An Optical Media Preservation Strategy for New York University's Fales Library & Special Collections

Annie Schweikert
Graduate Intern, Fall 2018
NYU Moving Image Archiving and Preservation

Table of contents

Abstract

At Fales Library & Special Collections, optical media—that is, CDs, DVDs, Blu-rays, and even MiniDiscs and LaserDiscs—represent **15%** of all digital data, but **86%** of all digital objects.[1] The amount of data accessioned on these discs has grown rapidly since 2013, averaging a **352%** increase on average each year.[2] The amount of data on optical disc across NYU's Special Collections is expected to continue growing for at least the next few decades as donors conclude their careers and donate their materials. The fragility of these discs renders them inappropriate for long-term storage. NYU must extract the information on these discs before the data becomes inaccessible.

In seeking to tackle this backlog, Fales hoped for a workflow that represented sound preservation practices while remaining accessible to student workers who may not have much digital preservation experience. In considering these needs, it is recommended that Fales use IsoBuster Pro to create physical (raw) ISO disc images of its data discs; logical (user data) ISO disc images of its DVD-Videos; use Exact Audio Copy to create one WAV and one CUE file for each audio CD; and not image commercial discs. These tools operate within graphical user interfaces in the Windows environment, and these workflows represent a one-size-fits-all workflow that creates bit-for-bit images of each disc at Fales, thereby avoiding curatorial decisions as to "how complex" the disc is.

Two considerations for the near future to facilitate the task ahead are worth noting. Fales alone holds enough discs—7562 (non-commercial) optical discs, by one non-exhaustive count—to justify streamlining the imaging process.[3] Disc robots, such as the RipStation and the Nimbie, may even be combined with command line tools to further streamline optical media preservation, as in one setup at the National Library of the Netherlands.[4] It could be quite possible for NYU to adapt these scripts to a local setup, and address the optical media backlog with speed.

The following report presents an overview of the diverse and unique difficulties posed by optical media, an exploration of the tools considered by Fales, and recommendations based on local specifications.

---

[1] These numbers were calculated using the statistics in MediaLog, a catalog of digital media in NYU archival collections developed by Digital Archivist Don Mennerich (http://medialog.dlib.nyu.edu). **Note that these numbers do not represent the entirety of the optical media held at Fales or at NYU, only that which has been inventoried on an item-level basis since 2014.**
[2] Using data in MediaLog.
[3] These numbers draw from the MediaLog, which represents only born-digital materials accessioned and cataloged since 2014, and the 2018 Special Collections Control Project report by Craig Savino. The MediaLog shows that optical disc counts for Fales are typically approximately 50% of the counts across all three special collections.
[4] Johan van der Knijff, "Image and Rip Optical Media Like A Boss," *Open Preservation Foundation* (blog), Open Preservation Foundation, 19 June 2017, http://openpreservation.org/blog/2017/06/19/image-and-rip-optical-media-like-a-boss/

I. Introduction

Located in New York University's Elmer Holmes Bobst Library, the Fales Library & Special Collections is one of the University's three special collections, alongside the University Archives and Tamiment Library and Robert F. Wagner Archives. Fales is notable for its large proportion of audiovisual media documenting the creative work of artists and writers, in particular the Downtown New York arts scene of the 1960s through the 2000s. As donors transition from the analog era, their materials increasingly arrive on a variety of digital media, of which optical media represents a large and fragile proportion.

Though optical media—that is, CDs, DVDs, Blu-rays, and even MiniDiscs and LaserDiscs—have relatively low storage capacities compared to many hard drives or the potentials of file transfer, they are accessioned in high volumes. Within Fales collections inventoried in MediaLog, optical media represent **15%** of all digital data, but **86%** of all digital objects.[5] These numbers are similar across all three special collections, where optical discs are 20% of total digital data and 84% of all digital objects.

The sheer amount of data accessioned on optical disc also increases with the influx of digital data at large. Since 2013, total data on optical disc has increased by **352%** on average each year, and the number of optical discs themselves has increased by **446%** on average.[6] Though optical discs are becoming less popular for the transfer and storage of data, the amount of data on optical disc at Fales is expected to continue growing well beyond its obsolescence in the consumer market. As optical disc structures were codified in the 1980s and 1990s and have remained common since, NYU could easily receive optical discs into the 2060s and beyond as artists conclude their careers and donate their materials.

Finally, despite their wide adoption, optical discs are threatened by obsolescence and fragility, and are categorically inappropriate for long-term preservation. Optical disc and their drives are becoming rarer as trends in hardware, production, and storage shift to file-based media. The discs themselves may not last long enough to become obsolete; both the discs and their signals are susceptible to data loss, and their failure is difficult to predict.[7] NYU must extract the information on these discs to a format that can be monitored for fixity before the data becomes inaccessible.

Workflows for preserving and processing optical discs must account for concerns specific to both audiovisual and digital material. The most common strategy of optical disc preservation is to image the discs, then to extract the files themselves from the disc image; however, this workflow is not appropriate for all discs, and some audiovisual data will require further intervention. This report recommends multiple workflows that take into account differences in disc structures and audiovisual files across optical media.

This report presents a summary of optical disc structures and current approaches to optical media preservation; then, drawing on these findings, it recommends a workflow and Archival Information Package structure for NYU. The report was completed in the fall of 2018 by Annie Schweikert, a graduate student in NYU's Moving Image Archiving and Preservation program, under the direction of Kelly Haydon, Fales Audiovisual Archivist, and Don Mennerich, Archival Collections Management Digital Archivist.

---

[5] These numbers were calculated using the statistics in MediaLog, a catalog of digital media in NYU archival collections developed by Digital Archivist Don Mennerich (http://medialog.dlib.nyu.edu). **Note that these numbers do not represent the entirety of the optical media held at Fales or at NYU, only that which has been inventoried on an item-level basis since 2014.**

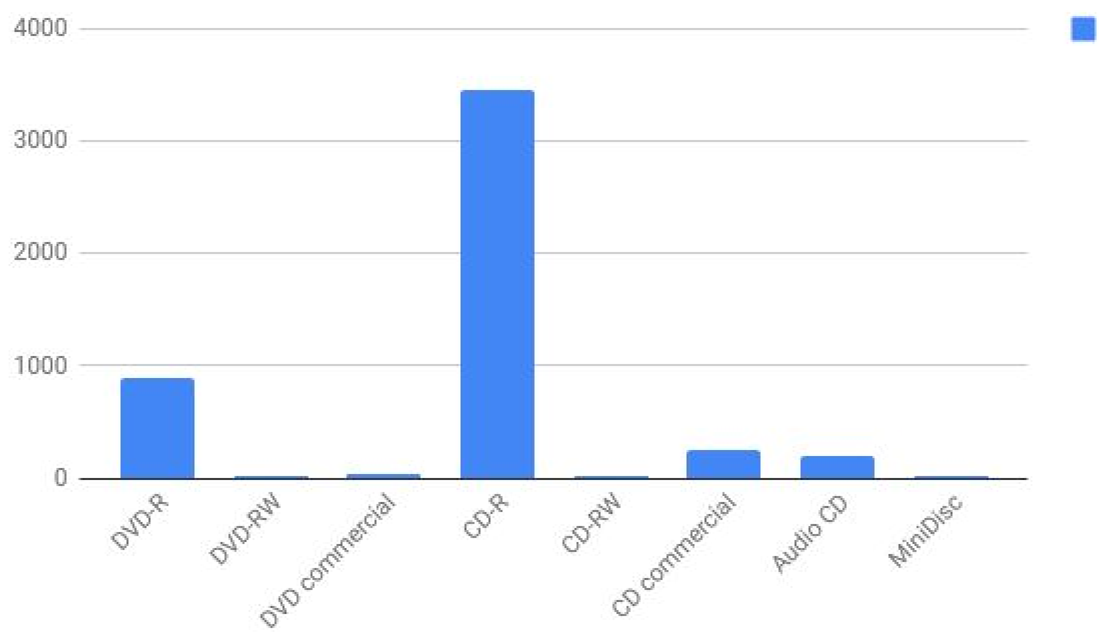
[6] Using data in MediaLog.

[7] Kevin Bradley, "Risks Associated with the Use of Recordable CDs and DVDs as Reliable Storage Media in Archival Collections: Strategies and Alternatives," UNESCO Memory of the World Programme, Oct. 2006, pg. ii. http://unesdoc.unesco.org/images/0014/001477/147782e.pdf

II. Optical disc structures

A. Timeline of optical media

Optical media may serve as carriers for specially-formatted digital audio and video, complex objects such as video games, or data (audiovisual or otherwise) in the form of files or programs. The most basic categorization of an optical disc is by its physical structure. This paper will focus on CDs and DVDs, as they comprise the vast majority of optical discs at Fales.[8] However, Fales and NYU Special Collections at large do also hold MiniDisc, LaserDisc, and Blu-ray media.



Total optical media objects at Fales

CDs consist of a base polycarbonate layer, which is covered with a layer to which data is written. This data layer consists of dye (for write-once discs) or metallic alloys (for rewritable discs), and is covered with a thin lacquer layer. On CDs, the top layer is the only data side, and scratches on this side are far more likely to affect the disc's readability. DVDs have the same base polycarbonate layer, but write data to a metal "reflector" layer (commercial DVDs) or a metallic alloy layer (for rewritable discs). Both sides of a DVD are polycarbonate and are therefore harder to scratch.[9]

Data on optical disc is recorded and read by laser. Data is written to recordable discs in "pits," tiny depressions, and "lands," or the spaces between these depressions. These binary states represent digital zeros and ones. Rewritable discs rely on a binary in the metallic alloy data layer between a reflective, "crystalline" state and a more matte, "amorphous" state.[10]

---

[8] Graph created using MediaLog statistics.
[9] Byers, 3-4.
[10] Byers, 11.

Common storage capacities of CDs and DVDs include:

- CD-R: 700 MB[11]
- CD-RW: 570 MB[12]
- DVD±R (single-layer, one-sided): 4.7 GB[13]
- DVD±R DL (dual-layer, one-sided): 8.54 GB[14]
- DVD±R DS (single-layer, double-sided): 9.4 GB[15]

For the purposes of disc imaging, the differences between the chemical makeups of optical discs are less important than the format and storage specifications detailed below.[16]

1. LaserDisc

LaserDisc, introduced to the public in 1978 by Philips and MCA, was the first commercially-available optical disc. LaserDisc is an analog format, though the analog signal is stored in the same way (through pits and lands) as digital signals are stored on subsequent optical discs. It competed with VHS and eventually DVD in the home entertainment market and, when in good physical condition, offered a superior-quality image to both. However, the LaserDisc, which consists of two single-sided 12-inch discs attached with adhesive, was a large and fragile format that could only hold up to 60 minutes of content, and was not recordable like its competitors.[17] For those reasons, as well as high costs, LaserDisc had limited commercial success. Players were produced until 2009, though the last LaserDisc titles were released in 2000–2001.[18] Online communities of LaserDisc collectors continue to discuss titles, players, and sources for both.[19][20]

A less successful derivative of LaserDisc called CD Video, which encoded analog video on a CD-sized (12-centimeter) disc, was introduced in 1987. It was never codified as a Rainbow Book standard, unlike its digital successor Video CD, also known as VCD, or the White Book disc. CD Video discs are recognizable for their gold color.[21]

2. Compact Disc

The familiar compact disc comes in a wide range of formats, almost all of which conform to one of the series of proprietary manufacturer specifications referred to as the "Rainbow Books," some of which have become official international standards. The Rainbow Books were largely authored by Philips and Sony,

---

[11] Paul Crowley and Dave Kleiman, *CD and DVD Forensics,* Rockland: Syngress, 2006, pg. 16.
[12] Crowley and Kleiman, 16.
[13] "Physical parameters of DVD," *DVD Technical Notes,* Moving Picture Experts Group, 21 July 1996, http://www.mpeg.org/MPEG/DVD/Book_A/Specs.html
[14] "Physical parameters of DVD."
[15] "Disc Size Configuration and Capacity," *Understanding Recordable and Rewritable DVD,* Optical Storage Technology Association, 2004, http://www.osta.org/technology/dvdqa/dvdqa6.htm
[16] For those interested in the technical specifications of these formats, chapter 3 of Fred R. Byers's "Care and Handling of CDs and DVDs" (CLIR/NIST, Oct. 2003) provides a concise summary: https://www.clir.org/wp-content/uploads/sites/6/pub121.pdf
Kevin Bradley's 2006 UNESCO report "Risks Associated with the Use of Recordable CDs and DVDs as Reliable Storage Media in Archival Collections: Strategies and Alternatives" provides a concise summary: http://unesdoc.unesco.org/images/0014/001477/147782e.pdf
[17] "LaserDisc," Dead Media Archive, NYU Department of Media, Culture, and Communication, 8. Dec. 2010, http://cultureandcommunication.org/deadmedia/index.php/Laserdisc
[18] "LaserDisc (1983–2001)," Museum of Obsolete Media, Media Archaeology Lab, n.d., http://obsoletemedia.org/laserdisc/
[19] "/r/LaserDisc" (forum), Reddit, https://www.reddit.com/r/LaserDisc
[20] "LaserDisc Database" (forum), LaserDisc Database, https://forum.lddb.com/
[21] Wikipedia contributors, "CD Video," Wikipedia, The Free Encyclopedia, 31 Jul. 2018, https://en.wikipedia.org/wiki/CD_Video

with occasional other corporate partners.[22] The list below covers some of the most common CD specifications that developed from these standards.

- **Red Book** (1980): Defines audio CDs. The first CD standard and used as the basis for all other Rainbow Book standards. Developed to hold up to 74 minutes of audio (later extended to 80). The first discs to use this standard were **CD-DA** *(Compact Disc Digital Audio)*, or **CD-Audio**, introduced in 1982.[23] Standardized as IEC 60908 in 1987.[24]
- **Yellow Book** (1988): Defines data CDs. Though the Yellow Book was not published until 1988, **CD-ROM** *(Read Only Memory)* discs conforming to the standard were introduced in 1985 to carry software and video games.[25]
    - **Green Book** (1986, subset of Yellow Book[26]): Defines multimedia CDs, such as video games and interactive encyclopedias. **CD-i** discs were released beginning in 1991, but never reached the same level of commercial success as CD-ROMs.[27]
    - **Beige Book** (1992, subset of Yellow Book[28]): Defines CDs specialized for storing high quality images. The **Photo CD**, introduced in 1992, was intended for photo processing labs to scan photos to disc. The image specifications have been reverse engineered and can be converted to modern formats using a number of tools.[29]
    - **White Book** (1993, subset of Yellow Book[30]): Defines video CDs. The **VCD** (*video; also known as Compact Disc Digital Video*) was introduced in 1993 and had some success before being replaced by DVDs beginning in 1998, which featured copy protection that VCD did not have.[31]
    - **Blue Book** (1995, subset of Yellow Book[32]): Defines mixed audio and data CDs, offering a way to store audio (Red Book) content and multimedia (Yellow Book) content on the same disc. Standardized as ISO/IEC 10149 in in 1989.[33] Discs that use this standard are known as **Enhanced CD** or **CD-Extra**. Early versions of CD-Extra, introduced in 1994, were known as "mixed-mode" and stored all the disc's data in a single session, with the data in either the first track or the "pre-gap" before the first track. By 1997, the Blue Book specifications for multisession discs (audio in the first session, data in the second) had taken hold.[34]
- **Orange Book** (1990): Defines CDs capable of audio or data storage. Part II, volume 2 of the book (describing CD-Rs) was standardized as ECMA-394 in 2010.[35] **CD-R** *(recordable; also known as CD-WO, or write-once)* discs were described in Part II of the Orange Book,[36] but the cost of

---

[22] Ronald K. Jurgen, "The CD Family," New York: McGraw-Hill, 1996; digital reprint by Philips Consumer Electronics B.V., 1996, pg. 36. https://www.lscdweb.com/data/downloadables/7/7/the-cd-family-3122-783-0068-1.pdf
[23] "Compact Disc (1983–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/compact-disc/
[24] IEC 60908:1999: Audio recording - Compact disc digital audio system, IEC, 10 Feb. 1999, https://webstore.iec.ch/publication/3885
[25] "CD-ROM (1985–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/cd-rom/
[26] Jurgen, 5.
[27] "CD-i (Compact Disc Interactive) (1991–1998)," *Museum of Obsolete Media*, Media Archaeology Lab, n.d., http://obsoletemedia.org/cd-i/
[28] Jurgen, 5.
[29] For a list of tools, see "Comparison of Photo CD conversion software" within the Photo CD Wikipedia entry: https://en.wikipedia.org/wiki/Photo_CD
[30] Jurgen, 5.
[31] "Video CD (1993–2000s)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/video-cd/
[32] Jurgen, 5.
[33] ISO/IEC 10149:1995: Information technology -- Data interchange on read-only 120 mm optical data disks (CD-ROM), ISO/IEC JTC 1/SC 23, July 1995, https://www.iso.org/standard/25869.html
[34] "Enhanced CD (1994–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/enhanced-cd/
[35] *ECMA-394: Recordable Compact Disc Systems CD-R Multi-Speed,* ECMA, Dec. 2010, https://www.ecma-international.org/publications/standards/Ecma-394.htm
[36] "The Great Books." *Oracle ThinkQuest,* n.d., archived at https://archive.fo/20121209124333/http://library.thinkquest.org/C0112823/greatbooks_cd.htm

recorders to write these discs was prohibitive until around 1995.[37] **CD-RW** *(rewritable; also known as CD-E, or erasable)* discs were described in Part III of the Orange Book, released as a supplement in 1997.[38][39] Users could quickly delete and overwrite files much as they would on other removable media, such as floppy disks and flash drives.[40]

For a list of rarer disc types (such as holographic CDs and business card CD-ROMs) organized by Rainbow Book family, please see the "Compact Disc Rainbow Books" page on the Museum of Obsolete Media website.

3. MiniDisc

MiniDisc was an optical disc format introduced in 1992. Sony intended the MiniDisc to replace the audiocassette, and made both recordable and pre-recorded (usually music albums) discs available. The format enjoyed little commercial success, with the exception of the Japanese market. MiniDiscs could hold up to 80 minutes of audio, and, in later variants, data as well. MiniDisc drives ceased production in 2013 and the discs are incompatible with CD or DVD drives due to their smaller diameter.[41]

4. Digital Versatile Disc

Digital Versatile Discs, also known as Digital Video Discs,[42] were introduced in 1995 in competition with VCD, LaserDisc, and the home videocassette market. Rival manufacturers settled on the DVD standard after years of developing incompatible video discs.[43] Soon after the introduction of DVD, two industry alliances formed: the DVD Forum, which promotes "dash" formats (DVD-R, DVD-RW), and the DVD+RW Alliance, which promotes "plus" formats (DVD+R, DVD+RW) incompatible with the dash formats. There is overlap between the membership of the groups, including Philips, Sony, and Yamaha.[44][45] This overlap may help explain why drives are typically able to read and write to both standards, though some early drives that can read DVD-ROM and DVD-R may not be able to read DVD+R discs.[46]

Many of the below formats have been standardized by the ISO; see the list of publicly available specifications for "dash" formats and the (paid) optical storage devices list for "plus" formats.

- **DVD-R** (1997): A DVD Forum specification for recordable discs to carry data or video.[47]
- **DVD-ROM** (1997): A DVD Forum specification for read-only discs (ROM=Read Only Memory), typically used to carry software and games.[48]
- **DVD-RAM** (1998): A DVD Forum specification for rewritable discs (RAM=Random Access Memory). A competitor of DVD±RW that ended production around 2008.[49]

---

[37] "Compact Disc-Recordable (CD-R) (1992–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/cd-r/
[38] Jurgen, 36.
[39] Margaret Rouse, "CD-RW (compact disc, rewriteable)," *SearchStorage,* TechTarget, Sept. 2005, https://searchstorage.techtarget.com/definition/CD-RW
[40] "Compact Disc-ReWritable (CD-RW) (1997–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/cd-rw/
[41] "MiniDisc (1992–2013)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/minidisc/
[42] "DVD," *Dictionary.com,* Dictionary.com, based on the Random House Unabridged Dictionary (*Random House, Inc*., 2018), https://www.dictionary.com/browse/dvd?s=t?s=t
[43] David Frankel, "DVD timeline," *Variety*, 23 Apr. 2007, https://variety.com/2007/digital/features/dvd-timeline-1117963613/
[44] "DVD Forum Member List," DVD Forum, 2004, http://www.dvdforum.org/about-memberlist.htm
[45] "DVD+RW Alliance Adds Write-Once Capability to DVD+RW Format," DVD+RW Alliance,17 May 2001, http://www.ip.philips.com/data/downloadables/1/5/0/8/pressrelease_dvdplusrw_alliance.pdf
[46] Byers, 8.
[47] "DVD-R (1997–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/dvd-r/
[48] "DVD-ROM (1997–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/dvd-rom/
[49] "DVD-RAM (1998–mid 2000s)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/dvd-ram/

- **DVD-RW** (1999): A DVD Forum specification for rewritable discs to carry data or video.[50]
- **DVD+RW** (2001): A DVD+RW Alliance specification for rewritable discs to carry data or video.[51]
- **DVD+R** (2002): A DVD+RW Alliance specification for recordable discs to carry data or video.[52]

While most DVDs are 12 centimeters in diameter, eight-centimeter MiniDVD±R/W formats emerged beginning in 1997.[53] These discs will require either a DVD drive specifically designed to play both DVDs and MiniDVDs (recognizable by an eight-centimeter indentation in the loading tray), or a plastic adaptor for the disc itself.[54]

5. Blu-ray

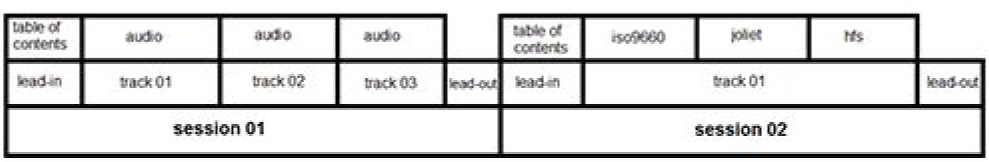
Blu-ray is a successor format to DVD. The major difference is Blu-ray's ability to store more densely-packed information, owing to its use of a "blue-violet" laser to read and write data (as opposed to DVD's red laser, which has a much longer wavelength that does not allow the same level of accuracy in reading and writing).[55]

Formats of Blu-ray include BD-ROM (read-only memory), BD-R (recordable), BD-RW (rewritable computer data storage), and BD-RE (rewritable HDTV storage). Blu-ray discs use the same UDF filesystem found on some CDs and most DVDs, meaning that imaging strategies will be quite similar save the hardware.[56] Luckily, Blu-ray drives are backwards compatible with most CDs and DVDs.[57]

B. Logical structures and filesystems

Unless otherwise cited, the information in section II.C comes from Alex Duryee's excellent "An Introduction to Optical Media Preservation," published in issue 24 of the Code4Lib Journal (16 April 2014).

The logical structure of optical discs has been heavily influenced by the original Red Book CD standard, which houses multiple audio "tracks" in one "session." The same vocabulary is used when discussing subsequent disc storage formats. Today, discs may be comprised of one or more **sessions**, each of which contains one or more **tracks**. **Tracks** store either **audio** or **data** organized within filesystems.



"A diagram of the logical structure of a multi-session CD" (Alex Duryee)[58]

---

50 "DVD-RW (1999–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/dvd-rw/
51 "DVD+RW (2001–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/dvdrw/
52 "DVD+R (2002–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/dvdr/
53 "MiniDVD-R (1997–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/minidvd-r/
54 Jack Gerard, "How to Play a Mini DVD," *It Still Works,* 22 Sept. 2017, https://itstillworks.com/12138690/how-to-play-a-mini-dvd
55 Optical Systems Group, "Document 462-10: Multimedia Archiving: Videotape, Compact Disc (CD), Digital Versatile Disc (DVD), and Blu-ray Disc (BD) Media," *Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range*, National Aeronautics and Space Administration, Feb. 2010, 3-1, http://www.wsmr.army.mil/RCCsite/Documents/462-10_Multimedia%20Archiving%20-%20CD,%20DVD,%20and%20Blu-ray/462-10_Multimedia%20Archiving%20-%20CD,%20DVD,%20and%20Blu-ray.pdf
56 3-1
57 3-3
58 Duryee; reproduced (cropped) under the Creative Commons Attribution 3.0 United States License.

A session functions as a standalone, logical "disc" within the physical disc itself. It is bounded by a "lead-in" area at the beginning (containing a table of contents) and a "lead-out" area at the end. Multisession writing became possible with the publication of the Orange Book in 1990. Typical multisession discs are defined by:

- Orange Book (CD-R/W): Allows users to write to the unwritten part of an already-burned disc.[59]
- Blue Book (CD-Extra/ECD): Allows consumers to play mixed audio and data CDs in regular audio players; the audio player will only recognize the audio (stored in the first session), while multisession drives will access the data in the second session.[60]
- Beige Book (Photo CDs): Rolls of film are added to a disc as they are developed, until the disc is full.[61]

If there is more than one session on the disc, the lead-in of each session will point to the next session on the disc; a multisession-compatible disc drive is required to interpret these pointers and read the disc beyond the first session.[62]

Discs with one session may still be complex, as one session can contain multiple tracks. Tracks are the units within the disc that hold the data itself. One session can contain any of the following:

- Multiple audio tracks (CD-DA)
- One data track with multiple filesystems (data CDs)
- Multiple types of tracks, for example data and audio tracks within the same session (CD-i)
    - Note that these discs are different from multisession discs (CD-Extra/ECD), which also contain audio and data on the same disc, but in different sessions.

1. Data discs

While discs are not partitioned as hard drives are (using a partition table),[63] they may—and often do—contain multiple filesystems that point to largely the same underlying data. The typical base filesystem is **ISO 9660** (standardized by the International Organization for Standardization in 1988),[64] a standard for data storage that all major operating systems can access. In order to provide access to all OS, ISO 9660 is limited in filename length (originally 8 characters) and size (4 GB)[65] as well as directory depth. Layered on top of this base filesystem are OS-specific extensions and filesystems, which point to the same data on the disc while providing enhanced features for users of that OS.

The four extensions most often seen in a small survey of NYU's collection of optical media are:

- **HFS** (1985): an Apple filesystem that supports longer filenames and Mac-specific metadata. Often contains some unique Mac-specific data as well as pointing to the underlying data.
- **Joliet** (1995):[66] a Microsoft extension to ISO 9660 that supports Unicode filenames (allowing for non-Latin scripts), longer filenames, and deeper directories.
- **UDF** (1995): a universal filesystem that supports longer filenames and more file attributes. Often associated with DVD-Video, but also appears on data CDs and DVDs as a "bridge format" along

[59] Jurgen (digital reprint), 21.
[60] Jurgen (digital reprint), 21.
[61] Jurgen (digital reprint), 21.
[62] Jurgen (digital reprint), 21.
[63] Crowley and Kleiman, pg. 33.
[64] *ISO 9660:1988: Information processing — Volume and file structure of CD-ROM for information interchange.* ISO/IEC JTC 1/SC 23, April 1988. https://www.iso.org/obp/ui/#iso:std:iso:9660:ed-1:v1:en
[65] Crowley and Kleiman, pg. 38.
[66] *Joliet Specification: CD-ROM Recording Spec ISO 9660:1988,* Microsoft Corporation, 1995. http://pismotec.com/cfs/jolspec.html

with ISO 9660, Joliet, and HFS+. Written by the Optical Storage Technology Association to replace ISO 9660.[67]

- **HFS+** (1998): an Apple filesystem that supports even longer filenames, and in Unicode. A replacement for HFS.[68]

Other filesystems and extensions that may be present include:

- **High Sierra Group** (1985): a filesystem that manufacturers created to serve as a standard for data storage with the CD-ROM (Yellow Book) specifications. HSG evolved into the international standard ISO 9660 before it came into wide use.[69]
- **Rock Ridge** (1993): a POSIX (UNIX-based) extension to ISO 9660 that supports longer filenames and POSIX-specific metadata.[70]
- **El Torito** (1995): a standard (technically not a filesystem) that makes CDs bootable, most often used with PCs.[71]

2. Audio and video data on discs

Proprietary specifications for audio on CDs (CD-DA) and video on DVDs (DVD-Video specification on top of a UDF filesystem) present considerations that affect processing procedures.

In **CD-DA** (Red Book) discs, audio data is not organized within files and filesystems, but instead encoded as a continuous stream of raw data. This data is indexed and split into tracks by the disc's table of contents. Of the 2352 bytes in a sector, ISO 9660 uses 2048 bytes for data and the rest for identification and error correction, allowing for filesystem-like navigation and consistency. In contrast, CD-DA uses each of these bytes for data, and as such loses significant error correction ability. One online ripping accuracy database provided accuracy ratings for consumer drives that averaged 95% as of 2013; the 2016 numbers show an increase to about 96.8% accuracy, which still allows for an unacceptable level of error for preservation purposes.[72] Because of the way the data is structured, CD-DA discs cannot be imaged, and because of their propensity for error, they must be extracted using software that accounts for inconsistency (typically by reading the data in each disc multiple times).

In **DVD-Video** ("authored") discs, video data is organized in the proprietary DVD-Video specification built atop a UDF filesystem. DVD-Video discs include a VIDEO_TS (Video Title Sets) folder, which stores the following files:

---

[67] *Universal Disk Format Specification, Revision 2.60,* Optical Storage Technology Association, 1994-2005, http://www.osta.org/specs/pdf/udf260.pdf
[68] *Technical Note TN1150, HFS Plus Volume Format*, Apple, 5 Mar. 2004, https://developer.apple.com/library/archive/technotes/tn/tn1150.html
[69] Paul Evan Peters, "CD-ROM Standards: The Fate of Z39.60," *Information Standards Quarterly*, National Information Standards Organization, July 1989, pg. 1-2. https://web.archive.org/web/20161118164014/http://www.niso.org/apps/group_public/download.php/6767/ISQ_vol1_no3_Jul89.pdf
[70] *Rock Ridge Interchange Protocol Version 1, Revision 1.0*, IEEE CD-ROM File Systems Format Working Group, 13 July 1993, https://archive.org/stream/enf_pobox_Rrip/rrip_djvu.txt
[71] *"El Torito" Bootable CD-ROM Format Specification Version 1.0,* Curtis E. Stevens and Stan Merkin, 25 Jan. 1995, https://web.archive.org/web/20110409235517/http://download.intel.com:80/support/motherboards/desktop/sb/specscdrom.pdf
[72] 2016 numbers were calculated by the author using the data from a forum post at https://forum.dbpoweramp.com/showthread.php?37706-CD-DVD-Drive-Accuracy-List-2016; 2013 numbers were calculated by Duryee from a similar 2013 post at http://forum.dbpoweramp.com/showthread.php?30430-CD-DVD-Drive-Accuracy-List-2013.

- **VOB** (Video Object): contain the video and audio streams, as well as subtitles and menus. VOB is the container format; the video is encoded in MPEG-2 in standard definition (PAL or NTSC); and the audio may be one of various codecs (LPCM, AC3, DTS) at a sample rate of 48 kHz.[73]
- **IFO** (Information): contain playback information essential to the DVD-Video functioning as a whole.
- **BUP** (Backup): backups of the IFO files.

The entire disc should be imaged as one file, as these files may not be separated or menu functionality will be lost.[74] However, the VOB files may be concatenated into a single video file for access.

Note that any corresponding AUDIO_TS folders will typically be empty, if not completely absent, as the audio data is present in the VOB files within the DVD-Video specification. AUDIO_TS folders were intended to carry audio information in the **DVD-Audio** format, which was a similar specification for carrying high-quality audio atop a UDF filesystem.[75] It enjoyed less success and was described as "extinct" as of 2007;[76] however, AUDIO_TS folders are still present on many DVD-Video discs. (Some suggest this structure is a legacy of early DVD players that require the presence of an AUDIO_TS folder—even if empty—to play.)[77] [78]

In some cases, audio and video are present on data discs and are not formatted according to the CD-DA or DVD-Video specifications. In these cases, the audiovisual materials are present as files (for example, .mov or .wav) and are treated as files within generic filesystem structures.[79]

3. Writing strategies

The ISO 9660 filesystem and its extensions, Joliet and Rock Ridge, write files contiguously. Many early writing strategies ("track-at-once," "disc-at-once,") are simple enough to avoid most disc writing errors.[80] Commercial discs also rarely encounter file accessibility issues, as they are written "disc-at-once."[81] However, users may have used the packet writing strategy (or "drag-and-drop"), introduced in 1997, to write their later ISO 9660 filesystems and many UDF filesystems.[82] This method, usually employed with rewritable discs, allows the user to delete and interact with files as if the disc were a piece of removable media. However, packet writing can fragment files, or place them in non-contiguous sectors on the disc. Rewritable discs are often non-contiguous at the file level, either, as deleted files are not overwritten until the disc is entirely full.[83] Forensic software will generally be powerful enough to interpret these incongruencies.

---

[73] "Video Data Specifications," *DVD Technical Notes*, Moving Picture Experts Group, 21 July 1996, http://www.mpeg.org/MPEG/DVD/Book_B/Video.html
[74] Lynda Schmitz Fuhrig, "And Action: The Ins and Outs of DVD Video Preservation," *The Bigger Picture* (Smithsonian Institution Archives blog), 3 Sept. 2013, https://siarchives.si.edu/blog/and-action-ins-and-outs-dvd-video-preservation
[75] "Understanding DVD-Audio: A Sonic White Paper," Sonic, n.d., archived 4 March 2012 at https://web.archive.org/web/20120304060434/http://patches.sonic.com/pdf/white-papers/wp_dvd_audio.pdf
[76] Jack Schofield, "No taste for high-quality audio," *The Guardian,* 2 Aug. 2007, https://www.theguardian.com/technology/2007/aug/02/guardianweeklytechnologysection.digitalmusic
[77] Christopher Breen, "Ripped DVDs and the empty AUDIO_TS folder," Macworld, 17 June 2013, https://www.macworld.com/article/2042164/ripped-dvds-and-the-empty-audio-ts-folder.html
[78] Though not sourced, this article suggests the Panasonic DMR-EX79E is an example: "The Empty Audio TS Folder," *Video University,* n.d., https://www.videouniversity.com/articles/the-empty-audio-ts-folder/
[79] The information in the above section II.C came from Alexander Duryee's "An Introduction to Optical Media Preservation," published in issue 24 of the Code4Lib Journal (16 April 2014), unless otherwise cited.
[80] Crowley and Kleiman, 30, 39.
[81] Crowley and Kleiman, 30.
[82] Crowley and Kleiman, 43.
[83] Crowley and Kleiman, 43-51.

C. Optical discs in preservation contexts

In general, the archival community is wary of physical deterioration and obsolescence of both discs and their players when considering discs for long-term storage. Estimates of the physical longevity of optical discs vary; while the Library of Congress simply estimates a lifespan of more than 30 years for all discs,[84] manufacturers provide ranges from 25 to 200 years depending on the disc type.[85] Rewritable discs, due to their chemical makeup, have a shorter lifespan and should not be considered for long-term preservation.[86] Longevity of the discs will also vary based on the manufacturer of the disc, the exact plastic and metal composition of the disc, and the accuracy of the drive (personal or commercial) used to burn the disc.[87] As discs are read by laser, even small changes can render the data unreadable. Common sources of damage include solvents, changes in heat and humidity, writing implements, labels, and even fingerprints.[88]

In considering discs for long-term preservation—whether as a preservation master format, or simply to assess the urgency of reformatting—it is also important to consider the longevity of the disc drives. Interpreting the data on an optical disc is a complex process that relies on processing done by the drive (far more than required by hard drives and floppy disks), meaning that information is extractable only so far as the drive can extract it.[89] Optical disc drive upkeep and support is shaky; as consumer, rather than professional, products, optical discs enjoy neither the robust quality control nor the IT support of a preservation ecosystem such as LTO.[90]

The availability of new drives is also decreasing, as disc drives have fallen out of favor in the commercial market. The most illustrative example of this change is Apple's removal of the optical disc drive in each of its products, a change that started with the MacBook Air in 2008 and became complete by 2013, when disc drives had been removed from all of Apple's new laptops and desktop computers. Apple's motives were aimed at trimming the size of its products—a laptop is much thinner without a disc drive—and likely also calculated the rise of convenient streaming media.[91]

In sum, estimates for longevity of optical discs depend on a network of physically vulnerable media and players aimed at consumers rather than rigorous preservation-level storage.

III. Imaging structure and recommendations

A. Type of capture

There are three ways to capture optical media:

---

[84] "CD-R and DVD-R RW Longevity Research," Library of Congress Preservation Directorate, accessed 1 Nov. 2018, https://www.loc.gov/preservation/scientists/projects/cd-r_dvd-r_rw_longevity.html

[85] Fred R. Byers, "Care and Handling of CDs and DVDs," Council on Library and Information Resources and National Institute of Standards and Technology, Oct. 2003, https://www.clir.org/wp-content/uploads/sites/6/pub121.pdf, pg. 13.

[86] Byers, 13.

[87] Kevin Bradley, "Risks Associated with the Use of Recordable CDs and DVDs as Reliable Storage Media in Archival Collections: Strategies and Alternatives," UNESCO Memory of the World Programme, Oct. 2006, pg. 7-10, http://unesdoc.unesco.org/images/0014/001477/147782e.pdf

[88] "Preserving CDs and DVDs," National Archives of Australia, n.d., http://www.naa.gov.au/information-management/managing-information-and-records/preserving/CDs-and-DVDs.aspx

[89] Crowley and Kleiman, pg. 27-28.

[90] Bradley, pg. ii.

[91] Josh Lowensohn, "Apple's plan to wipe out disc drives is nearly complete," CNET, 26 Oct. 2013, https://www.cnet.com/news/apples-plan-to-wipe-out-disc-drives-is-nearly-complete/

- **Physical (raw)** image capture: A bit-for-bit copy of all the data on the disc (2352 bytes per sector). This type of image will include both the 2048 bytes per sector of "user data"—the files accessed and changed by the user—and the layer of error correction that makes up the rest of each sector. [92] This approach is most useful with complex discs, such as those with multiple sessions (CD-Extra) or multiple tracks (CD-i).
- **Logical (user data)** image capture: A copy of all the user data on the disc (2048 bytes per sector). This type of image will not include the error correction in each sector. Note that DVD sectors are only 2048 bytes, all of which are error-corrected user data; other DVD data is inaccessible with consumer drives.[93] CD sectors are 2352 bytes.
- **Targeted** file extraction: Extraction of the files stored on the disc, without preserving the multiple filesystems and extensions that may also be present. This approach is most effective for discs serving as contemporary carrier mechanisms (for example, if a donor wants to transfer specific files and would otherwise do so over a file transfer protocol).

B. Type of image file

The following disc image file formats were selected for investigation because of their wide support in the tools under consideration and for their likelihood of sustainability. Each file format is either uncompressed by default or has an uncompressed option. For more specifics on these and other factors, this spreadsheet compiled by AVP for Harvard University Libraries provides a detailed breakdown of image formats.

- **ISO Disk Image File Format:** A logical image format that stores only the 2048 bytes of "user data" per sector, which includes filesystems and their extensions. Though the name implies an ISO 9660 filesystem, this format is filesystem-agnostic and does not conform to the ISO (or any) standard.[94]
- **Raw Formats (DD, IMG, BIN):** Physical image formats that store the exact 2352-byte sector sequences on the media; "any image that is solely an uncompressed sector-by-sector copy of stored bits (with no additional headers/footers/structure/metadata)."[95] It is sometimes possible to rename a raw image file with a .iso extension to open it in programs that do not recognize raw images.
    - Raw formats can be standalone files (DD) or navigated with sidecar files. The **BIN/CUE Format** is one example of the latter; the binary file (BIN) stores all 2352 bytes per sector, while a cue sheet (CUE), or a sidecar text file, describes the layout of tracks within the image.[96]
- **EWF-E01 Expert Witness Compression format:** The EWF-E01 format is a physical image that was formerly proprietary but has been reverse-engineered into an open specification.[97]

---

[92] "Track and Sector Modes," IsoBuster documentation, Smart Projects, 2018, https://www.isobuster.com/help/track_and_sector_modes
[93] Crowley and Kleiman, 16.
[94] "ISO Disk Image File Format," *Sustainability of Digital Formats*, Library of Congress, 27 Feb. 2017, https://www.loc.gov/preservation/digital/formats/fdd/fdd000348.shtml
[95] "Disk Image Content Model and Metadata Analysis: ACTIVITY 1: Comparative Format Matrix Analysis" (deliverable for Harvard Library), AVP, 25 Feb. 2016, https://wiki.harvard.edu/confluence/display/digitalpreservation/Disk+Image+Formats, pg. 14.
[96] "Disk Image Content Model and Metadata Analysis," 16.
[97] "Disk Image Format Matrix" (spreadsheet, deliverable for Harvard Library), AVP, 16 Apr. 2016, https://docs.google.com/spreadsheets/d/18t-fU8ZO20Pgio6-QyPYHP3BR07lqL226gg4vRZPl84/edit#gid=1603236156

- **WAV/CUE Format:** A single audio file (WAV) for the entire disc, combined with a cue sheet (CUE), or a sidecar text file describing the layout of tracks within the image.[98] This format is not a physical disc image, but an extraction of the audio content across a disc.

C. Capture tools

1. Software

Three major imaging tools were considered:

- **FTK Imager:** A free, proprietary imaging tool, created by AccessData for Windows computers. Currently used by the NYU archival processing team to image hard drives, floppy disks, and other non-optical born-digital materials. FTK Imager is a standalone tool that integrates with Forensic Toolkit, the (paid) forensic analysis tool also used by NYU to process and redact digital files. The maximum image size is 1024 megabytes, over which FTK Imager will segment the image into multiple files.[99]
- **IsoBuster:** FTK Imager's underlying imaging tool, which also runs in a Windows environment. A standalone tool. Does not segment image files.[100]
- **Guymager:** A free and open-source Linux tool. Often distributed as part of BitCurator, a suite of forensic imaging and reporting tools packaged as a Linux distribution.[101]

All of the tools under consideration support the creation of ISOs and BIN/CUE images, despite some differences in execution. For example, IsoBuster and FTK Imager will create .iso files from logical drives, while BitCurator creates .dd files, which may be interpreted as .iso files if their extension is changed.[102]

After some consideration, the digital processing team chose to prioritize tools that function in Windows environments. This environment is the default for NYU archival processing computers, including all computers that currently image other born-digital media with FTK Imager. Selecting Windows tools will avoid the installation and maintenance of virtual machines or partitions.

2. Hardware

The digital forensics lab at NYU Libraries hosts machines with DVD±R/W drives that have backwards read/write compatibility with CD-R/W and can read CD-ROM. These machines have built-in write blockers or access to removable write blocking hardware, which is best practice for rewritable discs.

Other workstations at Fales and at NYU Libraries typically also have DVD±RW drives, which should be backwards compatible with CD-R/W and CD-ROM. These workstations do not typically include write blockers. It appears to be difficult to write to discs without intensive intervention, but it appears operating systems can be modified to disable disc writing software; forum posts suggest that Windows XP could

---

[98] Alice Prael, "To Image or Copy—The Compact Disc Digital Audio Dilemma," *Saving Digital Stuff* (blog), Yale Born Digital Archives Working Group, 20 Dec. 2016, http://campuspress.yale.edu/borndigital/2016/12/20/to-image-or-copy-the-compact-disc-digital-audio-dilemma/

[99] "Accessioning Files from CDs and DVDs," Getty Institutional Records & Archives, March 2017, 5. http://files.archivists.org/groups/museum/standards/8.%20Workflow%20Documentation/Getty_opticaldiscs_accessioning.pdf

[100] Ibid, 5.

[101] "BitCurator," BitCurator, n.d., https://bitcurator.net/bitcurator/

[102] Note that the image formats available to the user depend on a combination of the disc structure and the tool used will narrow the user's options. For example, IsoBuster will extract only "User Data" (ISO, IMG, or TAO) for DVDs, but gives users the option to extract User Data or "Raw" data (ISO, BIN) for CD±Rs.

not write to discs without user intervention, but the writing software in Windows Explorer in Windows 7, 8, and 10 must be disabled in the registry.[103] Writing ability is important to disc interpretation, as read-only drives will not see any open (unfinished) disc sessions.[104]

Any discs of non-standard size (greater or less than 12 centimeters in diameter) will require a different type of drive. Some esoteric disc formats may be unreadable with modern drives—for example, DVD±R/W drives may not be able to read DVD-RAM discs[105]—but this survey cannot provide a definitive list.

D. Summary of workflows from other institutions

Much of the above research was guided by optical imaging workflows made public by other cultural heritage institutions. A general consensus has converged on a few common paths depending on disc type. Note that some of the below workflows may have been deprecated but not yet replaced online at the time of this report, and should only be taken as a snapshot of the institutional workflow at the time of publication. Also note that many institutions may have alternate back-up or more intensive workflows for discs that fail the initial imaging process.

Data and DVD-Video disc strategies:

- Some institutions create raw images for all discs. The Denver Art Museum[106] and University of California-Los Angeles[107] both currently create DD files using BitCurator's Guymager, while a 2014 white paper from AVP recommends the BIN/CUE format regardless of tool.[108]
- Other institutions create ISO disc images. (Note that it can be unclear whether documentation refers to ISOs as user data images only, or as raw images.) The imaging software chosen for this task varies:
    - IsoBuster at the British Library (2011)[109] and the Getty Research Institute (2017)[110]
    - FTK Imager at Yale (2016)[111] and at the Library of Congress Preservation Reformatting Division[112]
    - Command-line tools at the National Library of the Netherlands (2015)[113] and as one of several tools tested by George Blood Audio Video Film for the Library of Congress (on authored DVDs only, 2014)[114]
    - MediaGrabber (proprietary RipStation software) at the Library of Congress Veterans History Project (2018)**[115]**

---

[103] "sw write blocker for a cd/dvd drive?" (forum thread), April 2010, Forensic Focus Forums, http://www.forensicfocus.com/Forums/viewtopic//printertopic=1/t=5690/postdays=0/postorder=asc/start=0/finish_rel=-10000/
[104] "CD/DVD Inspector FAQ," InfinaDyne, n.d. http://www.infinadyne.com/faqcdrinspect.html
[105] Byers, 28.
[106] Eddy Colloton, telephone conversation, 20 Sept. 2018.
[107] Shira Peltzman, email to author, 24 Oct. 2018.
[108] Duryee.
[109] Angela Dappert, Andrew Jackson, and Akiko Kimura, "Developing a Robust Migration Workflow for Preserving and Curating Hand-held Media," *arXiv preprint arXiv:1309.4932*, 2013, 36 https://arxiv.org/ftp/arxiv/papers/1309/1309.4932.pdf
[110] "Accessioning Files from CDs and DVDs," Getty, 6.
[111] Prael.
[112] Personal observation during summer 2018 internship at American Folklife Center, Library of Congress.
[113] Johan van der Knijff, "Preserving optical media from the command line," *KB Research: Research at the National Library of the Netherlands* (blog), National Library of the Netherlands, 13 Nov. 2015, http://blog.kbresearch.nl/2015/11/13/preserving-optical-media-from-the-command-line/
[114] George Blood Audio Video Film, "Preserving Write-Once DVDs: Producing Disc Images, Extracting Content, and Addressing Flaws and Errors" (deliverable to Library of Congress), April 2014, 38-43. http://www.digitizationguidelines.gov/audio-visual/documents/Preserve_DVDs_BloodReport_20140901.pdf
[115] Personal observation during summer 2018 internship at American Folklife Center, Library of Congress.

  - And unspecified tools at Smithsonian Archives/Smithsonian Channel (as of 2018, according to the comments)[116]
- EWF images appear to be largely the purview of law enforcement, though Princeton's 2015 guidelines described imaging DVDs as EWF files using Guymager (while not imaging CDs).[117]

CD-DA and multimedia discs:
- Some institutions have published adjusted workflows for CD-DA. Both Yale (2016)[118] and the New York Public Library (2017)[119] specify that CD-DA content should be captured in WAV/CUE format (one WAV file per disc), as does Duryee's 2014 paper, uploaded to the AVP website.[120]
- Fewer public workflows exist specifically addressing multimedia discs, but the National Library of the Netherlands describes imaging Blue Book/CD-Extra discs by creating an ISO image with IsoBuster for the data contents and ripping the audio separately using dBpoweramp.[121]

IV. Recommendations

A. Imaging software

Two major factors guided the following recommendations:
- NYU's desire to stay in a Windows environment
- NYU's use of FTK to arrange and describe digital files

A Windows environment will dovetail with current hardware and operating system standards in NYU's special collections. BitCurator, a Linux distribution unsupported by NYU Libraries, would therefore require an institutional shift to Linux or at least to active maintenance virtual machine maintenance; these changes were deemed too disruptive for the workflows in place, and Windows tools were chosen instead.

NYU's use of FTK to perform file-based digital archival processing and description also influenced the following recommendations. As these workflows take place in FTK, it made sense to integrate the imaging of file-based (data) discs into the FTK environment.

With these preferences in mind, the following imaging tools are recommended:

- **FTK Imager** is recommended to image **data discs.** FTK Imager integrates into existing digital processing workflows at NYU, and is used at Yale and the Library of Congress.[122]
- **IsoBuster Pro** is recommended to image **DVD-Video discs.** IsoBuster, unlike FTK Imager, offers users the ability to specify the creation of a single disc image instead of segmented (multiple) disc images, which is crucial for discs containing large video files. In exploring the imaging of more complex discs, the Pro version of IsoBuster (licensing cost: $39.95) might be considered for

---

[116] Schmitz Fuhrig.
[117] "Instructions for Disk Imaging (v. 2.2)," Princeton University Archives, 30 June 2015, 1. https://drive.google.com/file/d/0B6NCn2bEXEBjWkVmSHJUVk9LRVU/view?usp=sharing
[118] Prael.
[119] "AMI Digital Asset Technical Specifications," *ami-specifications* repository, New York Public Library institutional GitHub account, last commit 23 Oct. 2018, https://github.com/nypl/ami-specifications#audio-group-3-optical
[120] Alex Duryee, "An Introduction to Optical Media Preservation," reprinted on AVP's website 18 Apr. 2014, https://www.weareavp.com/an-introduction-to-optical-media-preservation/
[121] van der Knijff, "Imaging CD-Extra / Blue Book discs."
[122] See section III.D.

its support of multisession discs and file extraction ability from all filesystems.[123] IsoBuster has been used by the British Library and the Getty Research Institute.[124]

- **Exact Audio Copy** is recommended for extracting **Audio CDs (CD-DA/Red Book)**. These discs cannot be imaged because of their propensity for error, so must be extracted using software that accounts for inconsistency. Exact Audio Copy is a Windows tool that accomplishes this task in a graphical user interface, and is used by Yale and recommended by AVP for this purpose.[125]

B. Image capture strategy

Considering the tools above, the following imaging file types are recommended to capture the full scope and structure of the discs represented in the collections:

- **Physical (raw) ISO disc images** of CDs, except for CD-DA. Physical images (capturing 2352 bytes per sector) are appropriate for bit-level CD preservation, because CD sectors consist of 2352 bytes—2048 bytes of user data and 304 bytes of other data, including error correction.
- **Logical (user data) ISO disc images** of DVDs. Logical images (capturing 2048 bytes per sector) are appropriate for bit-level DVD preservation, because DVD sectors only consist of the 2048 bytes of logical user data.
- **WAV/CUE files** of CD-DA discs. The single audio file (WAV) per disc retains a 1:1 disc:file relationship and allows bit-level media refreshment while sidestepping processing decisions about filenaming for multiple tracks on a disc with scattered metadata. The CUE sheet retains the layout of tracks within the image and allows the archivist to break down the preservation file into its original component tracks.

NYU's special collections may choose in the future to investigate making logical images of some data CDs. The "long tail" of esoteric and complex CD structures, especially of non-commercial discs, likely represents a small proportion of the overall collection. Optical discs were often burned to serve as a simple data carrier, for which a logical image would be adequate. In addition, physical images retain evidence of deleted files that NYU Libraries specifically ignores in digital processing workflows to protect donor privacy.[126] Finally, logical images would ease storage space demands; a logical image saves 304 bytes per sector, or up to 90.5 MB per disc (13% of the total size of a CD).[127]

However, given that NYU collects unique media on CD, in particular artistic works with complex disc structures, it is most prudent to make physical images as a default matter. Examples of CD formats that cannot be imaged logically include:

- Multisession discs, such as the Blue Book standard (Enhanced Music CD, CD-Extra, or CD-Plus).
    - Note that multisession writing (also known as "drag and drop" writing) was accessible to consumers and therefore may appear even in noncommercial discs.
- Multitrack discs, such as the Green Book (CD-i) standard or some Yellow Book CD-ROMs.

C. Image metadata and packaging

When uploading into NYU's digital storage, the ISO or WAV/CUE files should be treated as the digital object. Other sidecar files, such as a .md5 file, should be treated as metadata.

---

[123] "IsoBuster License models," *IsoBuster*, Smart Projects, 2018, https://www.isobuster.com/license-models.php
[124] See section III.D.
[125] See section III.D.
[126] Specifically, the digital archivist has set up a Forensic ToolKit ingest profile with settings that ignore deleted files.
[127] At a storage capacity of 700 MB/~300,000 sectors.

Upload into NYU's digital storage presents an opportunity to generate automated technical metadata for storage alongside the disc images. Currently, no comprehensive digital preservation management system is implemented at NYU; however, in transferring images to storage, NYU can run command-line reporting tools, and should consider fiwalk in particular as a descriptive tool for disc images. Disc images will be much more fully described after full processing, so these packages will be enhanced descriptively.

Tests with Archivematica, an open-source digital preservation system, have resulted in Archival Information Packages with METS/XML metadata describing the image file; logs for virus scans, file format identification, filename cleanup, and extraction; directory trees; and the extracted files themselves. NYU may wish to consider implementing this tool or another more integrated digital preservation tool.

V. Conclusion

A. Summary of recommendations

The following roadmap is recommended:

- **For DVDs**: create a user data (logical) **ISO disc image** using **IsoBuster Pro.**
- **For CDs**: create a raw (physical) **ISO disc image** using **FTK Imager.**
    - For any CDs that appear to comprise complex and mixed types of data (for example, a music CD that also holds a music video), consult with the archivist.
- **For audio discs** (CD-DA): create a single WAV file with **WAV/CUE** using **Exact Audio Copy.**
- **For commercial discs**: do not image unless deemed to be rare and integral to the collection.

These choices will minimize training and imaging time by taking place entirely within graphical user interfaces in a familiar and already-in-use Windows environment, and by ensuring bit-level preservation for each type of optical disc. By ensuring a minimum amount of technical training and curatorial decisions, this workflow is accessible to student workers and those without much digital preservation experience.

NYU may wish to further consider two potentially related opportunities to streamline the imaging process:

- **Disc robots:** Fales alone holds enough discs—7562 non-commercial optical discs and 1123 commercial in one non-exhaustive count—to justify buying a disc robot to automate the imaging process without human supervision.[128] Robot brands include the RipStation, which has been integrated into workflows at the Library of Congress,[129] the University of Michigan, and New York Public Radio;[130] and the Nimbie, which has been used at the British Library[131] and the National Library of the Netherlands.[132] The complete RipStation series is currently priced at $4595[133] and the Nimbie at $574.[134] Both are packaged with a limited slate of imaging tools and do not offer

[128] These numbers draw from the MediaLog, which represents only born-digital materials accessioned and cataloged since 2014, and the 2018 Special Collections Control Project report by Craig Savino. The MediaLog shows that optical disc counts for Fales are typically approximately 50% of the counts across all three special collections.
[129] George Blood Audio Video Film, 12.
[130] John Passmore and Trevor Owens, "Getting Public Radio's Legacy Off Ageing Rewritable CDs: An Interview with WNYC's John Passmore," *The Signal* (blog), Library of Congress, 21 Feb. 2014, https://blogs.loc.gov/thesignal/2014/02/getting-public-radios-legacy-off-ageing-rewritable-cds-an-interview-with-wnycs-john-passmore/
[131] Dappert, Jackson, and Kimura.
[132] van der Knijff, "Image and Rip Optical Media Like A Boss."
[133] "RipStation 7000 DataGrabber," MF Digital, n.d. http://www.mfdigital.com/data_ripping.html
[134] "Nimbie USB Plus Disc Autoloader NB21 Series," Acronova Technology, Inc., 2018, http://store.acronova.com/nimbie-usb-plus-bd-cd-dvd-autoloader-nb21.html

much customizability, but they could enormously speed up imaging efforts throughout NYU's special collections.

- **A command line workflow:** Use of the command line allows for powerful automation and customization inaccessible to Windows environments, and the BitCurator environment is packaged with tools specific to forensic disc imaging. The command line also allows further control of a disc imaging robot; the National Library of the Netherlands has combined a Nimbie and a set of command line tools to streamline its optical media preservation.[135] As the scripts are open source, it could be quite possible for NYU to adapt them to a local setup and address its backlog with speed.

[135] van der Knijff, "Image and Rip Optical Media Like A Boss."

Appendix

A. Proposed imaging workflows

For imaging and copying workflows, see this workflow document.

B. Proposed package structures:

The Submission Information Package should consist of:

- The disc image or WAV file
- The corresponding CUE sheet
- The corresponding MD5 file

Upon upload, the command-line tool **fiwalk** should be run on the object in the SIP. After processing, the package for long-term storage should contain:

- The disc image or WAV file
  - The fiwalk report
  - The corresponding CUE sheet
  - The corresponding MD5 file
- The extracted files
  - Technical and descriptive metadata describing these files (according to existing NYU Libraries procedure)

Access may be provided with the disc images themselves. These images cannot be accessed remotely using Fales's dissemination service (currently Box). However, once images are processed and the files extracted, Fales may choose to serve the extracted files instead. Until then, the package for access should contain:

- The disc image.

C. Proposed researcher access workflow

- For providing researcher access to copied CD-DA, serve the WAV file as you would another audiovisual file, or break down the WAV into its original tracks by following this workflow document.
- For providing researcher access to imaged DVD-Video, see this workflow document.
- For providing researcher access to data disc images, serve the disc image mounted in FTK Imager.

Processing procedures—that is, extracting and organizing files wrapped in a disc image—are outside of the scope of this document, but some technical suggestions are outlined below.

- Data discs: Extracting files from the disc image.
  - It is policy at NYU Libraries to extract files from disc images during digital processing. It is these extracted files that are monitored for long-term fixity. Currently, this action is performed manually in Forensic ToolKit, but may be streamlined with digital preservation systems; for instance, Archivematica automatically extracts files from ISO disc images in the process of creating a Dissemination Information Package.
- DVD-Video: Extracting files and transforming .VOB files into a single access video file.

- To produce a single access video file, the VOB files may be extracted from the disc image, concatenated, transcoded, and rewrapped into a more widely-supported container format.[136] Once files are extracted, transformation may be accomplished with the command line, potentially upon upload to NYU's digital preservation storage. A sample FFmpeg command to create a concatenated H.264/MP4 file is below (input_files are the .VOB files):[137]
```
ffmpeg -i concat:input_file_1\|input_file_2\|input_file_3 -c:v libx264 -c:a aac output_file.mp4
```
- CD-DA: Splitting a single WAV file into original audio tracks.
  - If a CUE file is present, a disc-length WAV file may be split into the disc's original tracks with the command line tool shntool (%n=track number, %t=track name, drawn from the cue sheet):[138]
```
shnsplit -f file.cue -t %n-%t -o wav file.wav
```
    - If the tracks were not named by the creator at the time the disc was burned (typical of consumer discs), the tracks will be extracted with generic filenames ("Track 01").

D. Physical handling guidelines

Some common signs of degradation:

- Visible scratches.
- Bending of the disc.
- "Disc rot," a catchall term for chemical deterioration of the disc that may appear as holes, white dots, or brownish discoloration. Its prevalence depends on the exact chemical makeup of the disc and varies between manufacturers and time periods.[139]

If you observe any of these conditions, prioritize these discs for imaging. Though imaging may not be completely successful, there is often still enough accessible data for a partial reading.

When handling discs, follow these guidelines:[140]

- Note that CDs are particularly vulnerable to scratches on the top of the disc (where labels are usually placed). DVDs are equally resistant to scratches on both sides. In both cases, only touch the edges and the center hole of the disc; do not touch flat surfaces.
- **Do not affix any labels.**
- Mark disc in center clear clamping ring **only**. Use a felt-tip, water-based marker without solvents, as opposed to alcohol-based (Sharpies are alcohol-based).
- To clean, use isopropyl alcohol and a clean soft cloth; wipe in a straight line from the center of the disc to the edge, not in a circular direction. Discs do not need to be cleaned regularly, but should be cleaned at the time of imaging.
- Store discs upright (not stacked) in dedicated cases.
- Like any other archival material, optical discs are sensitive to heat and should be kept in cool, dark climate-controlled storage; CLIR recommends 18 degrees Celsius and 40% relative humidity.

---

[136] Lynda Schmitz Fuhrig.
[137] "Convert DVD to H.264," *ffmprovisr* project site, AMIA Open Source GitHub account, 2018, https://amiaopensource.github.io/ffmprovisr/#dvd_to_file
[138] Jason Jordan, "shnsplit(1)" man page, March 2009, https://manpages.debian.org/testing/shntool/shnsplit.1.en.html
[139] Ernie Smith, "The Hidden Phenomenon That Could Ruin Your Old Discs," *Motherboard,* 6 Feb. 2017, https://motherboard.vice.com/en_us/article/mg9pdv/the-hidden-phenomenon-that-could-ruin-your-old-discs
[140] Guidelines are adapted from Byers, vi.

B. Questions for further exploration

- Some complex discs will have to be imaged on a case-by-case basis and will not be covered in the workflows; for example, any CD-Extra discs, with data and audio, will have to have the data imaged and the audio ripped. How to link the two files technically (in repositories and storage) and experientially (for access)?
- What to do with formats, such as MiniDisc and LaserDisc, that require special equipment and players? Such unusual formats should be imaged in tandem and in consultation with the Barbara Goldsmith Conservation Lab in NYU Libraries.
- If commercial discs are imaged because of rarity or relevance, will the contents be copy protected by the Content Scramble System? As DVDs become obsolete, will imaging commercial DVDs become fair use under Section 108 of the Copyright Act?
- Will Blu-rays become a significant part of the special collections at NYU? Blu-rays (BD-ROM, BD-R, BD-RW, and BD-RE) will require Blu-ray drives, most of which will be backwards compatible with CD/DVD±R/W;[141] the workflows described here can likely be adapted with some straightforwardness.

[141] A consumer-oriented (not archival) comparison of external Blu-ray drives is available at https://thewirecutter.com/reviews/the-best-external-blu-ray-drive/

Sources cited and consulted

All Internet sources last accessed between October and November 2018.

General sources

"BitCurator." BitCurator, n.d. https://bitcurator.net/bitcurator/

Bradley, Kevin (National Library of Australia, Canberra). "Risks Associated with the Use of Recordable CDs and DVDs as Reliable Storage Media in Archival Collections: Strategies and Alternatives." UNESCO Memory of the World Programme, Oct. 2006. http://unesdoc.unesco.org/images/0014/001477/147782e.pdf

Byers, Fred R. "Care and Handling of CDs and DVDs." Council on Library and Information Resources and National Institute of Standards and Technology, Oct. 2003. https://www.clir.org/wp-content/uploads/sites/6/pub121.pdf

"CD/DVD Inspector FAQ." InfinaDyne, n.d. http://www.infinadyne.com/faqcdrinspect.html

"CD-R and DVD-R RW Longevity Research." Library of Congress Preservation Directorate, n.d. https://www.loc.gov/preservation/scientists/projects/cd-r_dvd-r_rw_longevity.html

Crowley, Paul, and Dave Kleiman. *CD and DVD Forensics.* Rockland: Syngress, 2006.

"Disc Size Configuration and Capacity." *Understanding Recordable and Rewritable DVD.* Optical Storage Technology Association, 2004. http://www.osta.org/technology/dvdqa/dvdqa6.htm

"Disk Image Content Model and Metadata Analysis: ACTIVITY 1: Comparative Format Matrix Analysis" (deliverable for Harvard Library). AVP, 25 Feb. 2016. https://wiki.harvard.edu/confluence/display/digitalpreservation/Disk+Image+Formats

"Disk Image Format Matrix" (spreadsheet, deliverable for Harvard Library). AVP, 16 Apr. 2016. https://docs.google.com/spreadsheets/d/18t-fU8ZO20Pgio6-QyPYHP3BR07lqL226gg4vRZPl84/edit#gid=1603236156

Duryee, Alexander. "An Introduction to Optical Media Preservation." *Code4Lib Journal* issue 24, 16 April 2014. https://journal.code4lib.org/articles/9581 (Reprinted on AVP's website 18 Apr. 2014: https://www.weareavp.com/an-introduction-to-optical-media-preservation/)

"Expert Witness Disk Image Format (EWF) Family." *Sustainability of Digital Formats.* Library of Congress, 27 Feb. 2017. https://www.loc.gov/preservation/digital/formats/fdd/fdd000406.shtml

George Blood Audio Video Film, "Preserving Write-Once DVDs: Producing Disc Images, Extracting Content, and Addressing Flaws and Errors" (deliverable to Library of Congress), April 2014, http://www.digitizationguidelines.gov/audio-visual/documents/Preserve_DVDs_BloodReport_20140901.pdf

"ISO Disk Image File Format." *Sustainability of Digital Formats.* Library of Congress, 27 Feb. 2017. https://www.loc.gov/preservation/digital/formats/fdd/fdd000348.shtml

Jurgen, Ronald K. “The CD Family.” *Digital Consumer Electronics Handbook.* New York: McGraw-Hill, 1996. reprinted by Philips Consumer Electronics B.V., 1996. https://www.lscdweb.com/data/downloadables/7/7/the-cd-family-3122-783-0068-1.pdf

“Preserving CDs and DVDs.” National Archives of Australia, n.d. http://www.naa.gov.au/information-management/managing-information-and-records/preserving/CDs-and-DVDs.aspx

“Track and Sector Modes.” IsoBuster documentation. Smart Projects, 2018. https://www.isobuster.com/help/track_and_sector_modes

“Video Data Specifications.” *DVD Technical Notes*, Moving Picture Experts Group. 21 July 1996. http://www.mpeg.org/MPEG/DVD/Book_B/Video.html

Filesystem specifications

For a readable, detailed technical overview of optical disc filesystems and logical structures, see chapter 2 of Paul Crowley and Dave Kleiman’s *CD and DVD Forensics* (Rockland: Syngress, 2006).

“El Torito” Bootable CD-ROM Format Specification Version 1.0. Curtis E. Stevens and Stan Merkin, 25 Jan. 1995. https://web.archive.org/web/20110409235517/ http://download.intel.com:80/support/motherboards/desktop/sb/specscdrom.pdf

ISO 9660:1988(en): Information processing — Volume and file structure of CD-ROM for information interchange. ISO/IEC JTC 1/SC 23. April 1988. https://www.iso.org/obp/ui/#iso:std:iso:9660:ed-1:v1:en

Joliet Specification: CD-ROM Recording Spec ISO 9660:1988, Microsoft Corporation, 1995. http://pismotec.com/cfs/jolspec.html

Peters, Paul Evan. “CD-ROM Standards: The Fate of Z39.60.” *Information Standards Quarterly (formerly Voice of Z39).* National Information Standards Organization (NISO), July 1989. 1-3. https://web.archive.org/web/20161118164014/http://www.niso.org/apps/group_public/download.php/6767/ISQ_vol1_no3_Jul89.pdf

“Physical parameters of DVD.” *DVD Technical Notes*, Moving Picture Experts Group. 21 July 1996. http://www.mpeg.org/MPEG/DVD/Book_A/Specs.html

Rock Ridge Interchange Protocol Version 1, Revision 1.0. IEEE CD-ROM File Systems Format Working Group. 13 July 1993. https://archive.org/stream/enf_pobox_Rrip/rrip_djvu.txt

Technical Note TN1150, HFS Plus Volume Format. Apple, 5 Mar. 2004. https://developer.apple.com/library/archive/technotes/tn/tn1150.html

“Understanding DVD-Audio: A Sonic White Paper.” Sonic, n.d. Archived 4 March 2012 at https://web.archive.org/web/20120304060434/http://patches.sonic.com/pdf/white-papers/wp_dvd_audio.pdf

Universal Disk Format Specification, Revision 2.60. Optical Storage Technology Association, 1994-2005. http://www.osta.org/specs/pdf/udf260.pdf

Optical disc types

"CD-i (Compact Disc Interactive) (1991–1998)," Museum of Obsolete Media, Media Archaeology Lab, n.d., http://obsoletemedia.org/cd-i/

"CD-ROM (1985–)," Museum of Obsolete Media, Media Archaeology Lab, n.d., http://obsoletemedia.org/cd-rom/

"Compact Disc (1983–)." Museum of Obsolete Media. Media Archaeology Lab, n.d. http://obsoletemedia.org/compact-disc/

"Compact Disc Rainbow Books." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/audio/compact-disc-rainbow-books/

"Compact Disc-Recordable (CD-R) (1992–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/cd-r/

"Compact Disc-ReWritable (CD-RW) (1997–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/cd-rw/

"DVD." *Dictionary.com.* Dictionary.com, based on the Random House Unabridged Dictionary (*Random House, Inc*., 2018). https://www.dictionary.com/browse/dvd?s=t?s=t

"DVD-R (1997–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/dvd-r/

"DVD+R (2002–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/dvdr/

"DVD-RAM (1998–mid 2000s)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/dvd-ram/

"DVD-ROM (1997–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/dvd-rom/

"DVD-RW (1999–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/dvd-rw/

"DVD+RW (2001–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/dvdrw/

"DVD+RW Alliance Adds Write-Once Capability to DVD+RW Format," DVD+RW Alliance,17 May 2001, http://www.ip.philips.com/data/downloadables/1/5/0/8/pressrelease_dvdplusrw_alliance.pdf

"DVD Forum Member List," DVD Forum, 2004, http://www.dvdforum.org/about-memberlist.htm

ECMA-394: Recordable Compact Disc Systems CD-R Multi-Speed. ECMA, Dec. 2010. https://www.ecma-international.org/publications/standards/Ecma-394.htm

"Enhanced CD (1994–)." *Museum of Obsolete Media*. Media Archaeology Lab, n.d. http://obsoletemedia.org/enhanced-cd/

"The Great Books." *Oracle ThinkQuest,* n.d., archived at https://archive.fo/20121209124333/http://library.thinkquest.org/C0112823/greatbooks_cd.htm

IEC 60908:1999: Audio recording - Compact disc digital audio system. IEC, 10 Feb. 1999. https://webstore.iec.ch/publication/3885

International Organization for Standardization. "Publicly available standards." *International Organization for Standardization*, n.d. https://standards.iso.org/ittf/PubliclyAvailableStandards/index.html *(N.B.: List of DVD-R standards)*

International Organization for Standardization. "Standards catalogue: 35.220.30 - Optical storage devices. Including CD and magneto-optical devices (MO)." *International Organization for Standardization*, n.d. https://www.iso.org/ics/35.220.30/x/ *(N.B.: List of DVD+R standards)*

ISO/IEC 10149:1995: Information technology -- Data interchange on read-only 120 mm optical data disks (CD-ROM). ISO/IEC JTC 1/SC 23, July 1995. https://www.iso.org/standard/25869.html

"LaserDisc." *Dead Media Archive*. NYU Department of Media, Culture, and Communication, 8. Dec. 2010. http://cultureandcommunication.org/deadmedia/index.php/Laserdisc

"LaserDisc (1983–2001)." *Museum of Obsolete Media.* Media Archaeology Lab, n.d. http://obsoletemedia.org/laserdisc/

"MiniDisc (1992–2013)," Museum of Obsolete Media, Media Archaeology Lab, n.d., http://obsoletemedia.org/minidisc/

"MiniDVD-R (1997–)," *Museum of Obsolete Media,* Media Archaeology Lab, n.d., http://obsoletemedia.org/minidvd-r/

Optical Systems Group, "Document 462-10: Multimedia Archiving: Videotape, Compact Disc (CD), Digital Versatile Disc (DVD), and Blu-ray Disc (BD) Media," Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, National Aeronautics and Space Administration, Feb. 2010, 3-1, http://www.wsmr.army.mil/RCCsite/Documents/462-10_Multimedia%20Archiving%20-%20CD,%20DVD,%20and%20Blu-ray/462-10_Multimedia%20Archiving%20-%20CD,%20DVD,%20and%20Blu-ray.pdf

Rouse, Margaret. "CD-RW (compact disc, rewriteable)." *SearchStorage.* TechTarget, Sept. 2005. https://searchstorage.techtarget.com/definition/CD-RW

"Video CD (1993–2000s)." *Museum of Obsolete Media.* Media Archaeology Lab, n.d., http://obsoletemedia.org/video-cd/

Wikipedia contributors. "CD Video." *Wikipedia, The Free Encyclopedia*. 31 Jul. 2018. https://en.wikipedia.org/wiki/CD_Video

Wikipedia contributors. "Photo CD." *Wikipedia, The Free Encyclopedia.* https://en.wikipedia.org/w/index.php?title=Photo_CD&oldid=861191071

Imaging strategies and workflows

"Accessioning Files from CDs and DVDs." Getty Institutional Records & Archives. March 2017. http://files.archivists.org/groups/museum/standards/8.%20Workflow%20Documentation/Getty_opticaldiscs_accessioning.pdf

"AMI Digital Asset Technical Specifications," *ami-specifications* repository, New York Public Library institutional GitHub account. Last commit 23 Oct. 2018. https://github.com/nypl/ami-specifications#audio-group-3-optical

Colloton, Eddy. "Denver Art Museum Disk Imaging Workflow." 14 Dec. 2017. https://docs.google.com/document/d/1Z4LP8shWtdRYTkZrq1Q7nPomPWzJeoV369WC87kj0rM/

Colloton, Eddy. Telephone conversation, 20 Sept. 2018.

"Convert DVD to H.264," ffmprovisr project site, AMIA Open Source GitHub account, 2018, https://amiaopensource.github.io/ffmprovisr/#dvd_to_file

Dappert, Angela, Andrew Jackson, and Akiko Kimura. "Developing a Robust Migration Workflow for Preserving and Curating Hand-held Media." *arXiv preprint arXiv:1309.4932*, 2013. https://arxiv.org/ftp/arxiv/papers/1309/1309.4932.pdf

"Instructions for Disk Imaging (v. 2.2)," Princeton University Archives, 30 June 2015, 1. https://drive.google.com/file/d/0B6NCn2bEXEBjWkVmSHJUVk9LRVU/view?usp=sharing

Jordan, Jason. "shnsplit(1)" (man page). March 2009. https://manpages.debian.org/testing/shntool/shnsplit.1.en.html

Passmore, John, and Trevor Owens. "Getting Public Radio's Legacy Off Ageing Rewritable CDs: An Interview with WNYC's John Passmore." *The Signal* (blog). Library of Congress, 21 Feb. 2014, https://blogs.loc.gov/thesignal/2014/02/getting-public-radios-legacy-off-ageing-rewritable-cds-an-interview-with-wnycs-john-passmore/

Peltzman, Shira. Email to author, 24 Oct. 2018.

Prael, Alice. "To Image or Copy—The Compact Disc Digital Audio Dilemma," *Saving Digital Stuff* (blog). Yale Born Digital Archives Working Group, 20 Dec. 2016. http://campuspress.yale.edu/borndigital/2016/12/20/to-image-or-copy-the-compact-disc-digital-audio-dilemma/

Schmitz Fuhrig, Lynda. "And Action: The Ins and Outs of DVD Video Preservation." *The Bigger Picture* (blog). Smithsonian Institution Archives, 3 Sept. 2013. https://siarchives.si.edu/blog/and-action-ins-and-outs-dvd-video-preservation

van der Knijff, Johan. "Image and Rip Optical Media Like A Boss." *Open Preservation Foundation* (blog). Open Preservation Foundation, 19 June 2017. http://openpreservation.org/blog/2017/06/19/image-and-rip-optical-media-like-a-boss/

van der Knijff, Johan. "Imaging CD-Extra / Blue Book discs." *Open Preservation Foundation* (blog). Open Preservation Foundation, 25 Apr. 2017. http://openpreservation.org/blog/2017/04/25/imaging-cd-extra-blue-book-discs/

van der Knijff, Johan. “Preserving optical media from the command line.” *KB Research: Research at the National Library of the Netherlands* (blog). National Library of the Netherlands, 13 Nov. 2015. http://blog.kbresearch.nl/2015/11/13/preserving-optical-media-from-the-command-line/

Popular publications, forums, and commercial blogs

Breen, Christopher. “Ripped DVDs and the empty AUDIO_TS folder.” *Macworld*, 17 June 2013. https://www.macworld.com/article/2042164/ripped-dvds-and-the-empty-audio-ts-folder.html

“The Empty Audio TS Folder.” *Video University*, n.d. https://www.videouniversity.com/articles/the-empty-audio-ts-folder/

Frankel, David. “DVD timeline.” *Variety*, 23 Apr. 2007. https://variety.com/2007/digital/features/dvd-timeline-1117963613/

Gerard, Jack. “How to Play a Mini DVD.” *It Still Works,* 22. Sept. 2017. https://itstillworks.com/12138690/how-to-play-a-mini-dvd

“IsoBuster License models.” *IsoBuster.* Smart Projects, 2018. https://www.isobuster.com/license-models.php

“LaserDisc Database” (forum). *LaserDisc Database*, n.d. https://forum.lddb.com/

Lowensohn, Josh. “Apple's plan to wipe out disc drives is nearly complete.” *CNET*, 26 Oct. 2013. https://www.cnet.com/news/apples-plan-to-wipe-out-disc-drives-is-nearly-complete/

/r/LaserDisc (forum). *Reddit,* n.d. https://www.reddit.com/r/LaserDisc/

“Nimbie USB Plus Disc Autoloader NB21 Series.” *Acronova Online Store*. Acronova Technology, Inc., 2018. http://store.acronova.com/nimbie-usb-plus-bd-cd-dvd-autoloader-nb21.html

“RipStation 7000 DataGrabber.” *MF Digital.* Formats Unlimited, Inc., n.d. http://www.mfdigital.com/data_ripping.html

Schofield, Jack. “No taste for high-quality audio.” *The Guardian*, 2 Aug. 2007. https://www.theguardian.com/technology/2007/aug/02/guardianweeklytechnologysection.digitalmusic

Smith, Ernie. “The Hidden Phenomenon That Could Ruin Your Old Discs.” Motherboard, 6 Feb. 2017. https://motherboard.vice.com/en_us/article/mg9pdv/the-hidden-phenomenon-that-could-ruin-your-old-discs

“sw write blocker for a cd/dvd drive?” (forum thread). Forensic Focus Forums. April 2010. http://www.forensicfocus.com/Forums/viewtopic//printertopic=1/t=5690/postdays=0/postorder=asc/start=0/finish_rel=-10000/