PRESERVING DIGITAL PUBLIC TELEVISION

SURVEY OF DIGITAL FORMATTING PRACTICES IN PUBLIC TELEVISION PROGRAM PRODUCTION

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This report outlines the currently used digital video formats in the Public Television (PTV) production life cycle.   It is prepared as part of the activities of the project *PRESERVING DIGITAL PUBLIC TELEVISION*, funded by the Library of Congress as part of their NDIIPP Program[1]. The goal of the project is to design a long-term preservation repository where digital public television program materials can be stored and retrieved, despite the rapidly-changing environment of video production, editing and distribution, and the ongoing changes in digital storage design.

This paper offers a discussion of digital video file formats and related technical practices currently used in public television, in order to provide background for making decisions about how best to store these materials long-term. We hope that it will point towards developing some useful technical standards and best practices in the field, where very few currently exist.

PRODUCTION PROCEDURES

In this discussion, we will look at three main phases in which video content is prepared for broadcast:

- *Acquisition/Recording of Source Material*
- *Production/Post-production*
- *Distribution*.

As a program moves from phase to phase, it is handled by a number of individuals, each of whom is responsible for one or another aspect of the production process. At the same time, each is likely to have little knowledge of those activities outside their immediate tasks or phase in the production.

But because key elements necessary for successful digital preservation occur in *every* phase, an overview is necessary to keep the whole picture in mind and make sure nothing is missed.   Our discussion here is intended to assist in identifying these elements, so that appropriate preservation practices and standards can be consciously applied to the entire production chain.

Overview of Current Production Formats: (*Reference figures 1 & 2.)*

While some acquisition of video is still being done on analog videotape as well as 16mm and 35mm film, the post-production process is almost entirely done in the digital domain. As outlined below, it involves a wide number of different digital formats plus digitizing[2], ingesting[3], transcoding[4] and similar procedures which each contribute to the complexity of the final outputs. Understanding these procedures is critical to the success of setting standards

Source Materials -- Original and archival footage is delivered to the production unit for use in

[1] http://digitalpreservation.gov
[2] see glossary "digitize"
[3] see glossary "ingest"
[4] see glossary "transcode"

program production. This footage can be any number of digital formats. Since source material can also come from the Archives, this may include analog material, but for the purpose of this discussion, comments will be restricted to digital formats only. At the time this paper was written the physical formats most commonly used are (*see definitions below*):

- DV
- DVCAM
- DVCPRO
- Digital Betacam
- D3
- D5

Newer formats for standard definition:

- XDCAM

For HDTV it's:

- DVCPRO HD
- HDCAM
- HDV
- XDCAM HD

Editing and Rough Cuts -- The source material is screened/logged and the editorially relevant material is digitized to an offline edit workstation. While the source material may be digital videotape, it is not always a transfer or ingest process to place it on digital workstation – sometimes it may involve a re-digitizing process.

- Some workstations use the analog composite output of the digital tape machine for the source to digitize the material for the edit.
- Some workstations will use the Serial Digital Interface (SDI) - (SMPTE 259M) output of the digital tape machine. SDI converts the compressed digital essence from the digital videotape to an uncompressed digital bit stream.
- In both cases, a digital file is created on the workstation.

Depending on the workstation manufacturer, type and settings, a number of different digital file formats could be created. At WGBH, the digital file type usually created during the offline process, is

- An Avid Meridien JFIF compressed codec[5] 15:1, or
- A Final Cut Pro QuickTime file with the DV or DVCPRO codec.

Instead of SDI, DV and DVCAM source may be transferred via IEEE1394 (Firewire) to a QuickTime wrapped DV file. Therefore, at this stage, the digitized material is most likely at a *heavily compressed state* suitable only for an offline edit.

During the offline post-production process, rough-cut copies may be made by "printing" (output) the digital file back to videotape. These copies can be both analog (VHS) and digital (Digital Betacam) and are sent for screening, promotional editing and for post-production to Internet web sites. At each of these locations, the materials may be digitized again.

The final rough-cut program is sent as an edit decision list to the online edit workstation where the original source footage will be digitized again, this time with a *higher resolution*.

- Most projects using Avid workstations, at WGBH, use Avid Meridien JFIF compressed codec

[5] see glossary "codec"

2:1.

- In many cases, the audio tracks from the rough-cut will be sent to the online workstation as digital files. These audio tracks are sent as an Open Media Framework Interchange (OMFI) file.

Final Production -- Program materials are maintained as digital files during the editing phase of production.

The program master will then be printed back to videotape to be sent to the audio post suite for the final audio mix. Again, the audio tracks will be transferred via an OMFI file. Sometimes a copy of the program master videotape is used in the audio post suite to mix the final audio, and then the audio is sent back to the online suite for audio layback to the program master. Again, the audio is transferred via OMFI.

- The finished program master is printed to Digital Betacam videotape and sent to technical evaluation.
- Some program masters are further packaged in a digital linear online edit to add underwriter credits or to create distribution versions (Pledge, edited for content, etc.) and then are sent to technical evaluation.
- After evaluation, the 'master' tapes are shipped to the Public Broadcasting Service (PBS.)

High Definition – High-def (HD) editing uses the high definition source (HDCAM) in an online suite.

- At WGBH, the workstation is an Avid DS Nitris which can use a number of different internal codecs, including 10-bit uncompressed HD, Avid DNxHD as well as DV25, DV50, IMX (MPEG2 4:2:2, 50mps, I-frame only) and uncompressed Meridien JFIF standard definition (SD) formats.
- The finished master program is printed to standard definition videotape for use in the audio mix. Again the audio tracks are transferred to the post audio suite via OMFI. The final audio mix is transferred back as OMFI to the high definition suite for lay back.
- The finished program master is printed to HDCAM videotape for transfer to PBS.

16mm and 35mm -- Film is still used in acquisition, but the post-production work is done in video.

- The film is transferred to Digital Betacam for standard definition work and for off-line high definition. The digital edit is similar to the above.
- The differences come in the off-line/on-line for high definition. The off-line transfers of SD are edited in SD and the finished program is used to conform (use only the original material that is needed for the final program) the original material, which is re-transferred as HDCAM and edited. Or the film is cut and then transferred.
- Sometimes the cut film is also used for theatrical release.

Finished Programs -- All finished program masters are sent to PBS as digital videotape in either *Digital Betacam* for standard definition, or *HDCAM* for high definition.

Other then the tape label showing title, program number, length and producing station, metadata about this master is collected through *ORION*, a web service operated by PBS. These master programs (SD and HD) could be compared to an OAIS SIP, but for the *lack of metadata traveling with the essence.* [6]

[6] **OAIS (Open Archival Information System)** is a conceptual model for an archive that is charged with preserving information and making it available to a designated community. In the OAIS model, a ***Submission Information Package (SIP)*** is received into the repository, within which the information is stored as an ***Archival Information Package (AIP)***.

- The digital videotape copies of rough-cut and finished programs that are sent to creative services for promotional materials may be digitized yet again on a Avid or Final Cut Pro workstation using similar file format and codecs as mentioned in the offline and online processes above.

Promotional Materials -- Multiple weekly satellite feeds are sent from PBS as promotional reels to be used to edit promos for local broadcasts..

- These feeds are recorded on Digital Betacam videotape.
- Future workflow may require these feeds to be recorded on video servers as MPEG2 and then transferred through a Telestream[7] transcoder to Avid Meriden JFIF.
- Currently finished promos are printed back to videotape. Future workflow may use file transfer back through Telestream.

Web Distribution -- Video materials used on web sites are provided to the web developers on Digital Betacam videotape. The video is captured via Apple Macintosh computers and processed for file size and quality for web distribution. Multiple file formats are used for distribution.

- Files currently used include Windows Media, Real Media and QuickTime are used.
- The QuickTime codec are varied. The latest codec of choice is the MPEG4 H.264.

Upcoming Digital Source Formats

Digital video acquisition as a file is finding it's way directly from the camera.

- Both Panasonic and Sony have showed file-based cameras for use with both SD and HD capture. Panasonic is marketing solid-state recording (flash memory) and Sony is marketing a Blue-Ray optical disc.
    - The codecs are DV, DVCPRO and DVCPRO HD for Panasonic.
    - Sony is using IMX. HDV is a high definition format on mini cassette.

WGBH, like other PTV stations, is testing these tools for their possible use in production, and it is likely that by the end of this phase of the NDIIPP program, the PTV partner stations will be using these cameras. The predicted workflow would be similar to what has been outlined above for SD and HD post-production, but with a different *transfer* format.

- Since the video would already be file based, the files themselves can be transferred directly to the workstations for editing.

FORMATS IN THE DISTRIBUTION WORKFLOW AT PBS

Standard Definition (*reference figure 3*)

Currently programs are delivered to PBS on videotape (as noted above). Standard definition Digital Beta videotapes are played into an Avid workstation where they are encoded[8] to a 50Mbps IMX in a Material eXchange Format (MXF) OP Atom wrapper-ed file. The MXF files are stored on a large file store managed by MassTech. During this process, Windows Media (WM9) proxy copies are made for screening.

In this 50Mbps form, the files can be trimmed for time, if necessary, and promotion and funding additions or changes can be made.

That information can then be delivered to users as a ***Dissemination or Distribution Information Package (DIP*).**

[7] http://www.telestream.net/

[8] see glossary "encode"

The OP Atom MXF files are then converted to MXF OP 1A files in preparation for distribution. An Omneon media server is then used. The 50mpbs files are converted to 8Mbps MPEG2 Long GOP files which are transferred to the satellite uplink for distribution to the member stations. These 8Mbps files and the proxy files are also stored in the MassTech managed storage unit.

High Definition (*reference figure 4*)
Currently programs are delivered to PBS on videotape (as noted above). High definition HDCAM videotapes are played into an Avid workstation where they are encoded to a DNxHD 145 Avid HD codec. The DNxHD 145 files are stored on a large file store managed by MassTech.

In this 145Mbps form, the files can be trimmed for time, if necessary, and promotion and funding additions or changes can be made.

The Avid DNxHD 145 files are then converted to MPEG2 I-frame 35mbps files in preparation for distribution. The MPEG2 files are transferred to the satellite uplink for distribution to the member stations as a 19.4Mbps ATSC stream. These 35Mbps files are also stored in the MassTech managed storage unit.

FORMATS: DETAILED DISCUSSION

Throughout the production process, there are *primary formats* that are of special interest for digital asset management and preservation, and *secondary formats* that are necessary to carry out the production processes but which are ultimately incidental to preservation.

In the public television process, clear examples of primary formats include those related to acquisition and the standard formats required by PBS for distribution. (Other formats, such as those used for off-line editing or web dissemination, would be considered secondary.) Our focus here is on these primary formats, because they relate directly to preservation.

It is evident from the above discussion that program productions are edited, moved around, transferred and stored using many different devices in a wide variety of file formats and encodings. A chart of Digital ***Video Formats, File Formats and Codecs*** is shown as *Table 1*[9].

This section focuses on the formats and codecs mentioned above. We must also understand the difference between the terms *format* and *codec*[10].

- *Format* may refer to physical videotape that has a specific way analog or digital data is recorded on the tape.
- *Format* can also refer to a file format; the way data is represented in the file and how it is stored.
- Some file formats like QuickTime can also be a *wrapper*, in that the file can include many parts (sometimes called tracks), which may contain text and/or essence data.
- *Essence* is another term for the audio and video bits.
- The term *codec* is a concatenation of the terms *coder* and *decoder*. *Codecs* are a method of encoding the data -- in this document; the data are specifically audio and/or video. Transcoding can convert one codec to another. Encoding can mean the move from analog to digital and sometimes digital to digital. There are currently a large number of software codec in general

[9] A good general reference for free codecs is http://www.free-codecs.com/)
[10] http://info.wgbh.org/upf/glossary.html

use[11]. This report is restricted to those commonly use in PTV production workflow.

Part of the details to follow includes whether there is *open source support* for the codecs used. There are two well-known and supported open source players/decoders:

- MPlayer[12]
- VLC[13]

There are also two transcoders:

- MediaCoder[14]
- FFMPEG[15]

These player/decoders support a large number of the current codecs and can be very useful for review of material, transcoding and migration. The source code for these player/decoders is available and for the purpose of long-term archiving, it is recommended that the source be held with the stored material.

Registry and Licensing

Because there are so many formats to keep track of, some institutions are calling for a *global digital format registry*[16] as a centralized place to store and maintain references to the known formats.

But because of the proprietary nature of some formats, the actual specification of the formats will still rest with the intellectual property holder. These formats may also have licensing restrictions, which will contribute to complexity of the archival issues. And what insures that the IP holder would continue to steward the information?

Consequently, we do not think a global format registry is a practical solution to the problems of setting and maintaining format standards.

Wrapper Issues

For years we've known that acquisition and production equipment manufactures are not interested in the issue of digital video preservation; only those people actually involved with preserving materials are thinking about it. Moreover, very few people are thinking about what kind of *package* is needed to store digital video – not just the formats needed for video production and distribution, but also specifying which characteristics are appropriate and necessary for long-term digital storage.

As we approach the issue, archival formats are only just being realized (e.g. Adobe's work on PDF/A.) At the same time, the current thinking about trusted repositories emphasizes the need for both preservation and access – with the research emphasizing access and not long-term storage. So while these trusted repositories have databases of metadata with pointers to the essence files, the *wrappers* for the essence files are not addressed in their research. Organizing the essence and metadata together in some sustainable and readable fashion is a central problem we need to address.

At the Library of Congress, Carl Fleishhauer and Caroline Arms point to the "wrapper" capabilities of

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11 http://www.digitalpreservation.gov/formats/fdd/video_fdd.shtml
12 http://www.mplayerhq.hu/design7/news.html
13 http://www.videolan.org/vlc/
14 http://mediacoder.sourceforge.net/
15 http://ffmpeg.sourceforge.net/index.php
16 http://hul.harvard.edu/gdfr/

formats like WAVE, TIFF, and AVI. These structures are fairly intimate to the bitstreams[17], although, in every case, they are capable of wrapping multiple encodings. For example: an AVI file may contain Cinepak video, DV, MotionJPEG, etc.

In the same vein, "package" (or sometimes "bundle") describes higher-level structures, e.g. MPEG-21, MXF, AAF, and METS.[18] These packages "contain" files, which may include wrapper-files. Most packaging/bundling formats consist of metadata: they tell you what you have and how it should go together.

The OAIS reference model also refers to life cycle terms, where the critical packaging junctures are represented by the verbs "submit," "archive," and "disseminate." In the OAIS model, "produce" is upstream of "submit" and the OAIS model does not specify a "produce" package. In this zone--production/reformatting--one can make a case for AAF packaging. But when you get to "submit" and "sustain," it may be easier to support MXF, METS or MPEG-21 or some combination of packaging or wrapper.

From a different direction, Jerome McDonough, Assistant Professor of Library and Information Science at the University of Illinois, drafted a potential design based on his work with METS. While designed for descriptive, administrative, and structural metadata for the preservation of textual and image-based digital works, adapting it to put video into this framework is still to be tested but seems promising

There has been some success in the interchange of files with the work being done on MXF, and some opinions think it would be suitable for archival storage. But at this point we don’t know what this would look like –

- In addition to the program essence, what else should go into the package?
- If we use MXF, what set of instructions are needed to transfer the files to a repository?
- PBS has adapted MXF with an application specification called MXF-AS/PBS which is designed specifically for the *distribution* of programs. However, because it already addresses some of the issues relevant to program formats, it is also being looked at for use in preservation in a modified form.

As noted in earlier work on digital moving image and sound stored as files, the Universal Preservation Format (UPF)[19] calls for an “as human-readable” a file format as possible. Also, all information necessary for the recovery/display/playback of the media should be included in the file with the media. This would allow the file to exist on its own, with all the information for the re-creation of the material in the file (e.g. the source code for the decoding codec) and without the need for an external global registry. Since this universal wrapper would need to be updated with new or changed metadata, operational allowances would have to be made (e.g. metadata might be written to the end of the file.)

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[17] see glossary “bitstreams”

[18] The **Advanced Authoring Format** (**AAF**) is a professional file interchange format designed for the video post production and authoring environment. It was designed to be a data representation of works in progress, as compared to **MXF** (Material Exchange Format), which is for exchanging finished media products. **METS** is an open standard for encoding descriptive, administrative, and structural metadata regarding objects within a digital library that is necessary for both managing digital objects within a repository and exchanging objects between repositories. METS uses the *XML (eXtensible Markup Language*) schema of the web.

[19] http://info.wgbh.org/upf/index.html

Howard Besser points out in **Digital Longevity**[20] that a "scrambling problem" adds to the complexity of the archive issues. Dr. Besser refers to compression and encryption as examples of scrambling. There is an additional problem when a file is in a binary format that requires an external library to understand. This is similar to encryption.

MXF, which some believe can also be an archive format, uses a file formatting technique call Key Length Value (KLV.) A Key is interpreted to then explain the use of the following data Value of defined Length. This requires a library of Keys to decode the file. If the Key library is lost, the file is unusable. While the Key library may be maintained by a standards organization, the management of the Keys outside of the archival repository increases the long-term risk.

Wrapper Solution?

In order to carry forward the ideas of UPF, it might be necessary to create a super wrapper around a standard MXF wrapper. It may be possible to develop such a wrapper that also includes the necessary METS and/or PREMIS metadata. The approach would build on the draft of MXF-AS/PBS with the appropriate standardized codecs and metadata schema (e.g. PBCore) and which would also included the "to be defined" preservation metadata. This UPF super wrapper would also included the KLV keys.

While complex, such a construct would be based largely on existing parts that would enable decoding all the components of the file, specifically for the goal of long-term preservation.

Regarding wrappers and defining SIPs or AIPs, it is not out of the question that designing a preservation package for our content will require several years to perfect. In the meantime, we will be designing interim wrapper solutions that will test our approaches to storing and retrieving finished programs in a digital preservation environment.

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[20] http://www.gseis.ucla.edu/~howard/Papers/sfs-longevity.html

Table 1

DIGITAL VIDEO FORMATS, FILE FORMATS AND CODECS USED BY THE PTV PARTNERS

Digital Videotape		
Standard Definition	DV	Some confusion may arise with the term DV, which can be a referred to as a videotape format, a file format and/or a codec
	DVCAM	
	DVCPRO[21]	
	Digital Betacam[22]	
	D3[23]	
	D5[24]	
High Definition	HDCAM[25]	
	HDV[26]	
	DVCPRO HD[27]	
	D5 HD (see [24 above])	
Optical Media		
Standard Definition	XDCAM[28]	Sony Blu-Ray optical disc that records DVCAM or IMX files wrapped in MXF[29]. IMX can be at 30, 40 and 50 Mbps. Editing is now supported by a number of third party manufacturers.
High Definition	XDCAM HD[30]	Sony Blu-Ray optical disc that records MPEG2 at 18, 25 and 35 Mbps wrapped in MXF. Compatible with HDV at 25 Mbps.
File formats		
	DV[31]	Widely supported format. Most applications for video editing support DV and run on all current operating systems. There is open source code available for this format[32]. The source code is used is used in the open source player and transcoders.
	OMFI[33]	A file format, created by AVID, designed to allow work to be passed between different audio, graphic and video editing systems. Currently supported in Avid and other edit systems, the format is being replaced by the Advanced Authoring Format[34] (AAF), which is also open source.
	MPEG[35]	MPEG was created as a stream, and the file format is a concatenation of the stream.

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[21] http://www.digitalpreservation.gov/formats/fdd/fdd000183.shtml
[22] http://en.wikipedia.org/wiki/Digital_Betacam
[23] http://en.wikipedia.org/wiki/D3_video
[24] http://en.wikipedia.org/wiki/D5
[25] http://en.wikipedia.org/wiki/HDCAM - HDCAM_.2F_HDCAM_SR
[26] http://en.wikipedia.org/wiki/HDV
[27] http://en.wikipedia.org/wiki/DVCPRO_HD - DVCPRO
[28] http://bssc.sel.sony.com/BroadcastandBusiness/markets/10014/xdcam_info.shtml
[29] http://en.wikipedia.org/wiki/MXF
[30] http://bssc.sel.sony.com/BroadcastandBusiness/markets/10014/xdcamhd_info.shtml
[31] http://www.digitalpreservation.gov/formats/fdd/fdd000173.shtml
[32] http://libdv.sourceforge.net/
[33] http://en.wikipedia.org/wiki/OMFI
[34] http://www.aafassociation.org/index.html
[35] http://en.wikipedia.org/wiki/MPEG

		With the introduction of MPEG4, a file format specification was created.
	QuickTime[36]	Proprietary essence wrapper supporting many codec types. Supported on MacOS and Windows OS with limited support on Linux and other Unix OS through the OpenQuickTime[37] initiative as well as VLC, MPlayer and FFMPEG.
	Windows Media[38]	Proprietary essence wrapper supporting many codec types. Supported on Windows OS. Limited support on MacOS with Telestream QuickTime Flip4Mac WMF plug-in. Limited Linux and other Unix support through VLC, MPlayer and FFMPEG.
	Real Media[39]	Proprietary essence wrapper supporting limited codec types. Supported on MacOS, Windows and Linux. No support in VLC. Limited support in Mplayer and FFMPEG.
Codecs		
Standard definition	DV (see 21 above)	Recorders of this format generally use *hardware* for encoding. Transfer is generally done with IEEE 1394 (Firewire) interface, where the DV is pushed through the cable to the computer without change. This is *a transfer* not a *transcode.* Decoding/playing is supported through QuickTime player, VLC and MPlayer. Transcoding is supported through FFMPEG.
	DVCAM	
	DVCPRO	
	DVCPRO 50	DVCPRO 50 is part of the D-9 SMPTE (316M) standard. This format is a dual DV25 codec. This is a 4:2:2 codec. When transferred from tape to file, DVCPRO format is usually contained in a QuickTime or AVI wrapper. While it is possible to create a raw file like DV, is not normally found this way. Decoding or playing this requires either QuickTime or Windows Media Player. Also supported through the Matrox Software DV and DVCPRO and DVCPRO50 Video CoDec 2.5.0.63, MainConcept ProDV v.3.0.16, Pinnacle DV/DV50/DVHD100 and SoftLab-NSK DV CODECs Set v.2.21 codecs. Not currently supported in VLC or FFMPEG.
	Uncompressed SD	This codec can be 8 bits per sample or 10 bits per sample. It is a YUV[40] codec with 4:2:2 sampling. The recoded bitstream is usually captured via the serial digital interface (SDI) SMPTE 259M. Sometimes captured as RGB[41]. IYUV (YV12) in Windows Media but at 4:2:0. Supported in QuickTime. No support for 8 or 10 bit 4:2:2 in VLC, MPlayer or FFMPEG.
	IMX[42]	IMX is a Sony brand for MPEG2 at up to 50 Mbps, 4:2:2 Profile @ Main Level, I-frame only. Also known as SMPTE-356M. Wrapped in MXF. No support for the MXF wrapper in VLC, MPlayer or FFMPEG, but can be decoded if un-wrapped. Unwrapping supported by Flip4Mac MXF by Telestream.
	Avid Meridien JFIF[43]	Avid proprietary codec. Available from Avid for Windows and MacOS. Limited support in MPlayer, FFMPEG.
	MPEG (see 35 above)	MPEG-1, MPEG-2, MPEG-4 are from the ISO working group.

36 http://en.wikipedia.org/wiki/Quicktime
37 http://www.openquicktime.org/
38 http://en.wikipedia.org/wiki/Windows_Media
39 http://en.wikipedia.org/wiki/Real_media
40 http://en.wikipedia.org/wiki/YUV
41 http://en.wikipedia.org/wiki/RGB
42 http://en.wikipedia.org/wiki/MPEG_IMX - MPEG_IMX
43 http://www.avid.com/onlinesupport/supportcontent.asp?productID=10&contentID=3555&typeID=

		Supported in Windows and MacOS as well as VLC, MPlayer and FFMPEG. MPEG-4 part 10, also know at AVC or H.264
High Definition	DVCPRO HD (see [21 above])	DVCPRO HD is part of the SMPTE (370M) standard. This format is a quad DV25 codec. Uses down sampling. Supported in QuickTime. Transcode support in FFMPEG. Also supported by Apple, Avid and Matrox for editing.
	Avid DNxHD[44]	Avid codec designed for their edit system. Bit rates of 220, 145 or 36 mbps. The codec is placed in MXF by the edit system. The source code[45] for the codec is available from Avid. License for the use of this codec is confusing, further research needed.
	HDCAM (see [25 above])	Sony 8-bit DCT compressed 3:1:1 recording on tape. Not a codec per se. Usually handled via HD-SDI capture as uncompressed HD, as DVC Pro HD or Avid DNxHD.
	HDV (see [26 above])	Not like DV, this codec is like MPEG, using both intraframe and interframe coding. Editing support on all platforms but not at 24p. Support in VLC, MPlayer and FFMPEG.
	Uncompressed HD	Serial bit stream YCbCr saved to file. Defined in SMPTE 292M. Supported in Avid and Apple edit systems. IPTV tests were done using VLC.

[44] http://www.avid.com/dnxhd/
[45] http://www.avid.com/forms/DNxHDinfo.asp

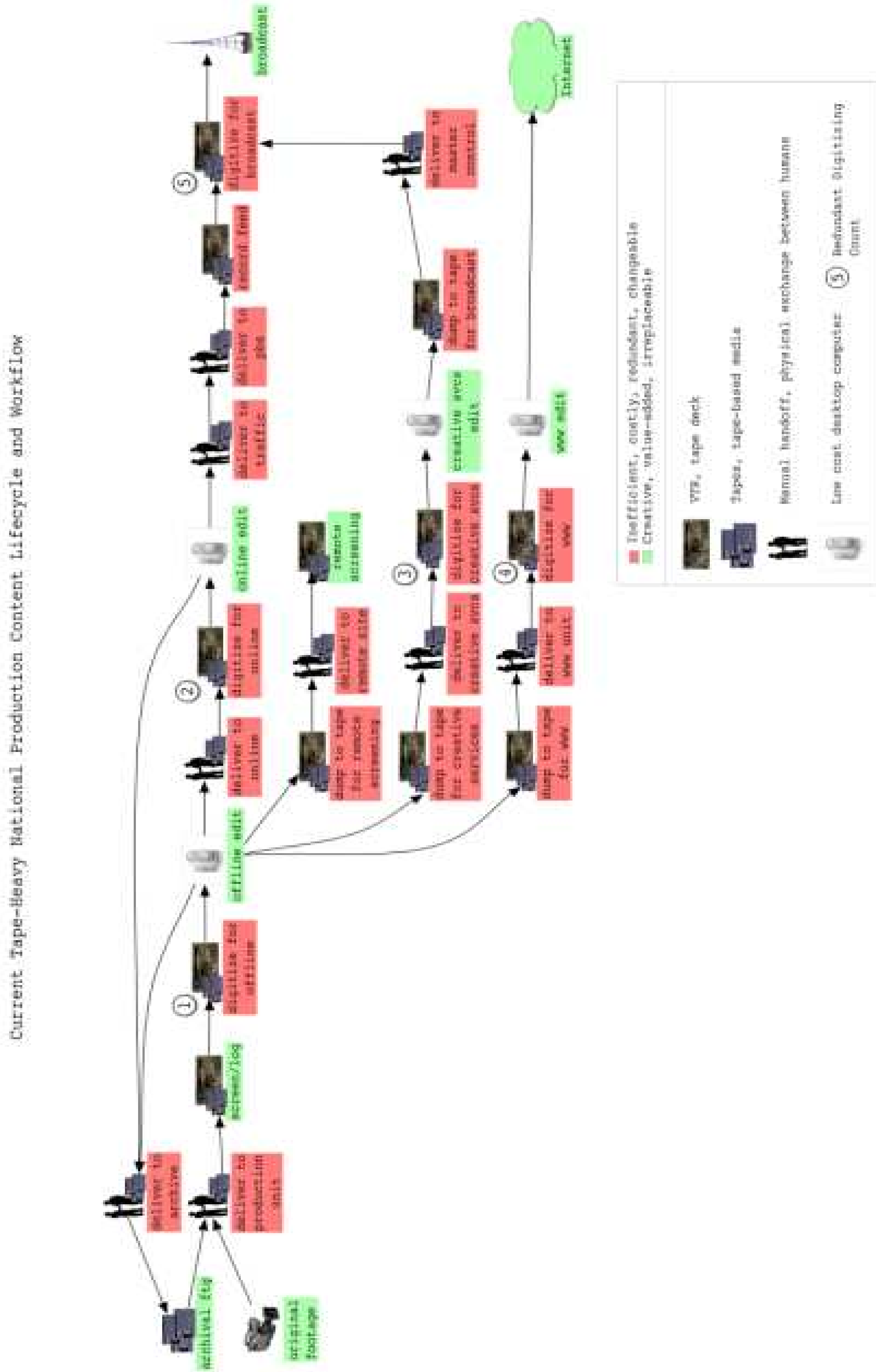

Figure 1 – Current Tape-Based National Production Content Lifecycle and Workflow

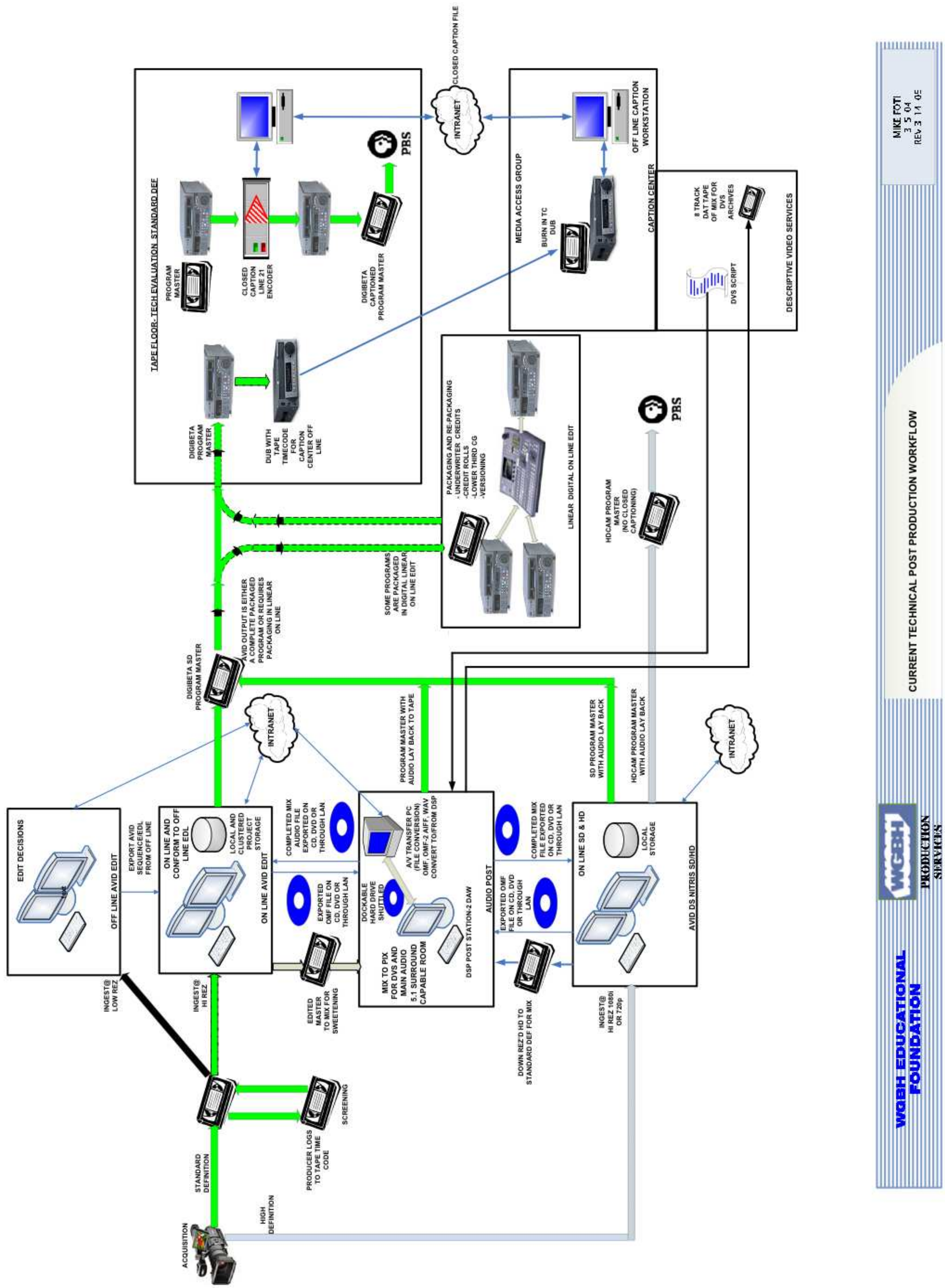

Figure 2 – Technical Post-Production Workflow (WGBH)

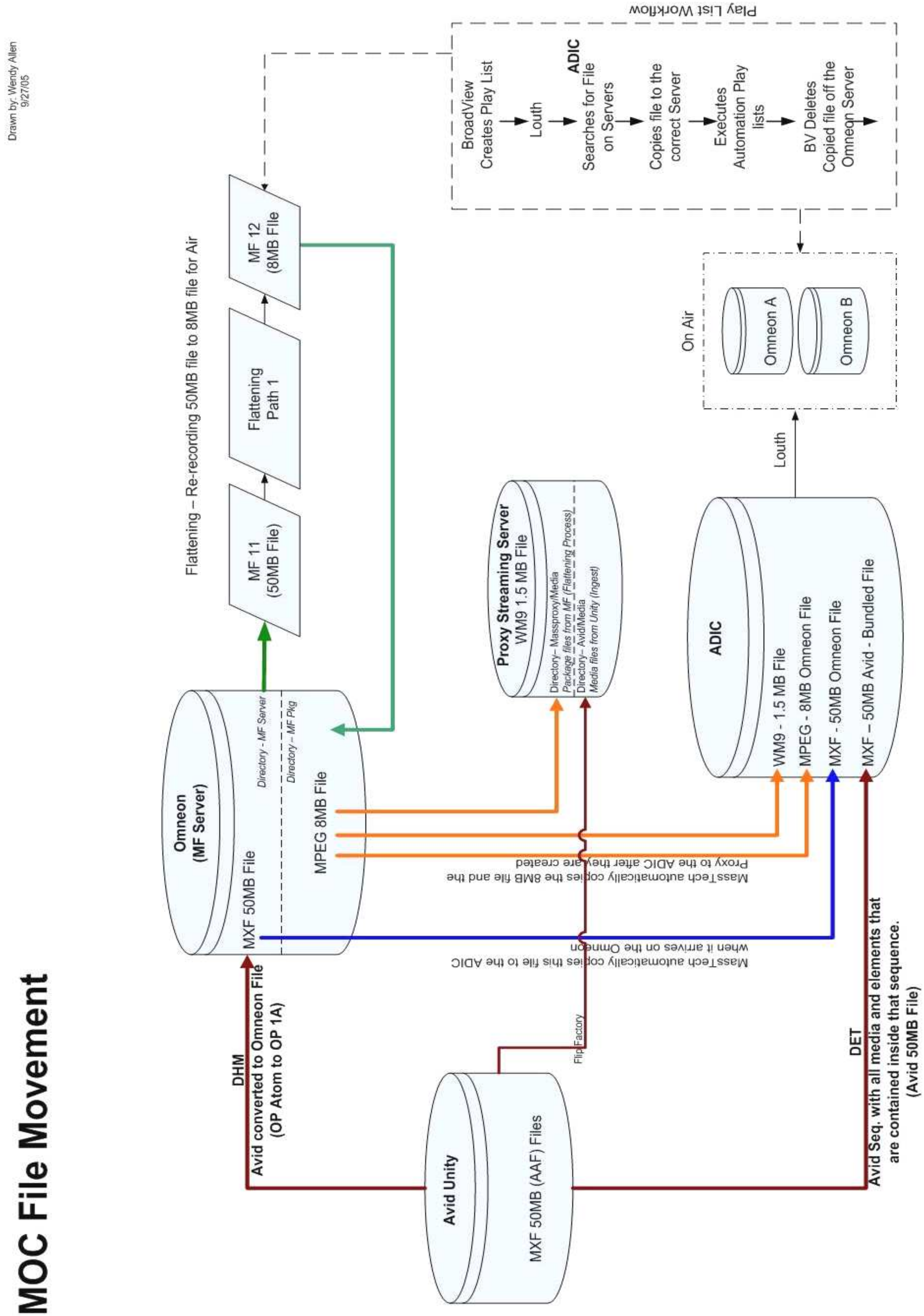

Figure 4 – PBS SD File-Based Program Distribution

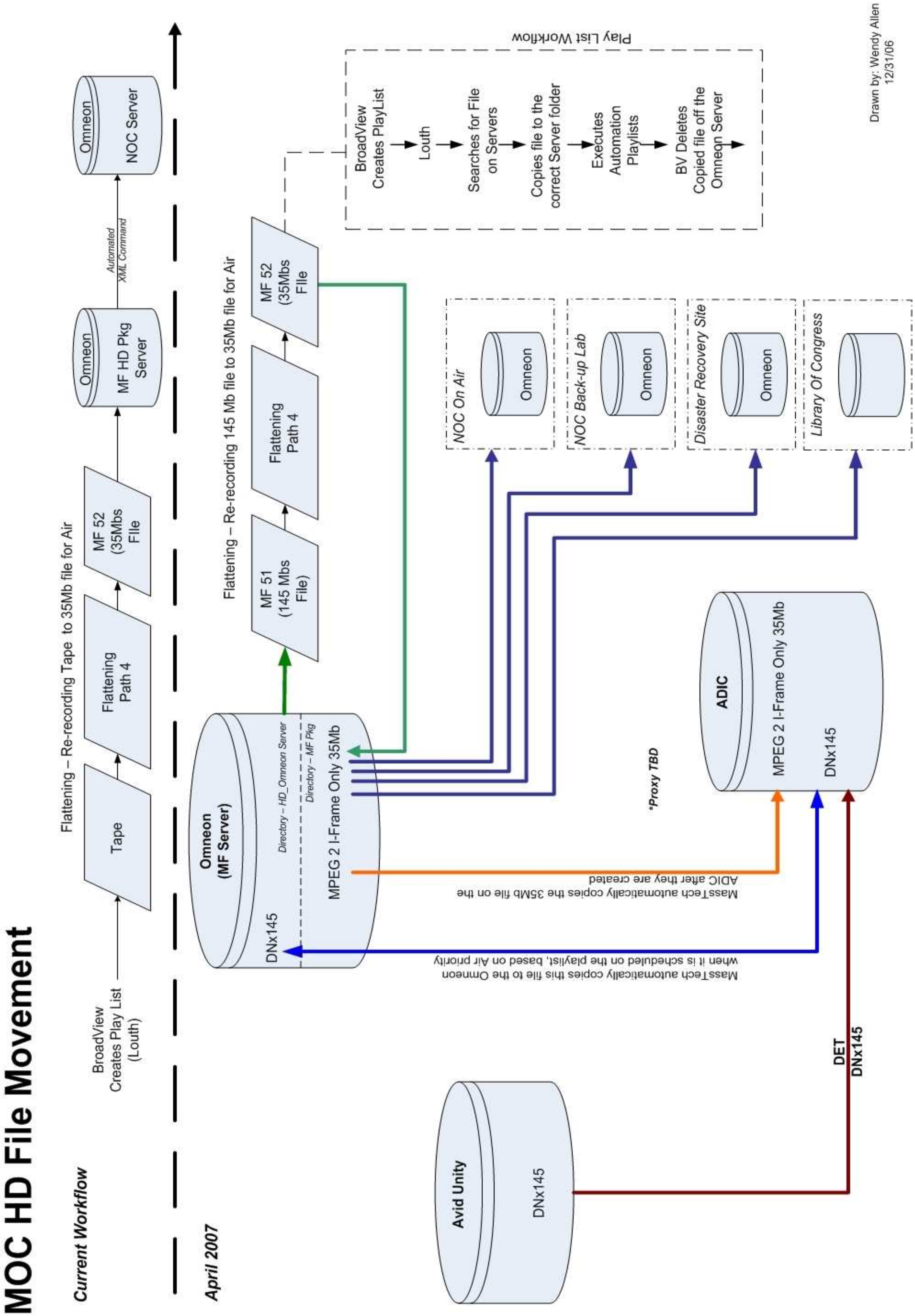

Figure 3 – PBS HD File-Based Program Distribution

APPENDIX A – GLOSSARY AND WIKIPEDIA REFERENCES

Additional terms can be found at: http://info.wgbh.org/upf/glossary.html

(General information frozen here to avoid unchecked changes at the Wikipedia site.)
(Referenced in alphabetical order.)

[17] **Bitstream**

Bitstream Transfer (or **Encoded Bitstream Transfer).**

A collection of data, as in video or audio data compressed to a file, transmitted between devices as a continuous series of transmitted bits.

[5**] Codec**

"Coder-decoder." A device that converts analog video and audio signals into a digital format for transmission. Also converts received digital signals back into analog format.

[23] **D3**

D3 is an uncompressed composite digital video tape format invented at NHK, and introduced commercially by Panasonic in 1991 to compete with Ampex's D2. It uses half-inch metal particle tape at 83.88mm/s (compare to D2's 19mm and 131.7mm/s). Like D2, the video signal is sampled at four times the color subcarrier frequency, with eight bits per sample. Four channels of 48khz 16-20 bit PCM audio, and other ancillary data, are inserted during the vertical blanking interval. The aggregate net (error corrected) bitrate of the format is 143 Mbps, and because the codec is lossless, it has been used in data applications. Camcorders were available which used this format, and are to date the only digital tape camcorders to use a lossless encoding scheme. The D3 transport in turn is derived from the MII transport. D3/D5 tapes come in small (161mm X 96mm X 25mm), medium (212mm X 124mm X 25mm), and large (296mm X 167mm X 25mm) cassettes, with format-specific recognition holes. Maximum D3 runtimes (in the Fujifilm lineup) are 50, 126, and 248 minutes respectively.

[24] **D5**

D5 is a professional digital video format introduced by Panasonic in 1994. Like Sony's D1 (8 bit), it is an uncompressed digital component system (10bit), but uses the same half-inch tapes as Panasonic's digital composite D3 format. A 120 min D3 tape will record 60min in D5/D5HD mode. D5 standard definition decks can be retrofitted to record high definition with the use of an external HD input/output box. The HD deck conversion does not allow for any error correction that exists on standard definition recordings, as the full bandwidth of the tape is required for the HD recording.

[24] **D5 HD**

HD D5 uses standard D5 videotape cassettes to record HD material, using an intra-frame compression with a 4:1 ratio. HD D5 supports the 1080 and the 1035 interlaced line standards at both 60 Hz and 59.94 Hz field rates, all 720 progressive line standards and the 1080 progressive line standard at 24, 25 and 30 frame rates. Four 48khz 20 bit PCM audio channels, or eight 48kHz 24 bit channels, are also supported. D5 runs at different data rates for different formats (taken from the hardware manual for the AJ-HD3700B:

- 323 Mbps (1080/59.94i/8CH, 720/59.94p/8CH, 480/59.94i/8CH)
- 319 Mbps (576/50i/8CH)
- 300 Mbps (1080/59.94i/4CH, 720/59.94p/4CH, 480/59.94i/4CH)
- 258 Mbps (1080/23.98p/8CH, 1080/24p/8CH)
- 269 Mbps (1080/50i/8CH, 1080/25p/8CH, 576/50i/8CH)

HD material is often captured for post production of film projects, especially on lower budget films, from the Super 16mm film format (15:9 aspect ratio crops well to 16:9 HDTV widescreen ratio) whereby the HD D5 scanning equipment is cheaper by the hour than a full resolution 2K film scan (which cannot be stored on videotape). Most importantly the 1920x1080 resolution at 24 progressive frames per second, with MPEG-2 or MPEG-4 compression, can be edited on high-end desktop computers in 2005.

[22] **Digital Betacam**

Digital Betacam (commonly abbreviated to *Digibeta* or *d-beta* or *dbc*) was launched in 1993. It supersedes both Betacam and Betacam SP, while costing significantly less than the D1 format and providing high quality and reliability. S tapes are available with up to 40 minutes running time, and L tapes with up to 124 minutes.

The Digital Betacam format records a DCT-compressed component video signal at 10-bit YUV 4:2:2 sampling in PAL (720×576) or NTSC (720×486) resolutions at a bitrate of 90 Mbit/s plus 4 channels of uncompressed 48 kHz PCM-encoded audio. A 5th audio track is available for cueing, and a linear timecode track is also used on the tape.

Some Digital Betacam equipment can also read Betacam and Betacam SP tapes. Along with the identical cassette size, this meant for easy upgrading.

Digital Betacam is considered to be the ‘gold standard’ of formats for standard-definition digital video, because it is capable of outperforming cheaper digital formats such as DVCAM and DVCPRO, and associated equipment is comparatively expensive. Panasonic offers the DVCPRO50 competing format, which has similar technical abilities.

Another key element that aided adoption was Sony's implementation of the SDI coaxial digital connection on Digital Betacam decks. Facilities could begin using digital signals on their existing coaxial wiring without having to commit to an expensive re-installation.

[2] **Digitize**
Digitization

The process of converting a continuous analog video or audio signal to digital data (ones and zeros) for computer display, manipulation or storage. For example, the action of making a copy in the form of a digital file for editing, by playing an analog source (e.g., videotape).

[27] **DVCPRO**

Panasonic specifically created the DVCPRO family for electronic news gathering (ENG) use (NBC's newsgathering division was a major customer), with better linear editing capabilities and robustness. It has an even greater track width of 18 micrometres and uses another tape type (Metal Particle instead of Metal Evaporated). Additionally, the tape has a longitudinal analog audio cue track. Audio is only available in the 16 bit/48 kHz variant, there is no EP mode, and DVCPRO always uses 4:1:1 color subsampling (even in PAL mode). Apart from that, standard DVCPRO (also known as DVCPRO25) is otherwise identical to DV at a bitstream level. However, unlike Sony, Panasonic chose to promote its DV variant for professional high-end applications.

DVCPRO50 is often described as two DV-codecs in parallel. The DVCPRO50 standard doubles the coded video bitrate from 25 Mbit/s to 50 Mbit/s, and uses 4:2:2 chroma subsampling instead of 4:1:1. DVCPRO50 was created for high-value ENG compatibility. The higher datarate cuts recording time in half (compared to DVCPRO25), but the resulting picture quality is reputed to rival Digital Betacam.

DVCPRO HD, also known as DVCPRO100, uses four parallel codecs and a coded video bitrate of approximately 100 Mbit/s, depending on the format flavor. DVCPRO HD is also 4:2:2. DVCPRO HD downsamples native 720p/1080i signals to a lower resolution. 720p is downsampled from 1280x720 to 960x720, and 1080i is downsampled from 1920x1080 to 1280x1080 for 59.94i and 1440x1080 for 50i. This is a common technique, utilized in most tape-based HD formats such as HDCam and HDV. Compression ratio is approximately 6.8:1. To maintain compatibility with HDSDI, DVCPRO100 equipment internally downsamples video during recording, and subsequently upsamples video during playback. A camcorder using a special variable-framerate (from 4 to 60 frame/s) variant of DVCPRO HD called *VariCam* is also available. All these variants are backward compatible but not forward compatible. There is also a DVCPRO HD EX format, which runs the tape at slower speed, resulting in twice as long recording times.

DVCPRO cassettes are always labeled with a pair of run times, the smaller of the two being the capacity for DVCPRO50. A "M" tape can hold up to 66/33 minutes of video. The color of the lid indicates the format: DVCPRO tapes have a yellow lid, longer "L" tapes made specially for DVCPRO50 have a blue lid and DVCPRO HD tapes have a red lid. The formulation of the tape is the same, and the tapes are interchangeable between formats. The running time of each tape is 1x for DVCPRO, 2x for DVCPRO 50, 2x for DVCPRO HD EX, and 4x for DVCPRO HD, since the tape speed changes between formats. Thus a tape made 126 minutes for DVCPRO will last approximately 32 minutes in DVCPRO HD.

[8] Encode

The process of transforming information from one format into another. The opposite operation is called **decoding**. It can be a process that combines or translates a video signal into a different format, or transforms a digital signal into a form optimized for transmission or storage, generally done with a codec.

[Encoding often involves **compressing** -- reducing the size of audio or video data through the use of a compression scheme.]

[25] **HDCAM/ HDCAM SR**

HDCAM, introduced in 1997, is an HD version of Digital Betacam, using an 8-bit DCT compressed 3:1:1 recording, in 720p or 1080i-compatible (1920x1080) resolution, and adding 24p and 23.976 PsF modes. The recorded video bitrate is 144 Mbit/s. Audio is also similar, with 4 channels of AES/EBU 20-bit/48 kHz digital audio. It is used for Sony's cinematic CineAlta range of products.

HDCAM SR, introduced in 2003, uses a higher particle density tape and is capable of recording in 10 bits 4:4:4 RGB with a bitrate of 440 Mbit/s. The increased bitrate (over HDCAM) allows HDCAM SR to capture much more of the full bandwidth of the HDSDI signal (1920x1080). Some HDCAM SR VTRs can also use a 2x mode with an even higher bitrate of 880 Mbit/s, allowing for a single 4:4:4 stream at a lower compression or two 4:2:2 video streams simultaneously. HDCAM SR uses the new MPEG-4 Studio Profile for compression, and expands the number of audio channels up to 12.

Some HDCAM VTRs play back older Betacam variants, for example, the SRW-5500 from Sony, an HDCAM SR recorder, plays back Digital Betacam, HDCAM and HDCAM SR tapes, and tape lengths are the same as for Digital Betacam, up to 40 minutes for S and 124 minutes for L tapes. In 24p mode the runtime increases to 50 and 155 minutes, respectively. HDCAM tapes are black with an orange lid, and HDCAM SR tapes black with a cyan lid. 440 Mbit/s mode is called as SQ, and 880 Mbit/s mode is called as HQ, and this mode currently (year 2005) only available in portable models.

[26] **HDV**

High Definition Video (HDV) is a video format designed to record compressed HDTV video on standard DV media (DV or MiniDV cassette tape).

HDV was designed to offer existing video production environments a cost-conscious upgrade path from standard-definition (SD) to high-definition (HD) video. Since HDV operates at the same recorded datarate (25 Mbit/s bitstream rate) as DV, HDV recorders share the same physical (MiniDV) tape transport as existing DV equipment. For the camera, the main expense is concentrated in the optics and imaging electronics. Compared to HD video equipment built on more professional standards (such as HDCAM and DVCPRO HD), HDV enjoys a tremendous cost advantage. HDV camcorders open high-definition video acquisition to consumers, amateur videographers, and low-budget TV production.

Although HDV and DV share the same (DV) tape format and the same recorded datarate, they use completely different video compression technology. The DV codec uses strictly an intraframe (spatial) scheme, whereas HDV uses the well-established MPEG 2 video codec. MPEG-2 applies both intraframe (spatial) and interframe (temporal) to video-compression, allowing HDV to achieve its higher spatial resolution at the target bitrate of 19.7 Mbit/s and 25 Mbit/s. Compared to more expensive HDCAM and DVCPRO HD equipment, HDV suffers from significantly more spatial and temporal (motion) artifacts. As a consequence of interframe (temporal) compression, HDV editing is more complex, and introduces greater distortion at the splice point (due to the interdependence of adjacent video frames.) Compared to conventional SD DV, HDV offers a much higher spatial resolution, so most observers are willing to accept the artifacts in exchange for a higher-definition picture. HDV audio uses lossy compression (MPEG-1 Layer 2) to reduce the audio bitrate to 384Kbps. DV audio uses uncompressed 16-bit PCM at 1536Kbps. As a result, HDV audio is technically inferior, although MPEG-1 at 384Kbps is regarded as 'perceptually lossless.'

Since HDV and DV use the same DV25 tape transport, at the same linear speed, recording times for DV and HDV are identical. That is, a 60 minute MiniDV cassette can store 60 minutes of either DV or HDV footage. As of yet, no HDV cameras can record HDV at LP speed, so the maximum record time on one tape is 80 minutes, as opposed to 120 with an 80 minute tape at LP.

HDV compression

Although HDV and DV share the same tape format and the same recorded datarate, they use completely different video compression technology. The DV codec is strictly an intraframe (spatial) compression. Each DV video frame is recorded as an independent picture, with a fixed bit allocation and uniform placement on the videotape. The HDV codec is based on MPEG-2 video compression, which employs both intraframe and interframe (temporal) techniques. Interframe compressors store only a fraction of the frames in a video as independent pictures -- called key frames -- and encode the remaining frames as changes relative to them. Consequently, HDV frames vary in size depending on their prior and future neighbors. In HDV 1080i, one in every 12 (25 FPS) or 15 (30 FPS) frames is a key frame. In HDV 1080p, one in every 12 (25 FPS) or 15 (24 or 30 FPS) frames is a key frame. In HDV 720p, one in every 6 (24, 25, or 30 FPS) or 12 (50 or 60 FPS) frames is a key frame.

MPEG-2 video enables HDV to achieve a much higher compression ratio than DV, but at the cost of motion-induced artifacts in scenes of complex motion. The artifacts are a limitation of the compression technology and bitrate allocated to the video bitstream. Motion artifacts are imperceptible for static shots and gentle pans, but may become increasingly detracting as motion complexity increases. For example, a moving riverbed may exhibit regions of picture breakup, depending on its portion of the total screen area. It is important to view these limitations in the proper context. Lighting, chroma content, camera motion, etc all play a role in the potential for artifacts. The television series "JAG" shot many scenes using HDV without any incident, shooting over extreme latitudes of sunlight over ocean water, with dark and light content in the subject matter. For the DV codec to approach the spatial quality of HDV, it would require more than four times the storage space. Encoders are constantly improving; The Sony XDCAM HD format is very similar to HDV. MPEG is the standard of the future, and as encoders improve, the potential for artifacts lessens.

Dropouts or errors in the compressed video bitstream affect HDV much more severely than DV. This is an unavoidable characteristic of interframe compression. Since frame data affects multiple frames (and not just the one it originated from), a dropout will impact all dependent neighbors. Frame-accurate editing is also made more difficult by the MPEG-2 codec. Any modifications to the video sequence require the surrounding group of frames to undergo a complete (and lossy) decompression/recompression cycle. However, virtually all professional non-linear editing software is now designed to work flawlessly with HDV.

For all its limitations, HDV is quite stunning on HD displays. Although free of motion-induced artifacts, DV tends to look fuzzy when scaled up to HD resolutions. Subjectively, most observers are willing to accept HDV's visual artifacts in exchange for a more detailed picture.

Resolution and aspect ratio

In HDV, the video frame is defined to have an aspect ratio of 16:9. Permitted resolutions are 720p and 1080i.

HDV 1080i, like other new HD recording formats, uses a pixel aspect ratio of 1.33 to store data in a more mathematically and algorithmically efficient way. HDV 1080i uses a pixel resolution of 1440x1080, but when displayed is scaled to an aspect ratio of 1920x1080 = (1440 x 1.33)x1080. While this reduces horizontal resolution, the loss is less than the numbers would suggest, because the vertical resolution is also reduced by interlacing. The benefit of adding pixels is reduced if resolution in only one direction is increased, while the other lags too far behind.

HDV resolution, while falling short of 1080p, is still a dramatic improvement over standard DV. Box area denotes effective resolution, not the intended shape of the screen.

Despite using "only" 1440x1080 pixels for 1080i, the perceived sharpness with HDV is much higher than that of PAL or NTSC DV formats. 1440 is still twice the horizontal resolution of DV and DVD formats. In total 1080i has a resolution of 1,555,200 pixels, which is 4.5 times larger than the resolution of NTSC DV (345,600 pixels) and 3.75 times larger of PAL DV (414,720 pixels).

This applies to the brightness information only, because color information (hue and saturation) is always subsampled (4:2:0 for HDV) to reduce data, be it HDV, DVD, DV or a professional video format because the human eye has less color resolution than brightness resolution. The color resolution of PAL/NTSC/DVD and HDV is only a quarter of their luminance resolution. However, colorspace isn't the only value in determining quality. For example, the Panasonic HVX200 records in the higher quality 4:2:2 colorspace, but it is fed lesser resolution from a 960 x 540 sensor that is significantly resampled, and depending on the resolution used, is feeding at a bitrate of only 40Mbps. Therefore, the camcorder is truly only delivering approximately 3:1:1 vs the 4:2:2 that the DVCPRO HD format offers.

Additionally, 4:2:0 is the color samping format of HD as it is deliverable over broadcast, meaning that HDV does not undergo any color conversion as most other formats require in the chain of acquisition, editing, and output. This alone offers a significant advantage to MPEG formats as an acquisition format.

[42] **IMX**

MPEG IMX is a 2001 development of the Digital Betacam format. It uses the MPEG compression system, but at a higher bitrate than Betacam SX. The IMX format allows for a CCIR 601 compliant video signal, with 8 channels of audio and timecode track. It lacks an analog audio (cue) track as the Digital Betacam, but will read it as channel 7 if used for playback.

Compression is applied in three different formats: 30 (6:1 compression), 40 (4:1 compression) or 50 Mbit/s (3.3:1 compression), which allows different quality/quantity ratios. Video is recorded at MPEG-2 4:2:2 Profile @ ML.

With its new IMX VTRs, Sony introduced some new technologies including SDTI and e-VTR. SDTI allows for audio, video, timecode, and remote control functions to be transported by a single coaxial cable, while e-VTR technology extends this by allowing the same data to be transported over IP by way of an ethernet interface on the VTR itself.

All IMX VTRs can natively playback Betacam SX tapes, and some, such as the MSW-M2000P/1 are capable of playing back Digital Betacam cassettes as well as analog Betacam and Betacam SP cassettes, but they can only record to their native IMX cassettes. S tapes are available with up to 60 minutes capacity, and L tapes hold up to 184 minutes. These values are for 525/60 decks, but will extend in 625/50. A 184 minute tape will record for, as the label itself specifies, 220 minutes.

IMX machines feature the same *good shot mark* function of the Betacam SX.

MPEG IMX tapes are a muted green, however, the new XDCAM format allows recording of MPEG IMX on a tapeless format, Professional Disc

[3] Ingest

The act of inclusion of material or assets within a system. Sometimes confused with the action of using technology to capture digital content from a variety of sources or formats for use with a specific application, device or workflow.

[35] **Moving Picture Experts Group**

The Moving Picture Experts Group (MPEG) is a working group of ISO/IEC charged with the development of video and audio encoding standards. Its first meeting was in May of 1988 in Ottawa, Canada. As of late 2005, MPEG has grown to include approximately 350 members per meeting from various industries, universities, and research institutions. MPEG's official designation is ISO/IEC JTC1/SC29 WG11.

MPEG (pronounced EM-peg) has standardized the following compression formats and ancillary standards:

- MPEG-1: Initial video and audio compression standard. Later used as the standard for Video CD, and includes the popular Layer 3 (MP3) audio compression format.
- MPEG-2: Transport, video and audio standards for broadcast-quality television. Used for over-the-air digital television ATSC, DVB and ISDB, digital satellite TV services like Dish Network, digital cable television signals, and (with slight modifications) for DVDs.
- MPEG-3: Originally designed for HDTV, but abandoned when it was discovered that MPEG-2 (with extensions) was sufficient for HDTV. (Do not confuse with MP3, which is MPEG-1 Layer 3.)
- MPEG-4: Expands MPEG-1 to support video/audio "objects", 3D content, low bitrate encoding and support for Digital Rights Management. Several new (newer than MPEG-2 Video) higher efficiency video standards are included (an alternative to MPEG-2 Video), notably:
- MPEG-4 Part 2 (or Advanced Simple Profile) and
- MPEG-4 Part 10 (or Advanced Video Coding or H.264). MPEG-4 Part 10 may be used on HD-DVD and Blu-Ray discs, along with VC-1 and MPEG-2.
- In addition, the following standards, while not sequential advances to the video encoding standard as with MPEG-1 through MPEG-4, are referred to by similar notation:

- MPEG-7: A formal system for describing multimedia content.
- MPEG-21: MPEG describes this standard as a *multimedia framework*.

[29] **MXF**

Material eXchange Format (MXF) is a container format for professional digital video and audio media defined by a set of SMPTE standards.

MXF is a "container" or "wrapper" format that supports a number of different streams of coded "essence", encoded with any of a variety of codecs, together with a metadata wrapper which describes the material contained within the MXF file.

MXF has been designed to address a number of problems with non-professional formats. MXF has full timecode and metadata support, and is intended as a platform-agnostic stable standard for future professional video and audio applications.

MXF has been developed to essentially carry a subset of the Advanced Authoring Format (AAF) data model, under a policy known as the Zero Divergence Directive (ZDD). This enables MXF/AAF workflows between non-linear editing systems using AAF and cameras, servers, and other devices using MXF.

MXF is in the process of evolving from standard to deployment. The breadth of the standard can lead to interoperability problems as vendors implement different parts of the standard.

Currently, MXF is fairly effective at the interchange of D10 (IMX) material, mainly because of the success of the Sony eVTR and Sony's eVTR RDD to SMPTE. Workflows combining the eVTR, Avid NLE systems, and broadcast servers using MXF in coordination with AAF are now possible.

Long-GOP MPEG-2 material interchange between video servers is improving, especially as broadcasters develop application specifications (AS's) they expect their vendors to implement.

As of Autumn 2005, there were major interoperability problems with MXF in broadcast postproduction use. The two data-recording camera systems that produce it, Sony's XDCAM and Panasonic's DVCPRO P2, produce files that are mutually incompatible due to opaque subformat options which are obscured behind the MXF file extension. Without advanced tools, it is impossible to tell these formats apart.

Additionally, many MXF systems produce split-file A/V, that is the video and audio components in separate files, and use a filenaming convention that relies on randomly-generated filenames to link them. Not only does this exacerbate the issue of knowing exactly what is in an MXF file without specialist tools, but it breaks the functionality of standard desktop computer techniques which are generally used to manipulate data on a level as fundamental as moving, copying, renaming and deleting. Using a randomly-generated filename is uninformative to the user, but changing the name breaks the loose database structure between files.

Also, MXF is unsupported by several prominent applications, including Adobe After Effects. The implementation in several products, including the prominent Avid Newscutter, is particularly wanting, and highlights the identification issue by easily confusing XDCAM and P2 MXF flavors. Despite MXF's purpose as an easily-archivable format, importing split-file MXF with external XML metadata intact can be brutally complicated.

The file extension for MXF files is ".mxf". The Macintosh File Type Code registered with Apple for MXF files is "mxf " (note the trailing space).

The MXF Standards

Base Documents

- SMPTE 377M: The MXF File Format Specification (the overall master document)
- SMPTE EG41: MXF Engineering Guide (A guide explaining how to use MXF)
- SMPTE EG42: MXF Descriptive Metadata (A guide explaining how to use descriptive metadata in MXF)

Operational Patterns

- SMPTE 390M: OP-Atom (a very simple and highly constrained layout for simple MXF files)
- SMPTE 378M: OP-1a (the layout options for a minimal simple MXF file)
- SMPTE 391M: OP-1b
- SMPTE 392M: OP-2a
- SMPTE 393M: OP-2b
- SMPTE 407M: OP-3a, OP-3b
- SMPTE 408M: OP-1c, OP-2c, OP-3c

Generic Containers

- SMPTE 379M: Generic Container (the way that essence is stored in MXF files)
- SMPTE 381M: GC-MPEG (how to store MPEG essence data in MXF using the Generic Container)
- SMPTE 383M: GC-DV (how to store DV essence data in MXF using the Generic

Container)

- SMPTE 385M: GC-CP (how to store SDTI-CP essence data in MXF using the Generic Container)
- SMPTE 386M: GC-D10 (how to store SMPTE D10 essence data in MXF using the Generic Container)
- SMPTE 387M: GC-D11 (how to store SMPTE D11 essence data in MXF using the Generic Container)
- SMPTE 382M: GC-AESBWF (how to store AES/EBU and Broadcast Wave audio essence data in MXF using the Generic Container)
- SMPTE 384M: GC-UP (how to store Uncompressed Picture essence data in MXF using the Generic Container)
- SMPTE 388M: GC-AA (how to store A-law coded audio essence data in MXF using the Generic Container)
- SMPTE 389M: Generic Container Reverse Play System Element
- SMPTE 394M: System Item Scheme-1 for Generic Container
- SMPTE 405M: Elements and Individual Data Items for the GC SI Scheme 1

Metadata, Dictionaries and Registries

- SMPTE 380M: DMS1 (a standard set of descriptive metadata to use with MXF files)
- SMPTE RP210: SMPTE Metadata Dictionary (the latest version is available here: http://www.smpte-ra.org/mdd/index.html)
- SMPTE RP224: Registry of SMPTE Universal Labels

[33] **Open Media Framework Interchange**

Open Media Framework (OMF) or Open Media Framework Interchange (OMFI) is a platform-independent file format intended for transfer of digital media between different software applications.

It is used by programs like Avid, Final Cut Pro, SONAR, Nuendo, Cubase, Logic Pro and Pro Tools.

[36] **QuickTime**

QuickTime is a multimedia framework developed by Apple Computer, capable of handling various formats of digital video, media clips, sound, text, animation, music, and several types of interactive panoramic images.

A QuickTime file (*.mov) functions as a multimedia container file that contains one or more *tracks*, each of which store a particular type of data, such as *audio*, *video*, *effects*, or *text* (for subtitles, for example). Each track in turn contains *track media*, either the digitally-encoded media stream (using a specific codec such as Cinepak, Sorenson codec, MP3, JPEG, DivX, or PNG [supported codecs]) or a data reference to the media stored in another file or elsewhere on a network. It also has an "edit list" that indicates what parts of the media to use.

Internally, QuickTime files maintain this format as a tree-structure of "atoms", each of which uses a 4-byte OSType identifier to determine its structure. An atom can be a parent to other atoms or it can contain data, but it cannot do both.

The ability to contain abstract data references for the media data, and the separation of the media data from the media offsets and the track edit lists means that QuickTime is particularly suited for editing, as it is capable of importing and editing in place (without data copying) other formats such as AIFF, DV, MP3, MPEG-1, and AVI. Other later-developed media container formats such as Microsoft's Advanced Streaming Format or the open source Ogg and Matroska containers lack this abstraction, and require all media data to be rewritten after editing.

QuickTime and MPEG-4
To create an MP4 file, choose MPEG-4 in the Export dialog.
On February 11, 1998 the ISO approved the QuickTime file format as the basis of the MPEG-4 Part 14 (.mp4) container standard. Supporters of the move noted that QuickTime provided a good "life-cycle" format, well suited to capture, editing, archiving, distribution, and playback (as opposed to the simple file-as-stream approach of MPEG-1 and MPEG-2, which does not mesh well with editing). Developers added MPEG-4 compatibility to QuickTime 6 in 2002. However, Apple delayed the release of this version for months in a dispute with the MPEG-4 licensing body, claiming that proposed license fees would constrain many users and content providers. Following a compromise, Apple released QuickTime 6 on 15 July 2002.

Profile Support
QuickTime 6 had limited support for MPEG-4 in that it could only encode and decode Simple Profile (SP). Advanced Simple Profile (ASP) features, like B-frames, were unsupported, making QuickTime-encoded MPEG-4 files compare terribly with XviD and other full-featured encoders. QuickTime 7 decodes both MPEG-4 SP and ASP, though the encoder is still SP-only. QuickTime 7's H.264 encoder is claimed to be Main Profile, but actually Baseline Profile plus 1 B-frame support, the decoder supports Baseline, Extended, and most of Main Profile [2]. High Profile features are unsupported.

Container Benefits
Use Passthrough to change to the MP4 container without re-encoding the stream.
Because both the MOV and MP4 containers can utilize the same MPEG-4 codecs, they are mostly interchangeable in a QuickTime-only environment. However, MP4, being an international standard, has more support. This is especially true on hardware devices, such as the Sony PSP and various DVD players; on the software side, most DirectShow / Video for Windows codec packs [3] [4] include an MP4 parser, but not one for MOV.
In QuickTime Pro's MPEG-4 Export dialog, an option called "Passthrough" allows a clean export to MP4 without affecting the audio or video streams. One recent discrepancy ushered in by QuickTime 7 is that the MOV file format now supports multichannel audio (used, for example, in the high-definition trailers on Apple's site[5]), while MP4 is limited to stereo. Therefore multichannel audio must be re-encoded during MP4 export.

[39] **RealMedia**

RealMedia is a multimedia container format created by RealNetworks. Its extension is ".rm". It is typically used in conjunction with RealVideo and RealAudio and is popular for streaming content over the Internet.
Typically these streams are in CBR (constant bit rate).
Recently RealNetworks has developed a new container for VBR (variable bit rate) streams, named RealMedia variable bitrate (RMVB).
Support of RealMedia is available in a wide variety of multimedia players for different architectures/platforms.

[41] **RGB Color Model**

The RGB color model is an additive model in which red, green and blue (often used in additive light models) are combined in various ways to reproduce other colors. The name of the model and the abbreviation 'RGB' come from the three primary colors, Red, Green and Blue. These three colors should not be confused with the primary pigments of red, blue and yellow, known in the art world as 'primary colors'.

The RGB color model itself does not define what is meant by 'red', 'green' and 'blue', and the results of mixing them are not exact unless the exact spectral make-up of the red, green and blue primaries are defined. The color model then becomes an absolute color space, such as sRGB or Adobe RGB; see RGB color space for more details. This article discusses concepts common to all the different RGB color spaces that use the RGB color model.

[4] Transcode

The direct digital-to-digital conversion from one format to another, preferably done to minimize loss of quality from repeated compression.

Transcoding can also refer to encoding files to a lower bitrate without changing video formats, a process that is also known as transrating. It may also refer to the process of directly changing assembled code to work on a different platform or operating system.

[38] **Windows Media**

Windows Media is a multimedia framework for media creation and distribution for Microsoft Windows. It consists of a software development kit with several application programming interfaces and a number of prebuilt technologies. The following are part of Windows Media:

Advanced Streaming Format (ASF)

- **Advanced Systems Format** (formerly **Advanced Streaming Format**) is Microsoft's proprietary digital audio/digital video container format, especially meant for streaming media. ASF is part of the Windows Media framework.
- The format does not specify how the video or audio should be encoded; it just specifies the structure of the video/audio stream. This means that an ASF file could be encoded with virtually any audio/video codec. This is similar to the function performed by the QuickTime, AVI, or Ogg formats. One of the objectives of ASF was to support playback from digital media servers, HTTP servers, and local storage devices.
- ASF is based on serialized *objects* which are essentially byte sequences identified by a GUID marker.
- The most common filetypes contained within an ASF file are Windows Media Audio (WMA) and Windows Media Video (WMV).
- ASF files can also contain objects representing metadata, such as the artist, title, album and genre for an audio track, or the director of a video track, much like the ID3 tags of MP3 files.
- Files containing only WMA audio can be named using a .wma extension, and files of only audio and video content may have the extension .wmv. Both may use the .asf extension if desired.
- Certain error-correcting techniques related to ASF are patented in the United States (United States Patent 6,041,345 Levi, et al. March 21, 2000) by Microsoft.

Although the format is publicly documented by Microsoft, its license limits implementations to closed-source development projects only. Interestingly, Apple's iTunes software now has the capability to convert WMA files to any iTunes-supported format.[1]

- The ASF container provides the framework for digital rights management in Windows Media Audio and Windows Media Video. An analysis of an older scheme used in WMA reveals that it is using a combination of elliptic curve cryptography key exchange, DES block cipher, a custom block cipher, RC4 stream cipher and the SHA-1 hashing function.
- ASF files have MIME type application/vnd.ms-asf or video/x-ms-asf. (Advanced Stream Redirector (ASX) files also have MIME type video/x-ms-asf.)
- The ASF container is usually streamed on the net through Microsoft's proprietary MMS protocol.

Windows Media Audio (WMA)

- Windows Media Audio (WMA) is a proprietary compressed audio file format developed by Microsoft. It was initially intended to be a competitor to the popular MP3 format, though in terms of popularity of WMA files versus mp3 files, this never came close to occurring. However, with the introduction of **WMA Pro** and Apple's iTunes Music Store, WMA has positioned itself as a competitor to the Advanced Audio Coding format used by Apple and is part of Microsoft's Windows Media framework.
- A large number of consumer devices, ranging from portable hand-held music players and handphones to set-top DVD players, support the playback of WMA files.

Origin

An initial reason for the development of WMA may have been that MP3 technology is patented and has to be licensed from Thomson SA for inclusion in the Microsoft Windows operating system.

Design

WMA is capable of VBR, CBR and lossless audio encoding in order to be marketed as a versatile format.
Windows Media Audio can optionally support digital rights management using a combination of elliptic curve cryptography key exchange, DES block cipher, a custom block cipher, RC4 stream cipher and the SHA-1 hashing function.
A WMA file is often encapsulated in an Advanced Systems Format (ASF) file. The resulting file may have the extension "wma" or "asf" with the "wma" extension being used only if the file is strictly audio. The ASF file format specifies how metadata about the file is to be encoded, akin to the ID3 tags used by MP3 files.

Codecs and versions

WMA began being widely distributed starting with the WMA 7 lossy compression based codec and has now reached version 9.2 (Windows Media Player 11). Microsoft's WMA bundle also includes three more codecs, a **Windows Media Audio 9 Voice** codec, **Windows Media Audio 9.2 Lossless** codec and **Windows Media Audio 10 Professional** codec (earlier known as

WMA 9 Pro). The WMA 10 Pro codec is based on a completely different technology which is not only superior to ordinary WMA in terms of quality and features, but also scales really well at low bitrates. However, the WMA Pro standard is often confused with the original WMA and thus is less popular. Also, the files are incompatible with older players and WMA Pro is yet to gain wide playback support in devices. WMA 10 Pro supports 96 KHz 24-bit audio as well as 5.1/7.1 discrete multi-channel audio.
Windows Media Player 11 is the latest version of Microsoft's media player. It adds low bitrate support for WMA Pro, support for ripping music to WMA Pro and updates the original WMA to version 9.2

Windows Media Photo (WDP)

Windows Media Photo (WMPhoto) is a still image compression algorithm and file format for continuous tone photographic images, developed by Microsoft as a part of the Windows Media family. It supports lossy as well as lossless compression, and is the preferred image format for Microsoft's XPS documents. It was previously known internally as *photon*.

Description

Windows Media Photo is an image codec that gives a high-dynamic-range image encoding while requiring only integer operations (with no divides) for both compression and decompression. It supports monochrome, RGB, CMYK and even n-channel color representation, using up to 16-bit unsigned integer representation, or up to 32-bit fixed point or floating point representation, and also supports RGBE Radiance. It may optionally include an embedded ICC color profile, to achieve consistent color representation across multiple devices. An alpha channel may be present for transparency, and EXIF and XMP metadata formats are supported. The format also supports multiple images per file. The format allows decoding part of an image, without decoding the entire image. Full decoding is also unnecessary for certain operations such as cropping, downsampling, horizontal or vertical flips, or cardinal rotations.
All color representations are transformed to an internal color representation. The transformation is entirely reversible, so, by using appropriate quantizers, both lossy and lossless compression can be achieved.

Compression algorithm

Windows Media Photo uses a reversible color space conversion, a reversible lapped bi-orthogonal transform and a non-arithmetic entropy encoding scheme, which is very efficient in preserving high frequency image data. This makes the algorithm retain a higher image quality at high compression ratios. The transform operation needs 3 multiply and add operations and 7 add or shift operations at the highest quality level and in the highest performance mode, 1 multiply and add operation and 4 add or shifts are required per pixel, giving the codec a high performance. Windows Media Photo processes images in 16x16 macroblocks.
WMPhoto supports various color formats and multiple fixed and floating point numerical representation, thus giving a wide range of compression options. To remain compatible across various devices, it differentiates *Basic* and *Advanced* formats. While digital photography needs are satisfied by the *Basic* format, 3D

rendering or advanced image processing scenarios require the *Advanced* format. Microsoft claims that Windows Media Photo offers a "perceptible image quality comparable to JPEG 2000 with computational and memory performance more closely comparable to JPEG and delivers a lossy compressed image of better perceptive quality than JPEG at less than half the file size, and that the lossless compression compresses images 2.5 times".

Container format

WMPhoto uses a TIFF-like file container to store image data in a table of *Image File Directory* (IFD) tags. A WMPhoto file contains image data, an optional alpha channel data, WMPhoto metadata, optional XMP metadata stored as XML, and optional EXIF metadata, in IFD tags. The image data is a contiguous self-contained chunk of data. The optional alpha channel, if present, is compressed as a separate image record, enabling decoding of the image data independently of transparency data in applications which do not support transparency.

Being TIFF-based, this format inherits all of the inadequacies of the TIFF format including the 4GB file-size limit, which according to the WMPhoto specification[1] "will be addressed in a future update".

Windows Media Video (WMV)

Windows Media Video (WMV) is a generic name for the set of video codec technologies developed by Microsoft. It is part of the Microsoft Windows Media framework.

Windows Media Video File Format

Windows Media Video

WMV (*.wmv) files use a subset of Microsoft's Advanced Systems Format (ASF) container format. These files can be played by players such as MPlayer or Windows Media Player, the latter being only available for Microsoft Windows and Macintosh systems. Many third-party players exist for various platforms such as Linux that use the FFmpeg implementation of the WMV codecs.

The video codec used within .wmv files is Windows Media Video. The audio codec would be either Windows Media Audio or the Sipro ACELP.net audio codec.

Windows Media Video Codecs

The codecs were originally developed as proprietary codecs for low-bitrate streaming applications. However, in 2003 Microsoft drafted a video codec specification based on its Windows Media Video version 9 codec and submitted it to the Society of Motion Picture and Television Engineers (SMPTE) for standardization. The standard was officially approved in March 2006 as SMPTE 421M, thus making the Windows Media Video 9 codec no longer a proprietary technology. Earlier versions of the codec (7 and 8) are still considered proprietary as they fall outside the SMPTE 421M standard.

WMV is not built solely on Microsoft in-house technology. It is believed that WMV version 7 (WMV1) was built upon Microsoft's own non-standard version of MPEG-4 Part 2. However, as WMV version 9 has been standardized as an independent SMPTE standard (421M, also known as VC-1), it's reasonable to believe[*citation needed*] that WMV has sufficiently evolved in a different direction than MPEG-4 to be considered a unique codec in its own right. There are currently (April 2006) 16 companies in the VC-1 patent pool. Microsoft is also one of the members of the MPEG-4 AVC/H.264 patent pool.

The video stream is often combined with an audio stream of Windows Media Audio and encapsulated in Advanced Systems Format files, carrying the .wmv or .asf file extensions.

WMV is generally packed into an Advanced Systems Format (ASF) container format. It can also be put into AVI or Matroska containers. The resulting files may be named .avi if it is an AVI-contained file, or .wmv or .asf if it is an ASF file, or .mkv if it is an MKV file. WMV can be stored in an AVI file when using the WMV9 VCM codec implementation. One common way to encode WMV in AVI is to use the VirtualDub encoder. Microsoft's Windows Media Player for the Mac does not support all WMV encoded files since it supports only the ASF file container. More files can be played with Flip4Mac and QuickTime or MPlayer for Mac OS X.

When encapsulated in ASF file format, WMV can support the controversial DRM restrictions.

Besides being a popular codec for distributing video on the Internet[*citation needed*], the codec is also used to distribute high definition video on standard DVDs in a format Microsoft has branded as WMV HD. This WMV HD content can be played back on computers or compatible DVD players.

Microsoft Media Services (MMS), the streaming transport protocol

Microsoft's streaming server **Microsoft Media Services** (also called **NetShow** Services) uses the Microsoft Media Server (MMS) protocol to transfer unicast data. MMS can be transported via UDP or TCP. If the Windows Media Player client cannot negotiate a good connection using MMS over UDP, it will resort to MMS over TCP. If that fails, the connection can be made using a modified version of HTTP (always over TCP). This is not as ideal for streaming as MMS over UDP, but ensures connectivity nonetheless.

Windows Media DRM, an implementation of digital rights management

Windows Media DRM is a digital restriction management service for the Windows Media platform. It is designed to provide secure delivery of audio and/or video content over a IP network, to a PC or device, and to restrict the user's rights of accessing his media content.

WMDRM includes the following components:

- Windows Media Rights Manager (WMRM) SDK for packaging content and issuing licenses
- Windows Media Format SDK (WMF SDK) for building Windows applications which support DRM and the Windows Media format
- Windows Media DRM for Portable Devices (WMDRM-PD) for supporting offline playback on portable devices
- Windows Media DRM for Network Devices (WMDRM-ND) for streaming protected content to devices attached to a home network

How it works

An analysis of an earlier version of the DRM scheme in Windows Media Audio revealed that it was using a combination of elliptic curve cryptography key exchange, DES block cipher, a custom block cipher, RC4 stream cipher and the SHA-1 hashing function.

Windows Media DRM is designed to be renewable, that is, it is designed on the assumption that it will be cracked and must be constantly updated by Microsoft. The result is that while the scheme has been cracked several times, it has usually not remained cracked for long.

Version 1 was released in April 1999 and supported basic business rules such as expiration dates. *Version 2* was released in January 2003 and is also known as version 7.x and 9, to keep in sync with the equivalent versions of Windows Media Player. *Version 3*, better known as DRM v10, was released in 2004. Earlier versions of the system have cracks available, meaning content protected with these versions can have the protections stripped. Version 10 was cracked in early 2005, but a software update was shortly pushed which sealed the relevant hole.

Generally, these sorts of cracks have all worked in the same way. Rather than break the encryption itself, which is practically incomputable, they hook or interfere with the "black box" component as it runs to dump out the content keys or the unencrypted content from memory. These sorts of techniques are brittle and easily patched by Microsoft via Windows Update.

Interoperability

The content delivered with the WMDRM encryption is not universally accessible but limited to those users running the Microsoft Windows OS.

Removal

Tools have been created to strip files of Windows Media DRM. For example, FairUse4WM, a program released on August 19, 2006[1] written by Viodentia has the ability to strip DRM from files protected with WMDRM version 10 and 11.[2] However, on August 28, 2006 Microsoft released a new version of the individualized blackbox component (IBX) to prevent FairUse4WM from working. Within 3 days, a new version of FairUse4WM was released circumventing this fix.[3] Microsoft informed partners that they are working to fix this issue again [4] and started threatening web site owners. [5] They soon followed up by filing lawsuits. [6] As of October 16th, distributors using the Windows Media DRM protection such as Sky By Broadband, are up and running using a patched codec.

WMV HD, Windows Media Video High Definition

Windows Media Video High Definition (WMV HD) is the marketing name for high definition videos encoded using Microsoft Windows Media Video 9 codecs. These low-complexity codecs make it possible to watch high definition movies in 1280x720 (720p) or 1920x1080 (1080p) resolutions on many modern personal computers running Microsoft Windows XP, although the hardware requirements are steep.

WMV HD is not a standalone video codec nor a special modification of the WMV9 codec. As of April 2006, all existing WMV HD titles are encoded using the VC-1 compliant Windows Media Video 9 (FourCC: WMV3) codec conforming to VC-1 Main Profile @ High Level specification. It is possible that in the future Microsoft will take advantage of the new VC-1 Advanced Profile codec dubbed Windows Media Video Advanced Profile (FourCC: WVC1) to encode WMV HD videos.

A number of WMV9-encoded high definition movie titles have been made commercially available on DVD-ROM discs, either as standalone discs or supplements to the regular DVD-Video titles. The technology was considered a stepping stone to true high definition optical disc formats (HD DVD and Blu-ray Disc) and Microsoft never intended the discs to be played on anything but personal computers. Most commercially sold WMV HD titles are copy protected using Microsoft Windows Media DRM technology. The licensing terms of DRM protected titles are determined by the content providers and not Microsoft Corporation. The soundtracks are commonly encoded using the Windows Media Audio Professional codec, often featuring 5.1 or 7.1 multichannel sound. The video and audio streams are encapsulated in Advanced Systems Format files. The future of the WMV HD DVD-ROM format is unclear as HD DVD and Blu-ray technology becomes available.

[40] **YUV**

The YUV model defines a color space in terms of one luminance and two chrominance components. YUV is used in the analog variant of the PAL system of television broadcasting, which is the standard in much of the world.

YUV models human perception of color more closely than the standard RGB model used in computer graphics hardware, but not as closely as the HSL color space and HSV color space.

Y stands for the luminance component (the brightness) and U and V are the chrominance (color) components. The YPbPr color space used in analog component video and its digital child YCbCr used in digital video (and in both digital PAL as well as in digital NTSC) are more or less derived from it (Cb/Pb and Cr/Pr are deviations from grey on blue-yellow and red-cyan axes whereas U and V are blue-luminance and red-luminance differences), and are sometimes inaccurately called "YUV". The YIQ color space used in the analog NTSC television broadcasting system is related to it, although in a more complex way.

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