Not Normalized

Born-Digital Camera Original Video Formats in the Archives

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A thesis submitted in partial fulfillment

of the requirements for the degree of

Master of Arts

Moving Image Archiving and Preservation

Department of Cinema Studies

New York University

May 4, 2020

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Abstract

Born-digital camera original video formats may be the most proprietary, unstable, and fleeting of audiovisual formats. Archivists are responsible for understanding these tricky formats' structures, their dependencies, and their ability to be preserved and maintained over time. Without an archivist's understanding of how to maintain these formats, institutions and individuals alike face the potential loss of an unknowable amount of audiovisual cultural heritage materials. If archivists do understand these formats and their needs, they gain the tools necessary to fulfill their mandate as archivists within an ever-changing realm of proliferating digital formats.

Acknowledgements

Thank you to the Moving Image Archiving and Preservation program faculty and administration for their support throughout this research process. A special thank you to my MIAP 2020 cohort, for all of it.

In addition, a warm thank you to:

S.O. O'Brien, Dave Rice, Catriona Schlosser, Rachel Curtis, Laura Drake Davis, Sylvia Smith, Brendan Allen, Linda Tadic, Yvonne Ng, Crystal Sanchez, Taylor McBride, and Nick Krabbenhoeft for speaking with me about their work and the role of these formats within it.

Paul Dougherty, for inspiring me to pursue this research.

Nicole Martin, for seeing me and helping me shape my madness.

Milo Thiesen and Blanche Joslin, for their advice, friendship, and intimidating expertise.

Morgan Hamel, for keeping me motivated during the COVID-19 quarantine.

Peg (mom), Ed (dad), and Phil (little brother). You made this possible.

Author's Note: Designated Community

I'd like to lead into this research paper by borrowing terminology from the Open Archival Information System reference model, and define my Designated Community.[1] This research is aimed toward providing a conceptual framework and high-level documentation for archivists, technicians, preservationists, content creators, and curators working in libraries, archives, museums, and other organizations, who either currently are – or may soon become – the custodians of large collections of video content. In particular, I feel for everyone (myself included) who is doing their best to understand and preserve the formats that are the heart of my thesis research: high definition, file-based, born-digital, camera original video formats.

It's my understanding that while digital video collections may be growing at an alarming rate, there's still a sense that they can be packaged and stored and dealt with at another time. I disagree with this sentiment, however casual it may be. All video formats, whether tape-based or file-based, require intentional, planned care if they are to be preserved. Digital video is constantly changing, and due to their complex, proprietary structures, camera originals are particularly difficult to track. I believe that we as a community of archivists need to consider the ways in which we're documenting the media formats currently in use by consumers, both for the sake of understanding the collections we're stewarding today, and in order to have a chance to understand the media of tomorrow. Digital video is being used on a wider scale than any other audiovisual format in history, recording more peoples' stories in new and inventive ways. It proliferates so fast that if archivists don't take the time to understand what's happening on a format level, we risk losing so much.

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[1] "Reference Model for an Open Archival Information System (OAIS)." *CCSDS & Panel, CCSDS*, 2012. https://public.ccsds.org/publications/RefModel.aspx.

Introduction

> *"It's just this little simple thing in the back of your mind, that these tapes are going to be important someday."*[2]
>
> William "Bill" Longen, former KTVU television editor[3]

Born-digital camera original video formats may be the most proprietary, unstable, and fleeting of audiovisual formats. Archivists are responsible for understanding these tricky formats' components, structures, dependencies, and their ability to be preserved and maintained over time. Without an archivist's understanding of how to maintain these formats, institutions and individuals alike face the potential loss of an unknowable amount of audiovisual cultural heritage materials. However, if archivists do understand these formats and their needs, they gain the tools necessary to fulfill their mandate as archivists within an ever-changing realm of proliferating digital formats. Audiovisual formats have been shaped by the timeline of developing technology, along with the buying power of consumers and a willingness for adoption, which can be tracked all the way from the first film projectors to the latest smart phone camera application. Archivists, while lacking the buying power of a mass market, have the ability to document and understand formats and technology, as well as to develop specifications to support archival work.[4] As such,

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[2] Maddux, Stu, director. *Reel In The Closet*. Interrobang Productions / Stu Maddux Films, 2015. Kanopy.

[3] The William A. Longen videotape collection is held by the GLBT Historical Society. Collection guide can be viewed online via the Online Archive of California here: https://oac.cdlib.org/findaid/ark:/13030/c8hx1h1h/.

[4] An example of archivists advocating for stronger preservation standards is the Codec for LossLess Archiving and Realtime transmission (CELLAR) working group, which is developing specifications for the Matroska container and FFV1 video codec.

archivists can increase the field's capacity for preserving cultural heritage materials in a fast-evolving, unpredictable digital market.

This research centers on a technical investigation and documentation of a very specific set of audiovisual formats: high definition file-based born-digital camera original video. It aims to name these formats as they are, all the way from the video files themselves, to the nested directory structure that contains them, to the ecosystem they are created within and manipulated by, and extending outward to the environments where born-digital camera original video might be collected, studied, re-purposed, monetized, and in some cases, simply accumulated. While archivists are likely familiar with issues in format migration related to the stabilization of formats on physical carriers like film and magnetic videotape, they are also increasingly responsible for formats that are born-digital, possibly had a short lifespan, and were created using capture codecs that have no chance of being open-source and can be reverse-engineered at best. Many of these formats may never have seen sustained support from manufacturers while consumers were actively using them. Still, these formats become the responsibility of the archivist whose mandate is to preserve original order.[5] These files and formats will always contain important information about provenance, and either need to be maintained as they are or documented by an established workflow. But do these workflows exist?

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[5] Original order, closely related to *respect des fonds*, is one of the fundamental principles of archival work. It refers to the practice of preserving the original organization of materials to enable the possibility of inferring relationships between items, thus gaining a sense of the individual file and the files as a whole. Digital materials can be difficult to consider as "ordered" because they're perceived to not have a physical or material quality, and digital camera originals are especially difficult because their nested directory structure is widely perceived as "meaningless" and something to be normalized or even discarded. In fact, these nested directory structures and the files within them can provide context for who may have shot or processed the camera card from which they came, which could be considered important in determining provenance. More information on original order in the Society of American Archivists (SAA) Glossary of Archival and Records Terminology: https://www2.archivists.org/glossary/terms/o/original-order. Further information on the *Video as Evidence* website: https://archiving.witness.org/archive-guide/resources/video-as-evidence/.

This thesis will not provide solutions, as "solutions" for archival purposes related to these particular HD video formats are highly contextual and specific, and are determined by a range of institution or individual-specific factors. Rather, it aims to suggest possible pathways toward solutions, which are grounded in technical documentation and will hopefully enable archivists to make informed decisions about their specific collections.

The Highest Standard

All documents are evidence of human activity, and the interpretation of video as evidence represents an ambiguous arrangement of files, folders, and relationships that is understood in different ways by different stakeholders. A powerful perspective from which to consider the basis of video evidence is that of a human rights activist or other citizen documenting human rights violations. When an individual creates video footage of a human rights violation in hopes of bringing about justice, to what standards should that material be held in order to make it useful?

The *Video as Evidence Field Guide*, created and maintained by the New York City-based human rights nonprofit WITNESS, is a document that empowers citizens and human rights activists to create, share, and preserve their video footage so it can serve to expose injustice to the public, and could aim to serve as evidence in criminal and civil justice processes.[6] WITNESS has been engaged in this work since the 1990s, and as such, the organization has observed the transition from tape-based digital video to file-based digital video, and they've helped develop video evidence from a wide range of sources. Sources can mean people, including (but not

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[6] WITNESS. "Video as Evidence: About This Guide." *Video As Evidence Field Guide,* v 1.0 (2016): 5. https://vae.witness.org/video-as-evidence-field-guide/ (hereafter referenced as *Video as Evidence*).

limited to) other nonprofit organizations, community groups, and individuals. Sources can also refer to the tools that create the video viles, including models of cameras and editing software, among other items.

A highlighted quote within the guide's "Stages & Standards of Proof" section reads:

> "The video you collect does not have to meet the highest standard to be valuable. It is often impossible for frontline documenters to collect trial-ready footage. However, if it is possible and practical to collect evidence to the highest standard, then why not do so? If you can, this will make it easier for everyone involved, from journalists and investigators to lawyers and decision-makers, to rely upon your content. The easier you make it for them to use the video you collect, the better your chances that they will not only see it, but that they will use it, even if not as evidence in court."[7]

Archivists are rarely able to influence (let alone choose) the preservation quality of their collections' acquisitions, which in turn affect the preservation quality of their collections' holdings. Whatever material arrives at an archive requires an adaptable archivist to create an environment in which precarious or poorly documented material can still be studied for its evidential value.[8] This is perhaps particularly true in the case of footage provided by on-the-

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[7] *Video As Evidence Field Guide,* 22.

[8] The evidential value of an archival object refers to the study of the conditions of its creation. In the case of a born-digital camera original file, an archivist might be able to understand how the contents of a camera card were created by generating a technical metadata report from Exiftool or MediaInfo, or they might understand something about its previous storage environment or custodian based on which elements of a nested directory structure are intact or deleted. More information about evidential value in the SAA Glossary: https://www2.archivists.org/glossary/terms/e/evidential-value.

ground activists who contend with less-than-ideal and sometimes dangerous shooting conditions. WITNESS works with community partners to create environments where hastily or clandestinely-shot footage retains evidential value. They do this by cultivating authenticity via the creation of a chain of custody,[9] which helps to establish provenance for the material.[10]

Beyond provenance, authenticity could also be established by verifying and authenticating the video files themselves to see if they've been tampered with, based on discrepancies between the media's native structure when it's first recorded, and that same material's structure when it is being used as evidence, in a courtroom or otherwise. Maintaining that kind of technical integrity with audiovisual material can be difficult, and the level of difficulty varies by format in addition to circumstance. But as WITNESS asks: if it is possible and practical to collect evidence at the highest standard, then why not do so?

Simplified, the answer to that question might read like this: neither manufacturers, content creators, nor archivists currently document born-digital video or workflows in a way that accounts not only for the amount of footage being created, but the range of different formats that footage is being created in. Archivists in particular might not know what we have in our collections, and we may not know what to ask for. So we might ask two new questions:

1. When is it possible and practical to collect born-digital video at the highest level?

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[9] Establishing a chain of custody is the process of documenting all custodians of a given record or collection of records over time, beginning from the moment the record was created, which helps to establish the accountability and reliability of materials. More information at *VaE* (https://archiving.witness.org/archive-guide/resources/video-as-evidence/) and the SAA Glossary (https://www2.archivists.org/glossary/terms/c/chain-of-custody).

[10] Provenance refers to the original source of an item, including where or by whom the item was created, or who initially received the item. Provenance influences the way an item might be organized -- items with different sources might be organized separately, for example -- and also influences its ability to be reliably used as evidence. More information in the SAA Glossary: https://www2.archivists.org/glossary/terms/p/provenance.

2. What does "highest level" mean for a given archive?

One way archivists in particular might determine when it's possible and practical to collect at a "highest standard" is by trying to understand specific formats in-depth. Jonathan Sterne, in his book *MP3: The Meaning of a Format*, effectively breaks down what it might mean to pursue a format theory, which focuses on the structures that influence the format itself, versus a theory of mediality, which focuses on the way individuals experience a mediated version of a format through a device. Sterne writes:

"Studying formats highlights smaller registers like software, operating standards, and codes, as well as larger registers like infrastructures, international corporate consortia, and whole technical systems. If there were a single imperative of format theory, it would be to focus on the stuff beneath, beyond, and behind the boxes our media come in, whether we are talking about portable MP3 players, film projectors, television sets, parcels, mobile phones, or computers."[11]

This thesis project aims to bring the reader into the world of performing format-specific research on born-digital camera original video formats. In its pursuit of what is beneath, beyond, and behind these formats, it aims to shed light on what the ingredients of these formats are, the conditions of their creation and use, a look into historical context, and – most importantly – what responsibility archivists to preserve them, whether to the highest standard, or maybe something different.

[11] Sterne, Jonathan. *MP3: The Meaning of a Format*. Sign, Storage, Transmission. (Durham, Durham, N.C.: Duke University Press, 2012), 11.

Chapter One

Definitions and Context

As if born-digital video were not complex enough as a self-contained format, the number of stakeholders involved in its creation, transmission, preservation, and migration further exacerbates its complexity. The way an archivist describes born-digital video will likely be different from the way a professional video editor might describe the same video format. Even archivists working in different institutions might have ways of describing born-digital video holdings or components. As such, this section will attempt to establish a baseline understanding for describing born-digital camera original video and its structure.

Born-Digital Camera Original Video Format: Definition

Within the context of this paper, a born-digital camera original video format is the audiovisual files, all associated metadata files, and (if applicable) the native directory structure that are created when a camera sensor writes data to a flash memory card. In other words, born-digital camera original video formats are any video files and file-related metadata that are migrated from a digital video recorder to another storage volume.

This research specifically focuses on *file-based* born-digital camera original video formats. This is distinguished from *tape-based* born-digital camera original video formats (including miniDV, DAT, and others). This distinction may seem overly specific; rather, it is a frequently-overlooked semantic distinction that must be addressed in order to create achievable workflows that enable preservation. File-based video formats are their own beast, even though their development as digital objects made up of binary code is intertwined with that of the tape-based formats.

Born-Digital Camera Original Video Formats: Navigation

This paper will provide different forms of documentation for four different born-digital camera original formats: native ProRes 422, XAVC, AVCHD, and XDCAM-EX. These forms of documentation will provide information about the video files associated with the formats, the directory structure within which the video files reside, information about associated metadata files, references to associated standards, and basic testing findings. XAVC will be documented within **Appendix B**, and all formats will be documented within a metadata spreadsheet attached to an Open Science Foundation project page. The section below anticipates the format documentation by describing a high-level overview of two HD formats and the differences between them from the perspective of an archivist. It will walk through a few basic ideas to consider when looking at formats:

1. Is there a directory structure, or are there just files?
2. How does a user navigate the directory structure?
3. Where are the video files? Where are the audio files?
4. Are there associated metadata files?

A good place to begin thinking through born-digital camera original video formats is by considering native ProRes, a format that is ubiquitous in both production and archival environments. Please see **Appendix A** for two ways of visualizing what ProRes files will look like as they are when they come off of their recording media in a macOS High Sierra computing environment.[12]

Figure 1 is a representation of four ProRes native video files in the command line interface tool Tree, and **Figure 2** is a representation of the same four files in the same folder in Finder.[13] Both representations communicate the same information: these files are delivered as standalone files, with no associated directory structure. An archivist can learn basic technical metadata about the files by using Mediainfo,[14] Exiftool,[15] or FFprobe,[16] and use that metadata to deduce which specific type of native ProRes these files are (in the case of these particular files, that specific type is ProRes 422[17]). Based on the source of these files and the way the files are named, the archivist might guess that this file naming convention comes directly from the camera that shot the files, so they can check technical metadata against the camera model named in the file naming convention to strengthen their assumptions about format. That technical metadata can be further compared against the Apple ProRes whitepaper[18] that is available for download online.[19] To determine whether these files can be decoded or played back, they can be

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12 For a timeline of Mac operating systems, please view this blog post: https://www.intego.com/mac-security-blog/timeline-of-key-features-added-to-every-mac-os-x-release-to-date/.

13 For more information about Tree, please visit: https://www.npmjs.com/package/tree-cli.

14 For more information about MediaInfo, please visit: https://mediaarea.net/en/MediaInfo.

15 For more information about Exiftool, please visit: https://exiftool.org/.

16 For more information about ffprobe, please visit: https://ffmpeg.org/ffprobe.html.

17 Sustainability of Digital Formats: Planning for Library of Congress Collections. "Apple ProRes 422 Codec Family." Accessed May 3, 2020. https://www.loc.gov/preservation/digital/formats/fdd/fdd000389.shtml.

18 "Apple ProRes: White Paper." Apple Inc., January 2020. https://www.apple.com/final-cut-pro/docs/Apple_ProRes_White_Paper.pdf.

19 Apple Support. "About Apple ProRes." Accessed May 3, 2020. https://support.apple.com/en-us/HT202410.

checked against the archivist's media players of choice, which might include Quicktime 7,[20] Quicktime 10,[21] Mplayer,[22] FFplay,[23] and VLC Media Player.[24]

Unfortunately, most other camera original formats are not so straightforward. For comparison, consider another format that is widely adopted in production environments: Advanced Video Coding High Definition, also known as AVCHD. When AVCHD footage is shot, it creates a nested directory structure rather than standalone video files. This means that when video footage is copied off of a flash memory card, the archivist will first view a root directory folder that they must navigate in order to find audiovisual files. Please see **Appendix A, Figures 3 and 4** for two ways of visualizing AVCHD media as it comes off of its recording media in the same macOS High Sierra computing environment.

In the case of AVCHD, the root directory is named PRIVATE. Within the PRIVATE directory is a package labeled AVCHD. In order to be opened, the archivist must right-click on the package and select "Show Package Contents" (as demonstrated in **Appendix A, Figure 5**). By clicking through to reveal the package contents, the archivist is presented with another package named BDMV and a folder named "CANON." The CANON folder in this case doesn't contain video files, so the archivist must right-click and "Show Package Contents" once more. The BDMV package contains four directories and two files. The files are .bdm files, and the

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[20] For more information about QuickTime 7, please visit: "QuickTime 7 User's Guide." Apple Inc., n.d. http://web.arch.virginia.edu/arch5420/docs/QuickTime_7_User_Guide.pdf.

[21] Information about the current release of QuickTime 10 can be found here: https://support.apple.com/en-ca/guide/quicktime-player/welcome/mac

[22] For more information about Mplayer, please visit: http://www.mplayerhq.hu/design7/news.html.

[23] For more information about ffplay, please visit: http://ffmpeg.org/ffplay.html.

[24] For more information about VLC Media Player, please visit: https://www.videolan.org/vlc/index.html.

directories are named BACKUP, CLIPINF, PLAYLIST, and STREAM. Upon browsing, the archivist can find the video clips in the STREAM folder, where they exist as .mts stream files.

To learn more about the video files, the archivist can follow the same steps as they did with ProRes to determine technical metadata (by checking the file in MediaInfo and other metadata extraction tools) and they can test the files for their ability to play back in the same media players of choice. However, an additional challenge for understanding AVCHD is determining information about the additional metadata files and the directory structure.

The archivist can search technical registries like PRONOM,[25] Wikidata for Digital Preservation,[26] or Just Solve the File Format Problem,[27] and find information about .cpi, .bdm, and .mpl files, and they'll find out that they're metadata files. But it's difficult to understand what metadata they contain, and what the relationships between all these files. Do archivists really need to keep them? It is time-consuming to manually navigate through the layers of directories, and the nested directory structure probably interrupts workflows or access points in a way that a single video file like ProRes wouldn't. What do archivists stand to lose if they only save the video files and not the associated nested directory structure and strange metadata files? Will the video files still play back? Will important provenance information be lost? Or are all of those files unnecessary?

At this point, this overview has covered basic user interactions with ProRes 422 and AVCHD formats. While a few potential complications have been identified, one question in

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[25] For more information about PRONOM, please visit: https://www.nationalarchives.gov.uk/PRONOM/Default.aspx.

[26] For more information about Wikidata for Digital Preservation, please visit: https://wikidp.org/.

[27] For more information about Just Solve the File Format Problem, please visit: http://fileformats.archiveteam.org/wiki/Main_Page.

particular might stand out: Which component – or components – of a video file determines what the format is called? Even among archivists, there seems to be no clear consensus. Some archivists insist that a file's codec determines its format name. If that were the case, ProRes would be referred to as ProRes, and AVCHD would be referred to as AVC. Others insist that the file's wrapper is equivalent to the format name. In that case, ProRes would be referred to as QuickTime, and AVCHD would be referred to as MPEG Transport Stream. But defaulting to a codec or wrapper in order to speak about a format feels as though it's leaving out important specificities. If professionals in the same field disagree, how are they supposed to communicate about deliverables, workflows, or other elements critical to preservation?

With this in mind, it's important to push this overview further: AVCHD is not the only HD video format that has a nested directory structure to describe its video files. These directory structures are all unique to their formats, and provide metadata that is unique to the manufacturer, the camera model, and down to the exact camera used to shoot the video. In **Appendix A** are Tree visualizations of two more widely-adopted formats, XAVC (**Figure 8**) and XDCAM EX (**Figure 9**), alongside the original Tree visualizations of ProRes **(Figure 6**) and AVCHD (**Figure 7**).

Viewed side by side, it's apparent that they all have different directory structures containing different types of files. The way these Tree visualizations might be read could allow the archivist to determine some patterns in the formats. For example, in AVCHD, for every .mts video stream, there is a corresponding .cpi file. It also allows the archivist to see which kinds of video wrappers (or lack of wrappers) are being used. ProRes uses QuickTime. AVCHD uses .mts stream files. XAVC uses the .mxf wrapper. XDCAM uses .mp4 files. These wrappers represent different codecs, different user bases, and different scales of standards bodies that govern them – and that's not even addressing the audio.

Formats: Commercial Name

For the sake of establishing a common vocabulary within this research paper, the term "format" will be closely aligned with the "Commercial Name" field within MediaInfo reports. As MediaArea CEO/CTO Jérôme Martinez notes in a post on SourceForge, the Commercial Name of a given format is generally what that file's associated corporation might use to describe the format within marketing materials without any technical specification behind it.[28] While this MediaInfo field is based on info from the specific video file rather than the metadata files associated with it, and even though this MediaInfo field may not require a technical specification to ensure industry-wide understanding and standardization, it acknowledges the fact that born-digital camera original video formats influenced by and communicated about through criteria that are at once standards-based and technically generic, and highly specific and subject to commercial interests and colloquial understandings.

Formats in the Archive, and Scaling Up

Knowing that there are so many components of born-digital camera original video formats, archivists might start to assess the risks involved with preserving them. They might ask:

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[28] SourceForge. "MediaInfo / Discussion / Open Discussion: Questions about 'Commercial Name' Field." Accessed May 3, 2020. https://sourceforge.net/p/mediainfo/discussion/297609/thread/6c928b2d90/.

1. If these formats are ingested into an archival repository, does the whole nested directory structure need to stay intact? Can the archivist just maintain the video files and discard the rest? Will the archivist need to transcode or rewrap the video files? Is it reasonable to transcode, rewrap, or otherwise normalize the video files based on the specifications of my archive?
2. Which components of the format need to be maintained in order to ensure that it will render in 100 years? Or in 5 years? Or even tomorrow?
3. Where does preservation information about these formats exist? How can an archivist perform obsolescence monitoring on complex formats?

Even in a high-level overview, it's clear that self-contained formats present a number of component parts, and that formats don't show standardization across manufacturers. This began to feel particularly overwhelming when adding the hallmark of digital video: its scale. Not only are there many different formats and components within them, there are a lot of people making a lot of video and not deleting any of it. When filmmakers were still working in film, the ratio between the total footage created for a project and the footage that appears in the final cut -- known as the shooting ratio -- was generally around 10-to-1.[29] Today, video editors working on feature films note that shooting ratios have surged, usually over 100-to-1, or even higher. This is in part because the cost of shooting material has shifted from film stock to material storage.[30] Digital video production exists in a perception of cheap storage and ease of use.

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[29] Nedomansky, Vashi, and ACE. "SHOOTING RATIO OF FEATURE FILMS." *VashiVisuals* (blog). Accessed May 3, 2020. https://vashivisuals.com/shooting-ratios-of-feature-films/.

[30] Morrow, Justin. "Shooting Ratios, From Hitchcock to 'Fury Road' to 'Primer' (and What They Mean to You)." No Film School, March 4, 2016. https://nofilmschool.com/2016/03/shooting-ratios-mad-max-fury-road-primer-hitchcock.

Video archiving is fundamentally incompatible with this idea. For archivists, storage is precious: as cheap as it has become, different tiers of storage and access to it are expensive, and the materiality of storage solutions is taking a toll on the environment in its use of nonrenewable energy and materials that are difficult to recycle.[31] Beyond storage, due to the nature of software, files and workflows will break, and archivists will have to troubleshoot them, frequently with limited resources. The added challenge is that video files continue to become more prevalent, more complex, and with the HD video world already shifted into 4K and 8K, all those files are getting bigger on a shorter timeline.

[31] Tadic, Linda. "The Environmental Impact of Digital Preservation (Presentation Slides)." Digital Bedrock - Digital Preservation Services. Accessed May 3, 2020. https://www.digitalbedrock.com/resources-2.

Chapter Two

The Lifecycle of a Born-Digital Camera Original Video Clip

While we can understand the way a born-digital camera original clip might behave when it arrives at an archive as part of an acquisition on a flash drive or hard drive, we can gain a much more holistic understanding of its arrangement, its provenance, and its future needs if we have a sense of its projected lifecycle. This lifecycle will be different in different archival environments, some of which will be discussed in the section on edge cases. This section will discuss a potential lifecycle of a format within a production archive.

The creation of a digital video clip can be complex, and this diagram provides a simplified model of the major milestones of a born-digital camera original video clip's life. This model was created with production workflows in mind: camera originals can go straight to archive, or they can cycle through post-production and the archive to be re-purposed or licensed.

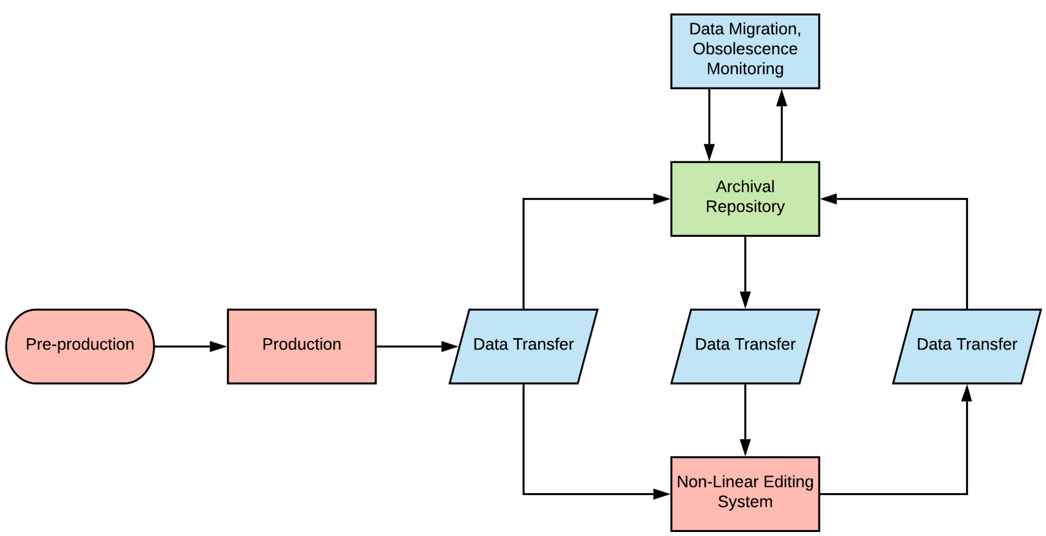

Figure 10: Lifecycle model of a born-digital camera original video clip.

First, decisions about production and editing are made in pre-production meetings. Next, a video is shot in production. From there, it can be transferred to an archive to be preserved, or it can be transferred to a post-production environment, where it is edited along with other video clips in a Non-Linear Editing System. Then, whatever is created during post-production is exported from the editing software and transferred to the archive or some other iteration of a repository for safekeeping. Post-production can continue to reference camera originals in the archive to create new works. The archive will continue to migrate formats in relationship to obsolescence monitoring.

While a key property of digital video (and digital files in general) is the ability to losslessly duplicate files, each of the steps in this model represents an opportunity to lose image quality, to lose or modify metadata, to break critical dependencies, and to otherwise introduce errors. The following sections will describe these stages step by step, beginning with Production.

Production

A few decisions are made prior to shooting a clip that inform the life of the clip in its creation. The type of camera that is used during the shoot will affect the clip quality and metadata, primarily based on the sensor and its ability to write data. The type of memory card being used in the camera will affect the quality of the clip as well as its metadata. After shooting, a memory card would ideally be ingested in its entirety to a stable storage volume. More likely, specific clips will be pulled from the card and transferred independently from the rest of what was shot, sometimes directly into a non-linear editing system (NLE).

The two major components of video file creation are the camera and the flash memory card. The camera determines which formats a cameraperson is able to shoot, which will determine the originating technical metadata (including bit rate, frame rate, and codec, among other things), how quickly data can be written to a storage volume, and what the directory structure will look like depending on whether it can shoot multiple formats.

Flash memory cards are solid-state storage media onto which the video files are recorded. Cards have their own file systems which will determine how video files are written, and will ultimately be the devices that transfer video files from one device to another.[32]

A helpful resource here for archivists would be a mapping between cameras, camera cards, and their file systems. If an archivist working with camera originals and is concerned about an error they can't track, a resource that guides them toward the possible materials that created the file (like the specific related cameras, or particular models or manufacturers of flash memory cards) would help save time on troubleshooting.

Data Transfer

The next step in the workflow is the file transfer, either to an archive or to a post-production environment. This is a critical point in the workflow where a number of different devices or software can be used to perform file transfers with different functions. A file transfer can be as simple as inserting a flash memory card into a card reader on a laptop and dragging and dropping files to a desktop, or transferring via a cloud-based file transfer service like WeTransfer.[33] At scale, file transfers are more likely to occur by way of dragging and dropping files onto an external hard drive and shipping it, or specialized offload software like ShotputPro,[34] which is

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[32] Rusen, Ciprian Adrian. "FAT32, ExFAT or NTFS? How to Format SD Cards, Memory Sticks and Hard Drives." Digital Citizen, March 28, 2018. https://www.digitalcitizen.life/fat32-or-ntfs-how-format-sd-cards-memory-sticks-and-hard-drives.

[33] For more information about WeTransfer, please visit: https://wetransfer.com/.

[34] For more information about Shotput Pro, please visit: https://www.imagineproducts.com/product/shotput-pro.

able to generate basic fixity reports. In an archival context, scaled up file transfers might occur using command line tools like Rsync.[35]

Because camera originals are created on flash memory cards and are created with the intention of becoming part of a larger work, they are by nature a format in motion. This data transfer stage is critical in moving video files from place to place, and it's also a critical stage to ensure that material is staying intact. Any data transfer stage should include fixity checks to ensure that video files are successfully transferred from their source to their destination.

Post-Production

The next step of the process is editing in a non-linear editing system, like Adobe Premiere, Final Cut Pro, DaVinci Resolve, or Avid. These editing systems are linked to the software environment they're designed for, and updates to operating systems will affect the functionality of the software and its ability to work with certain video formats. Nonlinear editing systems inevitably change the structure of a video clip, but in this model, what's more important to note is how they influence actions on the video files prior to their import into an editing system. For example, Final Cut Pro required videographers to transcode video files prior to import because of its limited decoding library; AVCHD, for example, needed to be transcoded to ProRes in order for the Final Cut Pro software to decode it. Premiere, on the other hand, allows a much wider range of camera originals to be imported directly into the software without transcoding; AVCHD, in this case, could be imported as AVCHD.

The production industry's workflow shift between Final Cut Pro and Adobe Premiere is likely linked to the more widespread appearance of camera originals in video archives. When

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[35] For more information about Rsync, please visit: https://rsync.samba.org/.

Final Cut Pro was the production industry's standard for post-production video editing from the early 2000s to late 2010s, the only camera original structure that could be decoded by the software was XDCAM. If a shooter shot XDCAM footage, they could import that footage with its native directory structure, video files, and associated metadata directly from a storage volume into the software and begin editing. Any other format needed to be transcoded into ProRes for editing. Logistically, this meant that most footage shot on DSLR cameras needed to be transcoded, usually by a production assistant (PA), which was a time-intensive process. Generally speaking, the PA would perform the following steps: 1) Review all footage and select which clips needed to be exported from the recording media for editing, 2) Ingest the appropriate footage and delete the rest, 3) Transcode all HD video files to ProRes.

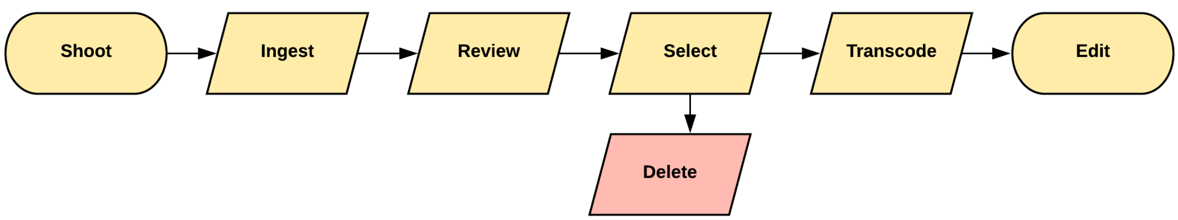

Figure 11: Preparing footage for edit in Final Cut Pro.

Transcoding DSLR footage to a high-performance editing format like ProRes also meant that the size of the footage nearly tripled. The typical bitrate of DSLR footage at the time was roughly 25 mpbs; ProRes footage scaled that bitrate up to 75-80 mpbs, just for the sake of being able to edit the footage. This meant that while only select footage was being transcoded and the rest deleted, the selected footage was tripling in size, which presented a storage problem.

Still, while this workflow was time-consuming, complicated, and frustrating for those who performed it, it incidentally familiarized camera departments – particularly the PAs – with their footage because of the review process. In addition, it forced directors of photography (DPs) and editors to be familiar with the formats they were shooting and editing: familiarity with and preparation for specific formats needed to be built into the workflow in order to ensure that that footage could be successfully edited.

The shift from Final Cut Pro to Adobe Premiere began in roughly 2015 and currently, in 2020, it has taken over the industry. The primary difference between these two software products that facilitated this transition, as described by video editors past and present, is Premiere's ease of use. Premiere possesses a broad library of format decoders, which enables many different camera original formats to be imported directly into Premiere to be edited. This completely dismantles the complicated Final Cut Pro workflow: with Premiere, there is no longer a need for a PA to review, select, ingest, and transcode footage. All of the footage can be ingested to a new storage volume directly from recording media, and from there, the footage is edit-ready: 100% of that footage can be imported directly into Premiere, decoded and parsed by the software.

Figure 12: Preparing footage for edit in Adobe Premiere.

The ease of this workflow comes with critical implications. On the one hand, camera original footage no longer needs to be transcoded to a higher-bitrate format like ProRes, so the camera originals can stay as-is upon ingest and import: no footage is being duplicated and then tripled in size. However, the erasure of the review process – coupled with the decreasing price of digital storage – means that all footage shot by a DP is then ingested, rather than a selection of clips. This presents a new style of storage problem: workflows enable production teams to save all of their footage, the shooting ratio falls further out of balance, and the size of HD video – especially as HD shooters switch to 4K and 8K workflows – continues to increase.

Archivists working with born-digital camera original video formats today, including those at the Smithsonian Institution and New York Public Library, have indicated in conversation that they rarely saw these formats prior to 2015, which was roughly when video production began to shift from Final Cut Pro to Premiere. Prior to 2015, these archives primarily saw ProRes clips or edited final projects that had been exported as ProRes masters. The rise of Premiere and its ability to read more content meant that archives, in turn, received more content to preserve.

Distribution

Where a finished video clip is headed will determine what its export format is, and that desired export format could determine both what the preservation format might be, and also might determine whether a camera original can be stabilized in a transcoded format that could better enable the creation of the distribution format. Born-digital clips can end up being distributed for theatrical release, for optical disk (DVD or Blu-Ray) release, broadcast, or for web, among other options.

Archive

When a format is being managed in an archive, there are a number of different smaller systems that might make up a larger digital preservation system, or there might only be the structure created by archivists through diligent organization via folders and file naming conventions. Two common systems that might be present within an archive are a Digital Asset Management system (or DAMs) as an access platform, and a digital repository for storage. There are a number of different vendors that supply these services, and suit different types of archival needs. Many of these systems don't support maintaining the folder structure of the camera original formats upon ingest, and so additional preservation actions must be taken by the archivist to prepare materials for ingest into the system. What is most important in any archive is that there are fixity checks on materials, the materials are evaluated for potential risks to future renderability, and there is redundancy and security in the storage of the materials.

An integral part of digital preservation is obsolescence monitoring and data migration. As aptly put by Trevor Owens in his 2017 book, *The Theory and Craft of Digital Preservation*: "Nothing *has been* preserved, there are only things *being* preserved."[36] Even if camera originals are safely received, packaged, and ingested into a digital repository, those formats need to be monitored to ensure that they are able to be played back, and depending on the needs of the archive, possibly decoded in an NLE like Premiere for the sake of repurposing and editing that footage. If a given format or generation of a format is rendered obsolete by an operating system upgrade, either a workstation needs to be designated with the compatible operating system, or that format needs to be transcoded to meet the new needs of the archive's computing environment. An archive with complex born-digital camera original video formats will need to consider what transcoding these files might mean for the provenance of the materials. [37]

Because camera originals are complex formats with minimal preservation-oriented documentation, it is useful to consider the stages of this production workflow and format

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[36] Owens, Trevor. "The Theory and Craft of Digital Preservation." LIS Scholarship Archive, July 15, 2017. https://doi.org/doi:10.31229/osf.io/5cpjt.

[37] Kromer, Reto. "On the Bright Side of Data Migrations." *International Association of Sound and Audiovisual Archives (IASA) Journal*, no. 49 (November 1, 2018). https://doi.org/10.35320/ij.v0i49.72.

lifecycle to be a mini-chain-of-custody. Each stage of a production workflow is another link in the chain that represents important provenance data and metadata, and potential transformations upon the material that are governed by a number of different individuals. Not only are the immediate stakeholders of a given institution linked to each stage of the workflow -- there are also the standards bodies approving the materials, or groups of engineers creating them, or working groups generating open-source software solutions, that govern the software used to work on the material.

Chapter Three

Format History

> *"[New] technology typically grows out of the formats and devices that are currently in use. So by learning how technology has progressed to where we are today, and the variety of uses in today's video world, you will create an excellent foundation for understanding the technology of tomorrow."*[38]

The advent of digital video formats represented a significant break in production and preservation workflows, to the point where analog and digital media at times might seem as though they represent entirely different requirements and idiosyncrasies. However, many of audiovisual media's idiosyncrasies that were established in the earliest days of celluloid film remain baked-in to digital formats to this day.

With this continuity in mind, this chapter will attempt a high-level historical overview of audiovisual format development. This overview will attempt to trace the development of camera original elements for celluloid film, analog videotape, digital videotape, and file-based video, and ask questions about where today's digital workflows and preservation criteria might be informed by other audiovisual media, whether obsolete or supported. How can production workflows across the history of audiovisual media be connected? Can born-digital production workflows borrow from film and magnetic videotape workflows, or should born-digital workflows primarily shift attention toward non-audiovisual, complex digital formats?

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[38] Weynand, Diana, and Vance Piccin. *How Video Works: From Broadcast to the Cloud*. Third edition. (New York, NY: Focal Press, 2016), 296.

Before diving into a longer timeline, it's useful to consider one format in particular: ½-inch open reel video. Half-inch open reel video is widely acknowledged as the first amateur video format, due in large part to one particular video tape recorder (VTR): the Portapak. Sony Corporation released the now-infamous Portapak in 1967, and the design of this VTR changed consumers' relationship to video.[39] The Portapak, as was suggested in its name, was portable: it was small enough to be carried like a bag with a shoulder strap, battery powered so the user wasn't tethered to a power source, and linked to a lightweight camera. It avoided some of the issues that made amateur film formats like 16mm and 8mm inaccessible to most consumers. As Jon Wilkman writes in his recent book, *Screening Reality: How Documentary Filmmakers Re-Imagined America*, ½ inch open reel video was a tenth of the cost of 16mm film production, allowed the user to playback material immediately instead of sending away to a lab for development, allowed audio and video to be recorded on the same medium, and the reels allowed for forty-minutes of recording time, rather than 16mm's ten minutes, and the tapes could be erased and reused.[40]

Still, at fifteen hundred dollars for the VTR-camera system, the ½ inch open reel format was still expensive and never quite caught on with the consumer market as Sony had hoped, but it was still adopted by artists, filmmakers, and forward-thinking institutions who gained access to the format by some means or another.[41] As a result, ½ inch open reel video represents some of

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39 Wilkman, Jon. *Screening Reality: How Documentary Filmmakers Reimagined America*. (New York, NY: Bloomsbury Publishing, 2020), 261 (hereafter referenced as *Screening Reality*).

40 *Screening Reality*, 261.

41 While it's difficult to overstate how influential portable audiovisual recording devices have been to the democratization of media across format history, they have nearly always been prohibitively expensive for most consumers. In the case of the Portapak, its widespread adoption was enabled by grants from agencies like the New York State Council on the Arts (more information here: https://arts.ny.gov/history), institutions purchasing recording materials to stay at the cutting edge of cultural programming, and occasionally by wealthy patrons buying camcorders for artists.

the most adventurous, pioneering time-based media art works, including the works of artists like Steina and Woody Vasulka, Shigeko Kubota, Nam June Paik, and Mary Lucier. The format also inspired the formation of video collectives like Queer Blue Light, Raindance Corporation, Videofreex, and TVTV, which created documentary video works that recorded the stories of marginalized people that might not otherwise see their stories told within the realm of broadcast television.

Furthermore, these groups generated publications like *Radical Software*, which was distributed by Raindance Corporation,[42] and books like *Spaghetti City Video Manual: A Guide to Use, Repair and Maintenance,*[43] both of which provided valuable resources to media makers. These publications, while created for video production, have had a profound effect on video preservation today, because they provide us with information about the workflows and dependencies involved with the creation of video. When video collectives wrote about the way they used video technology, they provided today's archivists with invaluable insight regarding the tools needed to preserve their work.

These publications were especially valuable because manufacturers were developing and changing ½ inch videotape technology as collectives were buying and using it. The format started off with individual manufacturers producing machines according to their own specifications. In 1969, the Electronic Industries Association of Japan (or EIAJ) was formed to create and establish a technical standard for the medium so tape decks could be interoperable with different tape stock, but one-off iterations of the format were still manufactured and

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[42] An archive of Radical Software publications can be explored here: https://www.radicalsoftware.org/e/index.html.

[43] More information about Videofreex can be found here: http://www.vdb.org/artists/videofreex.

adopted.[44] Without documentation of these formats, preservation today – over 50 years later – would be even more difficult than it already is.

The challenges of ½-inch open reel video can anticipate and inform the challenges of preserving born-digital video, in particular born-digital camera original video. When ½ inch videotape hit the market, not everyone using it was thinking about preservation: they were mostly just thrilled to have a method for telling their stories and making art. Archivists today are lucky that some media makers documented their work. How might that translate to born-digital workflows today? In 1967, amateur video was a growing industry, but the phenomenon of everyday people recording their lives was still quite rare. In 2020, video is everywhere, and video applications encourage the recording and widespread sharing of everyday life. Most people carry a camera, nearly everyone has the capacity to be a creator, and there are many different born-digital formats to choose from when someone decides to make their content.

Half-inch open reel video is an at-risk format today because there are a number of different iterations of the format, a scarcity of playback decks, and a lack of knowledge about the means to preserve them. Born-digital camera original video formats might not face the same obsolescence risks as ½-inch video today, but it can certainly learn from its trajectory. Born-digital camera original video formats proliferate in a number of forms, face compatibility with media player software upgrades, and have piecemeal documentation, usually from a non-preservation perspective.

Born-digital camera original video formats, with their complex, format-specific nested directory structures and associated metadata files, is the most at-risk video format we have. We've already outlined some of the perceivable risks: they have complex, format-specific nested

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[44] Bensinger, Charles. *The Video Guide*. 2d ed. revised. (Santa Barbara, Calif.: Video-Info Publications, 1979), 108.

directory structures, each of which contains different standards of video files and metadata files. In addition to what we can view through Finder and Tree, we also know that all of these formats are proprietary. A format might contain open standard components the way that XAVC's video clips are MXF, or a decoder might be reverse-engineered the way that ProRes' was in 2011, but these formats are still precarious and exist in a realm outside of consumer or archivist control, and they aren't always interoperable. While it is useful when media makers document their process and educate others about tools and workflows, the responsibility to understand these formats' structure, their dependencies, and their ability to be maintained will always fall to the archivist.

Timeline Overview

The arc of audiovisual format development can be divided into three distinct eras: film, magnetic videotape, and file-based digital video. Motion picture film is images and sound recorded on a nitrate, acetate, or polyester base by exposing a silver-based halide to light.[45] Magnetic videotape is images and sound recorded on an acetate base through a conversion of electronic energy to a magnetic pulse that rearranges oxide particles on the base. File-based digital video followed magnetic videotape, and these formats are created by recording binary to a storage volume. The following sections will provide more context for each medium, giving a more holistic sense of the ways in which each of them are connected.

Film

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[45] Enticknap, Leo. *Moving Image Technology: From Zoetrope to Digital*. (London, New York: Wallflower Press, 2005), 9 (hereafter cited as *Moving Image Technology)*.

The beginning of motion picture film is considered to be 1889, when three components needed to mass produce the technology were in place: "the ability to induce the perception of continuous movement effect mechanically, photographic emulsions which were fast enough to produce the images needed for these devices and a strong, flexible and transparent film base to support them on."[46] While file-based digital video no longer uses photographic emulsion or film base, the mechanically-induced perception of continuous movement -- also known as persistence of vision -- is still a significant component of contemporary file-based digital video.

Celluloid films are shot to an original camera negative. Workflows are built around creating duplicates of the original negative so the original negative doesn't have to be used again and again to make prints. By the nature of its media, film will wear out with use: we will never be able to create infinite copies of a film from the original camera negative because that negative will wear out over time. Even if we are able to create duplicate negatives from an interpositive that is one generation removed from the original camera negative, the workflow is built around the idea that the medium will lose quality with each passing duplication or generation. This was true both for 35mm film and for small gauge films, like super 8mm. The medium was shaped by competing standards bodies and manufacturers. Playback devices for film are projectors, which project prints. To this day, celluloid film is considered an archival medium, as it will keep well in the correct storage conditions and at present does not need to be migrated to mitigate obsolescence concerns.

Magnetic Videotape: Analog

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[46] *Moving Image Technology*, 10

Magnetic media was originally developed for news broadcast as 2 inch quadruplex tape.[47] Until the invention of magnetic media, news broadcasts were recorded on film and then preserved and re-broadcast by using kinescopes. This meant that the film had to be developed in a laboratory, which took time, and then recorded using the kinescope, which was a 16mm camera recording off of a video monitor, which made a recording for distribution that was of significantly inferior quality to the original. 2-inch quadruplex tape was developed as a more cost-effective and efficient way to create news broadcasts and reproduce them for audiences in different time zones, and in addition, it preserved the quality of these broadcasts. As magnetic tape began to develop, it became smaller and smaller and less cost-prohibitive. This eventually resulted in the aforementioned first widespread amateur audiovisual format: ½-inch open reel video. Playback devices are decks, which are often best-suited for particular video formats, but the development of consortiums led to the creation of interoperable playback decks.

Pre-Digital

By the advent of amateur video in the early 1970s, celluloid film and magnetic videotape had three major tracks of production: motion picture, television, and amateur/home movies. Film was being used for major motion pictures, had been phased out of television, and was still being used to create home movies. Magnetic videotape was not being used in the motion picture industry, was used widely in broadcast environments, and was beginning to see use in amateur media. Reproducibility and cost-effectiveness were issues across production environments. Film was always a one-time use medium, and prints for distribution could be struck from duplicate

[47] Quad Videotape Group. "Quad History." Accessed May 4, 2020. http://quadvideotapegroup.com/QuadHistory-PageIndex.htm.

negatives created by way of an interpositive print, but were always best struck from the source material. Magnetic media was reusable, but it was frequently recorded over and as such represents a loss of cultural heritage. If a broadcast was preserved, it had to be created as a duplicate tape, representing a generational loss of image quality.

Retrieval of these formats in a pre-digital environment meant organizing materials in physical space with a ledger that allowed for the organizational logic of the materials in space to be recorded in a reference document.

Magnetic Videotape: Digital

The first digital videotape format was Sony's D1, which was developed as a broadcast format in 1986.[48] SMPTE standardized the format, which recorded uncompressed digitized component video. D1 recorded a standard definition image, and ushered in the era of broadcasters making major infrastructural changes to their facilities. The format was prohibitively expensive, but over time, engineers were able to make changes that reduced the size and cost of the overall system. Digital tape developed over time to include component and composite video, different sampling algorithms, and playback decks that could accommodate tapes that were both analog and digital. Eventually, image compression entered the system, which encoded digital video into lossy and lossless compression schemas that allowed the information to travel with more ease across broadcast systems.

File-Based Digital Video

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[48] Duke, Laurie. "Uncompressed? Unimpressed: The Brief Yet Wondrous Life of the SMPTE D-1 Digital Video Tape Format," November 24, 2014.

File-based or tapeless digital video was introduced in 2003 with the XDCAM format from Sony. Panasonic followed suit shortly thereafter in 2004 with its P2 solid state memory cards.[49] In 2006, Sony and Panasonic introduced the AVCHD format as an inexpensive, tapeless, high-definition video format.[50] These formats opened the door to a new era of recording audiovisual media. Now, the usual relationships between recording, storage, and playback media wasn't tied to specific formats based on size and whether or not the tape was analog or digital, and there wasn't a 1:1 relationship between recording media and recording device, either. Different manufacturers created consortiums that helped develop new formats, and those manufacturers all created camcorders that could accommodate the new format. Some of these formats are standard definition, some are high definition, and more and more are shifting to 4K or even higher resolution. In order to keep up with the demand for more recording formats and better playback devices, manufacturers have reached into a realm of planned obsolescence to keep the video market thriving. This range of formats has opened up recording possibilities for digital cinema, digital broadcast, and the ubiquitous video content created by so many individuals across the world today, but with those possibilities comes big questions for long-term preservation and renderability.

Research Precedents

While born-digital camera original video formats are still largely undocumented and unstandardized, small research initiatives are building an exciting knowledge base. Crystal

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[49] Volk, Jonah. "A Producer's Guide to File-Based Digital Video Preservation," May 5, 2010.

[50] AVCHD INFORMATION WEB SITE. "AVCHD INFORMATION WEB SITE." Accessed March 18, 2020. http://www.avchd-info.org/format/.

Sanchez and Taylor McBride, who both work in Digital Asset Management at the Smithsonian Institution, began an initiative at the Smithsonian Institution to research camera originals, building risk analysis documentation to determine what could be supported within the Smithsonian DAMs and how it might be transcoded, rewrapped, or packaged to fit their use cases. Their research began as a crowd-sourced Google Doc,[51] which they presented at the 2018 Association of Moving Image Archivists conference, and has since become an internal Supported File Formats document[52] and additional collaborative work with Federal Agencies Digital Guidelines Initiative (FADGI) that documents the significant properties of digital video.[53]

In addition, Jonah Volk, who works in Preservation and Digital Conversion at Columbia University and is a MIAP instructor, wrote his 2010 MIAP thesis on file-based digital video preservation. This document has helpful information about production workflow, as has his Intro to MIAP paper on small-scale video production workflows.

Sanchez, McBride, and Volk's work has informed the research design for this thesis work in three main fundamental ways. First: camera originals began showing up in archives when the production industry shifted from using Final Cut Pro to Adobe Premiere. This references the production workflow discussed earlier in this paper: different decoder libraries within editing systems like Final Cut Pro and Adobe Premiere affect the way that camera originals arrive at the archive. Adobe Premiere has a robust decoder library, so editors can import nearly any camera

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[51] Google Spreadsheet. "Born-Digital Camera-Original Video: Practices and Risks." Accessed May 4, 2020. https://docs.google.com/spreadsheets/d/1OvZkGkizNnx_nZ9OVDOkJJIVFuIMK_7FYKC77YhoUac/edit?usp=embed_facebook.

[52] "Smithsonian DAMS Supported File Formats." Smithsonian Institution, June 2019. https://www.si.edu/sites/default/files/unit/OCIO/si_dams_supported_file_formats_2019.pdf.

[53] Smithsonian Institution. "Smithsonian Digital Asset Management System (DAMS)." Accessed April 27, 2020. https://www.si.edu/dams.

original format into the system. Final Cut Pro, on the other hand, had a more limited library, and so editors frequently had to transcode originals once their flash memory cards were ingested, and then they discarded the originals.

Second: Different stakeholders speak different languages, so the research needs to be social. People need to speak, and interact, and agree on what they need to make their workflows a success. If departments are siloed for one another, one department would have to guess what the other needs, and in this line of work, that is just not possible. Our work is too specific, and the technology is always changing. People need to be in communication to ensure long-term preservation of digital objects.

Third: Workflows are heavily influenced by institutional resources. Sanchez and McBride's work is influenced by the system requirements of the Smithsonian's Digital Asset Management system, and Volk's research was influenced by the technical support available to his use cases. That workflows vary from institution to institution is of course no surprise, but in the case of complex digital media formats, there will never be a best practice or a straightforward path to normalization. Workflows will depend on the tools available, stakeholders' willingness to use them, and the methods an institution or organization has available to make materials available to its designated community.

Beyond the planned research, it is also important to acknowledge the digital preservation work being done by practitioners in a range of institutions, all of whom are learning through their own research, the support of the digital preservation community, and a general sense of trial and error. These practitioners are working in a number of different organizations, all with different scopes of collection policies, relationships to video production, and needs for the verification and authenticity of the formats. These organizations include public libraries, independent news agencies, video forensics units, public defender services, art museums, human rights nonprofits, human rights NGOs, community centers, and more. All of their specific workflows provide insight into strategies we might use or tools we might need to make the preservation of born-digital camera original video formats a little bit easier, or at least less intimidating for the next archivist who opens a fileshare to find hundreds of gigabytes of video they might have to do something about.

Chapter Four

Format documentation

In addition to considering how past workflows might shape or guide today's digital audiovisual workflows, archivists should consider how they might find out more information about what they have with the tools that are available to them, and then use that information about those formats to guide the needs of the workflow. These formats each have different lengths of histories, different capabilities, different levels of openness, and different manufacturers. An example of documentation of the XAVC format can be viewed in **Appendix A**.

Edge Cases

The above description of a potential lifecycle is abstracted from the specifics of what might occur in a typical archive. While most archives containing audiovisual material might fall under the rubric of a university archive or a production archive, there are additional cases that are especially stringent and require a close evaluation of even camera original formats that might not last for the duration of a project because the formats have value as not just information, but as an object. In these cases, write blockers are frequently used, because the digital files themselves, both as an arrangement and as a flux recorded onto physical media, are media to be protected in its evidentiary state.

Evidence

If a video is to be used as evidence, it is important that it is maintained for its evidentiary value and is tampered with as little as possible. Details about the way the video was shot can lend clues for provenance, and particularly the time and location a clip may have been shot could be important to verify the authenticity of the media. Clips might not begin their life as evidence, but may become evidence; in this way, it is important to establish criteria for maintaining the clips in their evidentiary state. Clips might become evidence in a courtroom as part of media collected by law enforcement (which are therefore subjected to a forensic analysis), or as media collected by public defenders or human rights organizations.

Art Objects

Art objects retain their evidentiary value as editioned works created by artists that have a high monetary value. It is critical that these files be maintained as they are received both because of their value, and because they are frequently part of a system or a production workflow that is unique to the artist, and therefore are more precarious as they are not part of a best-practices oriented environment. Camera original formats created in an artist environment might not always be part of the final art object, but they might be submitted alongside the art work; these still need to be maintained with the integrity of the art object.

Government Records

Government records are legally required to be maintained in the form that they are described as. If a born digital camera original format is created as a government record, it needs to be maintained in that original format unless the description of the records state that they need to be destroyed after a certain date, or they need to be maintained as camera originals unless superseded by a different transcode format. Because these records are legal documents, if they are described in a certain way, their ability to be maintained in that way must be observed.

Research Reproducibility

A portion of this thesis research is dedicated to investigating ways to enable archivists to compile research and resources to be documented, shared, and reproduced. The research for this thesis project is compiled as an Open Science Framework (OSF) project.[54] This page breaks down the research into components and organizes the methodology and workflows in a clear, accessible way. The OSF project is integrated with a Zotero account, a Google Drive account for the sake of sharing PDFs, spreadsheets, and sample files, and a Github repository to share basic scripts for managing formats.[55]

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[54] The OSF page can be viewed here: https://osf.io/cwx94/.
[55] The Github repository can be viewed here: https://github.com/claire-a-fox/digital-camera-original.

Conclusion

To close, I'd like to take a moment to return to the quote from WITNESS that I borrowed to begin this presentation. The quote asked:

> "If it is possible and practical to collect evidence to the highest standard, then why not do so? If you can, this will make it easier for everyone involved, from journalists and investigators to lawyers and decision-makers, to rely upon your content. The easier you make it for them to use the video you collect, the better your chances that they will not only see it, but that they will use it."

This research has demonstrated that born-digital camera original video formats are complex and precarious as self-contained formats, they pass through the hands of a variety of stakeholders throughout their lifecycle, and archivists have developed myriad ways of maintaining these formats both through research and from doing the work every day.

While this is highly technical work, it is ultimately work that is in service of allowing peoples' stories to be told. Whether that story is told by providing authentic, verified evidence in a trial, by viewing an artwork from 2020 in 2070 as it was originally meant to be seen, or preserving a home movie shot on a DSLR that you received for your birthday, digital video preservation work is ultimately about giving people the chance to see and use their video material for as long as they can.

Appendix A: Images

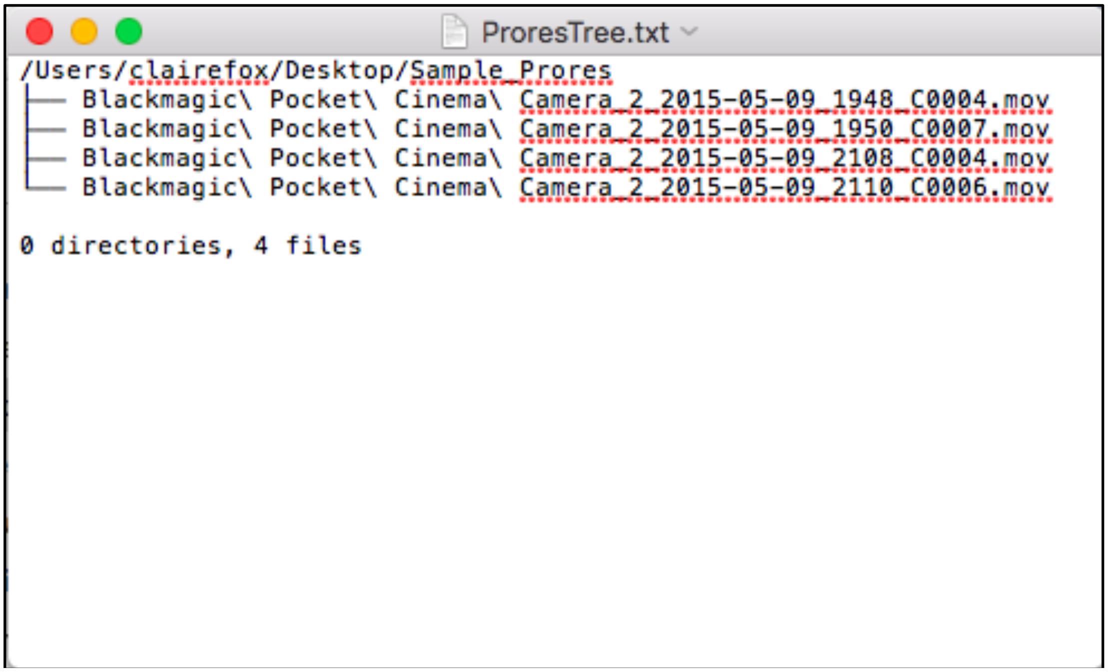


Figure 1: Four native ProRes files visualized in Tree.

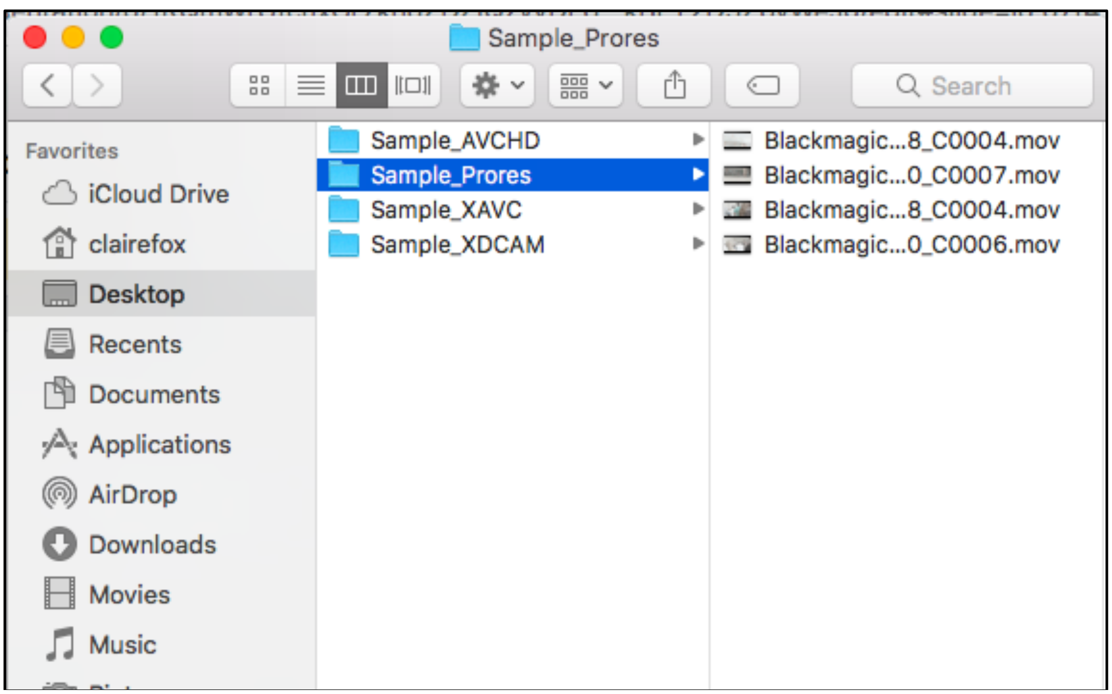
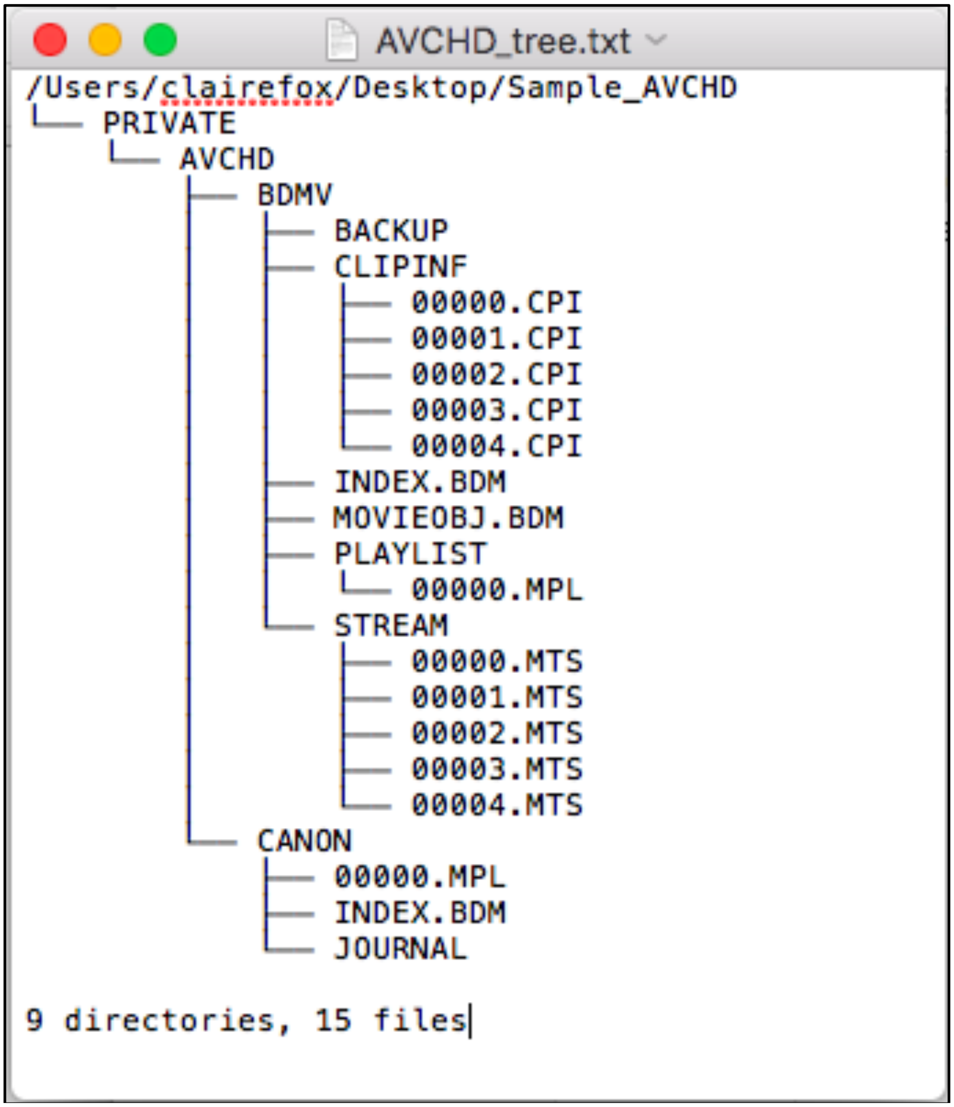


Figure 2: The same four ProRes files from Figure 1 visualized in Finder.

Appendix A: Images (continued)



AVCHD_tree.txt

```
/Users/clairefox/Desktop/Sample_AVCHD
└── PRIVATE
    └── AVCHD
        ├── BDMV
        │   ├── BACKUP
        │   ├── CLIPINF
        │   │   ├── 00000.CPI
        │   │   ├── 00001.CPI
        │   │   ├── 00002.CPI
        │   │   ├── 00003.CPI
        │   │   └── 00004.CPI
        │   ├── INDEX.BDM
        │   ├── MOVIEOBJ.BDM
        │   ├── PLAYLIST
        │   │   └── 00000.MPL
        │   └── STREAM
        │       ├── 00000.MTS
        │       ├── 00001.MTS
        │       ├── 00002.MTS
        │       ├── 00003.MTS
        │       └── 00004.MTS
        └── CANON
            ├── 00000.MPL
            ├── INDEX.BDM
            └── JOURNAL

9 directories, 15 files
```

Figure 3: AVCHD directory structure and files visualized in Tree.

Appendix A: Images (continued)

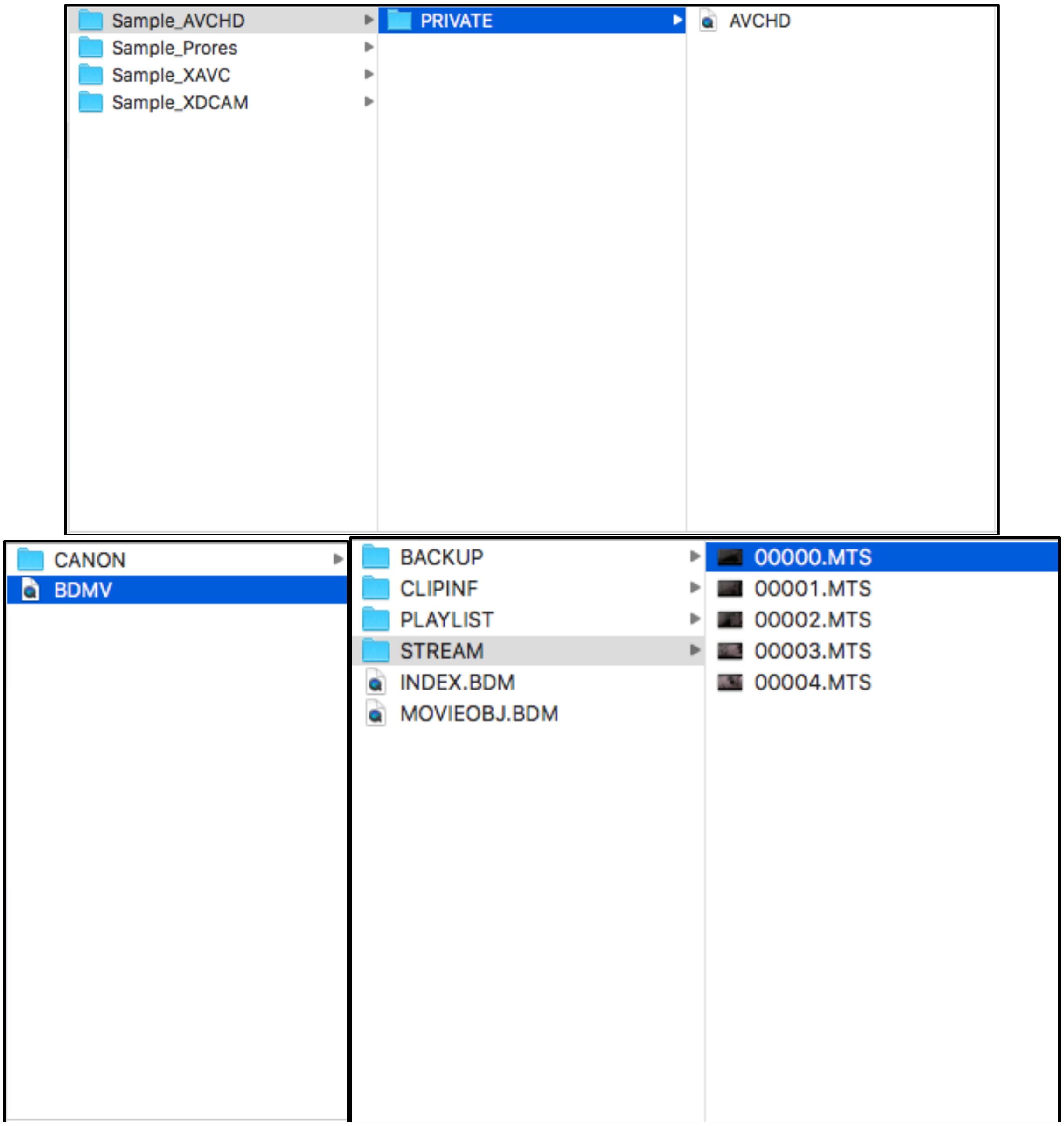


Figure 4: AVCHD directory structure and video clips visualized in Finder (divided where package contents needed to be revealed).

Appendix A: Images (continued)

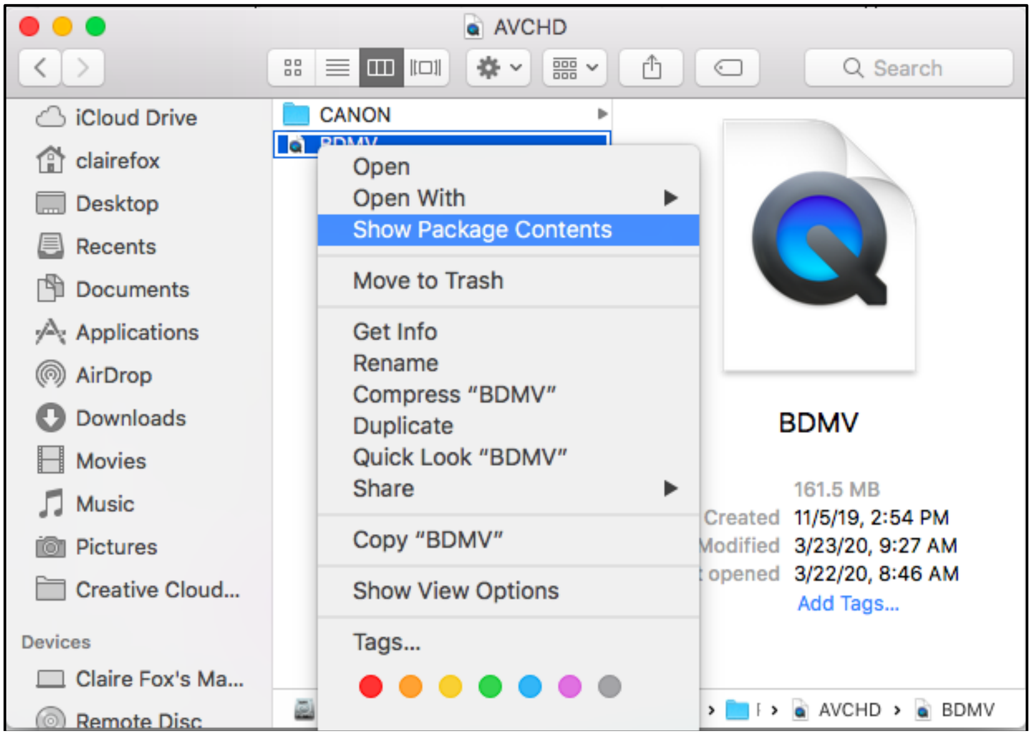
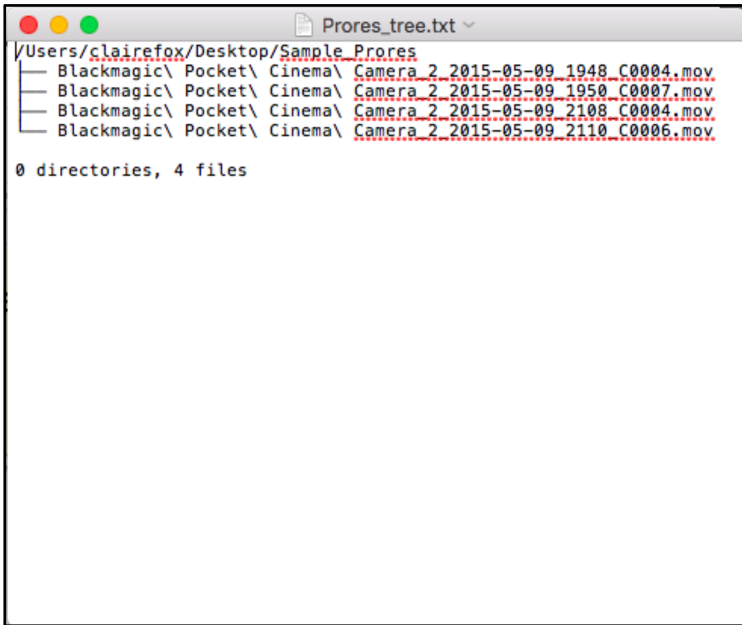
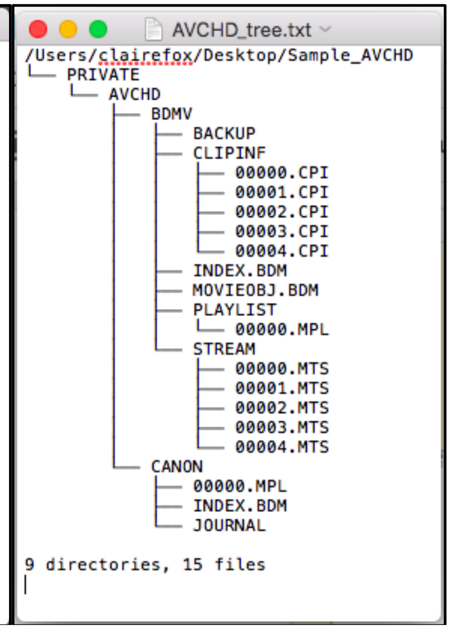


Figure 5: Image of right-clicking on BDMV package to reveal the next AVCHD sub-directory.

Appendix A: Images (continued)

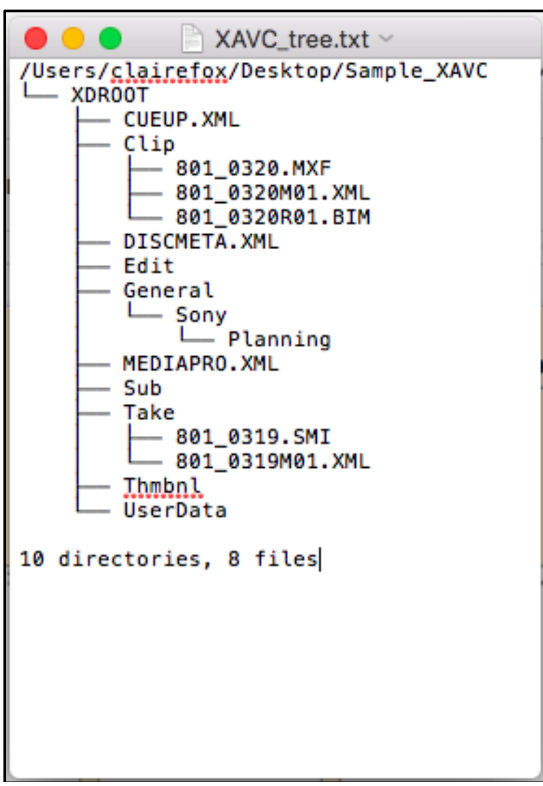


```
Prores_tree.txt
/Users/clairefox/Desktop/Sample_Prores
├── Blackmagic\ Pocket\ Cinema\ Camera_2_2015-05-09_1948_C0004.mov
├── Blackmagic\ Pocket\ Cinema\ Camera_2_2015-05-09_1950_C0007.mov
├── Blackmagic\ Pocket\ Cinema\ Camera_2_2015-05-09_2108_C0004.mov
└── Blackmagic\ Pocket\ Cinema\ Camera_2_2015-05-09_2110_C0006.mov

0 directories, 4 files
```

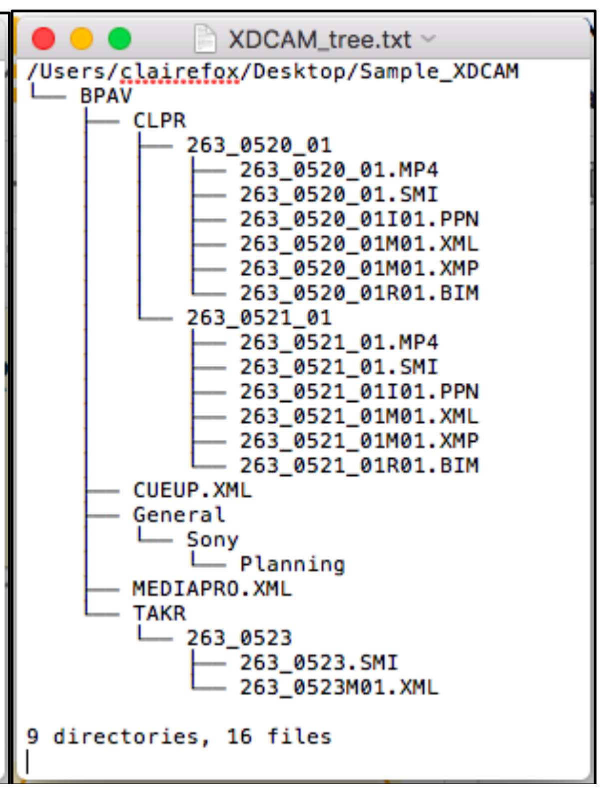


```
AVCHD_tree.txt
/Users/clairefox/Desktop/Sample_AVCHD
└── PRIVATE
    └── AVCHD
        ├── BDMV
        │   ├── BACKUP
        │   ├── CLIPINF
        │   │   ├── 00000.CPI
        │   │   ├── 00001.CPI
        │   │   ├── 00002.CPI
        │   │   ├── 00003.CPI
        │   │   └── 00004.CPI
        │   ├── INDEX.BDM
        │   ├── MOVIEOBJ.BDM
        │   ├── PLAYLIST
        │   │   └── 00000.MPL
        │   └── STREAM
        │       ├── 00000.MTS
        │       ├── 00001.MTS
        │       ├── 00002.MTS
        │       ├── 00003.MTS
        │       └── 00004.MTS
        └── CANON
            ├── 00000.MPL
            ├── INDEX.BDM
            └── JOURNAL

9 directories, 15 files
```

Figure 6 (Left): ProRes directory structure. Figure 7 (Right): AVCHD directory structure.



```
XAVC_tree.txt
/Users/clairefox/Desktop/Sample_XAVC
└── XDROOT
    ├── CUEUP.XML
    ├── Clip
    │   ├── 801_0320.MXF
    │   ├── 801_0320M01.XML
    │   └── 801_0320R01.BIM
    ├── DISCMETA.XML
    ├── Edit
    ├── General
    │   └── Sony
    │       └── Planning
    ├── MEDIAPRO.XML
    ├── Sub
    ├── Take
    │   ├── 801_0319.SMI
    │   └── 801_0319M01.XML
    ├── Thmbnl
    └── UserData

10 directories, 8 files
```



```
XDCAM_tree.txt
/Users/clairefox/Desktop/Sample_XDCAM
└── BPAV
    ├── CLPR
    │   ├── 263_0520_01
    │   │   ├── 263_0520_01.MP4
    │   │   ├── 263_0520_01.SMI
    │   │   ├── 263_0520_01I01.PPN
    │   │   ├── 263_0520_01M01.XML
    │   │   ├── 263_0520_01M01.XMP
    │   │   └── 263_0520_01R01.BIM
    │   └── 263_0521_01
    │       ├── 263_0521_01.MP4
    │       ├── 263_0521_01.SMI
    │       ├── 263_0521_01I01.PPN
    │       ├── 263_0521_01M01.XML
    │       ├── 263_0521_01M01.XMP
    │       └── 263_0521_01R01.BIM
    ├── CUEUP.XML
    ├── General
    │   └── Sony
    │       └── Planning
    ├── MEDIAPRO.XML
    └── TAKR
        └── 263_0523
            ├── 263_0523.SMI
            └── 263_0523M01.XML

9 directories, 16 files
```

Figure 8 (Left): XAVC directory structure. Figure 9 (Right): XDCAM-EX directory structure.

Appendix B: Format Documentation

XAVC

Format Description

XAVC is a recording format that was released on October 30, 2012 by Sony Corporation. The format was released to provide an option for professional shoots to transition from shooting HD 1920x1080 video to 4K, and offered three different flavors -- XAVC-I, XAVC-L, and XAVC-S -- to suit different users' needs.

Sample File

The following documentation is based on a sample file named 801_0320.MXF.

Property Name	**Property Value**
Resolution	1920x1080
Wrapper	MXF OP-1a
Video Codec	MPEG-4 AVC/H.264
Audio Codec	PCM
Compression type	Intraframe
Video Bit Depth	10 bit
Audio Bit Depth	24 bits
Video Bit Rate	114 mbps
Audio Bit Rate	1152 kbps
Frame Rate	25 fps
Scan Type	Progressive
Timecode	SMPTE
Chroma sampling	4:2:2
Color space	YUV
Number of video channels	1

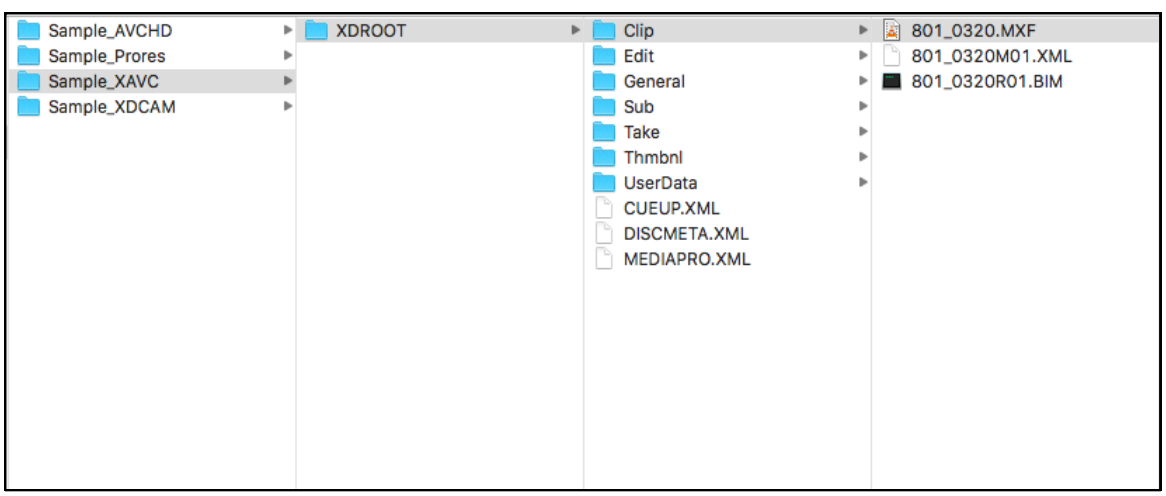
Number of audio channels	8
Number of other channels	4

Directory Structure

The directory structure visualized in Tree:

```
/Users/clairefox/Desktop/Sample_XAVC
└── XDROOT
    ├── CUEUP.XML
    ├── Clip
    │   ├── 801_0320.MXF
    │   ├── 801_0320M01.XML
    │   └── 801_0320R01.BIM
    ├── DISCMETA.XML
    ├── Edit
    ├── General
    │   └── Sony
    │       └── Planning
    ├── MEDIAPRO.XML
    ├── Sub
    ├── Take
    │   ├── 801_0319.SMI
    │   └── 801_0319M01.XML
    ├── Thmbnl
    └── UserData

10 directories, 8 files
```

The same directory structure visualized in finder:



General Questions

Are video and audio packaged together or independently?	Together
Can the video files play back if they are removed from the directory structure?	Yes
Are associated metadata files essential for playback?	No
Can Final Cut Pro decode the directory structure and locate the media?	Yes
Can Premiere decode the directory structure and locate the media?	Yes

Root Directory

The root directory is named XDROOT. The next directory level holds directories named Clip, Edit, General, Sub, Take, Thmbnl, and UserData, and three XML documents named CUEUP.XML, DISCMETA.XML, and MEDIAPRO.XML.

First Sub-Directory

- Clip contains 801_0320.MXF, 801_0320M01.XML, and 801_0320R01.BIM file.
- Edit is empty.
- General contains a subdirectory named Sony. Sony contains a subdirectory named Planning, which is empty.
- Sub is empty.
- Take contains 801_0319.SMI and 801_0319M01.XML.
- Thmbnl is empty.
- UserData is empty.
- CUEUP.XML, DISCMETA.XML, and MEDIAPRO.XML are not within a sub-directory.

XAVC has the following associated standards:

- MXF OP1-a
    - SMPTE 378-2004. Television -- Material Exchange Format (MXF) -- Operational Pattern 1a (Single Item, Single Package)
    - https://www.loc.gov/preservation/digital/formats/fdd/fdd000013.shtml

- MPEG-4 AVC/H.264
    - https://www.loc.gov/preservation/digital/formats/fdd/fdd000081.shtml
    - https://www.iso.org/standard/38573.html
- PCM
    - https://www.loc.gov/preservation/digital/formats/fdd/fdd000016.shtml
- SMPTE Timecode / SMPTE 12M-1 and SMPTE 12M-2

Associated Metadata Files

File Name	**File Extension**	**File Type**	**Description**
CUEUP.XML	.xml	Extensible Markup Language	Unclear
DISCMETA.XML	.xml	Extensible Markup Language	Metadata relating to the flash memory card (when card was formatted)
MEDIAPRO.XML	.xml	Extensible Markup Language	File-level metadata related to all clips shot on a given card (not for a specific single clip)
801_0319M01.XML	.xml	Extensible Markup Language	Metadata indicating frame rate
801_0320M01.XML	.xml	Extensible Markup Language	Contains exif metadata (including GPS metadata) specific to the video clip sharing the same name
801_0320R01.BIM	.bim	Business Intelligence Markup Language	Realtime metadata file, machine readable
801_0319.SMI	.smi	Synchronized Multimedia Integration Language	XML-based markup language for multimedia presentations

MediaInfo Report

```
General
Complete name                            :
/Users/clairefox/Desktop/Sample_XAVC/XDROOT/Clip/801_0320.MXF
Format                                   : MXF
Format version                           : 1.3
Format profile                           : OP-1a
Format settings                          : Closed / Complete
File size                                : 73.8 MiB
Duration                                 : 4 s 960 ms
Overall bit rate                         : 125 Mb/s
Encoded date                             : 2018-09-15 09:42:43.000
Writing application                      : Sony Mem 2.00

Video
ID                                       : 2
Format                                   : AVC
Format/Info                              : Advanced Video Codec
Format profile                           : High 4:2:2 Intra@L4.1
Format settings, CABAC                   : No
Format settings, GOP                     : N=1
Format settings, wrapping mode           : Frame
Codec ID                                 : 0D01030102106001-0401020201323104
Duration                                 : 4 s 960 ms
Bit rate                                 : 114 Mb/s
Width                                    : 1 920 pixels
Height                                   : 1 080 pixels
Display aspect ratio                     : 16:9
Frame rate                               : 25.000 FPS
Standard                                 : Component
Color space                              : YUV
Chroma subsampling                       : 4:2:2
Bit depth                                : 10 bits
Scan type                                : Progressive
Bits/(Pixel*Frame)                       : 2.193
Stream size                              : 68.4 MiB (93%)
Color range                              : Full
Color primaries                          : BT.709
Transfer characteristics                 : BT.709
Matrix coefficients                      : BT.709

Audio #1
ID                                       : 3
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
```

```
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #2
ID                                       : 4
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #3
ID                                       : 5
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #4
ID                                       : 6
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #5
ID                                       : 7
Format                                   : PCM
```

```
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #6
ID                                       : 8
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #7
ID                                       : 9
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Audio #8
ID                                       : 10
Format                                   : PCM
Format settings                          : Little
Format settings, wrapping mode           : Frame (AES)
Codec ID                                 : 0D01030102060300-0402020101000000
Duration                                 : 4 s 960 ms
Bit rate mode                            : Constant
Bit rate                                 : 1 152 kb/s
Channel(s)                               : 1 channel
```

```
Sampling rate                            : 48.0 kHz
Frame rate                               : 25.000 FPS (1920 SPF)
Bit depth                                : 24 bits
Stream size                              : 698 KiB (1%)
Locked                                   : Yes

Other #1
ID                                       : 1-Material
Type                                     : Time code
Format                                   : MXF TC
Time code of first frame                 : 00:33:29:17
Time code settings                       : Material Package
Time code, striped                       : Yes

Other #2
ID                                       : 1-Source
Type                                     : Time code
Format                                   : MXF TC
Time code of first frame                 : 00:33:29:17
Time code settings                       : Source Package
Time code, striped                       : Yes

Other #3
ID                                       : 11
Format                                   : Acquisition Metadata
Muxing mode                              : Ancillary data / RDD 18
Duration                                 : 4 s 960 ms
Frame rate                               : 25.000 FPS
CaptureGammaEquation_FirstFrame          : 0E06040101010605
IrisFNumber_FirstFrame                   : 11.314666
FocusPositionFromImagePlane_FirstFrame   : 2.738 m
LensZoom35mmStillCameraEquivalent_FirstF : 117.000 mm
LensZoomActualFocalLength_FirstFrame     : 73.500 mm
FocusRingPosition_FirstFrame             : 83.2535%
ZoomRingPosition_FirstFrame              : 0.0000%
AutoExposureMode_FirstFrame              : Manual
AutoFocusSensingAreaSetting_FirstFrame   : Full Screen Sensing Auto
NeutralDensityFilterWheelSetting_FirstFr : 1/4
ImageSensorDimensionEffectiveWidth_First : 24.003 mm
ImageSensorDimensionEffectiveHeight_Firs : 12.658 mm
CaptureFrameRate_FirstFrame              : 25.000 fps
ImageSensorReadoutMode_FirstFrame        : Progressive frame
ShutterSpeed_Angle_FirstFrame            : 180.0°
ShutterSpeed_Time_FirstFrame             : 1/50 s
CameraMasterGainAdjustment_FirstFrame    : 0.00 dB
ISOSensitivity_FirstFrame                : 2000
ElectricalExtenderMagnification_FirstFra : 100%
AutoWhiteBalanceMode_FirstFrame          : Preset
WhiteBalance_FirstFrame                  : 5500 K
CameraMasterBlackLevel_FirstFrame        : 3.0%
ExposureIndexofPhotoMeter_FirstFrame     : 1600
GammaForCDL_FirstFrame                   : 5
ASC_CDL_V12_FirstFrame                   : sR=1.0 sG=1.0 sB=1.0 oR=0.0 oG=0.0 oB=0.0
pR=1.0 pG=1.0 pB=1.0 sat=1.0
```

```
Other #4
Type                                     : Time code
Format                                   : SMPTE TC
Muxing mode                              : SDTI
Time code of first frame                 : 00:33:29:17
```

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