norm for many Americans.

Increasing access to the Internet meant more people were scanning their film photographs and

putting them online, which caused the number of JPEG files in the world to rapidly proliferate.

Thus, the JPEG began considering a new, more scalable version of the JPEG standard. In 1997

the JPEG working group put out a call for new compression technologies to be submitted for

their evaluation for fitness for inclusion in a new JPEG format (Ibid.). The ISO standardized JPEG

2000 as ISO/IEC 15444-1 in December of 2000 (Campbell, 2016). Some of the major players in

the testing and standardization of JPEG 2000 were: Kodak, Booz-Allen & Hamilton, Mitsubishi,

Ericsson, Texas Instruments, Motorola, the Sarnoff Corporation, Norwegian University of

Science and Technology, University of Maryland, Hewlett-Packard (Taubman). While there was

some representation from nonprofit entities like the University of Maryland, many of the most

influential actors in the standard's development were for-profit businesses.

Over the course of the early 2000s, SMPTE's working group called DC28, the Technology

Committee on Digital Cinema, began investigating technologies to implement for the

burgeoning transition in Hollywood from photochemical to digital cinema distribution. SMPTE

chose JPEG 2000, which can be used to encode each frame of video as a J2K still image, as the

encoding for moving image essences in digital cinema because of its ability to scale images and

for its lossless compression scheme (Nowak and Fößel, 2008). The term "motion JPEG 2000" is

often used for this video encoding even though it was never officially standardized as such

(Taubman). SMPTE also chose MXF as the container for these digital cinema materials, which

helped the format transition achieve major representation not only in the television broadcast realm but in the film production industry as well. This SMPTE digital cinema initiative included significant involvement by seven major Hollywood studios (Devlin, 2006). The close involvement of these studios led to MXF and JPEG 2000 becoming ensconced in the Hollywood and broadcast realms, as well as in the archives and libraries that preserve their materials.

4.2 MXF, JPEG 2000 AND THE LIBRARY OF CONGRESS

MXF and JPEG 2000 moved into the cultural memory realm in the early twentieth century when the Library of Congress began investigating them as a possible target container/encoding combination for their high-quality analog video digitization work. In a recent post on the email list for the Association of Moving Image Archivists, video engineer and preservation specialist Jim Lindner said this about JPEG 2000,

> JPEG 2000 was never positioned as a forever format. It was always discussed as a transition between analog then (around 2002) and the next one (what ever that will be). It was one link in a migration chain that extends outward in time. The really important part at that time was that it had mathematically lossless compression. Compression was a big deal at that time and considering the size of files and the cost of storage at that time consensus in the broadcast industry and elsewhere was to use lossy compression for archival storage of AV content. It was a real struggle to convince people to not use lossy compressed files.[15]

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[15] https://lsv.uky.edu/scripts/wa.exe?A2=ind1810&L=AMIA-L&P=86917. Accessed on January 8, 2019.

The Library of Congress, because of its enormous collection of moving image materials, began working with Lindner in the early 2000s to explore using JPEG 2000 as the output encoding for their high-quality digitization work.[16] Lindner developed the first JPEG 2000 video encoder and integrated it into hardware called SAMMA, or the System for the Automated Migration of Media Assets. SAMMA is a customizable stack of cassette video playback decks that can be set to automatically digitize a number of tapes. It is a 'set it and forget it' system that is especially useful for high-throughput digitization in large media collections. SAMMA can generate high-quality JPEG 2000 files with the option to wrap those files in the MXF container. The SAMMA system, while initially developed for the Library of Congress, became very attractive as a time-saving digitization tool for other institutions like the Smithsonian Archives and the Peabody Collection. The SAMMA technology moved outside the United States as well: the National Library of Norway also procured a SAMMA system around 2009.[17] MXF and JPEG 2000 are also used outside the United States in institutions like the Cinematheque Royal in Brussels, the City of Lausanne Archives and Institut National de l'Audiovisuel in France (Memoriav, 2017). With SAMMA came JPEG 2000 and MXF: as the hardware moved into memory institutions, so did the encoding and container technologies. Hardware support for digital standards is critical to their growth and adoption. Sterne points this out in his discussion of the development and spread of MP3 players like the Zune in the late 1990s and early 2000s. As Sterne notes, these playback devices allowed the MP3 to become an on-the-go music format in the mold of the cassette tape and the Sony Walkman decades earlier (Sterne, 2012). Without

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[16] James Snyder, personal interview, April 27, 2018.
[17] Lars Gaustad, personal interview, December 20, 2017.

reliable hardware to encode the analog video signal into a JPEG 2000 bit stream and wrap it into an MXF container, the standards would not be adopted by preservation institutions.

As it turns out, the media asset management needs of archives and libraries are similar to the broadcast and film realms: storage space is usually inadequate for the wealth of digital content being created or acquired, and media assets need to be self-describing for transport and ease of retrieval. However, not all institutions found MXF/JPEG 2000 files easy to create and/or decode. Some archivists were suspicious of relying on a unique piece of hardware for fear of vendor lock-in.[18] Other institutions like Indiana University, upon testing the files generated by the SAMMA device, found those files had interoperability problems with other software.[19] SAMMA, while useful for some institutions, was not a cost-effective or useful solution for all.

The Library of Congress' preference for MXF/JPEG 2000 owes to more than their use of SAMMA. The Library houses the United States Copyright Office and one of the stipulations of the assignment of copyright to a motion picture is that a copy of that picture be deposited into the Library's collections. Because Hollywood production companies were investing heavily in the development of a digital cinema standard using MXF and JPEG 2000, it was immediately clear to the Library that these kinds of files would begin flooding into its collections once digital cinema came to maturity.[20]

The SMPTE MXF standard is a complex network of specifications for various implementations or 'flavors' of the format. For this reason, one of the challenges of using the

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[18] Nick Krabbenhoeft, personal interview, January 18, 2018.

[19] Andrew DaPuzo, personal interview, March 23, 2018.

[20] Snyder interview.

MXF container is the wide array of vendor implementations of the standard and the lack of

conformance of those implementations with one another.[21] This lack of conformance can cause

confusion in memory institutions with respect to the specifications to which their files and/or

their encoding and decoding software and hardware must conform for proper production or

playback. I will return to this complexity in the Interview Data section below.

The wide array of conflicting and idiosyncratic implementations of MXF was a chief

reason the Library of Congress decided to draw up a document, called an "application

specification," that would clearly lay out the Library's preferred implementation of MXF and

JPEG 2000 as a kind of recipe for use in their preservation work. The Federal Agencies

Digitization Guidelines Initiative, or FADGI, of which the Library is a part, began drafting their

specification for MXF and JPEG 2000 in 2009. From 2012 to 2015 FADGI used the Advanced

Media Workflow Association, or AMWA, to help them develop the specification document. The

Library chose AMWA as the incubator for this document because of the organization's ties with

broadcasting and its track record of drawing up similar documentation for the BBC. The AS-07

development team included private vendors and developers like George Blood Audio and Video

and the Belgian audiovisual tool company EVS-OpenCube (Fleischhauer, 2015). James Snyder,

video engineer at the Library of Congress, was a strong proponent of developing AS-07 because

the standard would allow for ease of interoperability between compliant files and tools (Snyder

2011). Furthermore, the AS-07 document would provide a recipe for hardware and software

developers in order to ensure that their tools could be used by (and marketed to) the Library. In

the words of Carl Fleischhauer, the principal author of the specification, "AS-07 has been

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[21] Gaustad interview.

defined broadly, as a file format for the preservation and long-term archiving of audio-visual

content, ranging from theatrical motion picture content to broadcast and non-broadcast video

content to sound recordings as separate entities" (Fleischhauer, 2015, page 5).

Through the course of developing AS-07, the FADGI working group came to see the

limitations of MXF and JPEG 2000 in the cultural memory context. Some technological

affordances of MXF work very well in the memory realm - for example, the container has a

specified space for retention of closed captioning data, often carried in Line 21 of the video

raster.[22] However, because the focus of the MXF developers was for new, turn-of-the-century

digital video capture technologies, certain aspects of legacy analog video capture were not

considered in the initial development of the standard. For example, FADGI discovered that

MXF, as of 2011, did not properly define interlaced JPEG 2000 video - likely because MXF

developers did not seriously consider the need to digitize legacy video in the era of digital

production (Snyder, 2011). This lack of definition for how to handle interlacing complicated

FADGI's work and motivated them to petition SMPTE to expand the MXF specification to

correct it. I will return to this lack of treatment for interlacing in the discussion sections below.

After several years of working with AMWA to develop the AS-07 document, the Library

of Congress chose to move the specification into the SMPTE standardization stream. According

to the head of FADGI's Audiovisual Working Group, Kate Murray, developing AS-07 into a

SMPTE standard would give it "more staying power" in the audiovisual preservation community

because of that community's comfort with SMPTE's work and would also keep the document in

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[22] Kate Murray, personal interview, September 28, 2017

line with the broadcast industry because of its heavy involvement with the standards body.[23]

Murray describes the AMWA business model as "not a good fit" with the Library and the move

from AMWA to SMPTE for AS-07 jokingly as a "divorce."[24] The move to SMPTE standardization

is also important on technical and political grounds, because the Library's collections "include

significant holdings produced by broadcasters, content with complex added elements like

captions and subtitles, multiple timecodes, and other elements" (Fleischhauer, 2014). The

technical need for capturing information beyond just picture and sound is motivated at least

partially by the Library's need to be perceived as good stewards of every element of the

broadcasting and cinema materials in their charge, in a manner befitting the national library.

Murray noted that as they have developed AS-07, they have found issues related to MXF's

description and handling of the preservation and digitization of video and FADGI has relayed

them to SMPTE for correction.[25] In this way the AS-07 project has been a rare case of the

preservation community providing useful feedback to and influencing the work of the

production realm. As of this writing, AS-07 is still in a draft form.[26]

4.3 A BRIEF HISTORY OF MATROSKA

Unlike JPEG 2000 and MXF, the Matroska file format was not developed by a formal

standards body like the ISO or SMPTE. It has been in existence since 2002 and is based upon

EBML - the Extensible Binary Meta Language (Blewer and Rice, 2016). Matroska has had wide

adoption around the Internet as a piracy format, likely due to its completely open specification

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[23] Murray interview.

[24] Ibid.

[25] Murray interview.

[26] http://www.digitizationguidelines.gov/guidelines/MXF_app_spec.html. Accessed on January 24, 2019.

and its agnosticism with respect to the kinds of encodings it can contain. This association with

piracy is almost certainly a reason for its slow adoption within the film and broadcasting

industry (Yocum, 2016). The broad use of Matroska in piracy gave the format a kind of ubiquity

in certain copyright-violating sectors of the Internet, even though the broad implementation of

the format led to a wide array of idiosyncratic files scattered hither and yon. These idiosyncratic

files can lack conformance to shared specifications, meaning the files do not reliably play out in

similar, predictable ways across a shared array of playback software types.

Matroska was not specifically designed for piracy, but it *was* designed for use outside

the established, turn-of-the-twentieth-century media production realms. Steve Lhomme, now a

programmer with the VLC video player project, designed the format in 2002 out of a desire by

Lhomme, a French citizen, to collate and play out clips he was collecting from the French

national political campaigns of the time.[27] Lhomme was collecting video clips in order to expose

the inaccuracies presented by these candidates and he found the AVI file container to be

insufficient for the job, so he and a partner started working on a format they called TMF - the

Tronic Media Format - but when his partner left for military service, Lhomme took over the

work on his own. The goal of the format was to be able to collect disparate files (and file types)

into the same container. Because the 'packing' of content within a file reminded Lhomme of

the Russian nesting dolls called *matryoshka*, he adapted that word for the use of his new tool:

Matroska. On December 6, 2002, Lhomme started generating code for Matroska on

SourceForge, and a file format was born.

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[27] Steve Lhomme, personal interview, December 1, 2017.

Another factor in moving Matroska into the piracy realm was Lhomme himself. Steve promoted Matroska on Internet Relay Chat sessions and Web forums but, as he notes, people were reluctant to use Matroska until they could see the files for themselves, so Lhomme put Matroska files (often referred to as MKV files because of their .mkv extension) online for public consumption.[28] Lhomme believes that because he was putting broadcast content into his MKV tests and putting them online as sample files, it likely tipped off pirates that this new format would be the perfect tool for their work. This work, by the way, is something in which Lhomme is very open about participating.

While piracy likely slowed Matroska's acceptance by the for-profit film and video production realms, its flexibility has also made it attractive to the memory realm in recent years. I first heard of it while in a meeting of the Federal Agencies Digitization Guidelines Initiative (FADGI) at the Library of Congress in 2010. I was a coordinator of the Audiovisual Working Group of FADGI and was working on the application specification for the Library's use of MXF and JPEG 2000 in their video digitization work. One of the participants asked why we weren't looking at Matroska as a video container instead of MXF, because of the open-source nature of the MKV format. The resistance to this notion came from Library video engineers who had concerns about using a technology that was not standardized by a well-known body like the ISO or SMPTE. When I looked into Matroska, I decided that it should be represented in the Library's Sustainability of Digital Formats online resource and I created a page in that tool for

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[28] Ibid.

the MKV format.[29] This is, to my knowledge, the first official acknowledgement of the format by the Library of Congress in a public-facing document.

Over the course of a decade, Matroska's ubiquity in the online world made it difficult for hardware manufacturers to ignore. While Sony initially ignored the format because of its associations with piracy, after a decade of Matroska files circulating the Internet, Sony started producing Blu-Ray players that could decode the format. Apple's QuickTime Player can also play back Matroska files with the use of a plug-in. In 2011, the City of Vancouver Archives chose to use the Matroska container (with the FFV1 video encoding) for their master-quality video digitization, because of the Canadian government's requirement that its publicly-funded agencies must use, wherever possible, open and royalty-free technologies.[30]

4.4 A BRIEFER HISTORY OF FFV1

The FFV1 encoding began its life as an experiment. The programmers working on the FFmpeg transcoding software project in 2003 charged themselves with the task of developing a lossless video codec just to see if it was possible (Blewer and Rice). In this sense FFV1 started its life as an experiment by FFmpeg project leader Michael Neidermayer to see if he could develop an encoding free of the technical constraints of any existing codecs. Because of its experimental nature, FFV1 spent years languishing in obscurity and without some of the critical attributes needed for work in the memory realm, including a lack of formal documentation and a lack of support for high-quality, 10-bit video (Ibid.). These are two of the reasons JPEG 2000 found purchase in memory institutions before FFV1 did.

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[29] https://www.loc.gov/preservation/digital/formats/fdd/fdd000342.shtml. Accessed on January 8, 2019.

[30] Evelyn McLellan, personal interview, September 20, 2017.

In 2009, Hermann Lewetz, media preservation specialist at the Austrian Mediathek in

Vienna, embarked upon a project to digitize one thousand analog video recordings in order to

put them online.[31] Lewetz experimented with the Library of Congress' nascent MXF/JPEG 2000

specification but could not make the test video files provided by the Library play back properly.

Lewetz knew he needed to losslessly compress the high-quality video he wanted to create, so

he worked with fellow Austrian preservation specialist Peter Bubestinger to cast about for an

alternative to JPEG 2000 that would generate similar, if not better, files. They discovered FFV1

buried in the FFmpeg software and began running tests on it. They found the larger European

preservation community to be wholly ignorant of FFV1 but Lewetz found that it served his

needs perfectly, so he began to use it for his preservation work.[32] Lewetz was, in fact, so

impressed with FFV1 that he decided to present about its use in the Mediathek at the 2010

joint conference of the Association of Moving Image Archivists and International Association of

Sound and Audiovisual Archives. It was at this conference that FFV1 as a viable preservation

technology for master-quality video files was unveiled to the international media preservation

world.

Despite the resistance he experienced at the 2010 conference, Lewetz reports that

many preservation professionals, mostly Europeans but a few Americans as well, contacted him

later and inquired about his use of FFV1. Lewetz put the code for his implementation of FFV1

online alongside test video files, and to his surprise found that there were over one thousand

downloads of the files within months of his presentation.[33] He found that as people

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[31] Hermann Lewetz, personal interview, December 1, 2017.
[32] Ibid.
[33] Lewetz interview.

downloaded and tested the files for themselves, they became much more amenable to his point: that FFV1 is an effective alternative to JPEG 2000 and uncompressed video even though it does not share the official standardization of those technologies. However, FFV1 remained a hard sell when it came to actual implementation in most of the memory realm in 2010.

Fortunately for FFV1 and Matroska, in recent years big players have leapt into the pool with both feet. In 2013, one large European media producer, the BBC, began to explore the utility of FFV1 wrapped in an MXF container for digitization of some of their video materials. Ian Henderson, an archivist at the BBC, decided that JPEG200 and MXF combinations like the one the Library of Congress was exploring were "fully interoperable across mainstream vendor software encoder/ decoder implementations."[34] Henderson ultimately chose Matroska instead of MXF because of the former's platform-independence, the wealth of playback solutions for it, its robustness for embedding metadata and, critically, its open-source nature.[35] Henderson, in making this choice, found that there was little online information about Matroska and FFV1 in preservation contexts, so he turned to the Austrian Mediathek and the City of Vancouver Archives, to answer questions for him about their use of these tools. Their support helped him make his choice and the BBC became what was likely the first large-scale repository to adopt FFV1 and Matroska for the preservation digitization of video.

If there was a tipping point in the move to general acceptance in the archival community for FFV1 and Matroska, it was Indiana University embarking upon a massive, campus-wide audiovisual digitization project. In October of 2013, Indiana University President Michael A. McRobbie announced the Media Digitization and Preservation Initiative, or MDPI, which is an

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[34] Ian Henderson, personal interview. September 21, 2017.

[35] Ibid.

effort to digitize all of the video and audio holdings of the university by its 2020 bicentennial. In order to perform the massive amount of work needed to achieve this goal, Indiana University has partnered with Memnon Archiving Services, a Sony company. According to Mike Casey, the Director of Technology for MDPI, once all of the analog video and audio has been digitized, the digital objects will add up to 65 petabytes of data.[36] At the time of my interview with Casey and his coworkers in March of 2018, they had digitized about 5.5 petabytes of time-based media content.

As the MDPI project was in its infancy, Casey and his staff and colleagues had to make decisions about target formats and encodings for the massive digitization effort. They began casting about for technologies that would best serve their work and immediately found that JPEG 2000 and MXF would not work for them because of difficulties they had playing back the files properly (Casey, 2017). They also faced the same constraints - albeit at a larger scale - that many institutions faced in terms of storage space for time-based media and they knew that uncompressed video, sometimes considered the safest choice for digitization because a minimum of compression is applied to the bit stream, would take up a massive amount of space. As Memnon began to press the Indiana University staff for a decision, they began looking at FFV1 and found that it could losslessly compress the digital video even though it incurred a 25% cost for the CPU load on the encoding computers.[37] The processor-intensive nature of the FFV1 encoding process was deemed a small price to pay for compression that can save up to 40% of storage space and be encoded more quickly than JPEG 2000 because FFV1 has a simpler

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[36] Mike Casey, personal interview, March 23, 2018.

[37] DaPuzo interview.

compression algorithm.[38] The MDPI staff also found that using the Matroska format as container was preferable to MXF because of its relative simplicity and ease of use (Casey, 2017). I will discuss Indiana University's work with FFV1 and Matroska at greater length in the discussion sections below.

4.5 STANDARDS EMERGE FROM THE CELLAR

The work to standardize Matroska and FFV1 is a move to create documentation that can conform future implementations of these existing technologies to an agreed-upon template. The CELLAR (Codec Encoding for LossLess Archiving and Realtime transmission) project, which is currently in progress, is a working group within the Internet Engineering Task Force, a standards-making body that has, in the past, focused on Internet-related standards. CELLAR is working to standardize FFV1, Matroska and FLAC (the Free Lossless Audio Codec), all of which have existed 'in the wild' for over a decade. Referring to FFV1 and Matroska, the CELLAR website says:

> There are open source implementations of both formats, and an increasing interest in and support for use of FFV1 and Matroska. However, there are concerns about the sustainability and credibility of existing specifications for the long-term use of these formats. These existing specifications require broader review and formalization in order to encourage widespread adoption (Codec Encoding for LossLess Archiving and Realtime transmission, 2018).

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[38] Kromer interview.

CELLAR acknowledges that there are specifications for Matroska and FFV1, and that files of

these types already exist in the world, but that these files were 'wild' because of their

homemade nature (in the case of Matroska, often in the course of copyright-violating

filesharing) and could not be counted upon to rigidly conform to any published standard. It is

too soon to know if CELLAR will create a standard that "harmonizes" all of the various wild

implementations of Matroska, but it is currently one of the group's chief challenges.

CELLAR derives from the PREFORMA project, a European Union funded project to create

open-source software solutions for various media formats like PDF, TIFF, LPCM audio, FFV1 and

Matroska (Blewer and Rice). PREFORMA is best understood as a 'meta-standardization' project

- the goal of which is to produce standards that govern and can conform various

implementations of existing standards (Jancovic, 2017). According to Ashley Blewer and Dave

Rice, "the goal of the PREFORMA project is to create open source software for the most

eminent archival-grade media formats: PDF, TIFF, Matroska, FFV1 video, and LPCM audio"

(Blewer and Rice, section 3). One of the applications designed by PREFORMA is MediaConch,

which is a tool that can be used to check the conformance of a file to a particular standard. This

allows the user to see if, for example, a TIFF object truly conforms to the TIFF specifications. It

became apparent, in the course of the MediaConch work, that FFV1, FLAC and Matroska had

such loosely-defined specifications that a conformance checker would have a difficult time

approving these kinds of files. For this reason, people working on MediaConch realized that, for

their work to be effective, standards would need to be developed for these technologies,

whose completely open-source nature meant that existing files could not be expected to have

much conformity.[39] This was the genesis of CELLAR, which has been funded to some extent

with MediaConch funds.

The MediaConch contributors knew that a recognized standards body would be needed

in order to convey legitimacy on the documentation for Matroska, FFV1 and FLAC. They

considered SMPTE and ISO, both of which are natural choices for standardizing time-based

media encodings and containers, but both of those organizations kept their standards

documents behind paywalls and "payment for access to standards runs counter to the ideals of

the PREFORMA project" (MediaConch, 2015). One of the underpinning ideals of PREFORMA

was the belief that digital preservation is best performed with well-described and adaptable

technologies and paywalls were seen as an encumbrance to this ideal because they make the

standards documentation (and thus the recipe for making files and encoding/decoding

solutions) closed to anyone who can't afford it (Ibid.). The other standards body under scrutiny

was the Internet Engineering Task Force, or IETF, and it was immediately attractive because of

the free and open nature of their standards. IETF not only has no paywalls for their

documentation, but they also have no licensing barriers for their products and they make their

standardization work completely transparent and well-documented, which cannot always be

said for SMPTE or the ISO (Blewer and Rice). Furthermore, IETF was all the more attractive

because it has a history with time-based standards like the OGG container format, VP8 video

format and the Opus audio format, all of which are completely open (MediaConch). There was

initially mild disagreement within the group about using the IETF for standardization - it is, after

all, a bit unconventional to *not* use SMPTE or ISO for audiovisual formats - and some of the

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[39] Ashley Blewer, personal interview, September 13, 2017

group also questioned whether an Internet standardizing body would understand the needs of archives, but ultimately some of the members successfully made the argument to use IETF.[40] (The IETF does, in fact, have a long history of collaboration with archivists and librarians, even though most of that work was not with time-based media containers or encodings.)

It is important to note, however, that CELLAR is not only comprised of representatives of nonprofit entities. Google has representatives working on the CELLAR work, and they have added material to the Matroska specification that has no direct preservation-related import. For example, as Dave Rice told me, Google wants to see support for 3D and virtual-reality video streams which could be useful for their enterprise but has no immediate utility for archives and libraries. According to Reto Kromer, there is also the continual push by Google-employed participants to keep the nascent CELLAR Matroska specification backwards-compatible with WebM video, which undergirds much of YouTube.[41] The strong influence of Google, which will ensure that CELLAR's Matroska standard carries with it at least some of the politics of that business, is another example of the haziness in distinction between for-profit and nonprofit influence and impact described in the previous section.

The CELLAR work has proceeded briskly over the past two years and the standards for Matroska and FFV1 are nearing completion. Steve Lhomme told me that his work developing Matroska was done in his spare time, and the work did not move very quickly.[42] However, the CELLAR group has been able to marshal more resources than he ever could, and the

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[40] Blewer interview.
[41] Kromer interview.
[42] Lhomme interview.

conformance of the format to their nascent standard is able to move more quickly. As of this

writing, the CELLAR group is fast approaching finalized standards for FLAC, Matroska and FFV1.

CHAPTER 5: INTERVIEW DATA

In order to set the stage for discussions of the standards, their meanings to various professionals and how they are used in these professionals' work, it is necessary for me to include pertinent interview data. I have broken this section into two subsections - one for MXF and JPEG 2000; one for Matroska and FFV1. I will include my interviewees' verbatim quotes with minimal commentary in order to use this data to underpin the discussion sections which will follow. Comments from interviewees about AS-07 can be found throughout this section but they are mostly to be found within the JPEG 2000 and MXF section. Likewise, comments from interviewees about CELLAR and its work can be found throughout this section but are mostly to be found in the Matroska and FFV1 section.

5.1 JPEG 2000 AND MXF

One of the largest memory institutions to adopt JPEG 2000 for video preservation is the Library of Congress. James Snyder is a head of video engineering at the Library. He explains the Library's choice to adopt JPEG 2000 thusly:

Q: So, I want to come back around to something that you mentioned a couple of minutes ago that surprised me a little bit. You said that 10 years ago the Library of Congress was on the bleeding edge but not now. Can you dig into that a little bit?

A: Well that's because the industry itself has caught up to us. We were on the bleeding edge because folks like Carl and Jim Linder[43] and a couple of others made a brave

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[43] Carl Fleischhauer of the Library of Congress and Jim Lindner, video engineer and entrepreneur.

decision to say JPEG 2000 mathematically lossless wrapper was the way they wanted to

go. And Jim Linder created the team that created the first encoder. That was exceedingly

brave and about as cutting edge as you can be. You're not just cutting edge, you are the

knife that is cutting at that point. He saw a problem, and he said, I am willing to take it on

something new based on these standards that will solve this issue because JPEG 2000

was the first compression scheme that had a mathematically lossless, which means

completely irreversible or completely reversible, compression scheme that left no

footprint. That was remarkable, there was no other compression scheme at that point

that could do that. And so that was revolutionary, it was one of the revolutionary parts of

this business. Well the business since then has caught up, we've learned the lessons of

SAMMA and other folks have created other things like FFV1 and Matroska. other

institutions like NBC Universal and 20th Century Fox have adopted JPEG 2000 lossless

because they see the value of it. And also JPEG 2000, both lossless and lossy, has gained

a lot more traction in the industry. And so, there are quite a few product lines out there

which may not be mathematically lossless but they're the next steps down. Since the

decision was made here to do JPEG 2000 mathematically lossless, the digital cinema

industry has settled on irreversible 9/7 which is the first lossy version of JPEG 2000, it's a

hierarchy of lossiness. Mathematically lossless is up here and then there's all the lossy

formats. and so all your digital cinema stuff is now all JPEG 2000 irreversible 9/7.[44]

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[44] James Snyder, Personal interview, April 27, 2018.

James went on to explain how the Library of Congress, even though it is a very big institution, may not have much power to motivate the large moving image producers in the United States:

Q: The [Library of Congress] name helps a lot. It's the library everyone has heard of.

A: It's the library everyone has heard of, although it's interesting, here they have a certain perspectives which is like, we're the Library of Congress. Everybody's heard of us. And by extension, to them that means, and we are more important than everyone else. And Industry is going to listen to us. Whereas most of the content industry is like, oh the library. Yeah that's where we send our copyright submissions, right? And that's it. The Library of Congress is not even on their radar other than as a name. And so folks at the library are assuming, you know I've had lawyers, I've had administrator say, well why don't we just go to NBC and tell them what to do? And the answer is, because NBC is going to ignore you. But they don't want to believe that.

James Lindner's comments about JPEG 2000 in my earlier history section point to the most appealing aspect of the encoding for many repositories: its ability to maintain image integrity while still making video files small enough to save considerable resources during storage. Ashley Blewer, who has worked on the CELLAR group since its inception, has this to say about JPEG 2000:

Q: So, thinking about FFV1 and Matroska particularly, leaving aside FLAC for the moment, what would you say are the strengths of these two standards? So why would I - I'm working in preservation, let's say - why would I choose these and not choose something

else - MXF, JPEG 2000, AVI, the whole bevy of stuff out there. Why would I choose these?

A: I will be a preservation evangelist here! The obvious, simple answer is that they are open formats and so you're never locked out of having the knowledge to work on these themselves and they were picked for that reason. When we decided to go with IETF to standardize, that was a big important part of that too. So that would be open forever. For me that's the fundamental - there are adjacent reasons why they're good as formats, but overall it's because they're open that makes them such a good fit for preservation. Like there was that problem with JPEG 2000, like the Open JPEG standard which was really just like a hack on top of reverse engineering JPEG 2000 where there was like an error and so it's like you're already seeing signs of like, what prohibits the ability to do long-term preservation and these standards when you can't actually see how they're built.

Q: I didn't know about the error in the Open JPEG standard. Could you talk a little more about that? What is that?

A: I don't know that much about it. If you talk to Reto Kromer, he was really invested in calling it out. It's just that JPEG 2000 is not an open standard but they've sort of reverse engineered it to make it like you can build on top of it with Open JPEG but there was an issue in which it was just like not creating perfectly-replicated files. I don't know, I could pull up the details later. It's hard for me to articulate.[45]

One of the challenges in implementing JPEG 2000 for video is that the encoding cannot natively declare its own aspect ratio - it must rely on the file container to record this

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[45] Ashley Blewer, personal interview, September 13, 2017.

information. Dave Rice, archivist at CUNY and contributor to the CELLAR project, positions this as a potential liability of the encoding.

Q: Why would we choose lossless generally, and if we were going to, why would we choose FFV1 out of the array that we have to choose from, like JPEG 2000, FFV1-like, why would you choose FFV1 in particular?

A: ...I think FFV1 offers more - at least in version three and higher - offers more ability to be self-descriptive. So it can - FFV1 can declare its own aspect ratio, and interlacement data. With JPEG 2000, there's a lot of characteristics it's not able to save by itself, like it cannot save it to RGB or YUV. It needs to depend on the container to do that. So often, like, step processes that link the container to the encoding is defined through, like, a separate specification. So like, you know, it's possible to have a player that plays MXF and it plays JPEG 2000, but it doesn't play them together. Like, when they're in a single file. So like I think that - the difference in self-description means they're - there's more room for there to be interoperability issues with JPEG 2000 in MXF, than FFV1, which is more self-descriptive.[46]

According to Nick Krabbenhoeft, digitization specialist at the New York Public Library, JPEG 2000 had liabilities that made it unsuitable for use at the Library. One of the issues he sees with JPEG 2000 is that its standards documents are not free of cost.

Q: What informed the decision, from your perspective, to work with FFV1? Why that instead of something else, and was there something else that you tried before that?

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[46] Dave Rice, personal interview, September 8, 2017.

A: I have to admit, I had an initial comfort with MKV at the very least because of piracy in my earlier days and having known that format, it's kind of subtitling abilities. so that was one thing that sort of turned me on to looking into this combination. I know that's just the container but, it's like, hey I'm at least familiar, this is not a far out wacky idea. So the idea was just, we had the specs that said we are going to do it on compressed and the first thing that jumps out to me is, well what does lossless compression look like. It had been a fairly theoretical issue for me in the past, but it was something that I felt comfortable jumping into. So as I jumped into it, it came back to the question of the only two standards that people are really talking about are FFV1 and JPEG 2000. FFV1 it being based out of FFmpeg and FFmpeg being such a poor utility that is used in a lot of places, I felt there was some immediate comfort there that gave me a little bit of, or reassured me about its usefulness. JPEG 2000 for too long I had been reading up on people struggles with JPEG 2000, a lot from the still image community, but it's supposed to be a free and open thing that's done for library purposes, but that's… I would say that it being pitched like that actually made me look at it askance because it felt like having been so heavily pitch for our purposes, it never really got the backing, the industry backing but it needed to actually be used beyond those places. And then you look at analysis like Johan van der Knijff and people like that that I've been looking at the different implementations of the codec and libraries that can pull it off and how they are not all as good as one another, and if you, probably the better still images are locked behind commercial

paywalls. They're locked behind commercial licenses. So I was looking askance at it for that.[47]

MXF is the container format the Library of Congress has chosen for their master-quality time-based media materials. AS-07 is the Library's specification for how JPEG 2000 and MXF are implemented locally. James Snyder told me why the Library has invested the time and effort to develop a document like AS-07 and why standards are important to work like Snyder's:

...standards needed to be set because the only way that content can survive overtime with a high-level, high expectation that will actually survive, is to build things to standards. Because standards give vendors and code writers, all the people who create the machines in the software that makes all of this happen, standards are the only way to have anything close to a guarantee that files produced at the Library of Congress could be used at Indiana or NBC New York or the BBC in London or whoever needs to use the content, or the British library, or Library and Archives Canada. Library and Archives Singapore. . If [standards] don't exist you will have interoperability issues, you will have issues just like the first JPEG 2000 files where you couldn't play SAMMA files on another vendor's machine, on an OpenCube or something like that.[48]

Lars Gaustad told me that the National Library of Norway considered MXF but found that one of the challenges of implementing the container was the looseness of the standard,

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[47] Nick Krabbenhoeft, personal interview, January 18, 2018.

[48] Snyder interview.

which led to the broad array of implementations of it. The protracted development of AS-07 is also, according to Gaustad, a potential limiter for its adoption.

Q: What has happened that has made you [change your mind regarding Matroska and FFV1]?

A: Well first of all, this was at the very start of MXF and we didn't recognize the fact that it's such a broad standard which allows for so many different things so the fact that all different vendors chose different implementations of it and we ended up with a compatibility problem was not that was not something we foresaw at the moment. And then of course the different the different application schemas came around to two sort of well you had the broadcast industry got their variant on everything and then we had this work with AMWA, with FADGI involved in it, to develop the AS-07, and that has taken forever, and that is part of the problem with standards as it is, they take forever to develop and the world moves on as the standards are written. So which is why I thought we have to do a conformance sort of a work on the SAMMA files to make them compatible with what is now sort of the standard that everyone uses and I believe I will not make valid MXF. I think I will suggest that we move to a FFV1 and Matroska instead.[49]

Gaustad went on to talk about the problems, as he sees them, with implementing MXF across a wide array of tools:

Q: so I actually only have one more big question for you and it's asking you again to flesh out something that you said that stood out to me, you mentioned again at no time to

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[49] Lars Gaustad, personal interview, December 20, 2017.

wait that "MXF is a compromise of many interests and there are many incompatibilities"

and you've talked about this already a little bit but I was wondering if you could just kind

of flesh that out again. What did you mean about that, that many interests and many

incompatibilities?

A: the whole point of MXF involved quite a few of the vendors that were in the market as

well as archival people. And the fact that MXF is so full of choices, for which you can

choose to use in your implementation, makes it more and the fact that you have to make

AS-07. I mean all these flavors of it means that it was a compromise at the time when it

was written, and I guess that it was just I'm not sure if they should have worked some

more on this or ended earlier with a more stringent format that didn't allow for this and

so yeah. So I mean all the different vendors have different choices which means that if

there's some MXF that you can't play it on OpenCube and everything and all these things

which sort of suggests that it isn't a standard at all it's just a suggestion for something. So

of course that has changed with the application schema some things like that. But yeah I

think MXF was a compromise of all the different stakes that were in the development.[50]

The development of AS-07 is tied to the Library's use of the SAMMA videotape

digitization system. The earliest versions of SAMMA produced files that had interoperability

problems with other systems - to the extent that it was very difficult for the Library to find

vendors who could build solutions for these files. According to James Snyder:

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[50] Gaustad interview.

...The SAMMA guys when they invented the first JPEG 2000 encoder didn't actually, were not actually completely MXF compliant. And so what that means from an interoperability perspective is that when you played a SAMMA file on an OpenCube, if the OpenCube didn't know how to read it, the custom implementation of MXF in JPEG 2000 that SAMMA came up with, if the software has not been written to decode it properly, it can't decode it properly and that's why JPEG 2000 files, the early SAMMA files couldn't be played properly. And that's because the early SAMMA encode software writers made certain assumptions which turned out to be wrong. They were not standards-compliant.[51]

Kate Murray, who works for the Library of Congress as, among other things, the lead developer of the AS-07 specification, told me that the document serves not just as a recipe for making compliant files, but also has an educational function.

A: So AS-07 is an application specification that's geared to the needs of long-term preservation and archiving. And some of the unique features around AS-07 - well I would say, step back a moment and say, AS-07 as a specification is sort of a unique hybrid among specification documents, I would say, there's sort of the "shalls" and the "shoulds", right? The requirements, encoders, but the specification also includes a lot of background information for people who are coming to this in a new way, right? That they don't necessarily haven't thought about how to label their timecode, anymore-or pardon me, or have looked at their timecode before, or why they should keep multiple working

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[51] Snyder interview.

timecodes, legacy timecodes, and you know, why should they try to keep all of their

closed caption and what's the difference between time text? And there's all these other

areas. So I think there's a great value add, in the specification document itself, for those

who are sort of new to the experience of, sort of, these complex collections.[52]

Murray also notes that FADGI is not a standards-making organization:

[FADGI], you know, welcome[s] anyone to participate in that work who is a FADGI

member and we've had, you know, people participate as their time allows, right? So

we've had active participation, at various times, from the National Archives, even though

they're not an MXF user, and from other agencies and we have been working within

other standards bodies, right? So an important thing to note, as you know, is that

FADGI's not a standards body, right? We're in the guidelines - we're not a standards - you

know - We're not a standards organization. So we're looking at the standards that other

people make and basically creating a subset that we think, pulling from lots of other

documents and creating a subset that we think, you know, encapsulates the need for the

archiving preservation community…. So if we have a specification application, which is

published by FADGI-but if it's moved to a standards body, it will have more staying power

in the community. It's - you know, FADGI is well known, to an extent but not everyone

knows what FADGI is, right? And there's also - it's easier to map things, like new

encodings into MXF-like there's a bit of an ongoing effort, and I admit I don't know where

it stands at this moment, to map FFV1 into MXF, which would be great, right? So it's

much easier if you have a sort of a stable, labeled standard by a recognized standards

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body to increase adoption and to encourage, you know, vendors to build tools around that, if it's in a stable space.[53]

The SAMMA video digitization system was the catalyst for the AS-07 specification. The potential to 'set and forget' the SAMMA and use it to digitize video materials *en masse* with little or no supervision made the system very attractive to audiovisual repositories that had large quantities of cassette video. According to Herman Lewetz, the Austrian Mediathek considered a SAMMA but, upon finding that FFmpeg could not play SAMMA-produced files with color representation problems, decided against using SAMMA, MXF or JPEG 2000 - hence the decision to investigate FFV1.[54]

Scenesavers is an audiovisual preservation/digitization vendor near Cincinnati, Ohio. I interviewed Jim Bird, the head of the business and Jim Schupert, the head video engineer. They talked with me about their experiences trying to make AS-07-compliant files and trying out the SAMMA system.

Q: So can you tell me a little bit about, and again you may already have, but what are, what kinds of customers use FFV1 Matroska versus MXF JPEG 2000? So you've got LOC with this WGBH collaboration thing - are there other people who are asking for MXF and JPEG 2000 outside of them?

Jim Bird: We've had a handful, I can't remember offhand outside of the LOC but I know we've had, we lost one project because, we weren't really preaching, we were trying to

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[53] Ibid.

[54] Hermann Lewetz, personal interview, November 24, 2017. The audio recording for this interview failed completely and I was left with only the notes I took during.

talk them out of JPEG 2000 MXF and we tried a little too hard and they ended up

walking and voting with their feet.

Q: Are you able to say more about that?

Jim Bird: I'm not sure if I can remember who that was if that was something from Texas

maybe…

Jim Schupert: I'm not remembering yeah you know what you're saying sounds familiar

but I don't remember…

Jim Bird: I think we did eventually have them come back and do something but there

was a time when I would say we kind of couldn't do JPEG 2000 or at least we couldn't do

it to scale, and I think American Masters kind of forced us to tool it up to be able to

handle that so we really tried to talk people out of it for the longest time and we usually

were successful.

Jim Schupert: In truth my joke was, since the year 2000 I've been trying to do JPEG 2000.

I haven't been able to do it yet. it's just like oh yeah it's only within the last three years

that it's even been any kind of reality unless you had a SAMMA and we don't buy half-

million-dollar SAMMA boxes. we've had a SAMMA machine in this building, demo'd.

We've demo'd tons of stuff.[55]

According to Hermann Lewetz, the AS-07-compliant files that the Library of Congress is

creating are themselves black-boxed, in so far as the Library has not had much occasion to open

them and play them out. He believes that this is a potential problem for the Library because the

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[55] Jim Bird and Jim Schupert, group interview, March 22, 2018

Library's staff cannot be certain that these files will not have the kinds of problems that Lewetz encountered when he tried to create AS-07-compliant files.[56]

Lars Gaustad was, in 2009, very excited about the potential utility of MXF for the preservation realm. As he puts it:

Q: So what about the SAMMA system and MXF/JPEG 2000 appeal to you and your institution? Why did you choose that back in 2009?

A: Well MXF was a standard with a SAMMA variant that was developed prior to the standard which has caused some problems in terms of compatibility. But yeah it was the standard and we thought it was the one standard that was going to conquer the world in terms of moving image preservation.

Q: And what about it what made you think it was going to change or conquer the world, what about MXF?

A: Well it was it sort of covered all the necessary elements that you need to preserve to get the rdf and JPEG 2000 was losslessly JPEG 2000 was attractive choice. We do all bookscans in JPEG 2000 as well so we had quite a knowledge on the format. And yeah I guess that was mainly why I mean… We thought it was going to be the one the archival world was going to embrace, which they haven't in some sort of way, I think.[57]

Ben Turkus, of the New York Public Library, discussed his views on the Library of Congress' stature in the preservation realm as well as the future, as he sees it, of AS-07 and Matroska and FFV1:

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[56] Lewetz interview.
[57] Gaustad interview.

I mean, the Library of Congress, I think, is really, like, kind of like the elephant in the

room, on some level. Like, I think if they-so many people look to them to lead the way,

you know? And I think in this case, they have invested in something that - at least the

JPEG 2000 side of it, is not going to - I just don't think it's gonna win the day. The MXF

side of it? I think is super solid, you know, I would never diminish all of that hard work,

like, I go to read the shims and I don't even know what the hell I'm reading, you know?

Like, I know that people put time into doing this right and in some way-an FFV1 MXF

combo, I think, seems interesting and appealing, but it's not really something that you

can do, you know? But I think Matroska is going to make, you know - I see them doing

the things that they need to do to close the gap, you know? And I think it's gonna

happen. I think there's also, like, lots of interesting potential in MKV in general, you

know? And, I mean, the wide range of tools that are available? The fact that a lot of the

people that are working with this are like, you know-they don't care about archival

work, they care about, like, VR and 3D and stuff, you know? And like, they're - they're

kinda doing interesting, cutting edge, contemporary media stuff at the same time, you

know? And so if we can align ourselves with them, I think it's very smart.[58]

James Snyder acknowledges the risk of vendor lock-in, which has always been an issue

in the production and preservation realms since so much specialized technology is often only

produced by one vendor.

Q: So going with SAMMA, were you ever concerned about vendor lock-in?

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[58] Ben Turkus, personal interview, September 29, 2017. There were technical difficulties with this interview that led to the capture of only the interviewee's portion of the recording.

A: Of course, I mean vendor lock-in from my perspective, coming from the industry that I've come from, vendor lock-in is always a concern. Period. So that's why we keep having all these lectures from the office of contracts about, well you know, you need to do vendor diversity. And from my perspective it's like, dude, preaching to the choir. I have been part of efforts in the industry where we have spent, I've worked for major networks and production facilities over the years, and I've been part of projects where they have literally spent tens of millions of dollars and they have nothing to show for it after they have spent that money. Nothing to show for it, because they didn't do their homework, or maybe the rules weren't even invented yet, and so they went through this effort, spending tens of millions of dollars and realized, oh, we are in a cul-de-sac and we can't do anything… So I know from personal experience, having been a part of some of those effort, that it is really, really easy to spend millions of dollars and have nothing to show for it. And so that's what keeps me awake at night.[59]

As Hermann Lewetz said in our interview, the Library of Congress made their decision to push developers to make solutions because the Library has the money. According to Lewetz, the danger is that other, small institutions will look to the Library and try to emulate their solution, which would be too expensive for them.[60]

Kieran O'Leary of the Irish Film Archives gave his thoughts about AS-07 and his choice to not implement MXF and JPEG 2000:

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[59] Snyder interview.

[60] Lewetz interview.

Q: Did you consider using FADGI's AS-07 specification?

A: To be perfectly honest with you the first time I heard about AS-07 was when I heard Kate Murray talking about it in Berlin last year. So I was aware of JPEG 2000 and MXF but I wasn't aware of this kind of specific preservation profile for these standards which I'm thinking that's really what AS-07. It's a specification or profile of these different formats would that be fair to say?

Q: Yes.

A: No I think if I'd known about it I would have been really interested in it especially in the methods like how it handles timecode all those legacy timecodes. It's very well thought through. What I would have been interested in would have been like if there was clear free open source tools and workflows for creating valid AS-07 files but really early on. So I can't talk about AS-07 really but JPEG 2000 and MXF just seemed wrong to us and to me in particular and some of my research. It didn't seem like it was a very welcoming format to go from to use from an open source low budget vendorless way of doing things. And I think that's probably changed a little bit with lib open JPEG and maybe things like that. But I think for the most part it just didn't seem like something that I really wanted to do or that I really wanted to push for. I didn't put too much time into researching it. FFV1 and Matroska was just so much more attractive.[61]

Jim Schupert of Scenesavers discussed how the Library of Congress has been locked into a kind of path dependence with respect to JPEG 2000:

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[61] Kieran O'Leary, personal interview, September 20, 2017.

The other thing that I have to say if I were James Snyder it's going to be really hard for me to eat crow and say FFV1 is just as good, because I have ridden this JPEG 2000 horse so hard and we have built how many petabytes of JPEG 2000, or maybe it's beyond exabytes or whatever, it's going to be really hard to say, you know I've changed my mind. I'm now Republican. I used to be a Democrat. So I will say nobody ever got fired for buying IBM, nobody ever got fired for doing what the Library of Congress did. It would be really hard to say, well that was stupid.[62]

Lars Gaustad told me that AS-07's adoption has been slow, but there are still people interested in using it, despite the "gloomy" feelings of some of the people working on it.

Q: Thinking back to No Time to Wait, and the CELLAR group trying to standardize Matroska and FLAC and FFV1 - what are your impressions of how their work is being received by the field?

A: I actually think there's huge expectations to having a standard to which people can move in and say okay this is the standard it's easy it's open and I mean in Europe there's a lot of organizations that's actually starting to use FFV1, in Matroska and started before even the standardization but that would I do believe it's going to give it another boost. I know I was at the IASA conference in September and I talked to Jan at CubeTech… and he was actually a bit gloomy about the enthusiasm that was around FFV1 and the lack of support and enthusiasm for AS-07 and actually Carl [Fleischhauer] was a bit gloomy as

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[62] Bird and Schupert interview.

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well. So we had a sort of okay guys come on, there's still a lot of people who want to use AS-07.[63]

I asked him to talk more about AS-07 and his thoughts about its utility and potential future:

Q: so can you talk a little bit more about why these why Carl and the CubeTech folks were a bit gloomy? Perhaps it's fairly apparent but could you talk a bit more about what was said what happened there?

A: yeah so they I mean Carl has put a lot of work into the development of AS-07, and sort of been trying to push it ever since 2012 or something I think and sort of and he said I'm not quoting him I'm just trying to remember, he said it's a bit depressing to see that the all the work we put into it may come to nothing because everyone is so excited about FFV1.

Q: do you think that AS-07 really will come to nothing? What are your thoughts on that? I mean the library seems still to be committed to it.

A: No I don't think it will come to nothing, I think that the big institutions with a lot of resources will still be choosing AS-07. And I mean the ball is still out within the library as well I mean I haven't made any firm decisions on it, if AS-07 finally comes to something reliable, and we see that there are more than CubeTech that actually is producing products delivering it we may still want to keep it because even though I have a huge IT department that will not have any problems maintaining FFV1 and Matroska, so no I think that the big archives will still want to work with SMPTE standards and the IETF is sort of on a sideline or on the outskirts sort of standardizing body for universal

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[63] Gaustad interview.

preservation. But so no I don't think AS-07 is out.[64]

During a group interview I conducted with staff from Indiana University and Memnon about their massive-scale collaborative digitization project, I asked about the project's embrace of open-source technologies.

Andrew DaPuzo: Yes, in fact it continues. When we were at the, where were we recently, was it AMIA or one of the other conferences when he got up and started to talk about, and that's where I first learned about the vibrant community. So that was the other thing. Whenever you are talking about open source obviously, there's no 800 number to call for support. So you depend on the community of people that are working on this to share whatever they're doing and to answer questions when you have them. And there was a relatively small community when we first got started with us but we have seen over the last couple of years that it's just, I don't have the numbers that were presented at that conference that we were at, but that community has grown quite significantly. And that's one of the benefits, all of these people, because they're part of an open source community, are very much willing to help you out.

Mike Casey: IU, I think about the library here has a particular comfort level going open source and being part of the open source community based on other things that we've developed.

John Dunn: Yeah, and I think that extends to IU as a whole so IU kind of embraced open source.

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[64] Ibid.

Andrew DaPuzo: You know I know one of the questions is what do you prefer, open

source versus commercially available solutions and I represent Sony. So I have to be very

careful not to bash in any way commercially available solutions, and I wouldn't. Even to

begin with I wouldn't because obviously Sony sells lots of various different packed

solutions and has their own camera formats and of course Betamax and whatever

whatever. But I don't know where I was, I can't take credit for this story, but it actually

crystallized for me when I was at AMIA and somebody, and you may have heard the story

already, somebody tells a story period frequently people think open source is free. I don't

know if you've heard the story. And the guy says well, there's free like a beer and free

like a puppy. If somebody gives you a beer, you consume it and it's done. If somebody

gives you a puppy, while it may be free, it's going to cost you thousands of dollars a year

with food and veterinary bills and everything else. This goes back and I don't want to take

credit for the story. But for me that really crystallizes it. because of you of the resources

of the people here in the department they represent and an 8000 square foot data

center and more than 300 people working within your IT building within the cyber

infrastructure building, yeah, open source is probably a good solution for you. But if

you're working as an archivist in a library where you have to fight for your workstation

and you don't have any support other than the Microsoft number that you call, maybe

not. So I think there's room in the world for all of these things. And from a Memnon

perspective, we are both sides. We use commercial solutions as well as open source

solutions.[65]

Peter Bubestinger, an audiovisual preservation consultant in Vienna, talked with me about the differences in need, in terms of video image quality, between broadcasters and archivists:

Q: ...Would you say that everyone is pretty much on the same page for what quality means in terms of FFV1, let's say?

A: Well, if you speak about containing the image information that was retrieved from the AD converter, starting on the digital side, uncompressed, that comes over the SDI stream, I would say there's nothing better than lossless or uncompressed because there's not more information in there to be gained and no quality lost because no information is thrown away. So that's one thing. The other thing is that there is the visually lossless thing, especially popular and broadcast and production where they go like, yes, we know it's a lossy compression, but it looks really really good in the signal-to-noise ratio so on and so forth. Everything is peachy. That's good enough. And, but then this goes again into the lossy lossless thing, and I would say, I wouldn't say it has to be lossless. Regardless if you can deal with it or not, that's just stupid. But I'm a bit reluctant of encouraging people to just not even try if they could have a preservation copy. Now we come to the preservation thing because broadcasters, who I have the impression are receiving the market focus on what tool and formats are being built for the audiovisual domain, they don't have a preservation mandate. an archive is supposed to preserve the material as

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[65] Mike Casey, John Dunn, Andrew DaPuzo, group interview, March 23, 2018

good as possible, as long as possible, and make it accessible. A broadcaster doesn't have to. They are preserving it for their use and they have a different focus in preserving it.[66]

Nick Krabbenhoeft of the New York Public Library told me, the GLAM (Galleries, Libraries, Archives and Museums) realm tends to follow industry because of the perception that industry specialists have a deeper understanding of production. He questions the logic of this stance:

Q: Were there any kinds of social or NYPL cultural factors that influence the decision to go with something open source?

A: Oh, open source. Not really. I don't think the push back that we got was on the open-source side of things. I would say, Well it goes back and forth. Because I feel like in the community of AV digitization there's a strong sense of, we should be doing what industry's doing because industry has it figured out and we can buy their equipment and do their things and we'll be just as good as they are. So I think there was some amount of preference for industry standards like that, but FFV1/MKV - the only push back that we got from an industry point of view was George Blood, when we first talked to him about implementing this for our vendor work he said, well I'm working on the MXF packaging standards that they were putting together with JP2 and he tried to promote that. And we pushed back on him. But that's a vendor, that's not internal. But the open-

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[66] Peter Bubestinger, personal interview, October 17, 2017.

source part was not that much of a hurdle to overcome.[67]

During my Scenesavers interview, Jim Bird and Jim Schupert told me that they often encounter librarians and archivists who do not have a deep knowledge of media engineering and preservation and so they will ask the company to just do what the LOC does.

Q: As you see it are there social factors that motivate the choice of Open Source versus SMPTE / industry supported standards?

Jim Schupert: yeah I think you'd have to say yes because you see like in Europe where it's embraced and why is it tacked down here?

Q: what would you say that is?

Jim Schupert: in my opinion it's because, here's someone who is a librarian and their background is maybe in books and they don't really know this thing called a videotape and you have somebody from the Library of Congress who says JPEG 2000... well they got to be right! you would be foolish not to agree with the Library of Congress

Jim Bird: It's a very complicated technology and if your background is in library science you probably don't really know a whole lot about exactly how that works. It kind of reminds me of the story that's off-topic a little bit, but I'll bring it around: We had a colorist who worked for us that worked for the company that invented the DaVinci color corrector. He was a smart guy and a good colorist and a good artist, didn't build a machines, didn't design the machines, but he turned the knobs and he knew how it worked. Well there was a company that sued DaVinci for patent infringement and they

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[67] Krabbenhoeft interview.

sued every customer of DaVinci and we were one, we were named in the lawsuit

because we bought one. He had to go to court and give a deposition and their attorneys

advised him, if you don't understand what they are asking you technically, just say "I

don't know." And he said, "I sounded like the stupidest person on Earth because they're

asking me all these things about how the machine works and I was like, I don't know, I

just turn this knob and it looks pretty, and I turn this knob and it looks blue. I don't really

know." So you think about a librarian, somebody that majored in library science, an MLS

or whatever that is, And you're talking about video signal and video technology and

video encoding and compression and it's pretty complicated science and if you weren't a

video engineer or didn't work with video a lot or you don't really understand… It's kind

of like to Jim's point, the LOC is saying you better do this so who am I to argue with

really smart people at the Library of Congress?[68]

Lars Gaustad talked to me about the challenges of understanding complicated

documents like AS-07.

Q: When you are reading a standard is it that you have such a background of technical

expertise that it's easy for you or do you find yourself sometimes reading some of these

standards and you need help with them?

A: Yeah. I'm talking to colleagues about what does this actually mean in terms of some

of the standards yes. Especially when it comes to how standards… are hugely

complicated to comprehend especially if you come from an analog world. And so yeah,

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[68] Bird and Schupert interview.

but then there's all younger guys who can sort these things out. I mean if you take the

AS-07, I mean it's for most people an incomprehensible document I think.[69]

Brecht DeClerq, preservation specialist at the Flemish archiving institute called VIAA,

told me about his choice not to use MXF and JPEG 2000:

Q: Okay. So, what brings you into the CELLAR world? So you're talking now how your

analysis of the FADGI work, and how that might be suitable-or at least, you know, a

couple of different profiles of J2K, MXF, for the broadcaster, for the cultural heritage,

but what has brought you to considering FFV1 and Matroska?

A: Well, actually, already when we opted for MXF and JPEG 2000, we were well aware of

the disadvantages of it. The disadvantages that we identified were the fact that it

produces very large files that are difficult to handle, that is hard to find suitable playback

software for it, that in fact, sustainability-wise it's very strong, but the openness of the

format is relative in the sense that the knowledge about the-the specific knowledge

about how to wrap an MXF to - I'm sorry, MJPEG 2000, coded file into an MXF wrapper,

was back in those days, very limited...[70]

Jean-Christophe Kummer, a co-founder of NOA, an audiovisual preservation consulting

firm in Austria, told me that the amount of adoption of a format is the biggest technical factor

that informs their recommendations for archives. For example, one of the reasons they often

recommend the Microsoft AVI container is simply because it is so ubiquitous that there is a

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[69] Gaustad interview.

[70] Brecht DeClercq, personal interview, September 22, 2017.

strong likelihood that solutions for encoding and decoding AVI files will exist into the foreseeable future. He also found that the costs of standards documents can make a standard unappealing to some memory institutions he advises. MXF, in particular, has documentation that exists behind a paywall and that can make it unappealing to some, Kummer noted.[71]

In fact, the cost of SMPTE standards was a key factor in how the IETF/CELLAR work has played out. In the words of Ashley Blewer:

Q: Right. So, thinking about the IETF, which is what CELLAR is a working group within, why has this group chosen to work within the - to be a working group within the IETF? Why the IETF? Why not SMPTE or AMWA or somebody else?

A: Open, open and free. Like we're 100% dedicated to working in the open, open-source, like, open-access, open everything. So like IETF was like a, we almost had to have bend, see how we could like bend to fit into something like IETF. But IETF is just, because it's like something for archives isn't necessarily for the internet, so we had to sort of make the argument that something for preservation could be standardized through like a body that standardizes specifically for like internet-based standards. Yeah, like SMPTE or ISO or anything like that were gonna like charge people money, and it's gonna become like a closed standard, and that was like completely unacceptable for us morally. And then also just working on having this come out of MediaConch and MediaConch being funded by the European commission and the European commissioner requiring MediaConch to be open-source, we weren't gonna like build open-source tools on a non-open standard. And plus they were already open file formats to begin with, we weren't gonna try to

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[71] Jean-Christophe Kummer, personal interview, November 11, 2018. The audio recording for this interview failed completely and I was left with only the notes I took during.

close them off and make some sort of pay-to-play version like that would be completely

useless. Yeah, and so 100%, IETF was just picked because its ethos is in alignment,

politically, morally, with ours.[72]

Ashley Blewer asserts that the fact of a lack of broad buy-in with respect to FFV1 and

Matroska in the preservation realm may be a part of its slow adoption.

Q: So what, if any, are the limitations in FFV1 and Matroska? You can say 'none' or just

answer however you like.

A: I haven't been paid to think about why it's bad (laughs). There are no doubt reasons. I

think right now the primary one is less buy-in, which is something that happen in time,

but right now since it's an emergent format, less people trust it and so - that's sort of

like not intrinsic to the formats themselves. That's more like a social problem.[73]

Brecht DeClerq told me he has reason to believe we may see a cascade effect in the

encoding's adoption across the continent, particularly in broadcasting.

Q: Okay. Honestly, I think we're coming to the end - you've answered all of my

questions, but I just want to just kind of open it up to you. If there's anything else you

would like to add?

A: I could go on for ages about this stuff, because it's one of the most intriguing

discussions, and you're absolutely right to include, as well, social and technical aspects. I

am sincerely wondering when broadcasters will-if and when broadcasters will start to

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[72] Blewer interview.

[73] Ibid.

use FFV1. Because some vendors in the field, like NOA, they produce software for

digitization workflows and media asset-archive asset management, they have been

endorsing FFV1 a lot. And their argument, arguing constantly that "Yes, FFV1 is a good

choice for a broadcaster too!" and they come always up with the examples of Slovenia

and Slovakia, where they do it and it's a good choice and everybody's happy. But I am a

historian who has a background in public television archiving, which is a special, special

kind of audiovisual archive because of its sitting on both sides of the question mark, I

would say-with one leg where, having a social responsibility, heritage responsibility I

would [unintelligible], still a broadcaster, you know? So that used to be my perspective,

up until five year-four years and a half ago. That said, I truly wonder, and it will depend

on the broadcasting industry, whether FFV1 can really break through as a globally-

adopted standard, for video, in the sense that I've been following the standardization,

also, of WAV, and PCM, or broadcast format BWF as a standard for audio digitization, as

a standard of master files and audio digitization...[74]

Marion Jaks of the Austrian Mediathek observed considerable pushback to her

colleagues' presentation about FFV1 at the AMIA/IASA conference in 2010:

A: During their early tests of FFV1, many archives and libraries argued for using the AVI

container because of its simplicity and ubiquity, but that simplicity turned out to be very

limiting for time-based media because it could not encapsulate all of the ancillary data

that the Mediathek wanted to save. We thought that there's a lot of connection

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[74] DeClercq interview.

between Matroska and piracy, but the main reason [for using AVI] was to choose something common. We didn't want to have that much discussion over the container as well as like we have with FFV1 because at the time this was so new to choose FFV1, and we thought okay we take the critique for FFV1 but we stick with AVI which is common there's no there's not so much prejudice about AVI at the time and it's very simple and we don't need the whole functionality of Matroska for example. But we did think in the last couple of years to switch to Matroska this is actually on the plan, yeah, we're planning… We also got a lot of critique for AVI because of it being so simple and we did have to explain quite often when that happened that we don't put so much metadata in the container and that it was the reason or one reason to choose AVI. And I think now FFV1 and Matroska is becoming a common choice, more common than FFV1 and AVI so that'll be a good idea and the other thing is that when it comes to transcode bonded to the material we could use the bigger functionality of Matroska.

When I asked Jaks about the 2010 AMIA/IASA conference, at which her colleague Hermann Lewetz presented, she said the following:

A: What did happen was at conferences, my colleagues, peter Bubestinger, whom you talked to and Hermann Lewetz they when we made the decision the two were very outgoing about the decision because they thought FFV1 might be an option for other archives as well and they thought maybe we should spread the idea and they did get a lot of criticism in conferences and it also happened that and still happens today when

people from the Mediathek talk somewhere even if it's not technical at all, it's content based, the talk, we get criticized for using FFV1, so.

When I asked Jaks if the perceptions of FFV1 and Matroska are changing, she said this:

> A: I do think that it's getting better, but there's still it still happens that we are criticized and the criticism is very often not very much on a technical basis, I think it's often has something to do with FFV1 is by big archive, broadcast archives, not often considered very professional choice, and it does have a lot to do with prejudice I think.[75]

Lars Gaustad told me why the National Library of Norway moved to Matroska and FFV1 from MXF and JPEG 2000. The openness of Matroska's and FFV1's code was very attractive to him.

> Q: What about Matroska and FFV1 would be attractive at this point, over MXF and JPEG 2000?
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> A: Well, mainly because it's an open standard and I'm sort of obliged to choose open standards instead of closed standards in terms of policies, that's one of the commandments of the preservation isn't it? That's part of it and it's a huge community that's actually working and producing tools that that makes this easy for us.[76]

Hermann Lewetz voiced a frustration I heard registered often at the No Time To Wait conference when he told me that he is tired of broadcast archives behaving like they are the "normal" archives by speaking for nonprofit institutions like the Mediathek - institutions that

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[75] Jaks interview.

[76] Gaustad interview.

have very different workflows and obligations from broadcasters. He went on to tell me that, "I proved FFV1 is a serious tool for archiving."[77]

James Snyder claims that CPU power has increased enough over the years to make the computational power needed to encode JPEG 2000 video inexpensive to use, and this may obviate the advantages of FFV1.

Q: I wonder, if JPEG 2000 is essentially open, is it a matter of cost of technology, of the hardware, are the encoders expensive, is FFV1 somehow cheaper for the gizmos and wires and machines?

A: Not that I've been able to figure. If we have been talking 10 years ago, yeah, because JPEG 2000 does have a certain processing level because of the nature of how it works, where 10 years ago or even 5 years ago the ordinary computer platforms, it required more computing power to do a JPEG 2000 versus an FFV1. But that penalty, given how fast things are going with computing power, as far as I can tell that penalty has disappeared. It's no longer a penalty. So the original assumptions, which I had some issues with to begin with, they made an assumption, they didn't test it.[78]

Jean-Christophe Kummer advises many archives and libraries around Europe with respect to digitization and he told me in our interview that he finds the most vocal open-source evangelists to be younger professionals who started their careers after 2000 and come from a "geeky point of view" of self-taught, motivated coders who prefer to find their own solutions to

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[77] Lewetz interview.
[78] Snyder interview

problems rather than wait for large developers like Apple and Microsoft or standards bodies

like SMPTE or the MPEG.[79]

Snyder emphatically stated that JPEG 2000 is, essentially, an open specification and

anyone can write tools for it. He wondered aloud why the CELLAR group didn't just use it

because this would put them more in line with SMPTE and broadcasters and cinema:

Q: So I think the open source realm from which a lot of the CELLAR participants are

coming would say to you, well but I suppose if we don't have a tool, anyone could build

a tool. It's open code.

A: Well my question is, why didn't they do it with JPEG 2000? It's not like the JPEG 2000

code was copyrighted. They could have done that with JPEG 2000. Why did they decide

to do it with a different codec? To a certain extent I understand answer to that question,

which is, JPEG 2000 takes more processing by the nature of how JPEG 2000 is coded.

And that's a valid point. But with processing speeds and storage speeds being what they

are today, that differential is no longer valid. So my question is, you had a

mathematically lossless codec, why didn't you create open source tools for that? There

was nothing in the JPEG 2000 standard or licensing agreement that prevented people

from doing that. People did it because they, I'm speculating, my impression is folks

thought that there was a blockage to doing JPEG 2000 so they didn't even try. I may be

wrong, but as far as I know, no one in the open source community ever sat down with

the JPEG 2000 specs and tried to create open source toolkits from it, as far as I know

nobody has ever done that. And so my question then is, you had a spec where you could

have done that, you probably made your decisions based on conventional wisdom

which is, oh I think JPEG 2000 won't, the licensing agreement won't let me do it, so I

won't even ask the question. I'm going to invent my own thing over here which is FFV1

and now CELLAR.[80]

Hermann Lewetz presented his initial findings about his FFV1 experiments to many

members of the international audiovisual preservation community at the 2010 IASA/AMIA

conference. Lewetz told me in our interview that he experienced physical threats because of

this presentation - a vendor physically intimidated him by harshly putting his hand on Lewetz's

shoulder and intoning that his company "can't allow FFV1 for its customers." Furthermore,

Lewetz told me that he got bombarded with questions from conference participants, mostly

about the reliability of FFV1, and astonished reactions to his choice of using an encoding that

was not standardized by the ISO or SMPTE.[81]

Peter Bubestinger told me about Herman Lewetz's presentation for the 2010 AMIA/IASA

conference about using FFV1 and the reactions to it, including the intimidation Lewetz

experienced:

A: Herman said, okay I think we're ready, he can present this at a conference, because at

that time it was said there are only two things for lossless: uncompressed, or JPEG 2000.

And then Herman said, it was said to be a technical thing and there was nothing you

could do and we discovered FFV1 and then we said, hey let's tell others, let's exchange

opinions, maybe this is an option. And this is where the shit started. I remember

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[80] Snyder interview.
[81] Lewetz interview.

Herman returns from this conference, I don't remember which one it was, some IASA or AMIA, something that starts with i, and after he gave his talk about maybe there's a third option and even better it's freely available, it exists in FFmpeg and it's been in there since 2003, so there was now a plenitude of applications that supported this format without even knowing it. So we could just play back the files in VLC and basically any application that built against FFmpeg, and that are a lot, and also proprietary ones. They just supported this codec out of the box. And we were like okay, so we tell people, long story short, after this presentation and Herman returned I couldn't go there because it was like budget, only one person was allowed to be sent. He came back and he said, you know what happened? After I finish the presentation someone came up to me, put his hand over my shoulder, and said, we don't want our customers to know this or think about this.

Q: Interesting. Who was that?

A: I cannot say. Anyways. It was like, this sounds uncomfortable. And well, if you follow the discussions, that's where the infamous part started. Because now we were the Mediathek guys, known for, these are these open source weirdos that claim to have challenged the industry and they are ruthless, reckless, I don't know if that's the right word. They're using a format that no one knows and no one has heard of and that's really unprofessional and unresponsible [sp], it's not a standard, and how can they do this. And the head of the Mediathek came home from a conference a few months later and said, the people are shaking their heads what you guys are doing, I don't know what to tell them. I don't know if it's right what you are doing, what the hell.

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Q: Interesting. So after that conference, you guys became the "weirdos" and do you still feel that today?

A: Depends on whom you speak to. There are certain companies that suddenly they were kind of like really angry when we met at conferences. And that was really tense and there was not really a good dialogue, or not really a reasonable, rational dialogue. If anyone on the AMIA mailing list for example just typed in, if any question contained the letters FFV1, they'd be beaten to death almost. because then it was the same thing all over. How could you be so unprofessional to even ask this question, to even consider this format. Colleagues of mine and colleagues not of this institution but of another institution, got off-list emails that were like, I don't know if you know who I am, but please don't consider FFV1 because you shouldn't. And a very long text telling you that this format is just the worst thing that ever happened to preservation community. So it was really scaring people off and with people in the archiving domain who, judging what a digital format can do and what not and if it's good or not, that's really tricky. And if you don't have a computer science background, it's just impossible. So you have to rely on word on the street.[82]

Ben Turkus told me about how he sees attitudes changing about FFV1 and a potential generation gap with respect to its adoption:

it was something that George Blood identified at AMIA, like two or three years ago. Dave and my former colleague were giving a presentation that was based on Dave's, like,

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[82] Bubestinger interview.

sustaining consistent presentation. He wrote an article for the Tate all about how, you

know, there's like all of these attributes of digital and video files that we need to pay

really close attention to that were not, because they may impact playback down the

road, you know? And if we're not careful, things like aspect ratio and color space can be

totally screwed up. And, you know, I think FFV1 somehow came up in conversation

during this, and at the end George was kind of making this - made this kind of like, I think

somewhat like, wry statement about, you know, how it's like, "The cool kids are all

moving to FFV1," you know? And like, that's why people are into it, you know? And I

both was like, "Oh, it's like kind of dismissive, but also maybe true on some level." But for

me, like when I see the people that I respect the most in this field, the people that I go to

when I have questions working on this and trying to solve these problems, I think it-you

have to pay attention to it, you know? Like, I'm not going to say, "I will follow Dave Rice

blindly, wherever he goes." But, you know, I'm gonna take his recommendations

seriously and I think a lot of people feel the same way.[83]

Turkus claims that this divide can partially be explained by what he calls a "herd

mentality" within the audiovisual preservation realm wherein professionals from institutions of

similar profile tend to align their preferences with respect to standards, hardware and

software. Furthermore, he said that he believes FFV1 will win out:

...this is something that has, that I find both frustrating about the AV Archives world and,

maybe, encouraging on a different level, there's kind of like a herd mentality, and I think

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[83] Turkus interview.

in like the audio world, I find it frustrating, because I think broadcast wave is so ingrained

and there's some things about it that totally suck and there's an absolute unwillingness

to consider any alternative. But I think also, on the flip side, when we're able to get

together and say, "Let's build something for ourselves that actually, you know, will meet

all of our needs and give us a certain, you know, affordances that proprietary solutions

are not offering," There's tremendous value there. And, I mean, I've seen it in just the

few years that I've worked in this field, you know? There was no FF improviser to teach

me to how to use FFmpeg, you know? People weren't even really using FFmpeg all that

much that I knew of in the archives world. And now I use it every single day, to do all

kinds of stuff! You know, like the AMIA open source GitHub is like, home to some of the

most amazing resources. Ethan Gates' Cable Bible is a great resource, you know?

VRecord is huge, QCTools is huge, the AV Artifact Atlas is huge. Media Conch and Media

Info-like, all of these things are all connected, and to know that there can be a standard

being built that is part of this, I think is tremendously valuable. And I think it's going to - I

think people are going to, I think FFV1 is gonna win out, you know? I just don't - I think

it's just a matter of time, to be honest with you. But as Jim Lindner said, in his email,

standards are always changing and the fact that he's surprised on some level that JPEG

2000 is still a contender all these years later, when he was working on it back in like

2002, you know? I don't know, I mean, maybe, FFV1 MKV will have, like, a moment? And

then there will be something else later.

Ashley Blewer pointed out the need for support from administration and how standardization can help to gain that support from above:

Like my time at New York Public Library, I wasn't in charge of making those decisions but I worked closely with someone who is and him speaking to his stakeholders, you really sort of need proof of buy-in and I think that "it's not standardized" is a rhetoric that used to not use an open file format.[84]

Brecht DeClercq told me that sometimes standards discussions can almost take a religious timbre:

Q: Right, right. Okay, this is very, very helpful - thank you. Would you say that there-so, we've talked about the kind of technical reasons, but are there any kind of social dynamics within your organization? Any - an influential person's preference, or something like that, that has moved you towards, in particular, exploring FFV1?

A: I tend to say no. I tend to say no, in this - this is an interesting question, because I am not an IT guy, I'm a human scientist in the sense that I study history, and this is an interesting question on human actors could influence the discussion! I would say, indeed, I have seen in the world around me, that the discussion between MXF, JPEG 2000, and FFV1 MKV on the other side, it's slightly influenced by what I could maybe call ideological factors. I've always considered the heritage versus broadcast discussion as somewhat a, an almost pragmatic versus religious thing. Yeah, we [unintelligible] about the format and codec-codec and wrapper discussion, we have summarized it often here,

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[84] Blewer interview.

internally at VIAA as "the religious discussion." With the religious people. As to

summarize it, or metaphorize it, as a discussion that you cannot win with rational

arguments.[85]

Dave Rice describes the reasoning for his participation in CELLAR thus:

Q: Okay. So, talking about the CELLAR work, what drew you to working with this group?

A: I mean, I don't know - I was kind of initially involved in, working on the proposal to

charter a working group with the IETF, so I guess there's a question on what drew me to

participating in something with the IETF? I mean, but like, literally to answer your

question I was drawn to participate in the CELLAR working group because I helped start it

and I was supportive of the goals that we wrote down in the initial charter. But I mean, in

general, like I mean, I feel like it's kind of in the interest of the archival community to,

you know, be a stakeholder in the refinement of standards that we need to support

preservation work.[86]

This lack of fully-formed standardization caused one prominent video engineer and

digitization sage, Jim Lindner to publicly question Indiana University's choice of FFV1 and

Matroska. Mike Casey talked in our group interview at Indiana University about the response in

the Association of Moving Image Archivists to his 2017 white paper that detailed Indiana's

choice of technologies in their digitization initiative.

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[85] DeClercq interview.

[86] Rice interview.

Q: But you monitor the AMIA lists.

Mike Casey: I watch the New York Public Library use FFV1 and I think that our choice had something to do with that, I wouldn't speak for them but it's my sense. Other people are talking about it seriously.

Andrew DaPuzo: I think Mike's being a bit modest here. I think there are two issues, I think Mike and his team here a very well respected in the community so you're right, it isn't just the scope but the fact that they've done their research gives it some level of comfort within the rest of the community if you will. But we have to be clear about that, the rest of the community, because again I walk on both sides of this business, if you will. On the broadcast side you're talking about Indiana University and Mike Casey and they're like, who? But almost any cultural institution, whether it's a museum, higher education, anywhere in the world and fact if you mention Indiana University and Mike Casey it's like, yeah, I've heard him speak, I've seen his paper, I know what they're doing, I'm watching it very carefully at it's interesting. So within this community we find that if somebody has a question about FFV1, it's like, we'll check out what Indiana University is doing. And I'll tell you, more often than not, I'd say 9 out of 10 times, they're like, yeah we know that's why we're asking you. We know what they're doing, we want to know what you have to say. Which basically doesn't add a whole lot to the conversation.

Mike Casey: Part of my thinking and doing the white paper was that many times you choose a set of technologies and you want others to make the same choice because when you get to the point of needing of migration path in the future there are going to be resources and expertise to help get the tools that you need to go where you need to

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go. And of course I wanted to try to encourage the community of folks working on

cultural heritage preservation projects to consider FFV1 as a path to take in the hopes

that more people would go this route and we would not be standing alone.

Andrew DaPuzo: It benefits all of us because there's also the developer community,

right. Not only the past but the developer community now there are more people being

more innovative and I expect that only to grow in the future.

Q: You do see other people supporting it in terms of NYPL is also following a parallel

path. Have you encountered any resistance or anyone who has said, why are you doing

this, why wouldn't you use the FADGI spec or why would you do that... is anyone kind of

questioning it?

Mike Casey: Jim Lindner on the AMIA list definitely questioned what we were doing. He

did it very modestly for his time.[87]

Matroska and FFV1 have worked well for Indiana University but Peter Bubestinger

expressed some hard feelings to me about the school's use of these tools without investing

heavily in their development:

One short thing because you mentioned Indiana University. That was a major

breakthrough for the perception of FFV1. just because they put money where their

mouth is, but the bitter taste for me for my perspective is, so they have put a lot of

money into like, please digitize it in this format, and this is very helpful for our

community to have an argument that says, okay now can we please get over this

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[87] Casey and DaPuzo interview.

"nobody uses it and it's only a cheapo thing" because they're serious about it? The bitter

stuff is, I have not seen a single contribution from them, neither in time nor financially, to

what we did in order to make this format happen and keep it alive and so on and so

forth. And that's actually what I found a bit sad. But maybe they did and I just didn't see

it.[88]

James Snyder called the losslessness into question when he told me that FFV1 uses

interframe encoding - wherein image data is not encoded as discrete frames but instead is

predicted between key frames.

Q: ...So let's talk about the technology of FFV1, setting aside Matroska, maybe we will

come back to that and maybe not... would you say FFV1, all the industry concerns aside,

yeah it's about the same? Or do you have concerns at the technical level?

A: Oh yeah, I definitely have concerns. The only way to really know for sure whether

something does what it says it can do is to test it. And one of the problems with FFV1 is,

as far as I know, nobody has ever done the type of involved testing that JPEG 2000 went

through to make sure that it does all the things that says it can do. and one of the things

that was a red flag for me when I read the FFV1 back was that it had an interframe

coding ability. Interframe coding, at least previously with other codecs that do that, is

not mathematically lossless. so the problem is, until you actually get down and actually

get into the math and produced software and produce test files and test content that

can validate whether or not it can in fact do a mathematically lossless, perfect version of

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[88] Bubestinger interview.

content that's completely reversible with no footprint in it, no coding footprint in it,

until you do that testing you don't know whether or not FFV1 is truly mathematically

lossless and all its different modes. And so the inter frame coding part of it was a red

flag for me because if you enter frame code, that tends to mean that you are being

lossy, truly lossy.[89]

Jean-Christophe Kummer told me that he finds that brand-new archives tend to not

have any resistance to using FFV1 or Matroska, but older, established archives may resist them,

particularly if they have already sunk considerable costs into using something else.[90]

Ian Henderson, archivist at the UK Archives, told me some of the appealing features of

an archival encoding. These are features that went into the decision to adopt FFV1:

Q: What are the measures and/or signifiers for 'quality' do you and your institution apply

to the digital files that result from this/these standards?

A: In archival terms of 'quality': I would emphasise the aspects of (expected)

sustainability of the chosen format, it's lossless encoding, CRC per slice of FFV1 frame,

embedded set of technical, descriptive and identifying metadata, its open source nature

and ongoing development, standardisation process and documentation, and the ability

to edit and transcode, report on and perform checks on files all via freely available

tools.[91]

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[89] Snyder interview.

[90] Kummer interview.

[91] Ian Henderson, email interview, September 21, 2017.

James Snyder told me that a potential problem with FFV1/Matroska is that broadcasters may not be able to easily decode the files because of their preference for and investment in JPEG 2000 and/or MXF.

Q: you got name recognition, but your power is considerably constrained.

A: We have to, and this is another kind of interoperability, we have to work with them. We are part of an industry. We can't just put our foot down and say, we want you to do this and you will comply. Because the industry will probably say, pfft, no. seriously. So I'll tell you right now, if we went to NBC and said, we want all your copyright submissions to be in FFV1 Matroska, if we went to them today and said, all your copyright submissions have to be in CELLAR, it would be like, pfft. no. Why would we want to do CELLAR? It doesn't fit what we do, it doesn't fit our workflow, it doesn't have the feature sets, yada yada yada[92]

Audiovisual specialist Reto Kromer is a contributor to the CELLAR work and in our interview he told me how Google is a player in the CELLAR work and that Matroska is a key standard in YouTube's architecture.

Q: That leads me to the next question, which is very good. Have there been any, in the CELLAR group I'm thinking in particular with Matroska and FFV1, have there been any sorts of trade-offs or compromises in the design of these two would-be standards that you can think of?

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[92] Snyder interview.

A: to have peace and compromises regarding Matroska and the specifications because one of the goals that are underlining the project are that way keep as long as possible the compatibility with WebM Developed by Google, sometimes Google Implement something without having contact with the CELLAR group and then we try to find a way in which we can keep this compatibility alive without compromising too much. But sometimes there are things inside the specification that are not really elegant or not really nice, but they are allowed to have this compatibility. So sometimes you have to compromise on certain points. In Matroska, one of the goals of Matroska at the beginning was to allow to encode every audio visual element, even the interactivity of CDs and so on. That makes the structure a little bit complicated and all of these parts have been skipped out from WebM. But now WebM is developing independently, and it was [a fork from Matroska]. But now they have an independent development and we are trying on an individual level, because we know each other, to keep the compatibility alive as much as possible because for us, from the Matroska perspective, it is very nice if on the browser you have on the computer you can see DPX for instance, and you don't need a special software.

Q: Interesting. So would you say that this compatibility... so just a back up a little bit. One of the challenges, one of the compromises is to maintain compatibility with WebM, which is something that Google can change unannounced. This is because Google is such a big player? WebM is used so much and you want to make sure that the Matroska specification is compatible with it because of Google's power in the field?

A: No, no that's not the main goal. The main reason is that if a codec will be implemented

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automatically in the browsers, in the browser that you have on your computer, that would be a very very big step for using Matroska. And if we have this compatibility of data then you can read each Matroska file on a browser without any addition. And if these files don't use these very specific interactivity possibilities for CDs and DVDs, then you don't have problems. So you can play a Matroska file and you can play now a DPX that is inside a Matroska file.

Q: I see, so it's a benefit to a user and perhaps also a benefit to the adoption of, the increasing adoption of Matroska to maintain compatibility with WebM.

A: Yes, for me it's more, let's say a political question to make sure that Matroska is widely adopted.[93]

Steve Lhomme, Matroska's inventor, told me he considers the association of Matroska and YouTube to be a win for his creation and its legitimacy. He said he finds it amusing that his daughter, like most of the millions of YouTube users, consumes his invention without even knowing it:

Q: And what do you think? I mean, how does it make you feel that you created this thing fifteen years ago and now it's, you know, it's going through a standards body and perhaps being adopted more?

A: Uh, it's been fifteen years so actually there's been lots of steps to get there. Um the first step was actually when I was hired at DivX and just before I left, or right after I left, they decided to use Matroska for their own format. So that was the first victory. After

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[93] Reto Kromer, personal interview, October 18, 2017.

that, the other thing was of course there was a lot of demand because people were using

it to exchange illegal stuff and uh, and it became very popular because of that. Uh it's not

something we were looking for, something we actually made sure that even in that use

case people would be happy. So it worked very well. So the other important step was

when hardware manufacturers starting to make boxes that could read the Matroska files

or TVs that could read Matroska files. And from that moment I knew that it was going to

be there for a while and that a lot of people were using it. Then there was WebM, Google

and Mozilla created on their own, and like a month or two before it was released they

contacted us to make sure it was ok with them and give us the spec and see if there was

something wrong with how, what they did. So it was another big step to know that it

would be one of the main formats used on the web, especially um, as YouTube, like the

biggest video provider probably in the world, might be bigger than TV, so knowing that

people are, even I tell my daughter, she doesn't know but she's actually using Matroska

when she's watching YouTube. So yeah, that was all these steps that lead to the

specification and the fact that there's going to be a specifications and that it will be set in

stone will be actually, might be the highlight of all of that because that's actually what we

wanted when we started. Actually make a spec and people use it whatever way they

want. And um, it happened but it's still considered like illegal format or like a personal

project or whatever, so it's not considered as seriously as it should. So yeah, once that's

done then it will be another major step and we know it will be there for good, like

"mission accomplished" as George Bush would say.[94]

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[94] Lhomme interview.

According to Peter Bubestinger, the cost of standards is a barrier to access for many

institutions, particularly those of modest means:

Q: Right and the cost of access to the specification papers is prohibitive would you say?

A: It was just like a few thousand euros, just to then start the work of digging into, to

just figure out, I don't know how to say it. The budget thing with public institutions like

an archive, like the Mediathek, just the size of the Mediathek, it's the National Audio

Visual archive but as you know most of them are not that big. And most of them are

really really creative at figuring out a way of doing their work with the lack of resources

that I find all over the place. And spending 30,000 euros on one machine with the only

option of a decoder starting at 5000 for a single user license, that was the carbon coder

back then. So it was like, okay 35 and then we probably have problems that we don't

know how to deal with. Unless we ignore that and just use the MPEG-2.[95]

5.2 FFV1 AND MATROSKA

Matroska is an open technology. Jim Bird and Jim Schupert talked about how open-

source standards make sense in the digital realm in ways that SMPTE's closed standards may

not.

Jim Bird: Interesting. And that makes a lot of sense from a university community, to say

we want to be open. We don't want to be closed and tied to manufacturers.

Q: Right, because it's state taxpayers' dollars funding all of this, at a state university

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[95] Bubestinger interview.

Jim Bird: And the [solidness] of the SMPTE standard is if it's open source, just in terms of

longevity it's like the genie's out of the bottle, you couldn't stomp it out, it's everywhere,

everybody already has the source code and you know there's lots of people looking at a

lot of details about it. You know it's a little like DNS. Remember the frailty that was found

in DNS? There was in all DNS, about two years it was like oh my gosh, this has been

around since 1991. Well an open-source standard that is globally distributed, open,

eventually somebody was like, here's a way to make it better, here's a thing. You either

go with open and constantly evolving, that has levels, or lock down SMPTE big long

number.

Jim Schupert: Well like I said, SMPTE made perfect sense in the days of 1" machine. We

had Sony but we played Ampex tapes and it would have been a disaster if we would have

had to own every manufacturers'.

Lars Gaustad noted the speed with which the IETF is working to standardize Matroska and FFV1.

Q: The slowness with which [AS-07] developed has been part of what's prompted you to

switch over to FFV1 and Matroska not just the openness of the standards but the

slowness of the maturation of the FADGI standard you would say?

A: Yeah well even though Matroska and FFV1 aren't properly standardized yet, I mean

they are moving at the speed of light compared to normal standardizing work I think. I've

been involved with the standards in the audio engineering society back in the 90s and

early 2000s and it took us forever because one of the problems is it's voluntary work. I

mean you can always have your employer support you in it but still it's voluntary work

and you may meet twice a year so it takes forever to get results. That's been it is a bit

frustrating and I think the time scale of standardizing FFV1 and Matroska. It's

impressive.[96]

Reto Kromer discussed in our interview the "by and for archivists" nature of the CELLAR work:

Q: So thinking about the Matroska and the FFV1 work that CELLAR is doing, in your

words, what are these standards or specifications that are trying to become standards,

and who are they for? Like what is FFV1 and what who is it for, and what is Matroska and

who is it for within the CELLAR context?

A: Hey. Both the specifications are really now pushed and explained and so on inside and

archival world. So it's really done by and for archivists. It's not something that is

somewhere in the sky, but it's really concrete what can be used immediately and

Matroska, was born a container for archival purposes with political purposes, but archival

purposes. And FFV1 was not initially meant to be an archival format. It was more meant

to be an efficient codec I think for capturing and for working. I don't know exactly the

history of the codec but it's quite recently that it has been used really for archiving. Peter

[Bubestinger], he was very important and doing these first tests, but that's not so old.

And when I used first time FFV1, it was very long time ago, it was I think in 2003. That

was the version one of FFV1. And I used it for the first scanners that we have built in

order to have a stream and not a single image file that comes out. And I was using mainly

Huff YUV, but also FFV1 version 1. And now the migration that we did two and a half

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[96] Gaustad interview.

years ago, we migrated our archive from LTO 4 to LTO 6. We changed also the container

and the we changed also the container and the codecs, we changed FFV1 to Matroska,

FFV1 version 3 so now it's up to date and they would like to be able to do something

similar in the future with the formats that we use now.[97]

According to Ashley Blewer, one of the biggest challenges to this standardization is the

need for backwards-compatibility with the wealth of 'flavors' of Matroska files that have been

produced over the past 16 years.

> Q: What kinds of trade-offs or compromises have had to be made, from your
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> perspective, in, again, thinking primarily of Matroska and FFV1, within the context of the
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> CELLAR work, if any, in the design of the standard, standards?
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> A: Yeah, like I just mentioned, backwards-compatibility has come up a lot for Matroska,
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> just because there's so many Matroska files that have been made and have been made
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> in ambiguous ways. So maybe there are some way in which it would have been better if
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> it had been designed this way, but we're not going to change the design of it to
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> standardize, because it would create this like super-Matroska file, and… we wouldn't do
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> that.[98]

Dave Rice pointed out that CELLAR is not just comprised of representatives from

memory institutions. In fact, there are corporate interests involved in the work.

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[97] Kromer interview.

[98] Blewer interview

Q: So your charter is, kind of, narrowly defined as working with these three specifications - Matroska, FFV1, and FLAC?

A: Yeah, and kinda the first step is formalizing the language and expression in each of the specifications based on prior work of their individual communities. But often, in the charter, you'll see there is a subsequent step of making a new version of the specification, and what is added in the new version is just kind of based on the participants in the project. So, you know, because there are a lot of preservation folks in CELLAR, like, often new preservation features get proposed. Like, there's also folks from like, you know, Google that is using Matroska and its related format, WebM, to try to make all sorts of audiovisual material accessible that's coming to YouTube. Because YouTube's getting, like this hotpot, highly diverse collection coming all the time, but they need to make derivatives that are authentic to the original. So like, for instance, you know, the Google folks provided a lot of additions to Matroska, as far as like supporting virtual reality, or 360 degree video, or you're playing at, as like an eye in the center of space, and you need, like, you know, some sort of like glasses to help you, like, look around or scroll through. You know? It's not-it's not stuff that the preservation community is really struggling with yet, but you know, the communities that are trying to make videos accessible using the internet, like, you know, are working with that and things like Ambisonic sounds and stuff. In some ways, I find that this has been really helpful, that, like, there are different kind of communities participating in the process at the same time.[99]

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[99] Rice interview.

Dave Rice talked about the costs of standards documents and how this can affect their adoption in memory institutions.

MXF and Matroska, I mean, certainly have a lot in common, but, you know, I don't think - well, one thing that makes this a little tougher is that the SMPTE documentation is not public, so like, you can't cite it. Like, I could go to the SMPTE store, and be like, "Oh, there's an MXF specification that deals with something similar," and then decide if I want to put $300 on my credit card and download the PDF. You know, ordinarily, in the IETF, like, I'd prefer to use open specifications as a reference if I can. So like, if you go to the very bottom of the Matroska specification or the MXF one, you'll see a lot of cross-references to a lot of IETF documents. And like, you, if you're reading the specification and you see that this part is informed by another specification, like, you can click the link and go right there and read it. Like, it's all easily accessible. There are a few places that we link to ISO documents where, I think like some of them are public, but the use of them is a bit more constrained. But you could-you usually can still read it, but there are a couple places - I think particularly in FFV1 where it does cite ISO documents. I'm not sure if we cite any SMPTE documents yet. I mean certainly, the FADGI group isn't SMPTE, you know, I kinda consider their work a lot more transparent, than SMPTE normally. But their work builds upon SMPTE documents that, like, are not public. And it's like even when you go to SMPTE store, if you did want to download the PDF, you're very constrained in what you can actually do with the specification once you have it. Like it violates the license agreement if you download the PDF and I like, open it on my

iPhone and I have it open on preview on my computer at the same time. Like that is a violation of their license and makes it demand the specification be deleted. You know, so like - the terms of service over there get a little scary sometimes, if you like, read it. Yeah, but the FADGI work, I mean, on the other hand, like, they've been pretty solid at using Creative Commons licenses and using open documentation to build upon documentation that's not necessarily open.[100]

Josh Yocum, digitization specialist at the Northwestern University Archives, told me that the accessibility of the people working on the CELLAR standards is one of the main selling points, for him, of these technologies.

Q: Are there any dynamics in the larger audiovisual preservation world that have influenced your interest in FFV1? So any particular people or institutions - I think you've answered this a little bit, because you mentioned Reto Kromer and Kieran O'Leary, but is there anything in the larger AV preservation realm?

A: I mean, definitely one of the biggest - or one of the main things that I'd say directed me toward being more interested in FFV1 over JPEG 2000 was the fact that it was much easier to contact people associated with it, or people who were using it. Like, all I had to do was basically look at a listserv and find emails for people like Dave Rice, Kieran O'Leary, and we work - we use some of the same software as University of Illinois and they had recently done their big video digitization project with FFV1. So it wasn't very difficult to get contact information from them, plus they put out the white paper on

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[100] Rice interview.

FFV1, which once again, was more easy to find contact info, and generally speaking,

they were very responsive. I don't think there was anyone that I emailed about FFV1

who didn't respond to me in some capacity. Whereas, with JPEG 2000, I mean one of

the things I was curious about with JPEG 2000 was, in the FADGI - the FADGI Film

digitization documents, they mention how the Library of Congress is using JPEG 2000 for

film digitization, and that's something I'd heard previously, so I emailed the working

group, the AV working group person at FADGI to be like, "Can you tell me more about

this - like, how does JPEG 2000 work for archival film digitization?" and they forwarded

my email to the person who was in charge of that at the Library of Congress, and I never

heard anything back, so… it's kind of like - and there's not much information about

other people using that format, so, it was kind of like, "well, who else do I talk to about

that?" [101]

Brian Wheeler and Rob Mobley, two other technicians at Indiana University, gave their

thoughts about Matroska and its ability to embed captions into the file. According to them this

ability gives Matroska the advantage of helping the school be ADA (Americans with Disabilities

Act) compliant. Wheeler also noted that this ability may have given Matroska some

attractiveness in the piracy world.

Q: Right, at the University level. Is [captioning] a university rule that you have to have?

Brian Wheeler: actually it's an ADA thing.

Andrew DaPuzo: Yeah, ADA, That's not to say that everybody is in compliance, but if you

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[101] Josh Yocum, personal interview, October 4, 2017.

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are going to be in strict compliance with the ADA regulations, you need to offer closed captioning.

Rob Mobley: so I know that Matroska will allow you to embed the subtitles into the media itself, into the file. So it doesn't have to be a sidecar.

Andrew DaPuzo: Correct, that's what I'm saying.

Brian Wheeler: you can put that in there, you can put captions, you can put chapter marks, you've got all these other features. And that's possibly why the piracy community loves it so much, because you can more faithfully reproduce what was on a DVD. all of those bits had a place to live.

[later]

Brian Wheeler: It's my hope that as time goes on and more people pick up both FFV1 and Matroska as a pair, that we'll start to see more support in editing tools. That's a stigma of oh, MKV is piracy format, will go away and Premier will start to support it and we'll get some codecs and we can start using Premiere and we can start using other tools. I think it's going to be a long long time, but I think it will eventually get there.[102]

   According to Andrew DaPuzo, Sony never questioned Memnon's decision to implement FFV1 and Matroska was never questioned by Sony either, even with Matroska's history of association with piracy and Sony's earlier resistance to supporting the container in its early Blu-Ray players.

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[102] Rob Mobley and Brian Wheeler, group interview, March 23, 2018.

Q: Andrew this is a question for you. In the course of my research as I've talked to people about Matroska one of the things that I've heard from people who've been developing it and using it in the cultural heritage realm is that they have experienced a certain resistance and some quarters when they talk about Matroska because of its perception as a piracy format. You work with Sony and you're doing FFV1 Matroska. Can you say, has there been any eyebrows raised at the fact that were using this?

A: Absolutely not, not at Sony, and not within the market. Nobody's really had... the only push back we ever get is that we don't have the resources to work with it. Which comes back to that, free like a puppy story I told you before. They'll say, it's basically me and my Mac, I can't download the tools easily to play and work with it and my editing suite, I have Adobe or I have Final Cut. It's not as easy as Pro Res 422. That's really that's really the only push back I've ever gotten. Now having said that, some people prefer Ford and some prefer Chevy. So there's going to be those people who say, I like JPEG 2000. And there's going to be those people that say, I like FFV1. And our position in Memnon is fine, we do both. And as a service provider we have to do both. So the initial challenge for us was when Indiana University said they want to do FFV1 Matroska, limited community so we had to spend very hard our resources in Brussels… to develop it. But since that time, if a client wants it, it's not a problem. And again, never had the MKV been an issue for that because I've dealt with torrents before. I was at Sony and fact, working in New York City, and even the BitTorrent as itself isn't always used for piracy. So I had the misfortune to be working with a book publisher, a large one that had used a torrent like file delivery system and within I would say 10 minutes of opening that file, I had half a dozen Sony

security people visit me in my office. Because they had detected through their firewall that this file had comes through and rather than block it, the position at the time was, we're going to go to the person who downloaded it and find out what's going on. Have a very serious conversation. So Sony takes this to be clear, very very seriously. but never an issue with MKV.[103]

James Snyder told me he intended to write a letter to Casey, detailing some of things the white paper got wrong about JPEG 2000, but he ultimately chose not to.

A: So that white paper, yeah I've written an answer that I've never sent Mike Casey. I've written an email several years ago when I first saw that white paper. He made some assumptions in there that were incorrect and I was going to ask him about it but I thought, it was probably politically expedient not to do that. Because you still have to work with them.

Q: Was that one of the assumptions?

A: There was one thing, I'll have to go back and look at my notes but there are some statements in his white paper that were just flat-out wrong. Like a statement about why they didn't choose MXF, and the reason they didn't choose MXF was flat-out wrong. it means he didn't do his research. Or whatever to do his research didn't do their research or didn't understand how it works. And then there's the other questions I would have, which is, you came to these conclusions but I kind of assumed we've got the same goal which is long-term survivability of the content, and this is the decision tree that we went

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[103] DaPuzo interview.

through, and you came up with a different answer. Logically we should have come up

with the same or very similar answers and yet you came up with a fundamentally

different answer. one was based on some incorrect assumptions, but it also looks like

your decision tree was different. And this is where me as an academic wants to go, was

this because you started out with your own.. I'm an engineer, you're a librarian, you're

an archivist, a content archivist. We are two sides of the same line. I have to do

technology implementations and so I see it from that point of view, how do you enable

long-term survivability. When someone is from the other side where they don't know

how the technology works and they have to make their best guess.[104]

Dave Rice told me that archivists tend to choose formats and encodings that are best

supported in their community.

Q: So, why does our community - why would we choose lossless generally, and if we

were going to, why would we choose FFV1 out of the array that we have to choose

from, like JPEG 2000, FFV1 - like, why would you choose FFV1 in particular?

A: ...[A]s far as to why use FFV1 over JPEG 2000, I guess like my primary answer to this

choice would be that an archivist would likely prefer to use the choice that's best

supported from the community that they draw support from. So like, you know,

obviously, like in broadcast and cinema distribution communities, there's a strong

preference for JPEG 2000. With open media and more like, FFmpeg based communities,

it'd be more, sort of, FFV1. You know, if most of my peers and colleagues were in the

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[104] Snyder interview.

FFmpeg community and I was trying to manage JPEG 2000 as a preservation codec, like I might not have as much ready access to its expertise or advice that I needed. You know, likewise, somebody using FFV1 in a print distribution lab or something, like, have similar challenges.[105]

According to my interviewees at Indiana University, their choice of Matroska and FFV1 was largely informed by a desire to use completely open technologies in order to help ensure the sustainability of their digital outputs into the future.

Q: Circling back around to something I told you I was going to ask you about, I'm going to ask you about. So in your white paper, Mike, you said that, "we have aligned ourselves with a large and active FFmpeg community rather than a private company." Can you tell me more about what that stance means?

Mike Casey: I'm hoping that John and Brian will have something to say.

Q: It's a question for everyone but... that's a pretty specific political stance...

Mike Casey: it may be a different response for me than from the others, but this goes back to the whole open-source argument. What path do you want to take? And here I'm trying to look over a very long period of time. What makes sense to sustain these objects, these digital objects, for the next 50 or 100 years or whatever it might be. It's very hard to look that far. But does the path that runs through private companies and proprietary software, does that give you the best chance to sustain these things? Or is it the path that runs through open source Solutions. And ultimately I thought that aligning

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[105] Rice interview.

with the open source community, with FFmpeg, made more sense for the longevity of

the preservation effort that we were concerned about.

John Dunn: From my point of view, and I would be interested in hearing Brian's thoughts

as well, I saw MKV FFV1 versus MOV V210 less as an open source versus proprietary or

open source versus Apple issue because both formats are pretty effectively supported in

open source, even though QuickTime is technically an Apple proprietary technology, it's

very well-documented and very well supported in FFmpeg.

John Dunn: So open standard versus a proprietary standard.

John Dunn: Yeah even though it's not fully into technically an open standard, it's de

facto an open standard because you have the source and you have multiple

implementations. So I guess that was less of a concern.

Brian Wheeler: I remember a lot of conversations about patents. We were discussing

MP4s and MOV's we did talk a lot about where patents fall in all of this -

John Dunn: I don't think it was a major factor.

Brian Wheeler: I don't know that it was a major factor in our discussion, but I know it

came up multiple times. I guess the thing is, you don't know it which point a vendor is

going to switch directions, which is their prerogative. but having, for all intents and

purposes, open formats for all of this content and an open implementation of those

formats definitely is a desirable thing. I know one thing we did was, I'm writing a very

specific version of FFmpeg... And it's still the same version we're running and one of the

things we discussed was, do we escrow the source or do we escrow our binaries. And I

was like, no we're not going to do the binaries because that means you have to bring

everything else along. But if you have the source and you have the configuration used to build it, then at some point in the future if something dramatic changes we can go and reproduce what we have based on the exact... cuz you know bugs will get fixed or things will change and you may not get the exact same output based on some fixes. So we do have it locked down to that and we do have a copy of that source somewhere on HPSS in the MDPI space. I think just having it open was the primary goal.[106]

Scenesavers chose FFV1 because of its ease of use, which contrasted to the difficulty they found in using JPEG 2000. For them this was not an ethical choice as much as it was a strictly technologically-driven one.

Q: No I do, but you're, we gonna go ahead and start talking about stuff that could be useful for research.

Jim Bird : Well I was gonna say just from my perspective that Jim probably can get deeper into, he writes more of the code and those types of things, but uh, JPEG 2000 for instance has always been hard and FFV1 has always been easy. JPEG 2000 to get it to work and playback has always been hard and expensive and uh, sketchy, and FFV1 has always been free and easy. So you know, from our perspective, from a very practical point of view it's just way simpler to deal with.

Jim Bird: FFV1 just makes more sense, it's just so much easier to implement. So much - it's free. And I don't know, even with JPEG200, and Jim can share some of our testing in the past, we've had a devil of a time just - are we making the correct file? What does it

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[106] Mike Casey, John Dunn, Andrew DaPuzo and Brian Wheeler, group interview, March 23, 2018.

play back in? We've got a handful of playback choices and it plays here but it doesn't play there, and some of them are the SAMMA free player.

Jim Bird: So what you're gonna see here is, if you say, "we must have JPEG 2000," we'll do it, but if we have a choice we're gonna steer you to FFV1.

Q: Interesting, OK, so you do, you do have a definite preference?

Jim Bird: Oh yeah.

Q: And when you talk to a client, you're just like -

Jim Bird: If somebody says, "we want it compressed" we might say we can do that, but doesn't this make more sense?

Q: It's gonna be huge.

Jim Bird: And the cost of storage has come down dramatically, so uncompressed isn't as big a problem as it was back in the Jim Linder SAMMA days when uncompressed was a huge problem. And uncompressed is simpler, you know there's that whole issue of containers and proprietary and what's going to happen in the future and all of that. But it's just been interesting and I think our observation has just been that this is just, it just works. It's way easier and the quality certainly seems to be comparable. The file sizes are comparable. Way easier to work with.

Jim Schupert: And the way easier expands into a whole lot of open source tools, MediaConch, Media Info, that basically can deal with FFV1 and an MKV and you got a JPEG 2000 and it's like, yeah I'm sorry.[107]

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[107] Bird and Schupert interview.

According to Ashley Blewer, the openness of Matroska and FFV1 is a large part of their appeal to preservation specialists:

Q: Why would I choose [FFV1 and Matroska]?

A: I will be a preservation evangelist here! The obvious, simple answer is that they are open formats and so you're never locked out of having the knowledge to work on these themselves and they were picked for that reason.[108]

Josh Yocum told me that the culture of amenability to open-source tools at Northwestern University influenced their decision to explore FFV1.

Q: Are there any social dynamics within your institution, that might be a reason to choose or not to choose FFV1 - a preference of a particular staff member, or anything like that?

A: I mean, I think we definitely-we do have a number of open source projects that we contribute to on the development side, I'm not super familiar with a lot of those, but I know it occasionally gets tossed around as one of the cool things that we're doing? Like, "look at these open source projects we're working on!" so I mean there is some atmosphere of, "open-source is a good thing to be contributing to." I'm not sure I'd say there's anyone specifically who directly worked with this, who may have had that kind of influence on it, because a lot of this reviewing documents and making, at least, kind of lobbying for the adoption of FFV1 was from me. And that was kind of, at the question of, "what's a good archival format?" and I mean, I guess I would certainly prefer an open

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[108] Blewer interview.

format for - especially one that's linked to FFmpeg, because FFmpeg's a program I've used a lot. And it's a program that I have, maybe, a little more faith in it being future-proof, than say, like, a proprietary Adobe format or something like that, or something like - I mean, I think the big thing at the end of the day, was just how much easier it was to test. With JPEG 2000, it just left a lot of questions about like, "well, how do we know that our files are actually good? And what's the guarantee that this format will be the actual format that we'll want to rely on in like five or ten years? And if we adopt JPEG 2000, what's the escape strategy for that?"[109]

Ben Turkus talked about open source tools and the importance, as he sees it, of institutions supporting the open source movement:

I think, in general like, I do believe that it's important for institutions of a size-institutions working on projects similar to IU's, and NYPL's, to actually, like, take a stand and say, you know like, "We believe that this is the right decision to make," and that there's like, intrinsic value in knowledge-sharing and putting it out there for people, you know? And I think-it's good for me to see other institutions, I felt the same way about BAVC, you know? And it - you know you see that list on the FFV1 Wikipedia page of institutions making the leap growing all the time, you know?[110]

Steve Lhomme, the creator of the Matroska file format, discussed with me the associations the format has had since its beginning with online multimedia piracy.

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[109] Yocum interview.
[110] Turkus interview.

Q: Mm hmm, mm hmm. So I guess the only big question, I just wanted to kind of return to something that you mentioned a little while ago, and that was related to piracy. You know, Matroska being used, and probably still being used, for piracy. I just wanted to kind of have you expand on that. You know, what are your thoughts about that? That you've created this thing and it's being used in this way that, you know, in some places is illegal?

A: Umm...actually, uh, for many years the format, I mean basically before sellers started or maybe before CELLAR started, or maybe before WebM but maybe even after WebM basically the format was there and nobody was touching it or doing anything with it. I mean, changing anything or adding anything, it was just there, and people were just using it and mostly for illegal stuff. So it seemed for a while that Matroska was just destined to be the format for piracy and that was it.

Q: Mm hmm.

A: I mean, for me I just thought, ok I created this format is used for piracy and pretty much nothing else, well that's still good because I download illegal stuff.

Q: Haha OK.

A: Actually um, I had a guy on the IRC channel that was there talking to me in private because he was actually one of these pirate people and because they are racing to be the first to release a file or an encoding as soon as the TV show ends, they use the fastest computer you can have and all the tools they can think of to be the first to do it. And he created his own Matroska mixer, everybody else was using FFmpeg but he created his own to make sure it's the fastest and he can release this stuff so he kept

asking all kinds of questions about the format and how to either improve it or how to

use it better for his use. So that was very interesting and so this guy gave me an account

on an FTP for all these, where all these pirate people can download free everything that

they want. So for a year or two I could download everything I want because I created

the format.[111]

Ian Henderson enumerated the following factors that led the UK Archives to adopting

FFV1 and Matroska for some of their archival digitization work:

The FFV1 codec in combination with LPCM held within the MKV container seemed a

simpler, practical option with a number of positive aspects for (non-Production/

Broadcast focused) video archiving:

· The relative simplicity of the combination suited our purposes

· MKV is capable of containing multiple multimedia streams within the one file, so all

available video and audio streams can be preserved (12 audio streams from HDCAM-SR)

· FFV1 is a lossless compression, intra-frame video codec, - picture information in each

frame is captured

· Its flexible and supports diverse source-video characteristics (different pixel formats, bit

depths, chroma-subsampling ratios, and a wide range of colour-space)

· Version (3+) of the codec incorporated check-summing per slice of frame, - if any digital

change occurs to the bit-stream in storage or copy operations, then upon decode

(frameMD5 report) it should be able to identify the affected area

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[111] Steve Lhomme, personal interview, December 1, 2017.

· A compression ratio comparable to JP2000

· It is platform independent

· FFV1 is available as part of the open-source libraries of FFmpeg and the FFV1 spec is

freely available, ensuring technically accessibility in future years FFV1

· Files can be played back in freely available media players

· MKV is an open standard, open source container format

· MKV has extended tag support for metadata[112]

As Nick Krabbenhoeft noted, the New York Public Library has found that using the

Matroska container for their video materials may render them more compliant with the

Americans with Disabilities Act by making it easier to embed subtitling information in the files.

[T]he fact that MKV is a very containerized format that you could potentially do things

like add a new metadata container at the end of something or add a subtitle track on to

something, which I'm very much looking forward to in the future that potentially we

have some accessibility. The videos that were doing are not accessible, and there might

be accessibility requirements for those videos in the future, and so being able to run up

and get closed captioning done for these materials or any other accessibility

requirements that we want and then include that information into the same package

was very attracted to me. We would have to generate a whole new file checksum, but

that would be less arduous task than would be without the slice [checks] and other

internal check summing measures that MKV and FFV1 offer. So there was an

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[112] Henderson interview.

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adaptability to the MKV format that I really like and I thought would make our lives easier in the future hopefully if we have to make major decisions about those materials.[113]

Ben Turkus expressed his thoughts about the future of Matroska thus:

I think Matroska is going to make, you know - I see them doing the things that they need to do to close the gap, you know? And I think it's gonna happen. I think there's also, like, lots of interesting potential in MKV in general, you know? And, I mean, the wide range of tools that are available? The fact that a lot of the people that are working with this are like, you know-they don't care about archival work, they care about, like, VR and 3D and stuff, you know? And they're kinda doing interesting, cutting edge, contemporary media stuff at the same time, you know? And so if we can align ourselves with them, I think it's very smart.[114]

FFV1 has features that make the encoding attractive to its adopters. One is the ability to embed frame-level fixity-checking hash values. Ben Turkus explains some of his pragmatic reasons for preferring FFV1:

And you know, VRecord obviously is, you know, one of the few tools that are available where you can actually capture directly to FFV1 and Matroska. And it was one of the considerations, I think, at NYPL, so, you know, if the options were capture directly to V210 QuickTime and transcode, or just go straight to FFV1, you're gonna save a lot of

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[113] Krabbenhoeft interview.
[114] Turkus interview.

transcoding time. You also get, you know, a lot of the internal fixity things that are, you

know, the real bonuses of FFV1 right at the point of capture, you know? You get frame

MD5s, you also get QCTools reports, which was very important to me because that

processing takes forever as well, and if we can get them right there when we're making

the files, it's… potentially extremely useful, you know?[115]

Furthermore, the ease with which FFV1 and Matroska interact with the FFmpeg

transcoding software made Turkus' decision to use the encoding more attractive than

QuickTime MOV:

I noticed the second I got to NYPL because we were still receiving QuickTime files from

our vendors, and one of our vendors, because of the imagined communication's ingest

server that they used, the MOV files that they were creating had no information in them

related to scan type or scan order, and no information related to color management,

color space, color transfer characteristics, matrix coefficients, et cetera. And so what

making the switch to FFV1 MKV has allowed us to do is actually give the vendors very

specific FFmpeg strings that will, like, hard encode that information into the files. And

that's been kind of something that we've been working on, doing testing, checking with

Dave, making sure that we have that all right. But, to me, it's like, "We can make all of

our files more consistent by making this switch too," and I think that's kind of an

important thing.[116]

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[115] Ibid.

[116] Ibid.

As Nick Krabbenhoft of the New York Public Library told me in our interview, employing lossless compression for video materials at the Library was initially a pragmatic choice.

> [O]ne of the first things that was coming out of my program within the first 6 months was I said, we keep doing uncompressed, somebody says there's a 15 million dollar storage bill if we do this entire mass digitization program. If we start using lossless compression, we can cut that in half. So why don't we start looking at that, why don't we do that kind of a thing.[117]

In speaking with Andrew DaPuzo, I laid out Matroska/FFV1 adherents as one population and MXF/JPEG 2000 adherents as another. He told me there was a third group:

> By the way I see three areas, to be clear. Talk about the FFV1 community, let's say, open source was the term I think you used. You have the JPEG 2000/MXF group. There's a third group, if you expand beyond cultural institutions to broadcasters or just to intellectual property right owners to begin with, and that's the guys that just don't give a damn. That's the group where a master file is good enough, a mezzanine file is good enough. Right? So they're happy with the Pro Res 422. I have some people happy with MP4s. So when you start talking to the preservation community, frequently the conversation goes to, preservation file, mezzanine file, proxy file. Or access, right? You're talking to a broadcaster, again, there are always exceptions, but generally speaking I talked about a master file and a proxy. That's it.[118]

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[117] Krabbenhoeft interview.
[118] DaPuzo interview.

Erik Dix, archivist at the Notre Dame University Archives, told me that technological

factors were not all he took into account when choosing FFV1 for his work:

Q: Okay. So, we talked a little bit about the technology, are there any kinds of social

dynamics in your organization that have informed your choice? So this could be things

like cost, this could be things like, you know, personal preference of other places on

campus-I think we've talked about this a little bit, but if you could kinda reiterate that?

A: Yeah, I think definitely cost, because for a long time the archives have - I mean,

compared to maybe other, smaller archives, they have a pretty good budget, but there

was never any money here for large digitization projects. For the longest time I did all

the audio only, because that was something I could put on CDs or DVDs, which is not

ideal, but that could be done, but video was definitely not in the cards. And then the

push for a tape library, and there was other entities on campus who wanted to use a

tape library, so we were able to hook into that and so then, we could do this and

definitely is a cost factor. And at the time, was also a storage factor.

Q: So is cost and storage not neces-

A: And then the other thing I think I like, because I'm from Europe, and FFV1 came out

of Europe and I thought, "Ooh, that's kind of cool."

Q: Okay, interesting, so there's kind of a loyalty to the continent there?

A: Yeah, yeah.

Q: Okay. What kinds of dynamics, if any, in the larger audiovisual preservation

profession have informed the choice? So, are you conforming to any professional best

practices by choosing FFV1, or deferring to any-

A: I hope so! I mean, I look things up online and I know that-and then Peter kept me informed, saying, "Yeah, the National Archives of Great Britain is using it, and these people are using it, IU is using it now," so I thought- and I'm using it longer than IU, so, "ooh, I'm on the cutting edge here," so I thought that was kinda interesting. And I know they used the MKV container, but they also have people that can program things for them, so...[119]

The UK Archives reviewed many encodings and containers for their preservation work and have recently settled on FFV1 and Matroska. Ian Henderson explains thusly:

Following a period of research into the few viable lossless options for video (uncompressed, JP2 in MXF and one or two other lossless codecs), and after seeking views from AV experts, I did recommend the combination of: FFV1 v3 codec for the video encoding, LPCM for audio, and the MXF container. At the time, I was not assured that current JP2/ MXF formulations were necessarily fully standards-compliant or, perhaps more important still, fully interoperable across mainstream vendor software encoder/ decoder implementations. Some users stated that they had issues accessing content of MXF files created by previous generation software, and other reports suggested that levels of metadata could be lost across workflows, where different vendor software could interpret and map metadata variably.[120]

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[119]Erik Dix, personal interview, September 8, 2017.
[120] Henderson interview.

The cost of tools factor in the adoption of a standard. Marion Jaks, archivist at the Austrian Mediathek, told me that for the cost of workstations affects the choice, for her, of FFV1 versus JPEG 2000.

> But FFV1 at the time was not around as a choice so we the next step was to evaluate different lossless codecs and that was after this evaluation we came up with FFV1. Yeah. And so it started and we found a with FFV1 we wouldn't need there wouldn't be no dependency on hardware we would have it would be so much easier to do everything we wanted there was already so many open source applications around with which we could use FFV1 and it also had to do with our video digitization system that we could have four streams over four interspersed stations working with digitization with FFV1, but the same price that it would have cost us to buy one workstation with JPEG 2000 lossless which was yeah at the time promoted.[121]

Jim Schupert and Jim Bird talked gave their thoughts about why audiovisual technologies find traction in libraries and archives:

Q: As you see it are there social factors that motivate the choice of Open Source versus SMPTE / industry supported standards?

Jim Schupert: yeah I think you'd have to say yes because you see like in Europe where it's embraced and why is it tacked down here?

Q: what would you say that is?

Jim Schupert: in my opinion it's because, here's someone who is a librarian and their

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[121] Jaks interview.

background is maybe in books and they don't really know this thing called a videotape

and you have somebody from the Library of Congress who says JPEG 2000... well they got

to be right! you would be foolish not to agree with the Library of Congress

Jim Bird: It's a very complicated technology and if your background is in library science

you probably don't really know a whole lot about exactly how that works.[122]

   Kieran O'Leary chose FFV1 primarily for its space-saving capacity, but as he began using

tools to create and decode FFV1 bit streams, he had to learn more programming. This changed

the nature of the work that he did, and led to him having a place in his heart for FFV1:

...With just a very very you know entry level command line skills I was able to get FFV1

and Matroska support but of course they the vendors never told us that, you know might

be opening up those possibilities you know using open source tools with that. But then

what I realized quickly was you can't just transcode to FFV1 and Matroska, you have to

do your lossless verification which is like a three step FFmpeg process and scripts ended

up being the way to do that and so I learned how to code then because I needed to write

this script and one thing led to another and now I'd be quite proficient, programmer

since then I've moved on from bash to python but I do other languages as well and I

write a lot of software for here. And it all kind of started from the FFV1 investigation and

it changed my life you know? It changed my job and it changed my role and I got to travel

all over the world because of the it brought me into this larger community this global

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[122] Bird and Schupert interview.

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community of archivists and I've been to all these different countries and been invited to

speak at workshops and like so yeah it has a very personal place in my heart you know?

According to Ashley Blewer, FFV1 has value to preservation beyond its lossless

compression because it has the potential to embed checksums at the video slice level in FFV1

can save preservation specialists' time:

I think the checksumming and validation elements are really key, I think that's what really

played a big role in why they were selected. Like, Matroska having like, checksums at

every point in the file so you can have it in just certain sections, you can keep the video

portion completely like fine, so it's easier to pinpoint if there's a problem, where that

problem is rather than just saying the entire file, which would be true of a lot of other

things. Well maybe not the standards that are image-based, I think you'd be fine there.

And then FFV1 as well, right? Where it can do frame-level or even slice-level, so it's really

easy to sort of narrow down and pinpoint where a problem is. We don't have time to

waste our time sort of going through the entire file to figure out what the problem is and

how detrimental it is.[123]

Brecht DeClercq told me that he sees market forces as being challenging for audiovisual

preservation in the memory realm:

Q: Would you say that there - so, we've talked about the kind of technical reasons, but

are there any kind of social dynamics within your organization? Any influential person's

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[123] Blewer interview.

preference, or something like that, that has moved you towards, in particular, exploring FFV1?

A: I tend to say no. This is an interesting question, because I am not an IT guy, I'm a human scientist in the sense that I study history, and this is an interesting question on human actors could influence the discussion! I would say, indeed, I have seen in the world around me, that the discussion between MXF, JPEG 2000, and FFV1 MKV on the other side, it's slightly influenced by what I could maybe call ideological factors…. And I still believe that we are able to make abstraction of any personal, or, I would call it ideological, argumentation. But in the background, there is also - there is still the open-source movement, eh? And we have been confronted, with what I would call, some rather ugly side-effects of capitalism that influenced this discussion - because, for example, let me give you one example, the availability of encoders of EVS, OpenCube encoders, and MXF toolkits, encoders, has been a problem for one of our service providers. And only two weeks ago, one of our service providers told me that he had heard from one of his software partners, who delivers encoding software to him, that the MJPEG MXF encoding and wrapping could become problematic in the near future. So, to make things short, we are feeling the pressure of the markets, and the market is influenced by market mechanisms like the availability of tools, the availability of MXF and JPEG 2000 wrapping, encoding, you could keep on going.[124]

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[124] DeClercq interview.

According to Dave Rice, it is also an express goal of CELLAR to create documentation

that is both technically precise but also readable by people in the preservation community,

which is not always the case with SMPTE and/or ISO standards.

Q: Well, what kind of language? Like, language, what do you mean?

A: I mean, at the beginning, it was a little difficult to sorta understand the writing style

that IETF normally uses, but I mean now I really appreciate the kind of more, like, legal

way things are written, because it makes concepts of validation really precise. And like

still in the FFV1 specification, there's aspects of the document that I don't understand.

You know, there's a couple sections of the FFV1 documentation that would be written in

LaTex equations, like, it would just kinda look like really complex math. But it wouldn't

be highly contextualized. But like, folks in the FFmpeg community that were familiar

with the FFV1 encoder in FFmpeg and knew - had an understanding of the components

used in the math, you know, would be able to read that aspect of the FFV1 specification

and, you know, put it to use. But I mean, I found it a kinda challenge, to learn how to

read that. So I think like, the goal I eventually had, is if you're in a specification and it's

kinda turned into this kinda, like, mathematical equation, or part of pseudo-code, that it

should be clear how it should be clear, like, how somebody who understood that well

would read it out loud. Like, you know, if you're looking at something that just seems a

bit undecipherable, there would at least be some guidance to know how to speak it in a

way that you could dissect it into smaller pieces and could then understand. You know,

certainly some of the language is technical in these specifications, because the encoding

is, in some ways, complex. I mean, at least for me.[125]

I asked Jim Schupert and Jim Bird about their interest in the CELLAR work and they told me about their participation on the email list:

Q: Have you participated in any way in the CELLAR work?

Jim Schupert: I'm on the mailing list and I read about it often and go to the website and sometimes will email back and talk about things like for instance the whole MP3 FLAC wave is something that I've been kind of like, yeah go get them! let's make that happen! More of a cheerleading then developing anything or whatever.

Q: Moral support.

Jim Schupert: Yeah like I think that's a good idea too.

Jim Bird: head cheerleader.[126]

Because time-based media content can, in the digital age, be relatively easily shared between institutions and repurposed in documentaries, television programs and news broadcasts, it is likely that FFV1 and/or Matroska will turn up even in realms that have chosen not to use them. As James Snyder pointed out to me, even though the meaning of the term 'broadcast' has shifted to include computer and handheld device screens as well as television screens, interoperability of files and delivery tools must still be governed by standards:

How do you ensure long-term survivability, and the answer that comes from that is, you choose well-documented international standards that are also interoperable because

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[125] Rice interview.
[126] Bird and Schupert interview.

you have to interoperate with industry. Otherwise, if you can just watch it on computer

what the hell good is it if you can't get it to NBC Universal if they want to use it in a

Dateline episode? What the hell good is all this work that we are doing if it cannot be

used for the rest of the industry, if all you are doing is doing it on a computer or on a

phone or whatever. So if your goal is usability, interoperability, and survivability, certain

things start to present themselves as logical assumptions behind that. One of which is,

you must use well-documented international standards that Define how the signals are

created, are written, and two data, how the data is written, yada yada yada.[127]

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[127] Snyder interview.

CHAPTER 6: THE FOUR STANDARDS AS BOUNDARY OBJECTS

A key assertion of this chapter is that these standards can, at times, act as boundary objects - technologies that can "inhabit several intersecting social worlds" (Star and Griesemer, 1989, page 393). Boundary objects can have different roles for different users and, perhaps more importantly, these objects may have different meaning for different users. Another finding discussed in this chapter is that there is no clear dividing line between for-profit and nonprofit participation in the development of closed or open-source standards. When I embarked upon this work I thought that the open-source standards Matroska and FFV1 would have little, if any, input from for-profit actors. As it turns out, the story was far more complicated.

Through the course of this research the audiovisual preservation profession has seen an important shift in the development of technologies for audiovisual digitization and preservation. For decades, the time-based media preservation community has had to rely on hand-me-down technologies - software and hardware - from the broadcast and cinema production realms in order to carry out their work. The archives and library communities have rarely collaborated with standards bodies like SMPTE or the MPEG in order to develop these tools in the past. This is not the case for the IETF, which has seen considerable library and archives collaboration over the years. For example, the BagIt File Packaging Format, which is used very widely in digital preservation work in libraries and archives around the world, is an IETF 1.0 specification that was developed with considerable input from the Library of

Congress.[128] Despite the raised eyebrows by some audiovisual engineers when they consider the CELLAR group's choice of the IETF for standardization of Matroska, FLAC and FFV1, it actually has a broad history of library/archive input. As of this writing, there is a boom in the development of open-source, do-it-yourself preservation and digitization solutions - software for digitizing video, repository solutions for packaging digital content for storage, metadata harvesting tools and so on. In other words, the standards and specifications governing video digitization are becoming more participatory, with much more buy-in by the people actually doing the cultural memory work. This increase in archivist and librarian participation in the development of video standards is another finding of this dissertation that is explored in this chapter.

6.1 CHALLENGES AND CONSTRAINTS OF TIME BASED MEDIA PRESERVATION IN THE MEMORY REALM

In order to properly describe the adoption and adaptation of technologies like MXF, Matroska, JPEG 2000 and FFV1 in the media preservation realm, it is critical to depict the challenges and resource constraints of that realm. Media preservationists, particularly those in the nonprofit cultural heritage realms, encounter many challenges in their work. Equipment and format obsolescence and fragility, technical knowledge bases that are shrinking over time and the lack of universal best practices and target formats in digitization all plague the endeavor of time-based media preservation and accessibility. As Peter Kaufman puts it, media

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[128] https://datatracker.ietf.org/doc/rfc8493/. Accessed on May 21, 2019.

preservation is a "defensive vocation" involving pitched battles with all of these factors in what

is, on a long enough timeline, inevitably a long defeat (Kaufman, 2018).

Furthermore, video digitization in the cultural memory context is still a relatively young

endeavor, having only been performed in many American libraries and archives since the turn

of the century. As the editors of the recent technical guidance document by the International

Association of Sound and Audiovisual Archives, *IASA-TC 06 Guidelines for the Preservation of*

*Video Recording*s note, "video preservation practices are not yet mature, format specifications

are still being refined, and there is relatively little actual experience" (Fleischhauer and Bradley,

2018, page B-34). The lack of intimate familiarity with the highly technical nature of analog

video engineering and digital formats in many memory institutions complicates or completely

obfuscates decision-making with respect to digitization outputs. To further complicate matters,

the ongoing, unimpeded breakdown of analog carriers means institutions may only have one

chance to digitize an analog object before it irreparably breaks down. This means archives may

only have one chance to 'get it right' with respect to performing the best digital transfer

possible.[129]

The cost of video digitization is another challenge facing time-based media

preservationists. Analog video technology, which is no longer produced or supported by its

designers, is notoriously cranky of maintenance and continually more costly to procure. To

further complicate matters, an institution almost certainly has limits with respect to which

media formats it and/or the vendors it contracts, can afford to support (Ibid.). For example, an

archives may have all the technology required to digitize VHS cassettes but have no capacity to

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[129] Bird interview.

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digitize U-Matic cassettes. Thus the complexity and costs of video digitization can narrow the

scope of the kinds of material and content to which a memory institution can maintain access.

These interoperability problems are part and parcel of the audiovisual preservation realm, and

are nothing new to the current digital/digitization era, as James Snyder made clear in our

interview.

One of the costs of video digitization that may not be immediately apparent, but is no

less potentially crippling to a small, modestly-funded institution, is the cost of storage of digital

assets. Compression, in the digital realm, refers to a wide, complicated array of technologies

employed to minimize the file size of digital objects while, ideally, maintaining varying

measures of the objects' image and/or aural qualities. Applying non-lossless compression to the

digital surrogate created from an original recording can, and often does, irreversibly eliminate

picture and/or sound quality from that surrogate. For this reason, archives tend to use caution

when employing compression in the creation of digital objects because this irretrievable loss of

information can create digital objects that do not accurately represent all of the qualities of the

originals. However, uncompressed video files tend to be large, unwieldy and costly to store. For

example, digitizing one hour of analog-sourced video object to high-definition, uncompressed

digital video can result in a file of over 600 gigabytes in size.[130] For this reason, one of the chief

challenges faced by archivists is "how to maintain the essence of audiovisual content in the

smallest and most manageable package possible" (Gilmour and Davila, 2005, page 1).

The cost of digital storage, the need for fidelity to originals and the large sizes of

uncompressed video files all combine to motivate archives' interest in employing lossless

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[130] https://www.digitalrebellion.com/webapps/videocalc. Accessed on November 23, 2018.

compression. This kind of compression is comprised of various technological schemes to encode video in such a way that it can be of smaller file size while it is in storage and then 'unpacked' to a higher level of image and/or aural quality for playback. Lossless, in this context, means that "the output from the decompressor is bit-for-bit identical with the original input to the compressor" (Ibid., page 2). In other words, there is no loss of information at the bit level between the compressed and uncompressed iterations of the content. This compression can serve the archival mandate of minimal loss of aural and visual quality from the original object while, in many cases, halving the storage needs for the archives. For an institution like New York Public Library, this storage savings is part of the appeal of FFV1, as evidenced by Nick Krabbenhoeft in our interview.

Employing lossless compression, as many of my interviewees reported, is usually a decision made for economic reasons. The amount of savings, especially for large institutions like the Library of Congress, can be considerable. This potential for savings is the chief reason for the adoption and spread of technologies like FFV1 and JPEG 2000 in the memory realm. While this offset of storage costs make these technologies very attractive, they are not without risk. Bit flips while in a compressed state can magnify errors as the video is uncompressed, causing significant picture and/or sound dropouts in playback. Furthermore, the wavelet compression employed in many lossless compression schemes does not lend itself to being edited natively in tools like Final Cut Pro or Adobe Premiere. Therefore, errors in a compressed file can render it unusable and unfixable, as Brian Wheeler pointed out. Nonetheless, lossless compression has staked out a claim in the realm of cultural heritage preservation and is unlikely to be supplanted by highly storage-intensive uncompressed technologies in many institutions.

The meaning of technologies like FFV1 and JPEG 2000 is, for many in the preservation realm, tied to notions of savings - of space and, by extension, of money.

6.2 HOLLYWOOD, THE BROADCAST INDUSTRY AND THE MEMORY REALM

Audiovisual preservation and digitization is a highly technology-intensive endeavor. Video playback and capture involves technological artifacts that are often unique and irreplaceable - once they are no longer produced, they are nearly impossible to reverse-engineer and reproduce. For most audiovisual playback and digitization devices, it would require an entire factory to create replacement parts. The means of production of video technologies are so complex and costly that most memory institutions - which do not tend to generate much revenue - rarely have as much influence over this industry as broadcast and film production companies. Andrew DaPuzo at Memnon pointed out this lack of influence by the preservation realm, which was a factor that influenced the MDPI's choice of open-source standards.

As Langdon Winner notes, technology adoption often requires social and political arrangements (Winner). SMPTE can be seen as a social/political/economic arrangement between producers and hardware/software developers because the standards body is made up of professionals from all of these realms. Furthermore, because audiovisual capture technology is continually evolving in terms of image quality and other characteristics like 3D, virtual reality and so on, developing tools for production is usually more profitable than developing tools for the capture/playback of obsolete formats. Audiovisual media preservation is a niche market, which means many institutions have had to build workflows and budgets around procuring,

repairing and employing existing, cast-off technologies. Others turn the media digitization work

over to vendors, which can lead to a kind of path dependence as the same vendors are used

over and over by more institutions. Archives and libraries are enmeshed in a system that moves

media playback devices from the production realm into the memory realm and, ultimately, into

the waste stream where their lives end. Another reason for the memory realm's dependence

on industry is librarians' and archivists' belief that the production realm has anticipated most, if

not all, potential problems with a particular technology and that it is fully formed and

trustworthy. As Nick Krabbenhoeft and Jim Bird both pointed out, large institutions like the

Library of Congress can have a strong influence on the choices of smaller shops without

audiovisual expertise on staff. In these cases the reputation and size of these entities gives

them a certain power and influence over the decisions made by others who do not have similar

influence.

6.3 HOW AND WHY STANDARDS MATTER IN MEDIA PRESERVATION

Audiovisual preservation and digitization is an endeavor that is steeped in highly

technical standards. From the NTSC standards that describe various aspects of analog video

signals to the digital encoding and format standards that are the focus of this research,

multimedia-related standards are boundary objects that move between the worlds of memory

institutions, media production and media dissemination. As Josh Yocum, a media preservation

specialist I interviewed, stated in a guidance document he created for Northwestern University,

libraries and archives often find themselves "piggybacking on the standards used by the

recording/broadcast/movie industry" (Yocum, n.p.). Part of this piggybacking owes to the

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nature of the video signal and the preservation mandates of many institutions: because the

'ancillary' data - like closed-captioning information - that travels along with the human-readable

video information and human-audible sonic information may have value to the historical

record, archives often find themselves on a parallel mission with broadcasters who also want to

create tools for clearly capturing that information (Fleischhauer and Bradley). Standards are

considered to be so important in the realm of digital preservation and digitization that the

National Digital Stewardship Alliance holds as one of their core recommendations the fostering

of best practices and the development of standards governing these endeavors (National Digital

Stewardship Alliance).

Standards in the audiovisual production and preservation realms are rarely developed in

anticipation of future needs because those needs are usually not entirely clear. This owes

largely to the difficulty in anticipating how audiovisual technologies will change over time.

While it is true that MXF was developed because of the then-impending shift from media-based

information retention to media-independent digital infrastructures, the standard was, at least

initially, a reflection of what the standard developers could foresee within a very limited

context of late-90s broadcast. The resulting standard was, in part, a reflection of the lack of a

specified way of handling interlacing in video. The SMPTE MXF working group of the time did

not anticipate a context within which the capture of legacy, interlaced video would be a

priority. Because end users are often unaware of the efforts and politics that go into standards

making, it is usually only these cases wherein a standard 'breaks' and its limitations are made

manifest that these politics can come clear (de Vries).

As in any technological enterprise, the audiovisual preservation realm relies on standards largely because of the need for interoperability between the digital objects being created and the various tools and environments with which they will interact. James Snyder told me that he views standards as being guarantees of interoperability. This view also informs many discussions in the preservation realm. Uniformity among objects in a digital repository can be very useful as it minimizes the infrastructure needed to create and play them back. It is not simply the fact of a technology being standardized that ensures its utility for a memory institution, however. After all, there are many competing standards that require different software and, in some cases, environments to implement. Some preservation specialists like Nick Krabbenhoeft insist on a kind of parsimony in their work: the smallest array of standards implemented for encoding and packaging their digital media objects. Furthermore, as Jim Bird noted, the wide array of potentially idiosyncratic implementations of standards like MXF and JPEG 2000 can make a specification like AS-07's SMPTE backing mean very little. After all, if there are many different flavors of MXF and/or JPEG 2000 files and encoding and decoding software in the wild, how does an institution benefit from strict conformance to AS-07? One of the questions that must be asked when studying a standard and its utility to the world is how do the standards hold users accountable for creating objects that do not conform to those standards.

Once again, the broad array of MXF and JPEG 2000 files in the world troubles the enforceability of the standard. Another challenge to enforceability lies within the MXF standard itself. As Lars Gaustad pointed out in my interview with him, there is no singular SMPTE MXF standard - instead there are dozens of standards documents consisting of extensions, revisions

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and implementations of the core, original document. This has diluted the power of the standard to some extent and allowed for highly elastic interpretations. The CELLAR group is currently facing a similar challenge: how to create a standard that is parsimonious enough to *be* a standard but is still a large enough tent to include the past 15 years' worth of interpretations of Matroska from all over the world. As Bowker and Star put it, this is the challenge of a standard: balancing the tension between broad interoperability and clearly delineated interpretive flexibility (Bowker and Star, 1998). CELLAR is attempting to balance that tension by including many different types of players in the standards-making: for-profit businesses, archivists, librarians, open-source coders and various kinds of users of Matroska, FLAC and FFV1.

When viewed from a social construction of technology lens it becomes apparent that the best technology does not always win out, and that there may, in fact, not be a *best* technology - that a standard is the result of an evolution of compromises and negotiations leading to a specification that had the virtue of being the minimum set of technological affordances that the standards body members could agree upon (MacKenzie and Wajcman). Some members of CELLAR argue that the openness and transparency of the nascent standards for FFV1 and Matroska - the fact that the development work is not taking place behind closed doors but is accessible to all online - means that these standards will have greater utility to the memory institutions because, in theory, they can see how the sausage is made and can contribute to that making freely and in real time (Bubestinger, Lewetz and Jaks 2016). This transparency is not allowed by SMPTE, which can make influencing the SMPTE standards impossible for those outside their closed-door meetings.

The chief complaint Hermann Lewetz received from his presentation in 2010 was that FFV1 and Matroska were not standardized by bodies like SMPTE or the MPEG. Industry-influenced standards have been a critical part of audiovisual preservation since its inception. The perception of stability and Hollywood and broadcast industry approval can make a video standard seem much more appealing to a memory institution that does not employ specialists who have a deep understanding of video engineering. Many of my interviewees cited the lack of SMPTE and/or MPEG standardization for FFV1 and Matroska as cause for concern about adopting them, especially with the landscape being so sparse in terms of their use in memory institutions prior to Indiana University's public endorsement of them. It became clear to some preservationists that, in order for FFV1 and Matroska to find purchase in libraries and archives, they would need to be standardized by a body that the memory realm *and* the broadcast/Hollywood realms would recognize as an authority in digital video technology.

In the case of the Library of Congress and AS-07, their use of MXF and JPEG 2000 is largely driven by the powerful and high-profile donors to their collections. After all, as James Snyder pointed out to me, the digital cinema specification uses lossless JPEG 2000 and donors such as Twentieth Century Fox and NBC use J2K as well. The Library is constrained in their ability to choose which standards to implement, hence their decade-long investment in AS-07. With respect to FFV1 and Matroska, it is too soon to tell, but many of the CELLAR participants believe that the IETF's transparency in the standards-making process will help to make the end users of these standards more aware of the work that went into developing them. This could lead to a considerable shift of power into the hands of smaller institutions within the GLAM community with respect to these technologies.

6.4 THE PURPOSE AND MEANING OF AS-07

As Kate Murray reminded me throughout our interview, FADGI is not a standards body

and they do not see the AS-07 specification as a true standard. It is, as she notes, more of a

recipe for generating video files of very clearly defined characteristics. She also told me that

there is no "one format to rule them all" with respect to preservation-quality digital video, and

that this means the AS-07 specification can have an educational component for other

institutions trying to make decisions about their own digitization work.[131] While Murray

described AS-07 to me as, for the moment, not being a true standard - insofar as it has not been

generated by a recognized standards body - the language of the document is very similar to

many standards. It behaves very much like a standard in that it rigorously describes the many

elements that video files must have in order to be in conformance with the specification. The

document describes levels of constraints that range from 'gentle' to 'moderate' to 'strong' in

order to put conformance to the specification on a continuum (FADGI, 2017). For example, if a

user generated a video file with a gentle level of constraint to the AS-07 specification with

respect to a particular aspect of the video object, the file would likely be able to be decoded

with any MXF-compliant software. However, if the user conformed an aspect of a file to a

strong level of AS-07 constraint, the user could be assured that this file would, if only in this

particular aspect, precisely mirror a similar file produced by the Library of Congress. So while

there is no power to enforce the FADGI specification outside the Library of Congress, any

vendor, donor or other user who wanted to create tools to create and/or decode files for use

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[131] Murray interview.

with the Library of Congress, or any user who wanted to make files in line with the Library's

workflows, would probably be safest adhering to the strongest level of constraints within AS-07

possible. This is how the AS-07 document functions precisely like a coordinative standard - by

focusing on interoperability and compatibility. As James Snyder told me, the slow, methodical

standards-making and review process of SMPTE is one of the reasons he feels assured that,

when a SMPTE standard is finally released to the public for use, it is ready to go "right out of the

gate" because, in his opinion, the body has already worked out nearly every bug and potential

use case for the standard.[132]

There are politics encoded into the standards that AS-07 uses. The initial poor support in

JPEG 2000 for interlaced video, as I described in the History section above, is a clear indicator of

a kind of politics - in this case, the broadcast industry's prioritization of new technologies over

the old - encoded into the design of MXF. This oversight, which, in Langdon Winner's words

represents how "design or arrangement of a device or system could provide a convenient

means of establishing patterns of power and authority" (Winner, page 134). Encoded into the

MXF container by SMPTE was a vision of the user and the user's environment that ran counter

to the archives realm. The broadcast industry can leverage far more economic power over the

design of new moving image and sound capture technologies than most of the American

memory realm. As James Snyder pointed out, even the Library of Congress has very minimal

influence over the standards employed by television and cinema producers in the United

States. In the Library of Congress, because it is the nation's copyright submission office, MXF

and JPEG 2000 easily moves between the production and archives boundary. The flow of

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[132] Snyder interview.

materials over this boundary is part of what informs Snyder's view of MXF and JPEG 2000 as being standards appropriate for theatrical and television dissemination and archival preservation.

6.5 IS THERE NO TIME TO WAIT?

The adoption of FFV1 and Matroska in libraries and archives has grown considerably in the past few years. One of the methods the CELLAR working group members use to promote these technologies is the annual No Time To Wait conference. This conference, now coming into its fourth year, takes its name from a Library of Congress blog post about video preservation and the pressing need for agreed-upon standards and best practices for rapidly-deteriorating analog video materials.[133] This conference, so far only held in Europe, brings together preservation professionals from around the world to discuss issues primarily related to open source technologies and time-based media preservation. Unsurprisingly, CELLAR has had a prominent presence there since the conference's inception. I attended No Time To Wait 2, which was held in Vienna, and presented about the early stages of this dissertation research and observed the proceedings. The conference, which was funded by the PREFORMA grant, was free to attend and kept its registration capped at 100 participants. One of the organizers, Dave Rice, (who is also a prominent member of CELLAR) told me during the conference that he was proud of the inexpensive, pitch-in nature of the conference and how it is proof that motivated conference organizers can do more with less. Ashley Blewer compared it to other conferences by saying that traditional professional gatherings expend resources needlessly by

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[133] https://blogs.loc.gov/thesignal/2014/12/comparing-formats-for-video-digitization/. Accessed on November 14, 2018.

supporting the vendor ethic of "wining and dining" potential clients, while No Time To Wait

eschews this work because the open-source community doesn't need it and finds it wasteful.[134]

I found that many attendees found the informality - and the lack of a conference fee - to be

harmonious with the ethic of the open-source software development realm. The conference

streamed the various presentations over the two-day event and, again in keeping with the 'free

and open' ethic embraced by most of the participants, hosts the video streams on YouTube

under a Creative Commons Attribution license.[135]

The name of the No Time To Wait conference comes from the perceived need by the

audiovisual preservation community to stop waiting for large shops to develop standards and

best practices that smaller shops can use and instead take on the burden proactively

developing their own standards. Since the viable playback ability of analog video materials

diminishes with every year that passes, many participants in No Time To Wait noted in their

presentations that there is a sense of urgency to their work. Throughout the No Time To Wait

conference that I attended, presenters described demands for technologies that could be

responsive to predicted future needs instead of simply responding to the outmoded needs of

the past. Participants argued for tools that could potentially sidestep the hand-me-down model

of memory institutions that, in the past, took broadcast and Hollywood standards and

retrofitted them to work - sometimes inadequately - for the needs of cultural preservation.

How does the CELLAR work exemplify this shift from 'hand me down' technologies and

what does it mean for the media preservation realm? The CELLAR ethic, which is inherited from

MediaConch, is to "coordinate a community driven effort" that will "facilitate the

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[134] Blewer interview.

[135] https://www.youtube.com/c/MediaAreaNetOfficial. Accessed on November 14, 2018.

standardization of featured file formats that face a documentation or standardization gap"

(MediaConch). The goal of the CELLAR work is to move Matroska, FFV1 and FLAC out of their

niche uses and into a kind of ubiquity among preservationists. FFV1 lived in a niche, nestled,

hibernating within FFmpeg until Herman Lewetz discovered it around 2010. Matroska lived in a

niche, that of online video piracy, before it began to be used by the City of Vancouver Archives

around the same time. Indiana University, New York Public Library and CELLAR are all moving

Matroska and FFV1 out of these shadowy niches and into the sunlit realm of international

cultural memory digitization and preservation.

There are other important reasons for some of my interviewees' interest in CELLAR. Ben

Turkus pragmatically cited the fast, clear responses he receives to his questions on the CELLAR

email list. Brecht DeClercq cited CELLAR's nonprofit status and the openness of the standards

they are producing as a potential corrective to the periodic difficulty finding support for tools

that fail due to market pressures, what he calls the "ugly side effects of capitalism" in

preservation. Dave Rice noted that the lack of barriers to access to the CELLAR work means that

more archivists will feel empowered to participate and influence the design work in favor of the

particular needs of the preservation community instead of for-profit industries. It is also an

express goal of CELLAR to create documentation that is both technically precise but also

readable by people in the preservation community, which is not always the case with SMPTE

and/or ISO standards. This level of clarity is not always achieved by the more intensively

engineering-specific conversations that play out on the email list, which is a chief reason why

Jim Schupert of Scenesavers claimed to be a "lurker" in that space - watching, monitoring but

not often participating.

6.6 PROFIT, NONPROFIT AND THE INDISTINCT DISTINCTIONS BETWEEN THEM

When I embarked upon my research for this dissertation I articulated the work as an

exploration of the distinctions between the for-profit and nonprofit standards development

and implementation realms. It became apparent to me that this boundary is a porous and hazy

one at best. While it is clear that MXF is a heavily broadcaster-influenced standard, it was, as I

noted earlier, developed with considerable input from nonprofit broadcasters in a standards-

making body (SMPTE) that is not profit-seeking, even though it charges for its standards in

order to fund its standards-making work. The Library of Congress' work on AS-07 is done under

the auspices of both FADGI, a collaborative body comprised of representatives from twenty-

one American federal agencies, and standards-making bodies like SMPTE and AMWA, both of

which have significant representation by businesses that are motivated mostly by the potential

maximization of profits. For-profit entities have a very clear potential return on the investment

of effort on standards like MXF and specifications like AS-07: the profits they could accrue from

making and selling tools that are compliant with those technologies. Furthermore, collaboration

on these standards and specifications can give businesses the ability to influence them from the

ground up and tailor them for their own interests. The Library's adoption of MXF and JPEG

2000, and its continual adherence to them because of digital cinema, can be seen as an echo of

the original public-private partnership between the Library and Hollywood that motivated the

moving image copyright deposit system's development nearly a century earlier (Frick).

While standards-making is an exercise characterized by the push and pull of sometimes

competing ethics and perspectives, efforts like MXF, JPEG 2000 and AS-07 can be viewed as

sites of alignment between public and private entities. The MDPI project is a similar zone of

convergence, made all the more notable for the fact that it represents a synergistic endeavor

that ultimately results in the preservation of information materials that are, for the most part,

owned by the state. Clearly this dissertation cannot be simply the story of profit versus

nonprofit groups, with respect to standards. Further complication of the clear delineation of

these two kinds of entities comes in the form of open source standards development.

6.7 THE PRESERVATION REALM SLOWLY EMBRACES FFV1 AND MATROSKA

Trevor Pinch, in writing about the adoption of the Moog synthesizer in the mid to late

twentieth century, argues that the instrument's salespeople played a critical role in creating a

market for it. With its wires and electronic patch-bay appearance, the early iterations of the

Moog did not look very much like an instrument, which created a hard sell for salespeople until

the release of the MiniMoog, which had a keyboard and much more comforting, musical

appearance (Pinch, 2005). Lewetz's presentation at 2010 served a very similar function - that of

a salesman trying to convince a skeptical audience of the utility of a technology that did not

have the appearance of a preservation encoding. Lewetz told me in our interview that he got

bombarded with questions from participants, mostly about the reliability of FFV1, and

astonished reactions to his choice of using an encoding that was not standardized by the ISO or

SMPTE. Lewetz, because he got pushback at the Mediathek about this choice, told me he was

surprised by this response from the international preservation community. He even claims that

he felt physically intimidated by one prominent audiovisual preservationist who interrogated

him very closely (intellectually and physically) after Lewetz's presentation. Peter Bubestinger

told me that a high-profile video digitization vendor told him that his company couldn't allow

FFV1 to be produced for their customers, mostly because of the company's allegiance to SMPTE

standards.

According to audiovisual preservation experts Ashley Blewer and Dave Rice, "FFV1 is an

efficient, lossless video encoding that is designed in a manner responsive to the requirements

of digital preservation" (Blewer and Rice, section 2). FFV1 natively contains attributes that

preservation professionals like Rice and Blewer find useful for their work. Provenance - the

proof of an unbroken chain of custody from donor to archives - can be difficult to construct in

the digital realm. One method favored in many digital preservation sectors is the use of

checksums - machine-generated and machine-readable alphanumeric codes that validate - or

not - based on changes to the bit stream of a digital object. Checksums are useful tools but lack

a kind of granularity that large video files require. For example, if even a single bit in a 200

gigabyte video file flips, that file will fail its checksum validation. However, this failure usually

does not tell the preservationist exactly *where* the damage to the file exists, meaning repair of

the file may be impossible and a completely new file must be created - a time-consuming and,

depending on the quality of the original source, sometimes impossible task. Where JPEG 2000

breaks down the video frame as planes, FFV1 breaks down the frame as slices, or chunks of the

lines that make up a video image. The Matroska format can embed multiple checksums for a

digital object, meaning that combining the granularity of FFV1's slice-level encoding with the

Matroska format can give great precision with respect to where checksum failures occur in a

file.[136] I should note that, to my knowledge, none of my interviewees are encoding their FFV1

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[136] Henderson interview.

bit streams with checksums at the frame level. It would stand to reason that this level of checksum generation and encoding could negatively impact the computational efficiency of FFV1, at least with respect to the generation of the bit stream. While this may not affect the playback of such an FFV1 object, generating slice-level MD5 or similar values could put a heavy burden on a processor.

That said, this level of checksum generation can, in theory, allow the preservationist to precisely target the repair of a media file. In our interview, Ben Turkus told me this "internal fixity" of the FFV1 bit stream makes it very attractive to him. Dave Rice made a similarly pragmatic argument for FFV1 when he told me the encoding can store information about the interlacing scheme and aspect ratio natively within the coding without relying on the container. These are some of the factors that were encoded into the FFV1 technology from its inception that, unbeknownst to its early developers, primed it for use in the memory realm.

Matroska's adoption in the memory realm was similarly slow. While it proliferated widely in the piracy realm, it lay fallow for several years out in the 'legitimate' media worlds until 2010, when it was adopted as the WebM container, which is used in HTML5 audio and video elements that allow browsers like Opera, Firefox and Chrome to natively decode and play back time-based media. One of the chief reasons for the choice of Matroska for this purpose was its royalty-free nature.[137] On2, the company that developed the VP8 video encoding technology which was a core part of WebM, was acquired by Google in 2010. Google immediately started transcoding the videos in YouTube to WebM, meaning that Matroska became the container for the world's largest online digital library (Blizzard, 2010). Steve

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[137] https://www.webmproject.org/about/. Accessed on January 8, 2019.

Lhomme, Matroska's inventor, told me he considers this a win for Matroska and its legitimacy.

He said he finds it amusing that his daughter, like most of the millions of YouTube users,

consumes his invention without even knowing it. Once again Matroska proved itself to be a

boundary object by straddling the open-source realm and the for-profit realm while serving

both.

Google's investment in the WebM backbone of YouTube and its participation in the

CELLAR group's work have caused a major shift in my articulation of the landscape in which the

players operate. In the early phases of my work, I sketched out a sharp distinction between for-

profit entities (the Hollywood and broadcast entities collaborating on MXF and JPEG 2000) and

nonprofit entities (the archivists, librarians and other specialists at work on the CELLAR

standards). However, it quickly became apparent to me that Google's involvement in the

CELLAR work as well as the participation of consultants like Jean-Christophe Kummer and

businesses like Scenesavers in CELLAR breaks down the false dichotomy of open-

source/nonprofit and industry/for-profit with which I started the research. Furthermore, as

Peter Bubestinger pointed out at No Time To Wait 2 in Vienna, open-source does not

necessarily mean a lack of profit.[138]

Both FFV1 and Matroska began to move out of their niches and into broader realms of

use. Part of the reason for this is the nature of technological development which, in the words

of Lucy Suchman, et. al, involves ongoing appropriation and refashioning of existing

technologies (Suchman, Blomberg, Orr, & Trigg, 1999). While Matroska was not designed

specifically for cultural heritage preservation, its design was elastic enough to be very amenable

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[138] https://www.youtube.com/channel/UC-NF6EF-tN0S0FrJUD20-ww/videos. Accessed on April 4, 2019.

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to this kind of use. For this reason, the potential for use in piracy was almost certainly encoded

into Matroska from its inception. However, since Matroska has the ability to enclose almost any

kind of content, and because it is freely available without cost, it has comfortably situated itself

in the memory realm. Furthermore, its support in Blu-Ray players and the ability of QuickTime

Player to play Matroska files back (with the help of the Perian plug-in) has helped it move from

piracy into the "legitimate" content consumption realms.[139] It is worth noting that Matroska

was designed as a 'delivery' format and not a 'production' format. Its chief use is for bundling

bit streams together for final playout, not for editing.

6.8 BIG PLAYERS CHOOSE MATROSKA AND FFV1

Like the Moog salesmen in Pinch's study, Bubestinger and Lewetz had to make a market

for FFV1 by articulating it as a viable technology even though it looked and felt different from

the standardized tools that came before. Lewetz's presentation 2010 helped to expose the

"market" of audiovisual repositories to the notion of using FFV1. WebM and piracy gave

Matroska a foothold in the dissemination of video content online. Neither of these

developments, however, caused very many American memory institutions to take a chance on

these technologies. Video digitization is a resource-intensive and costly endeavor and choosing

encoding/container combinations is not done lightly by most institutions. This is because

choosing a file format and/or encoding that, for whatever reason, cannot be easily decoded in

the future, can lead to, at best, a costly re-digitization of source material and, at worst, the

complete inability to re-digitize that material because of the age-related failure or complete

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[139] https://www.Matroska.org/technical/guides/faq/index.html. Accessed on April 3, 2019.

obsolescence of the analog original. The adoption of FFV1 and Matroska in preservation contexts was also slowed by the lack of audiovisual specialists in libraries and archives. It is far safer, politically, for archivists and librarians to adopt technologies that are championed by large institutions with high name recognition like the Library of Congress than argue for esoteric tools like FFV1 or Matroska, the merits of which may require a high degree of understanding of video engineering in order to explicate. Video digitization in the memory realm is a bit like a pool party wherein participants are willing to dip a toe into the water but no one wants to jump in until they see someone else safely do it first.

As Langdon Winner points out, sometimes technologies are adopted simply because of their compatibility with other technologies (Winner). The fact that tools like VLC Player and FFmpeg can create and/or play back Matroska and FFV1 files made them much more attractive to early adopters. Another of these early adopters is the Notre Dame University Archives. One of the staff in the Archives, Erik Dix, told me he uses the FFV1 encoding to losslessly compress video for storage because the encoding works seamlessly with Virtual Dub, the software they use to digitize their analog originals. Virtual Dub does not easily create or decode the Matroska container, so Dix wraps his FFV1 essences in the Microsoft-developed AVI file format. The Notre Dame Archives, like many similar institutions, operates with considerable budgetary, staffing and resource constraints that force them to use inexpensive, user-friendly tools like Virtual Dub to do their digitization work. Thus, as Winner suggests, FFV1 and Matroska more easily find purchase in these institutions if they are compatible with existing technologies that are cheap and easy to implement.

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Matroska and FFV1 have worked well for Indiana University but Peter Bubestinger expressed some hard feelings to me about the school's use of these tools without investing heavily in their development. This frustration exemplifies an ongoing problem in digital preservation - that of the 'free rider,' or the danger of institutions using resources without replenishing them. In other words, the best outcome for a library or archives is for someone else to do the work and expend their resources with respect to digital preservation and digitization (Blue Ribbon Task Force). While a standard is, technically, a non-rival technology - that is, a standard can be used over and over without being used up - Bubestinger's concern is that the effort that goes into developing and adapting a standard is not infinite. He is troubled by Indiana's high-profile use of FFV1 and Matroska without being comparably present and active in the CELLAR development work.

Indiana's choice to use FFV1/Matroska has had a cascade effect with other large institutions and their video preservation work. The New York Public Library has also chosen FFV1 and Matroska in order to save resources. Ben Turkus, audiovisual preservation specialist at the Library, told me that he spoke with a vendor while the Library was trying to make a decision about video formats, and that vendor pushed hard for the Library of Congress' MXF/JPEG 2000 combination, but the openness of the code for FFV1 and Matroska and the internal fixity element of FFV1 made that combination much more attractive. Mike Casey told me that the New York Public Library's adoption of FFV1 and Matroska was likely influenced by Indiana University's choice. As of this writing, the Irish Film Archive, the National Library of Norway, the City of New York University TV and RTV Slovakia have also begun using FFV1 and/or Matroska. The Wikipedia entry for FFV1 is the most up to date resource that lists

memory institutions that implement the encoding for preservation.[140] Clearly FFV1 and

Matroska have arrived as preservation technologies that are perceived as legitimate by many

memory institutions.

6.9 INDIANA UNIVERSITY AND MEMNON

The story of audiovisual media preservation in the cultural memory realm is at least

partially the story of the influence that the American television broadcast and Hollywood

cinema production industries can exert on nonprofit institutions like libraries and archives. (It

should be noted that there are many for-profit repositories in the broadcast and cinema realms

as well.) This influence can play out at the level of digitization work, as exemplified by the joint

digitization work of Indiana University and Memnon, a Sony company. This kind of influence can

also be felt at the level of the standards that govern the object-level outputs of digitization.

Collaboration between for-profit and nonprofit entities takes place in standards development.

It also takes place in the implementation of those standards. Digitization - particularly mass-

digitization at scale - is a complex endeavor involving costly equipment and, often, many

employees.

I visited Indiana University and toured the MDPI workspaces in March of 2018. The

MDPI is housed in a large facility off campus, and people staffing the project are either

employed by Indiana University or Memnon/Sony. I found the cultures between Memnon and

IU are overlapping but very distinct. Memnon tools and staff are mostly concerned with the

high-throughput digitization of massive quantities of cassette-based video. These large, open

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[140] https://en.m.wikipedia.org/wiki/FFV1. Accessed on January 8, 2019.

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workspaces involve multiple playback decks operating nearly continuously throughout the

week with large monitors that display many video streams simultaneously, allowing one or two

staff members to oversee the digitization of many tapes at once. This system, with its very high

videotape-to-staff ratio, leverages Memnon's resources to digitize large quantities of materials

that need minimal supervision, allowing for highly efficient digitization of materials that have,

on average, very few playback issues. This high-volume digitization work contrasts and

complements the work that Indiana University staff are doing in other workspaces in the same

building. Indiana University staff are performing, for the most part, digitization and

conservation work on single items that require close attention and inspection. Items that are

exhibiting playback issues and/or common breakdown syndromes like binder hydrolysis require

more cautious and time-consuming handling and playback than the Memnon systems can

efficiently handle, so they are set aside for the Indiana specialists. Nonetheless, the workspaces

for the Indiana staff are very different from the Memnon environments: where Memnon's mass

digitization spaces are open and heavily staffed, the Indiana spaces are rooms consciously

designed to allow a handful of staff to work in low-light, low-noise conditions allowing for

critical listening and viewing.

  After my tour of the space, I performed a group interview with several Indiana

University and Memnon employees. Throughout the interview the participants repeatedly

made clear that Memnon is about efficiency and moving quickly, while the Indiana staff handle

the objects that fall outside of the parameters of the Memnon workflow. One of the key

requirements for sustainable digital preservation from the 2010 report by the Blue Ribbon Task

Force On Sustainable Digital Preservation And Access is the need for building the preservation

endeavor as "an economic activity firmly rooted in a compelling value proposition, clear incentives to act and well-defined preservation roles and responsibilities" (Blue Ribbon Task Force, page 7). Memnon and Indiana University are working within the MDPI in a way that creates and adheres to very well-defined roles that leverage the various strengths of a large for-profit technological innovator and a large nonprofit, state-funded academic institution.

Memnon, because of its size and its nature as a Sony company, has wide affordances with respect to quickly hiring staff and providing cutting-edge technology for the playback and digitization of legacy materials. (I observed that many obsolete playback decks that had been pressed into service at the MDPI laboratory were, in fact, made by Sony in decades past, leading me to think that Memnon may be in a particularly advantageous position with respect to procuring hard-to-find parts for these machines' upkeep.) Indiana, on the other hand, is able to leverage its specialists, who have training that can take decades to acquire, as well as equipment that staff has customized over decades of use, to the per-item, intensive repair, playback and digitization of at-risk and/or particularly valuable items. The flow of analog and digital objects through the MDPI project, and especially the ongoing hand-off of materials from Memnon staff to Indiana University staff for their assessment, conservation and digitization, as well represents a very close form of collaboration between for-profit and nonprofit entities and ethics. However, as my interviewees continually asserted, there is more to this partnership than just workflows: it also represents a synergy between ethics as well. Where Indiana University represents, to many of the MDPI workers a slower-paced, more deliberative value system that prizes an extreme attention to detail in singular objects, the Memnon/Sony system holds as its highest regard the fast, efficient digitization of high quantities of material.

6.10 FLEXIBLE STANDARDS; PERMEABLE AND IMPERMEABLE BOUNDARIES

MXF, JPEG 2000, Matroska and FFV1 began their lives outside the cultural memory preservation realm. They have all, over the past two decades, moved into use in many kinds of libraries and archives. The developers of MXF designed it as a standard specifically for the American television broadcast industry and, while it is still widely used in that realm, the Library of Congress' AS-07 specification has helped to expose it to the worlds of libraries and archives. JPEG 2000 has seen a similar move from an ISO standard for online still image delivery to moving image dissemination and preservation as part of digital cinema. FFV1, developed as a lark by the early developers of FFmpeg and included in its encoding libraries, has seen increasing adoption in American and European libraries, archives and broadcasters thanks in part to the work of the Austrian Mediathek and Indiana University. Finally, Matroska spent its youth as a format used almost exclusively by online video pirates but has matured into a robust container format embraced not only by preservation professionals but also by content producers like Sony as part of their consumer video playback technologies.

Interpretive flexibility - the ability for a technology to have different meanings for different users - is critical to making that technology function as a boundary object. Some of the four standards analyzed in this dissertation operate better as boundary objects than others. There is considerable interpretive flexibility in the cases of Matroska and FFV1, largely because of their lack of standardization by a formal standards body prior to CELLAR's work. Matroska's broad use in the online piracy realm for nearly a decade and a half prior to CELLAR allowed for very loose implementations of the format all over the world. While it has created backwards-

compatibility challenges for CELLAR, the multitude of Matroska 'flavors' has helped the format

find a wide adoption prior to its entry into libraries and archives as a tool for video

preservation. Today Indiana University, the Austrian Mediathek, the BBC and other memory

institutions employ the format extensively in their preservation endeavors. Furthermore, a

search for a current, popular movie on a BitTorrent site will usually yield at least some

Matroska versions of the film. Matroska files can also be played back on many Blu-Ray players,

including those marketed by Sony, a vocal opponent of online piracy. Clearly Matroska is a

technology that can move between sociotechnical worlds. Similarly, FFV1's open specification,

and its relative ubiquity as an encoding bundled into the popular FFmpeg software, have

allowed the technology to find homes in memory institutions like Indiana University as well as

some eastern European broadcasters.[141] As Reto Kromer noted to me, Adobe may soon include

support for FFV1 in their popular Premiere editing software. Because Premiere is used by

amateur and professional video editors, the inclusion of FFV1 in the software would see its

interpretive flexibility increase considerably as it moves further into the realm of video

production.

Matroska and FFV1 have become boundary objects largely because of the looseness and

openness of their specifications. Several of my interviewees cited the open nature of the

CELLAR standardization work and the lack of cost of the standards documents as selling

features for Matroska and FFV1. The fact that much of standards-making work plays out over

email lists, GitHub threads and synchronous, open online IETF working means many more

contributors can participate in the work. These communication avenues can allow more players

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[141] Several presenters at No Time To Wait 2 in 2017 discussed the growing use of FFV1 in broadcasting in Europe. Available at https://youtu.be/zHnvAM_CHUQ and https://youtu.be/n1XYEVtxzU8. Accessed on April 18, 2019.

to speak and have input on the work than in traditional, closed-door standards-making meetings that may require travel and membership costs.

By contrast, MXF and JPEG 2000 were both developed in that traditional standards-making mode by SMPTE and the ISO. This mode, coupled with the high cost of the standards documentation caused several of my interviewees to be less drawn to working on and/or using MXF or JPEG 2000 than their CELLAR counterparts. Furthermore, the IETF has a history of collaboration with librarians and archivists that SMPTE does not share. SMPTE, because its makeup consists largely of Hollywood and broadcast specialists and technicians, strongly directed the development of MXF towards the needs of those industries, as evidenced by the issues related to interlaced video that came to light during the early AS-07 work. Before the Library of Congress' work on AS-07, the library realm had little input in the development of MXF or of JPEG 2000 as a video encoding. As Kate Murray told me, AS-07 may become a SMPTE standard over time, but as of this writing, the cultural memory realm (outside of federal agencies like the Library of Congress and the National Archives and Records Administration) has still had very little input in MXF's evolution. Some of my interviewees noted problems making AS-07-compliant files on their own software/hardware infrastructures, which is also a telling example of the challenges MXF and the JPEG 2000 video encoding are currently having with respect to finding a home in many memory institutions.

In conclusion, MXF and JPEG 2000 have had trouble finding the interpretive flexibility needed to live comfortably in both the library/archives world and the broadcast/cinema production realms. This likely owes at least in part to the closed nature of the SMPTE and ISO standards bodies. In those standards bodies, few if any librarians and archivists have had the

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ability to participate. That lack of participation, coupled with the cost of the standards

documents and encoders/decoders for JPEG 2000, can be significant barriers to entry for many

memory institutions. By contrast, Matroska's early life as a piracy format helped to ensure its

ubiquity and made for a highly flexible technology. After all, without the compulsory power of a

standards body and/or patents behind the format, who could say what was or was not a

properly-formed Matroska file? While the free-range nature of early Matroska files has been

vexing for the CELLAR group, it has helped increase the user base and the interpretive flexibility

for the format. This flexibility, coupled with the low barriers for entry for CELLAR participants

has helped Matroska and FFV1 to become boundary objects that have found homes in the

production, piracy and cultural memory preservation realms.

CHAPTER 7: THE SOCIAL CONSTRUCTION OF THE FOUR STANDARDS

The trajectories of JPEG 2000, MXF, Matroska and FFV1 as they moved from their niches to more widespread use in the memory realm have been convoluted and, to some of their developers, surprising. One of the key arguments of this dissertation is that the transition of these technologies from niche to widespread implementation in libraries and archives was driven not just by the technical affordances of these standards but also by social factors. As this section will show, the technological features of the standards are very useful for their implementation in preservation contexts. However, these standards - Matroska and FFV1 in particular - required advocacy by influential users as well as adaptation for the specific needs of the library/archives realm in order to allow for their growing uptake into memory institutions. Furthermore, the move from niche to widespread use has not been a smooth transition for the four standards. There has been shifting resistance and acceptance of these technologies throughout the cultural memory realm.

7.1 POLITICAL ECONOMY AND THE CHALLENGES AND NEEDS OF THE MEMORY REALM

The broadcast and Hollywood cinema realms and the nonprofit cultural memory realm all engage in media preservation, digitization and dissemination. The participation of for-profit actors in the CELLAR work as well as the negotiations of the Library of Congress with SMPTE and AMWA over the AS-07 specification reveal a lack of boundary between nonprofit and profit-seeking actors with respect to the four standards under scrutiny in this research. The lack of a rigid boundary between profit-seeking and nonprofit entities in standards development argues

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for a political economy analysis on standard-making endeavors. Where traditional economic

models often articulate actors as being rational and free to spend their money as they like, the

political economy lens focuses on the real-world constraints that impede actors' budgetary

agency (Mosco). Thus this political economy analysis of the adoption of digitization standards in

the American cultural memory realm must include a survey of the resource constraints that

have made the for-profit realm's 'hand-me-down' digitization technologies so appealing to

these institutions.

The speed with which the memory realm must move in order to capture magnetically-

recorded information before the carriers pass out of their viable playback lifespans has been a

kind of limitation, or governor, on the ability of many libraries and archives to experiment with

new technologies. As Andrew DaPuzo pointed out, the ticking clock of magnetic tape

breakdown has motivated many institutions to situate themselves in what one interviewee

referred to as the "the 'don't give a damn' world." In other words, many institutions have such

a massive backlog of materials in need of digitization, coupled with insufficient staff hours to do

the work, that they are disinclined to experiment with new technologies. Archivists, as Peter

Bubestinger asserted in our interview, "just need tech to work." They prefer to use software,

hardware and format/encoding standards that have the perception of being "tried and true."

This perception often comes from the preponderance of these technologies in large institutions

like the Library of Congress, television stations, Hollywood and so on. This preponderance is

often made manifest in professional email lists, organizations and conferences wherein

members of the for-profit and nonprofit worlds interact. Adoption of technologies tends to be

self-reinforcing - the more well-adopted a standard is, the greater the perception that this

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standard will be a safe bet for long-term viability. This is the logic that underpins, for example,

Jean-Christophe Kummer's advocacy for the AVI format. In the case of adoption, the use of a

standard in high-profile institutions can encourage initial adoption in other institutions. While

this power is initially located in these large institutions, the influence becomes more distributed

as adoption is also broadened.

The wide array of video formats is also a kind of limitation for memory institutions.

Magnetic videotape was designed for an ethic of just-in-time image capture in televisual

broadcast and evolved into the realm of home video in the last three decades of the twentieth

century. Neither of these environments tend to have a direct mandate to preserve their

productions for the greater historical record. Furthermore, the evolution of magnetic video

media has moved at high speed as image capture and playback technologies have improved,

which has led to a wealth of incompatible formats (Wasser, 2001). In the words of Bijker and

Pinch, who argue from a Social Construction Of Technology perspective, "the developmental

process of a technological artefact is described as an alternation of variation and selection"

(Pinch and Bijker, 1987, page 28). If we can construct 'magnetic analog video' as a kind of

technology, the ongoing success/failure cycles of technologies like U-Matic, Betamax and VHS

are a perfect example of a broad, oceanic technological state with periodic and temporary

swells of successful technologies and frequent whirlpools of unsuccessful ones. These failure

cycles put at a disadvantage any institution not well-funded enough to collect playback

equipment for this wide array of formats, in particular those formats that, because of market

forces, did not have the benefit of being inexpensive and widely available. A further

complication is that memory institutions have little or no influence over how the materials in

their collections were produced. These institutions must be prepared to ingest a wide array of materials that are often not produced to any particular specifications (Fleischhauer, 2003).

The broadcast and cinema industries, largely through their participation in SMPTE and their strong buying power with respect to hardware and software, have been able to influence the development of standards directly. Large institutions that focus on broadcast and/or Hollywood collections, like the Library of Congress, tend to use the standards that derive from SMPTE. As Dave Rice and James Snyder both put it, standards in the audiovisual preservation realm have the most utility when donors and repositories agree on using them. This need for conformance to donor specifications creates an easy symmetry between the broadcast/Hollywood realm and their depositories. However, the aforementioned wealth of formats and resource constraints of smaller institutions makes finding an easy symmetry between donors and collectors complicated. Some institutions have other constraints on which standards they can use. For example, as Lars Gaustad noted in our interview, the National Library of Norway's preservation policy states the need to follow international policies with respect to standards and digitization, which means they must look to projects like PREFORMA for which technologies to implement. The City of Vancouver Archives is an example of an institution operating under a state-mandated constraint to use, wherever possible, open-source technologies in their work. Not all institutions willingly conform to industry standards. Josh Yocum made this clear in our interview as he argued that archives should make their own decisions, informed by local practice and, furthermore, he claimed that the fact that MXF is good for broadcasters is not a selling point for him.

Another potential constraint is access to expertise and guidance that can help support

preservation and digitization activities, particularly when problems need to be assessed and

solved. As Dave Rice put it, if an archives chooses JPEG 2000, it automatically aligns them with

industries like cinema and broadcast. However, if most of his peers and colleagues were part of

the FFmpeg and open-source realm, it might make access to expertise regarding MXF or JPEG

2000 harder than it would for FFV1 or Matroska. Another critical tool for creating and/or using

technologies for creating and playback digital video files is the standards documentation itself.

In my conversations with implementers of Matroska and/or FFV1, a common theme is the cost

of access to the standards documents themselves. MXF, in particular, has documentation that

exists behind a paywall and that can make it unappealing to some, as Jean-Christophe Kummer

noted. In order to see the 'recipe' for how MXF files are constructed, one must pay high fees in

order to access those documents. This can slow the development of DIY tools for creating and

decoding these kinds of files.

Matroska and FFV1, in contrast, both have openly-accessible documentation about how

to use them. Time and again in my interviews, the costs of standards documentation was a

barrier to access. In fact, the cost of SMPTE standards was a key factor in how the IETF/CELLAR

work has played out, according to Ashley Blewer. Kate Murray noted that FADGI understands

the problematic nature of paywalls for many institutions, so she hopes to make AS-07 a free

and accessible SMPTE standard. According to Peter Bubestinger, the cost of standards is a

barrier to access for many institutions, particularly those of modest means. The constraints that

smaller institutions operate under have complicated the adoption of costly standards. These

constraints have also helped to motivate the development and adoption of free and open

standards like those being produced by CELLAR.

7.2 THE TIDE TURNS IN FAVOR OF FREE AND OPEN STANDARDS

FFV1 and Matroska are coming of age in a time of cheaper and easier-to-access tools for

creating and handling digital time-based media objects. The decreased cost of tools like VLC

Player and FFmpeg as well as the free and open nature of Matroska and FFV1 have propelled

their adoption by many memory institutions. It is possible that this adoption will cause a

cascade effect - now that many institutions here and abroad have chosen FFV1 and Matroska,

more will take the plunge. This means, as I was reminded by James Snyder, that everyone

working in large preservation facilities will have to deal with these products, like it or not.

Snyder noted that, because broadcasters in the United States have made up their minds about

MXF and JPEG 2000, it is unlikely they will change any time soon. However, as more archives

choose Matroska and/or FFV1, content producers like NBC will have to be able to transcode

and/or play out these standards. Meaning that these open source technologies will, over time,

even insinuate themselves into sectors of industry that would not otherwise use them for long-

term preservation purposes. The distinction between submission and preservation is important

to point out here - a broadcaster may need to have the technology to ingest and transcode

FFV1 while still not generating such files for their preservation packages.

Where the previous section dealt with the constraints that can affect choice of video

standards, this section will discuss some affordances that can make certain standards more

appealing to those working in video digitization and preservation. One such affordance - the

ease of file handling that comes from aligning with the production industries - has been made apparent in the above section. This section will treat the growing shift in alignment from industry standards to open-source standards in memory institutions. In 2017, Mike Casey wrote a white paper outlining Indiana University's digitization workflows and their format choices for the MDPI project. Casey discusses several standards under consideration by the MDPI staff, including JPEG 2000 and MXF, both of which the staff decided were unfit for the project because of playback errors in test files and/or the costs to implement. In the paper, Casey said the following: "We also believe that it is more fruitful, given our specific preservation requirements, to align ourselves with the FFmpeg community rather than with QuickTime developers and Apple." (Casey, 2017, page 7) While Casey told me in our interview that he did not intend this statement to be a rallying cry, it has, nonetheless been a very important declaration. The declaration, which was intended to be pragmatic, has been interpreted by people like Nick Krabbenhoeft as a clear example of the archival community going its own way and lessening its reliance on the production industries. It is worth noting that, with Google's participation in CELLAR's standards development of Matroska, there is still production industry involvement in that technology. YouTube is, after all, a content dissemination avenue for many Hollywood production companies like Paramount Pictures[142] and 20th Century Fox.[143] However, Google's involvement in CELLAR has never been strongly promoted on the working group's website, which means its participation may not be apparent to all CELLAR participants or to all adopters of CELLAR's standards.

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[142] https://www.youtube.com/channel/UCF9imwPMSGz4Vq1NiTWCC7g. Accessed on April 4, 2019.

[143] https://www.youtube.com/channel/UC2-BeLxzUBSs0uSrmzWhJuQ. Accessed on April 4, 2019

Indiana University's white paper was, according to Krabbenhoeft, one of the reasons for the New York Public Library's investment in FFV1 and Matroska. Casey's statement has sent ripples throughout the media preservation realm. James Snyder told me he intended to write a letter to Casey, detailing some of things the white paper got wrong about JPEG 2000, but he ultimately chose not to.[144] This shows that not everyone in the preservation community agrees that Indiana's direction is sound. However, Brian Wheeler made clear in our interview that part of Indiana's reasoning for choosing FFV1 and Matroska was the growing number of tools for creating and decoding the files, and stability of the FFmpeg transcoding tool and library.

One of the key reasons that many memory institutions are shrugging off the path-dependence of industry-preferred standards is the free and open nature of tools like FFmpeg. Another transcoding tool called Virtual Dub, which is licensed under the GNU General Public License, includes support for FFV1.[145] The openness and public licensing of this tool is what motivated Erik Dix, archivist at the Notre Dame University Archives, to use Virtual Dub. And its integration of FFV1 allows him to digitize video at high quality while saving storage space. The broadcast and cultural heritage realms have very different views on audiovisual preservation: the former privileges speed and efficiency, while the latter is often willing to sacrifice those two factors in favor of high image and/or sound quality and faithfulness to original recordings (Lorrain, 2014). Thus, tools like Virtual Dub, which Dix admits can be cranky at times and in need of patience in updating, patching and retrofitting, can find a better home in libraries and archives than in fast-turnaround, high-stress environments like broadcasting. Tools like Archivematica, VRrecord, FFmpeg and Virtual Dub, because their code is open and freely-

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[144] Snyder interview.

[145] http://www.virtualdub.org/gpl.html. Accessed on December 13, 2018.

accessible, allow for a kind of transparency and ease of 'getting under the hood' in order to

make adjustments necessary for local practice. This responsiveness to an institution's

idiosyncrasies, coupled with direct, quick access to the tools' coders, can make these tools

more appealing than costly, 'black-boxed' technologies like Adobe Premiere. FFmpeg is *only*

available under a copyright-free license - people cannot pay for the tool even if they wanted to

- and the website for the tool has an active forum that encourages information sharing

between users. The No Time To Wait conference is an avowedly open source-aligned space that

encourages collaboration and knowledge sharing between participants. The panels and

presentations at the conference are overwhelmingly comprised of open source evangelists.[146]

The cost of tools is, of course, also a factor in their adoption. As Peter Bubestinger and

Marion Jaks told, JPEG 2000 workstations can be very costly to build. Compare these costs with

the cost-free FFmpeg, VRecord or Virtual Dub software and the appeal becomes apparent. This

sharp disparity in cost has been felt by software manufacturers. Furthermore, the ease of

access to open source tools has encouraged libraries and archives to actively participate in their

development and adaptation. As Lars Gaustad noted, the slow movement of AS-07 through its

development process has been a factor in its slow adoption and of the evolution of Matroska

and FFV1 past it.

In the case of Matroska and FFV1, the technologies themselves have made them

amenable to memory institutions. Encoded within these technologies are affordances that align

with mandates common to the memory realm. For example, many American memory

institutions strive to make their materials compliant with the dictates of the Americans with

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[146] http://bit.ly/nttw2program. Accessed on December 13, 2018.

Disabilities Act (ADA), either out of choice or legal requirement.[147] As Nick Krabbenhoeft noted,

the New York Public Library has found that using the Matroska container for their video

materials more efficiently renders them ADA-compliant than other containers because of the

ease of embedding subtitles into the files. Andrew DaPuzo's comment that FFV1 and Matroska

handle "where you put stuff flawlessly" shows Indiana University's choice of these technologies

was motivated no only by the need to save space but also by their experience that the

FFV1/Matroska combination is robust and reliable in terms of where different types of data are

embedded in the container. This perception of the robustness of FFV1 is furthered by the

potential time-saving nature of FFV1 as laid out by Ashley Blewer. Archives and libraries tend to

have ongoing resource constraints so the efficiency of FFV1 can be an important part of the

meaning of the standard for those in the memory realm. Another critical element of the

meaning of FFV1 and Matroska as preservation solutions for those in the memory realm, as Erik

Dix told me, is the openness of these standards' documentation. These are some of the

features that have made FFV1 and Matroska so appealing to the CELLAR community for their

standardization work. These features also align Matroska and FFV1 with the mandates and

ethics of the memory realm and, for some of my interviewees, encourage their preference over

MXF and JPEG 2000.

The use of Matroska and FFV1 is growing with broadcasters too - at least those

overseas. European actors are not constrained by Hollywood/copyright/DMCA regimes or the

idea that Hollywood norms represent the needs of all preservation institutions. As Ian

Henderson told me, the BBC reviewed many encodings and containers for their preservation

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[147] https://www.ada.gov/. Accessed on May 21, 2019.

work and have recently settled on FFV1 and Matroska, largely because formulations of

MXF/JPEG 2000 like AS-07 were not found to be fully interoperable abroad a wide array of

software encoder/decoder tools. The work of Hermann Lewetz at the Austrian Mediathek has

had far-reaching effects as more broadcasters have chosen Matroska and/or FFV1. One such

broadcaster, RTV Slovenia, presented about their recent adoption of FFV1 at 8/10 bits standard

definition (720 by 608 lines) for their preservation. This growing adoption of FFV1 and Matroska

gives some credence to Jim Schupert's assertion that open-source standards are more readily

embraced in Europe than here in the United States. Jean-Christophe Kummer agreed with

Schupert's sentiment when he said that Americans are in the SMPTE realm and Europeans are

not. European institutions do not have the same industry-heavy path dependence as

Americans. When speaking about the European audiovisual preservation community, Carl

Fleischhauer of the Library of Congress and FADGI says:

> These were specialists - several in Europe - who are strongly drawn to open source
>
> specifications and tools. My sense is that members of this group are eager to embrace
>
> formats and tools that "just work," and they are less firmly committed to capital-S
>
> standards. (I can imagine one of them saying, "Let's just do it - we have no time to wait
>
> for lengthy standard-development and approval processes.") Many open source
>
> advocates are bona fide experts, skilled in coding and capable of developing systems
>
> "from the bottom up." (Fleischhauer, 2014).

Fleischhauer's comment points to a European preservation community that has a pragmatism

combined with an ethic of 'do it yourself' and a lack of commitment to "capital-S standards" like

those created by SMPTE. All of these elements combine to make many FFV1, Matroska and

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their encoding/decoding tools very attractive to European broadcasters, librarians and archivists.

7.3 AS-07, JPEG 2000 AND THE CHALLENGES OF THE BLACK BOX

AS-07, a specification built upon MXF, initially a television broadcast standard and employing standards-making groups with high broadcast and Hollywood representation, has met with mixed reactions in the larger audiovisual preservation realm. Part of the reason for AS-07's sluggish adoption is that, while the specification itself is openly-available to all on the FADGI website, the tools it is built upon, MXF and JPEG 2000, suffer from a 'black box' problem. The workings of black-boxed technologies are often inscrutable to their users and do not lend themselves to being reverse engineered, retrofit or changed. They also tend to enter markets with a feeling of inevitability - of perfect formation even when, in reality, they may lack perfect closure and are not compatible with all use cases (Kaghan and Bowker, 2001). MXF entered the wider media preservation community via the broadcast realm, which did not have the same mandates, workflows or infrastructure limits as the GLAM world (Lorrain). With broadcasters, preservation must always be sidelined in favor of production (Bubestinger, 2016). JPEG 2000 was initially similarly maladapted for the preservation realm, as Ashley Blewer noted about the "hacked" nature of Open JPEG. The lack of participation by the GLAM community in the development of MXF and JPEG 2000 led to standards that are not ready for use without significant retrofitting. In the case of MXF, this retrofitting involves time-consuming back-and-forth with SMPTE, which, as Kate Murray noted, is necessary for AS-07 to be useful with respect

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to digitizing legacy materials. The black-boxed nature of MXF and JPEG 2000 has caused

repercussions in AS-07 and its adoption outside the Library of Congress.

Key to the difficulty in implementing MXF and/or JPEG 2000 in preservation contexts is

the nature and limits of the technologies themselves. The aforementioned issue with MXF and

interlaced video has been a challenge for AS-07. As Dave Rice told me, one of the challenges in

implementing JPEG 2000 for video is that the encoding cannot natively declare its own aspect

ratio - it must rely on the file container to record this information. FFV1 can declare its ratio

irrespective of container, which can make it a more appealing encoding. FFV1 can also record

its interlace information in the encoding, potentially obviating the interlacing issue FADGI faced

with MXF. JPEG 2000 is also very computationally 'expensive,' meaning computer processors

involved in the creation of J2K files must be advanced and costly. (It is worth pointing out once

again that, depending on the number of checksums generated and embedded in its bit stream,

an FFV1 object could also be computationally intensive to produce.) According to Nick

Krabbenhoeft, part of his problem with JPEG 2000 is that it never got the audiovisual

production industry backing it needed to succeed and grow, leading to a video encoding that

was never fully mature before it got pressed into service by the Library of Congress. A further

challenge to the AS-07 specification itself, according to Lars Gaustad, is that it is a highly

technical document, developed by video engineers that are very specialized. Brecht DeClerq

agreed that the challenging content of AS-07 is a reason that some archivists choose not to

invest in it.

The initial poor support in JPEG 2000 for interlaced video, as I described in the History

section above, is a clear indicator of a kind of politics - in this case, the broadcast industry's

prioritization of new technologies over the old - encoded into the design of MXF. Encoded into the MXF container by SMPTE was a vision of the user and the user's environment that ran counter to the needs and mandates of the archives realm.

The Library of Congress' work on JPEG 2000 and MXF was initially tied to their investment in the SAMMA video digitization system. Other archives and libraries also tested out SAMMA systems. The National Library of Norway purchased a SAMMA in 2009, largely because of the Library of Congress' use and because, as Lars Gaustad puts it, the belief, held by many institutions of the time, that MXF was going to revolutionize video preservation. The problems other institutions like Scenesavers and the Austrian Mediathek had with SAMMA hardware and software exemplify the black-box problem wherein the technology was not amenable to examination or alteration by users. The problems with the resultant SAMMA files further exemplify the black-box problem. SAMMA's designers did not anticipate the need to adapt or alter its technology, which led to a system that required continual tinkering in order to get it right, even after it was released to the market.

Part of the challenge of AS-07 is the relative slow speed with which it has been developed. I worked on the specification for almost three years, from early 2010 to the end of 2012, and as of this writing the document is still unfinished. This slow development process has allowed other tools - notably Matroska and FFV1 - to find purchase with institutions that had at one time considered MXF and JPEG 2000. The broad flexibility of MXF may be part of the problem for its adoption - its developers could not foresee all potential implementations of the container, which led to many 'homebrew' variants of it as well as many SMPTE extensions of the standard (Gaustad). The lack of a standard SMPTE extension developed specifically for

preservation has led to many institutions having incompatibility problems with encoders and decoders (Lorain, 2015). Audiovisual technology vendors have, in recent years, become more withholding of the inner workings of their tools, which further complicates the compatibility of files across software tools (Bubestinger). Once again, the black box becomes problematic for MXF/JPEG 2000 users. This black-boxing can also lead to a path-dependence problem called 'lock-in,' wherein an institution, upon finding a software/hardware combination that works, is loath to experiment with other technologies (Mason). This can leave an archive or library in a precarious position if the vendor changes its technology or goes out of business completely. The Library of Congress, because of its reliance on SAMMA and its close ties to the broadcast and digital cinema standards, runs the risk of lock-in as well, as James Snyder told me.

Vendor lock-in has been a reason AS-07 is unpalatable for some institutions. As Hermann Lewetz says, the Library of Congress made their decision to push developers to make solutions because the Library has the money. According to Lewetz, the danger is that other, small institutions will look to the Library and try to emulate their solution, which would be too expensive for them. This belief is shared by Kieran O'Leary at the Irish Film Archives, who found AS-07 to not be useful for low-budget shops that do not have strong ties to vendors. The Indiana University MDPI tested AS-07 but also decided against it because, in comparison to other options, AS-07 presented "greater technical complexity and a lack of available tools for this option. It was felt that JPEG 2000/MXF presented greater risk for us over time" (Casey, 2017, page 3). As recently as 2016, the FADGI AS-07 test files showed errors which made them problematic for testing.[148] While the Library must continue along its MXF/JPEG 2000 path

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[148] Murray interview.

because of its associations with industry, it is also facing the problem of 'sunk costs,' wherein it must continue down its path because of the amount of resources that have already been put into SAMMA and AS-07, as well as the thousands of these files the Library has already created. There may also be a bit of face-saving as well. As Jim Schupert noted, if the Library moved away from MXF/JPEG 2000, it would require telling Congress and the audiovisual preservation community that this expensive journey has not resulted in quite the zeitgeist that the Library thought might come of this venture. It should be noted that, as Lars Gaustad said in our interview, there is still a place for AS-07 and MXF/JPEG 2000 in larger repositories with access to resources to support the standards and the Library of Norway may still adopt something like AS-07 if the specification becomes more broadly adopted. However, at the moment, it does not appear likely that smaller shops with greater resource constraints will be able to easily implement AS-07 or similar MXF/JPEG 2000 combinations.

The black-boxing of the MXF and JPEG 2000 standards, potential for vendor lock-in, lack of AS-07 compliant tools and Byzantine complexity of the standards have combined to pave the way for the CELLAR standardization work. This informed Ben Turkus' comments about Matroska closing the gap between large and small institutions. This attitude is shared with several of my interviewees that are CELLAR contributors as well as preservation specialists at the New York Public Library, Indiana University and others. Furthermore, over the past couple of years Scenesavers has been an increasingly more vocal advocate for FFV1 and Matroska, as Jim Schupert and Jim Bird told me in our group interview. This is in part because, as Jim Schupert said, Scenesavers is still unable to create files that precisely match the specifications laid out by AS-07. The CELLAR standardization work is an attempt to give archivists and

librarians more agency in the development of digital video standards than they have ever had before. The CELLAR standards documentation is also freely available to anyone with an Internet connection, unlike the SMPTE standards, which live behind paywalls. As Marek Jancovic puts it,

PREFORMA's strict open-source policy is a strong signal that archiving, whether institutional or private, does not need to rely on black-boxed hardware and software inherited from the broadcasting and production industries whose functionality is pre-determined by vendor's financial interests and planned obsolescence. Open-source philosophy is also the reason why standardization is pursued at the IETF, instead of other standards bodies such as ISO or SMPTE, which restrict access to documents via paywalls (Jancovic).

Reaction to the use of the IETF to standardize these formats has been mixed in the audiovisual preservation community. In my interview at Scenesavers, Jim Bird and Jim Schupert told me they see the choice of the IETF over SMPTE as sound because of how quickly IETF can successfully generate standards - and how notoriously slowly SMPTE works. That slow speed is, however, a selling feature for James Snyder because, to him, it means a SMPTE standard has been deliberated over enough to be trustworthy.

The choice of the IETF did raise some eyebrows. One of my interviewees, Lars Gaustad, referred to the IETF as an "outskirts" organization, outside the usual media standards generating realm that is, admittedly, "moving at the speed of light." James Snyder wondered aloud in our interview why the CELLAR group chose not to use JPEG 2000 instead of FFV1 to begin with in order to be more in line with SMPTE and the digital cinema community. Snyder

claims that CPU power has increased enough over the years to make the computational power

needed to encode JPEG 2000 video inexpensive to use. He sees CELLAR's choice of FFV1 over

JPEG 2000 to be an example of the open source community wanting to go their own way and

consciously refusing to align with industries like Hollywood and American television

broadcasters. Even though some audiovisual preservationists - particularly those who come

from Hollywood and/or broadcasting - may look at CELLAR askance, Reto Kromer made clear in

our interview that he is proud of the fact that this standardization effort, unlike any audiovisual

preservation standards in the past, is largely taking place "by and for archivists." Many of my

interviewees cite the participation of archivists as a chief reason for their interest participating

in and/or observing the CELLAR work. Furthermore, CELLAR's choice of the IETF may be a signal

that, for many institutions, the tide is turning from industry standards toward open source

technologies for video digitization.

7.4 THE GROWING ALLEGIANCE TO OPEN SOURCE STANDARDS

The change in attitude toward open-source technologies in the memory realm is

perhaps one of the most important findings of my work. Where there was open hostility from

some quarters in 2010 to the thought of using loosely-defined tools like Matroska and FFV1, the

work of CELLAR to standardize these tools and the work of institutions large and small, both

here in America and abroad, have changed minds about the utility and soundness of using

them. This has also helped to break down some of the entrenched resistance to open-source

tools and to change the mindset that it would be somehow unprofessional to use open code

instead of traditionally designed and disseminated specifications and standards. The use and

fostering of the development of open source tools is, in fact, a recommendation for the digital

preservation community by the National Digital Stewardship Alliance (2015). For the purposes

of this discussion, "open" simply means that the code for a technology is openly-available

without a paywall. As Peter Bubestinger noted in our interview, it is common to mistake "free

and open source software" with "freeware". Although open source software is often free of

cost, this is not mandatory. Therefore "open source" is not the opposite of "commercial", but

merely the opposite of proprietary, closed source code.

For some institutions the choice to use open source technologies is pragmatic. FFmpeg,

FFV1, Matroska and other open source tools are used in audiovisual preservation shops large

and small, for-profit and nonprofit. Indiana University's decision to use FFV1 at a massive scale

was largely driven by the "it just works" ethic of both Memnon and Indiana. In fact, as Andrew

DaPuzo noted, Sony never questioned Memnon's decision to implement FFV1 and Matroska

was never questioned by Sony either, even with Matroska's history of association with piracy

and Sony's earlier resistance to supporting the container in its early Blu-Ray players. According

to John Dunn, pragmatism was the motivating factor at Indiana, as the choice of Matroska and

FFV1 was less about open vs. proprietary than it was about documentation access and the

potential for viable playback/encoding tools as well as quick and easy support from the growing

user base. Jim Schupert agreed with this sentiment - Scenesavers chose FFV1 because of its

ease of use, which contrasted to the difficulty they found in using JPEG 2000. For them this was

not an ethical choice as much as it was a strictly technologically-driven one. When I asked

Ashley Blewer why CELLAR chose FFV1, FLAC and Matroska to standardize, she found the

openness of these technologies to be key to their usefulness in the preservation realm. Rob

Mobley, video engineer at Indiana University, has seen an increased interest in open source

solutions and a "do it yourself" approach to retrofitting these tools for local practice.

While pragmatism, usually born out of staff, infrastructure and funding considerations,

tends to win out with respect to format/encoding choice for libraries and archives, there

appears to be a growing number of professionals who choose to align themselves with the

open source realm for ethical reasons. In the words of Marek Jancovic, the choice of codec

tends to be ideological as well as pragmatic (Jancovic). With respect to Indiana and

Northwestern, both institutions, according to Josh Yocum and Mike Casey, have a 'culture of

openness' that helped FFV1 and Matroska easily find purchase with IT staff and administrators.

Ben Turkus argues that the open source ethic is one of "we're all in this together" and that it is

important for preservation professionals to consciously support the open source development

realm. While Mike Casey's 2017 white paper, according to its author, was not intended to be a

rallying cry, the tone of the No Time To Wait presentations, give the impression of a community

of preservation professionals that is forming a conscious resistance to industry standards.

Matroska and FFV1 are being standardized in an open-source fashion by the CELLAR working

group. They were each born of open-source realms as well. As Steve Lhomme noted in our

interview, he created and disseminated Matroska's code via open tools like Internet Relay Chat

rooms, email and online Web forums. Ian Henderson, in talking about the FFV1 encoding in our

email conversation, said that it has always been available as part of the open-source FFmpeg

tool. Henderson's comment illuminates the appeal, for some of the professionals I interviewed,

of openness generally and FFV1 and Matroska because of the belief that the accessibility of

their code will increase the sustainability of digital objects created to their specifications into

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the foreseeable future (Bradley). In the case of FFV1, its early obscurity, nestled as it was deep within FFmpeg, has likely been a boon to the CELLAR working group. Its obscurity means that, unlike Matroska, there have been few implementations of FFV1, which means fewer interoperability and backwards-compatibility issues with which to contend in the standardization work (Jancovic).

This lack of conformity represents one of the challenges that CELLAR faces - that of backwards-compatibility. At the file-production level, as Vincent Mosco notes, the distinctions between producers, distributors and consumers can become indistinct (Mosco). CELLAR is attempting to create *coordinative standards* from the loosely-interpreted FFV1 and Matroska specification. This term, as used by Raymond Werle, refers to standards that are self-enforcing and gain their quasi-mandatory status from a kind of path dependence (Werle). In the case of the CELLAR standards, path dependence could be achieved by the need for interoperability of files and software within and between repositories. As can be seen from the above quote from the CELLAR website, the working group believes that widespread adoption, and by extension sustainability, can only be achieved by the credibility of these formats conferred by their standardization. According to Ashley Blewer, one of the biggest challenges to this standardization is the need for backwards-compatibility with the wealth of 'flavors' of Matroska files that have been produced over the past 16 years. As Timmermans and Epstein note, "standards also rarely harmonize or globalize, but each standard, in its own specific way, can bring some of these goals closer" (Timmermans and Epstein, page 84).

The CELLAR group's work has helped to pull FFV1 and Matroska out of sub rosa niches and into more mainstream appraisal and use. The inherent affordances of these technologies

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made them amenable to the library and archives community - a community that is now, through the auspices of the IETF, conforming them to standards that will aid their use and adoption in memory institutions. Ashley Blewer asserted that the fact of FFV1 and Matroska being standardized by a reputable body like the IETF can greatly increase the support of administrators who might otherwise be unfamiliar with them. Indiana University's white paper in 2017 cite the CELLAR efforts as "a positive evolution towards sustainability for long-term preservation" (Casey, 2017, page 7). Furthermore, the increasing use of FFV1 by broadcasters in Europe is, according to Brecht DeClerq, reason to hope for a cascade effect in the encoding's adoption across the continent. Marion Jaks of the Austrian Mediathek observed considerable pushback to her colleagues' presentation about FFV1 at the AMIA/IASA conference in 2010, but told me that now she is seeing far less resistance to the encoding as of our interview in 2017. During their early tests of FFV1, many archives and libraries argued for using the AVI container because of its simplicity and ubiquity, but that simplicity turned out to be very limiting for time-based media because it could not encapsulate all of the ancillary data that the Mediathek wanted to save.

Many of my interviewees expressed support for open-source technologies on ethical grounds. This support was often articulated as a conscious disavowal of the SMPTE/broadcast/cinema realms. In my interview at Scenesavers, Jim Schupert referred to the divide between adopters of MXF/J2K or Matroska/FFV1 as a 'North vs South' divide, implying that it can be very contentious. This sense of contentiousness seems to underpin Ben Turkus' comment about taking a stand for open-source. Openness and sustainability are so commonly intertwined in the literature of digital preservation that, to some practitioners, they are one

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and the same. As Lars Gaustad put it, he felt obliged to make the move to the CELLAR standards "because of the commandments of digital preservation." Hermann Lewetz voiced a frustration I heard registered often at the No Time To Wait conference when he told me that he is tired of broadcast archives behaving like they are the "normal" archives by speaking for nonprofit institutions like the Mediathek - institutions that have very different workflows and obligations from broadcasters. However, not all broadcasters take issue with open-source technologies. WGBH, one of the premiere public broadcasting stations in the United States, has recently adopted FFV1 for their preservation digitization work. While the attitudes of some broadcasters may rankle archivists like Lewetz, there are many who are in alignment with the Austrian Mediathek in terms of willingness to implement open-source standards. Lewetz noted with some vindication in our interview that, "I proved FFV1 is a serious tool for archiving."

Jean-Christophe Kummer advises many archives and libraries around Europe with respect to digitization and he told me that he finds the most vocal open-source evangelists to be younger professionals who started their careers after 2000 and come from a "geeky point of view" of self-taught, motivated coders who prefer to find their own solutions to problems rather than wait for large developers like Apple and Microsoft or standards bodies like SMPTE or the MPEG. James Snyder echoed this sentiment. In our interview, Snyder emphatically stated that JPEG 2000 is, essentially, an open specification and anyone can write tools for it. He wondered aloud why the CELLAR group didn't just use it because this would put them more in line with SMPTE and broadcasters and cinema and it would, by his estimation, function at least as well as FFV1. He claims that computer processors have evolved such that the computational load of encoding and decoding J2K is now negligible and encoder hardware isn't that costly

anymore. (Cost of encoding/decoding hardware and software was cited by several interviewees as an impediment for using JPEG 2000.) Ultimately, Snyder argued that the CELLAR allegiance to FFV1 and Matroska is just an example of the open source community wanting to go their own way. While many of my interviewees - and many more of the No Time To Wait participants - have very clearly well-informed technological and infrastructural reasons for their preference of FFV1 and/or Matroska, they continually made reference to their allegiance to the ethic of freely available code.

7.5 THE RESISTANCE TO OPEN SOURCE

While this new, open-source mode of digitization technology development has been growing, it has not been without resistance from entrenched communities. The 2010 presentation by staff from the Austrian Mediathek to the joint conference of the Association of Moving Image Archivists and International Association of Sound and Audiovisual Archives revealed a resistance to the FFV1 codec in particular and non-SMPTE/MPEG standards in general. Hermann Lewetz told me that he experienced physical threats because of this presentation - a vendor physically intimidated him by harshly putting his hand on Lewetz's shoulder and darkly intoning that his company "can't allow FFV1 for its customers." Peter Bubestinger, who attended the conference session told me that people in the SMPTE-standard camp called the Mediathek presenters "open source weirdos" and "reckless" for their choice of FFV1. George Blood, a popular audiovisual preservation/digitization vendor and frequent AMIA attendee, has long been an MXF adherent. In 2011, he wrote that "the MXF wrapper was developed with broad industry and user support... as it is more widely adopted, vendor support

and interoperability proven, and experience grows, it is an excellent choice in the long term" (Blood, page 26). Ben Turkus relayed a comment made by Blood at the 2010 conference. According to Turkus, during a session Blood said, "The cool kids are all moving to FFV1." Turkus told me this comment exemplified a generational divide he has witnessed at AMIA, one in which youth aligns with open-source adherence and age aligns with SMPTE/MPEG/ISO adherence. Turkus claims that this divide can partially be explained by what he calls a "herd mentality" within the audiovisual preservation realm wherein professionals from institutions of similar profile tend to align their preferences with respect to standards, hardware and software. Marion Jaks of the Austrian Mediathek told me that her institution initially chose to use AVI because it was a politically safer choice than Matroska. They already knew FFV1 was controversial in 2011 and didn't want to add MKV, partially because they were already getting pushback from the community because of FFV1 and because MKV was well-known as a piracy format. While the adherents to a particular standard usually have clearly-defined reasons for their allegiance, among my interviewees there was a clear preference for well-adopted standards, which could be explained, in part, by a desire to align with libraries/archives of similar profile. This is a key point in the political economy analysis of these standards' adoption. Mosco argues that social relations organized around power, even in the face of resistance, can be a strong motivator for choice of technology (Mosco). Turkus' comments point to an audiovisual preservation world wherein adoption of technology is not just motivated by a cold, logical analysis of affordances and constraints, but also by social ties and the prestige of professionals and institutions. Peter Bubestinger could see that social aspect when he told me that he finds that, in attending conferences like AMIA and IASA, people don't feel comfortable

engaging in public conversations because they are afraid they may look bad or not look like they know enough and that it is easy to be stigmatized by some professionals for the choice or alignment with FFV1 or Matroska. Nonetheless, after he presents at conferences, Bubestinger is usually bombarded by one-on-one emails from people who are interested to know more about these tools.

The lack of standardization is a common argument against trusting a container or encoding, as Ashley Blewer told me. This resistance, as seen at the AMIA/IASA conference in 2010, is part of what the CELLAR standardization work is trying to overcome. Adherents to the value of standards *qua* standards can passionately defend this logic, which can lead to the quasi-religious timbre to some discussions related to standards choice, according to Brecht DeClercq. According to Dave Rice, FFV1 and Matroska's adoption is growing, but it is growing slowly, likely because the CELLAR work is, as of our interview in 2017, still in process and no fully-defined, final-draft standards have yet been released from the group. According to Mike Casey, this lack of fully-formed standardization caused one prominent video engineer and digitization sage, Jim Lindner to publicly question Indiana University's choice of FFV1 and Matroska.

Even in the world of open source, standardization still conveys some safety. More testing of the encodings and containers will likely yield more adoption as well. As Marek Jancovic notes, "the mathematical losslessness of FFV1 is mainly a symbolic and speculative potential" and will require rigorous, thorough testing in order to sway more potential users (Jancovic, page 53). James Snyder called this losslessness into question when he told me that because FFV1 uses interframe encoding - wherein image data is not encoded as discrete frames

but instead is predicted between key frames - it cannot truly be called lossless.[149] The interframe nature of the FFV1 codec may haunt its reputation as video engineers continue to call its losslessness into question. Regardless of the "speculative" nature of FFV1, the resistance to it and Matroska have been breaking down for many archives and libraries, particularly those with a culture of open source adherence and/or a pragmatic will to 'just get something done.' In his audiovisual consulting business, Jean-Christophe Kummer told me that brand-new archives tend to not have any resistance to using FFV1 or Matroska, but older, established archives may resist them, particularly if they have already sunk considerable costs into using something else. He has even found that any stigma regarding Matroska and its association with piracy has, for the most part, dissolved with his clients. Open-source technologies still have a do-it-yourself patina to them, however, and there is a lingering belief in the preservation realm that technologies that do not arrive fully-formed from well-known industry may require tinkering to implement. In the words of Andrew DaPuzo of Memnon, "open-source isn't free like a beer, it is free like a puppy - it can cost you later." Institutions without the resources to allocate for trial and error may have little inclination for technologies that may require retrofitting down the road and thus may find industry standards, with their luster of inevitability and completeness, more appealing. Even large institutions like the BBC can find open source tools useful. As Ian Henderson of the BBC told me, FFV1 has appeal to him precisely because of its open source nature, as well as the ease with which it can now be generated and transcoded with available tools.

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[149] https://en.wikipedia.org/wiki/Inter_frame. Accessed on December 18, 2018.

Resistance to FFV1 and Matroska may also derive from alignment with the broadcast industry. James Snyder told me that a potential problem with FFV1/Matroska is that broadcasters may not be able to easily decode the files because of their preference for and investment in JPEG 2000 and/or MXF. Broadcasters require technical infrastructure and knowledge not just to preserve files but to play them out over the air as well, both over terrestrial (over-the-air) and cable transmission. Because broadcasters like NBC are geared for MXF and MPEG playout, they are, at least for the near term, unequipped for broadcasting MKV/FFV1 files. These open-source standards are relatively easy to play back on computers that have tools like VLC Player. However, as James notes, it is one thing to be able to play back content on a computer, but another entirely if a broadcaster needs that footage someday. Through the course of our conversation, James and I theorized that many implementers and supporters of FFV1 and Matroska, because of their library/archives backgrounds, are thinking of the content in their care as likely to be delivered in the future over computers more than over broadcast networks. This conversation illustrates that the differences between open-source and industry-developed standards adopters is not a nonprofit versus for-profit distinction. It is rather, at least partially, a difference in vision for how media materials in an institution's care are likely to be delivered: open-source adopters tend to see their media as being delivered over computer screens while industry adherents continue to see cinema screens and television screens as the primary delivery mechanisms for their content. The time and resource constraints that librarians and archivists tend to work with are, furthermore, pushing them to focus on the near-term goal of harvesting content from decaying physical carriers, which can push them toward the pragmatic, open-source mindset. While James understands the resource

scarcity that these shops are working with, he is still very worried that this content will be

difficult to act on later. It is likely the current path dependence of broadcasters and cinema

producers (with their current investment in digital cinema specifications that rely on MXF

and/or JPEG 2000) will continue to resist FFV1 and/or Matroska, even after the CELLAR group

finishes its work.

7.6 QUO VADIS?

As of December 2018, Apple has declared JPEG 2000 to be a "legacy format" that will no

longer be supported in future iterations of its Final Cut Pro software.[150] The encoding/container

realm changes very quickly - often more quickly than archives and libraries can anticipate. JPEG

2000, like many standards, can be seen as a boundary object, that "inhabit[s] several

intersecting social worlds" such as broadcast, cinema, computer information technology and

the memory realm (Star and Griesemer). Apple's declaration could be evidence that JPEG 2000

could soon come to face an impermeable boundary around the realm of nonlinear editing (NLE)

software.

FFV1 and Matroska adherents have been lobbying Adobe Premiere to include these

standards in future versions of their popular Premiere NLE. Reto Kromer told me that Adobe is

considering including FFV1 as a supported encoding in the software, which could give FFV1 a

foothold in the production and broadcast realms. According to Brian Wheeler, Matroska may

take longer to find a home in the production world, because of its early association with piracy.

However, the rapid proliferation of MKV files, initially by pirates and now by institutions like

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[150] https://support.apple.com/en-us/HT209000. Accessed on December 17, 2018.

Indiana University, mean the format is unlikely to disappear in the near future. To paraphrase

Vincent Mosco, piracy and freeware threaten capitalism's ability to contain them (Mosco).

As technologies evolve, there is no set, natural rule saying one standard will win out

over another in any given context (Bowker and Star). FFV1, Matroska, MXF and JPEG 2000 have

all found evolved outside of their designers' intentions and found themselves pressed into

service in ways that were not anticipated by their developers. CELLAR's work to standardize

Matroska and FFV1 will help to stabilize those technologies, as will the spread of their adoption.

As we continue to move into a world where content is delivered over computers as opposed to

on television and movie theater screens, FFV1 and Matroska will likely continue to have to

appeal to institutions that have little or no association with those traditional avenues of

dissemination. MXF and JPEG 2000, because of the difficulties many of my interviewees have

expressed with respect to their implementation, is likely to continue to be preferred in

institutions with strong ties to cinema and television. There is an irony here in that MXF was

designed to deal with a wide array of potential content distribution channels (Devlin, 2006).

Matroska and FFV1, at the moment, appear to be better equipped to handle this proliferation

than their older, industry-designed counterparts. FFV1, in particular, is poised to find broader

purchase outside its current niche. Reto Kromer is working to expand the FFV1 standardization

beyond video into the photochemical film digitization realm. Marion Jaks told me she has seen

a rise in acceptance for the Mediathek's choice of the encoding. And, perhaps most compelling

is an apparent acknowledgement of FFV1's utility as a high-quality, long-term preservation

encoding by Jim Lindner, who had been a vocal critic of the Mediathek's presentation in 2010.

In a recent post to the AMIA email list, Lindner had this to say: "The great thing about soft

formats like JPEG 2000 and FFV1 is that they can be readily documented in human readable form on a long-lived medium. Any competent computer programmer could figure out how to read it and transcode to whatever the current preferred format is."[151]

The stabilization of a technology is not a singular event. It is, instead, a process that often takes years (Pinch and Bijker). CELLAR is working to stabilize FFV1 and Matroska by standardizing them - creating clearly-defined and widely agreed-upon documentation that will confer upon these 'wild' technologies a status that the preservation realm can deem trustworthy. Standardization will almost certainly help FFV1 and Matroska to proliferate. Another aid to this proliferation is the growing acceptance of open source technologies as legitimate tools for doing preservation and digitization work. As Ben Turkus told me, the "embrace of open-source is one of the more transformative developments in AV realm." Jim Schupert agreed with that sentiment when he told me that "the genie's out of the bottle" with respect to open source standards. He went on to say that while SMPTE as the audiovisual standards body made sense in the analog video days because of the need for playback decks and tapes to be interoperable regardless of manufacturer, they are no longer the only - or the most efficient - game in town, as evidenced by the speed with which CELLAR is working. As the lines between traditional brick-and-mortar archives and the Internet continue to blur, standards like FFV1 and Matroska - which are well-suited for modestly-funded institutions that focus on free dissemination of content online, will grow in appeal.

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[151] https://lsv.uky.edu/scripts/wa.exe?A2=ind1810&L=AMIA-L&P=86917. Accessed on November 30, 2018.

CHAPTER 8: CONCLUSION

8.1 SOME NOTES ABOUT THE LIMITATIONS OF THIS STUDY

All research is imperfect and, admittedly, my discussion of video standards could be broader than what I have presented here. I have consciously limited my dissertation to an analysis of MXF/JPEG 2000 (as they are manifested in AS-07) and Matroska/FFV1 (as they are manifested in the CELLAR work) in order to appropriately scale this work to something that can be accomplished within two years. Nonetheless, this work has found itself limited by factors outside of my control.

One limitation to my work owes to the newness of these standards, particularly CELLAR's Matroska and FFV1, which are not yet completed. It is still very early days for the CELLAR group and their standards. While there are institutions that are using FFV1 and/or Matroska for their video digitization, I do not know of any that are implementing CELLAR's nascent specifications as written because this dissertation analyzed these documents as they are - *in medias res*. The newness and the modest spread of these standards means my discussion of why they are being adopted in libraries and archives - a key component of my research question - has been limited to archives and libraries in the United States and parts of Europe. As of this writing, I do not know of South American, Asian, African or Australian libraries or archives who have implemented FFV1 or Matroska.

Scaling the work down allowed me to complete it within two years' time, as was my mandate as a student. The massive scale of the implementation of these standards posed a challenge to the work. Matroska, FFV1, JPEG 2000 and MXF are technologies that have spread

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across the globe. Describing and analyzing the political, ethnic, gender and culture differences in the worldwide users of these standards is far beyond the scope of this work. In order to scale this work to a manageable size, I have necessarily placed limits on the populations from which I drew my subjects. It is worth noting that this population was almost uniformly white and college-educated. (I am also both of these things.) While there is no reason to believe that other demographics would implement these standards differently, it would nonetheless be useful to see how these standards are adopted and adapted beyond my sample population.

This newness of the CELLAR standards has also limited the amount of published documentation related to them. While I believe this makes my research all the more timely, it still remains to be seen how many institutions will adopt CELLAR's standards and how sustainable the files produced to these specifications will be in coming decades. This limitation is also imposed on the AS-07 side of the research, since that document is also still to be finalized and is not yet 'ready for prime time.'

My access to SMPTE and ISO working documents and participants was also limited because I am not a dues-paying SMPTE member and I did not have access to the ISO's archives in Geneva. I turned to published resources like Bruce Devlin's *The MXF Book* to piece together the brief history of that standard. Mr. Devlin and Oliver Morgan, two world-class MXF experts, did not respond to my requests for interviews. I also drew liberally from *JPEG 2000: Image Compression Fundamentals, Standards and Practice* by David S. Taubman and Michael W. Marcellin to fill out the J2K portion of the history. I was not able to have conversations with either of those writers.

It is important to note that I do not stand outside the audiovisual preservation community. I have spent the last two decades as a practitioner of audiovisual preservation and production. This background has certainly enhanced my ability to gain access to people, places and documentation that might be difficult for other researchers without similar means. Much of my work at the Library of Congress, aside from working on the AS-07 specification, was on the Sustainability of Digital Formats online resource.[152] In 2015 I wrote a pair of guidance documents for the University of Illinois at Urbana-Champaign Library's Preservation Department and in them I recommended considering Matroska and FFV1 for their in-development video digitization lab. As of 2019, I do not know if they have chosen to use these technologies. My participation in the development and adoption of these standards has given me certain notions about what quality and sustainability mean in the digital preservation realm. While I have tried to leave my general preference for Matroska and FFV1 for university libraries out of this work, they are worth noting here.

As I work to understand how the video standards development groups under my scrutiny negotiate the meanings of these concepts, I have tried not to lead my interviewees in any way as they answered my questions. I do have notions about which standards are more useful in different contexts, but I did not share those notions with my interviewees before, during or after our interviews. While I do not believe objectivity is possible in any study, I did not want to inadvertently use my current or past standing in the audiovisual community to influence how my interviewees articulated their thoughts or positions relative to the four standards under discussion. The purpose of this dissertation is *not* to make assertions about

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[152] http://www.digitalpreservation.gov/formats/. Accessed on January 8, 2019.

which standards are better or worse. "Better" and "worse," with respect to these standards, are conditional terms. The purpose of this research is to describe for the reader some of the power structures, practices, limitations and ideologies that drive the adoption of these standards.

8.2 IN CONCLUSION

My intention in writing this dissertation is twofold. First, this dissertation serves to position FFV1, Matroska, MXF and JPEG 2000 within the history of audiovisual preservation in the twenty-first century. Second, this work uses the interviews I conducted with standards developers and implementers in order to show how the political, economic and social forces involved in standards-making by SMPTE, the ISO, CELLAR and the Library of Congress affect the ability of the four standards to become boundary objects that are (or are not) adopted in digital cinema, broadcasting, libraries and archives. Standards do not emerge fully-formed into any profession. Standards come from negotiations and compromises between actors. Making these compromises and negotiations visible to the preservation community can help deepen the understanding of why the standards we use function as they do and why they are (or are not) adopted in various institutions.

The joint AMIA/IASA conference of 2010 was, perhaps unbeknownst to many participants, a turning point in the preservation of analog video. Representatives of the Library of Congress presented about their work developing a specification with the Advanced Media Workflow Association for MXF and JPEG 2000. Meanwhile, the Austrian Mediathek presented about their work with FFV1. The two presentations can be viewed as representing two kinds of

ethics with regard to standards adoption. Where the Library of Congress represents a more

traditional deference to established audiovisual and image standards bodies like SMPTE and the

ISO, the Mediathek's implementation of FFV1 represents a more pragmatic, 'do-it-yourself'

attitude. These choices are also informed by the power dynamics within which these two

entities are enmeshed. The Library of Congress, with its close ties to Hollywood, television and

its situatedness within the American copyright regime, must show preference for standards

employed by large industry producers. The Austrian Mediathek, because it is not so

encumbered - and because it is not as well-funded - has a different combination of latitude and

constraints with respect to how it can (and/or must) spend its preservation resources. While

not intended as a shot across the bow of 'traditional' (SMPTE/ISO) standards-based digitization,

the Mediathek's presentation represented a potential shift to the realm of open-source

preservation technologies.

As can be seen in the decade since the AMIA/IASA conference, more institutions, large

and small, have been taking up the open-source cause by turning away from tools like MXF and

JPEG 2000 and towards FFV1 and Matroska. This is, in part, fueled by a growing adoption of

freeware tools for video editing, transcoding and digitization in libraries and archives. This

adoption is often motivated by pragmatic concerns related to limits on funding, staffing and

infrastructure. However, there is also a change in attitude among some librarians and archivists,

characterized by a greater willingness to work at the command line and build and retrofit tools

rather than relying on technologies that were not designed for the memory realm. This

attitude, for some, brings with it a strong and explicit allegiance to the open-source realm, as

characterized by the No Time To Wait conferences and the 2017 Indiana University white paper about their Media Digitization and Preservation Initiative.

One of the key findings of this dissertation is that the story of MXF, JPEG 2000, Matroska and FFV1 is the story of technologies that evolved from their niches into a larger realm of use. In the cases of MXF and JPEG 2000, the evolution was fairly linear because of the input that the film, video and broadcasting realms had in their designs and expansions. This input, as well as the standards' adoption in cinema and television production, meant that MXF and JPEG 2000 had a relatively easy fit with institutions like the Library of Congress and the BBC. Matroska and FFV1 have had less straightforward transitions into the memory realm. Matroska is a technology that, like the MP3 a decade before it, had strong associations with multimedia piracy and illegal dissemination of content in its first decade. Its utility in the preservation realm is one of the reasons that it has been embraced by 'legitimate' actors including, in the case of the Indiana University and Memnon collaboration, one of its early detractors, Sony. This issue of piracy is, perhaps, a potential avenue for future research. What is the association, if any, between the utility and ease of use of a technology like Matroska for at-home piracy and archival digitization and preservation? In other words, can it be said that if a technology is easy enough to use for pirates, it is easy to use for archivists that do not have a specialization in audiovisual production or preservation? This research could parallel Sterne's discussions of the MP3 achieving ubiquity through technologies like Limewire and Napster in his history of the format (Sterne).

This dissertation also shows how the audiovisual preservation realm is changing and embracing more open-source, participatory technologies. FFV1 was built as an informal

experiment and lay buried within the FFmpeg tool library until an archivist who was unsatisfied

with 'off the shelf' technologies like MXF and JPEG 2000 dusted it off and gave it a 'what the

hell' attempt at implementation. The growing underground experimentation with FFV1 and

Matroska in memory institutions had the feel of the subaltern for several years as the highly

critical and, in some cases, hostile reception from many of the established preservation sages to

the Mediathek's AMIA/IASA presentation scared early adopters from going too public with their

work. It was not until the CELLAR working group began their standardization of Matroska and

FFV1 that these experiments lost their 'Frankenstein's unhallowed arts' patina and emerged as

real, viable attempts to adapt these technologies to high-quality preservation practice. Indiana

University's explicit embrace of Matroska and FFV1 have, for many institutions, sealed the deal

and encouraged them to also take up the open-source cause.

The Library of Congress has been working on AS-07 for a decade. The Library's reliance

on MXF and JPEG 2000 does not just represent an alliance with cinema producers and television

broadcasters. AS-07, and the standards that undergird it, also represents a traditional, top-

down paradigm in content distribution characterized by the strong influence media producers

can exert over the means of their content distribution. In these cases, this distribution consists

of movie theater screens and broadcast television screens. Matroska and FFV1, coming as they

do from the open-source information technology realm, represents a different paradigm - that

of content being delivered over desktop, laptop and handheld computer devices. In this realm

of streaming and downloadable content, memory institutions have as much agency with

respect to production and dissemination as have Hollywood and television broadcasters. This

shift, combined with the potentially ongoing need of Hollywood and broadcasters for archival

materials in their productions, could ensure that FFV1 and Matroska will insinuate themselves even into realms that currently are, at best, otherwise ambivalent to them.

Another key conclusion of this dissertation is that the four standards serve as boundary objects by having different meanings for the various users who implement them. Broadcasters, cinema producers, online video pirates, archivists and librarians are all using MXF, JPEG 2000, Matroska and FFV1. The technical affordances of these technologies allow all of these people to do their work, but they can signify different things to different users. For example, users at the Library of Congress may view MXF and JPEG 2000 as important tools for aligning the library with television broadcasters, cinema producers and the American copyright regime. Users of Matroska and FFV1 in a library like Indiana University's may view those tools as important signifiers of a break with large technology producers like Apple and standards bodies like SMPTE. Users of Matroska online may view that technology as a useful way to encapsulate bitstreams ripped from a Blu-Ray or DVD and disseminate it online in clear, flagrant violation of American copyright policy. These technologies and their technical affordances can help them move between types of users and have meanings for them that are sometimes complementary and sometimes competing.

Large institutions like the Library of Congress have the ability to develop tailor-made specifications for the digitization of these analog objects but specifications of this kind tend to be bound to the needs of the American broadcast and Hollywood production industries. While the open-source community, as exemplified by the CELLAR working group, has been working to standardize encodings and formats for the cultural heritage community over the past few years, many of the institutions that would best benefit from these tools may still be unaware of them.

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Therefore, understanding how standards like MXF, JPEG 2000, Matroska and FFV1 are developed is critical to preservation because, at the moment, there are no widely agreed-upon target digital video standards in the cultural heritage realm. Video encoding and format standards are fundamental tools in preserving analog time-based media. Furthermore, understanding the development and evolution of these standards is critical to the decision making involved in creating sustainable digital audiovisual materials.

The technological affordances of MXF, JPEG 2000, Matroska and FFV1 made these standards appealing to librarians and archivists but they required recognition of their potential utility, adaptation for the needs of the memory realm and institutional adoption to lend them credibility. Nevertheless, the adoption of MXF and JPEG 2000 outside cinema and television broadcast has been halting at best. The adoption of FFV1 and Matroska in libraries, archives and with some broadcasters has been on the rise in the past few years. It is, however, still too soon to know how well AS-07 and the CELLAR standards will be adopted because none of those standards or specifications have been released to the public in their final forms as of this writing. Once AS-07 and the CELLAR standards are finalized and released to the public, there will be considerable promotion on professional communications channels by both of these development groups. This promotion will likely encourage experimentation with, and adoption of, these standards. Once these standards have been released in their final, finished forms, this dissertation could have particular utility in telling the story of how these standards came to the preservation community. It is my hope that other scholars and/or practitioners will continue to study the development and implementations of these technologies in cultural memory contexts and broaden the analysis of their adoption to include other professions and cultures.

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APPENDIX A: INSTITUTIONAL REVIEW BOARD APPROVAL

I ILLINOIS

Office for the Protection
of Research Subjects

IORG0000014 • FWA #00008584

Notice of Approval: New Submission

April 30th, 2019

Principal Investigator	Jerome McDonough
CC	Jimi Jones
Protocol Title	So Many Standards, So Little Time: An Analysis of Two Video Digitization Standards and Their Development Groups. A Doctoral Dissertation by Jimi Jones
Protocol Number	17816
Funding Source	Unfunded
Review Type	Exempt
Review Category	2
Status	Active
Risk Determination	No More than Minimal Risk
Approval Date	June 6, 2017

This letter authorizes the use of human subjects in the above protocol. The University of Illinois at Urbana-Champaign Institutional Review Board (IRB) has reviewed and approved the research study as described.

Exempt protocols are approved for a five year period, after which time they will be closed and archived. Researchers may contact our office if the study will continue beyond five years.

The Principal Investigator of this study is reponsible for:
- Conducting research in a manner consistent with the requirements of the University and federal regulations found at 45 CFR 46.
- Requesting approval from the IRB prior to implementing modifications.
- Notifying OPRS of any problems involving human subjects, including unanticipated events, participant complaints, or protocol deviations.
- Notifying OPRS of the completion of the study.

Office for the Protection of Research Subjects
University of Illinois at Urbana-Champaign
(217) 333-2670
irb@illinois.edu

APPENDIX B: PARTICIPANT CONSENT FORM

I L L I N O I S
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Consent to Participate
So Many Standards, So Little Time: An Analysis of Two Video Digitization Standards and Their Development Groups.

You are invited to participate in a research study on the development and implementation of video digitization standards. This study is being conducted by Jimi Jones, doctoral candidate, and Assoc. Professor Jerome McDonough, both of the School of Information Sciences at the University of Illinois at Urbana-Champaign.

This study will take up to two hours of your time. You will be asked to participate in an interview regarding your experiences with the audiovisual standards development groups CELLAR (Codec Encoding for LossLess Archiving and Realtime Transmission) and/or FADGI (Federal Agencies Digital Guidelines Initiative). This interview will be conducted in person, over the phone or on Skype and will be recorded for transcription purposes. This interview will be circulated among the members of the research team named above and your name and identity may be included in the final publication that will come from this research. Synchronous, recorded interviews are an important part of this research but if you do not wish to be recorded, you may decline to participate in the study.

Your decision to participate or decline participation in this study is completely voluntary and you have the right to terminate your participation at any time without penalty. You may skip any interview questions that you do not wish to answer.

Due to the small nature of the video digitization community, it may be difficult to obscure identities during the course of writing about and presenting this research. You have the option at the end of this consent form to allow individually identifiable information about yourself to be disseminated as part of this research. This may include quotes attributed to you or observations of your work practices. If you do not agree to have individually identifiable information about yourself disseminated, we will do our best to obscure your identity, but there is still a risk that people familiar with the video digitization field will be able to identify you. There may also be times when the university and state bodies responsible for research oversight may need to review data to ensure that proper research procedures took place.

1

All research data will be stored on an encrypted hard drive during and after the research. The outlet of dissemination for our research results will be Jimi Jones' doctoral dissertation, which will be publicly defended in May of 2019. There may also be conference presentations and or journal publications based on this work. If you do not wish to participate in this work because you may be identified, you are under no pressure to participate and you can withdraw at any time.

Although your participation in this research may not benefit you personally, it will help us understand how social, technological, management and market factors can come together to influence the design and implementation of video digitization standards in the cultural memory realm.

There are no risks to individuals participating in these interviews beyond those that exist in daily life.

Your decision to participate, decline, or withdraw from participation will have no effect on your grades at, status at, or future relations with the University of Illinois.

If you have questions about this project, you may contact

Jimi Jones (jjones7@illinois.edu) or Professor Jerome McDonough (jmcdonou@illinois.edu)
School of Information Sciences
University of Illinois at Urbana-Champaign
501 East Daniel Street
MC-493
Champaign, IL 61820-6211
Jimi Jones: 217.898.0179
Jerome McDonough: 217.244.5916

If you have any questions about your rights as a research participant in the study, please contact the University of Illinois Institutional Review Board at 217-333-2670 or via email at irb@illinois.edu.

You will be given a copy of this consent form for your records.

2

I consent to allow individually identifiable information about myself to be published, shared or otherwise disseminated as part of this research:

☐ No
☐ Yes

I have read and understand the above consent form, I certify that I am 18 years old or older and, by signing this form, I agree to participate in this study.

....

Signature   Date

University of Illinois at Urbana-Champaign
Institutional Review Board

Approved: _____ 6-6-17 _____
IRB #: _____ 17816 _____

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APPENDIX C: INTERVIEW QUESTIONS FOR STANDARDS DEVELOPERS

1. Do you consent to having this interview recorded?

2. Please give your name.

3. Can you tell me a bit about your professional background?

4. What drew you to the (CELLAR or FADGI) work?

5. What motivates your participation in the group? Are you participating in order to represent a particular organization or group? Or are you participating as an expert just to help out the cause?

6. Tell me about the standards. Who are they for and what do they do?

7. What are the strengths of the standards? Why would someone choose to use them?

8. What do you think are the limitations to that standard?

9. What kinds of members are in the standard group in which you are participating? What kinds of backgrounds do the other members have?

10. Would you say that the standards group has a leader?

11. What kinds of formal or informal rules does the group operate under?

12. How would you say archivists, engineers and preservation specialists' ideas of quality and sustainability differ? In what ways are they the same?

13. Do these differences influence the standards discussions, and if so, how?

14. Do you think these differences have had an impact on the standard itself? How?

15. What sort of trade-offs or compromises did you have to make in the design of the standard?

16. How do the members of the group evaluate the positives and negatives of these compromises?

17. What tools do you use for collaboration on the standards making work? (GitHub, Skype, etc)

18. Can you describe some challenges you've encountered in your work on this standard?

19. Why would you consider those to be challenges?

20. How has the larger audiovisual preservation/engineering community interacted with

    your group?

21. What sort of input or feedback have they provided?

The following two questions were only for CELLAR participants

22. Why has your standards development group chosen the IETF to work with?

23. How do the IETF, PREFORMA, CELLAR, MediaConch all relate to each other?

24. Do you implement these standards in your own work? If so, how?

25. Is there anything more you would like to add?

26. Is there anyone else you would recommend I talk with?

APPENDIX D: INTERVIEW QUESTIONS FOR STANDARDS IMPLEMENTERS

1. Do you consent to having this interview recorded?

2. Please give your name.

3. Can you tell me a bit about your professional background?

4. What is your role with respect to audiovisual preservation or digitization in your institution?

5. What standards are you using in your preservation work? (FADGI or CELLAR)

6. If neither, are you working with any similar combinations of MXF, J2K, FFV1 and/or Matroska?

7. Have you participated in the development of these standards? If so, how?

8. How long have you been implementing these encodings/containers in your digitization work?

9. What kinds of technical factors have informed which of which standard(s) to choose for

your video digitization and preservation work?

10. What kinds of social dynamics within your organizations have informed this choice?

11. What kinds of dynamics, if any, in the larger audiovisual preservation profession have informed this choice? Are you conforming to any professional best practices by making the choices you've made?

12. How would you describe the users of the digital audiovisual files that you are making with these standards?

13. How do the needs of these users influence the decisions you have made regarding what standards to implement?

14. What are the measures and/or signifiers for 'quality' do you and your institution apply to the digital files that result from this/these standards?

15. Can you describe your workflow for making these files?

16. What technologies do you use for creating the files and quality control of them?

17. Is there anything more you would like to add?