Barcode Scanners, MiniDV Decks, and the Migration of Digital Information from Analog Surfaces

by Dave Rice and Stefan Elnabli
AudioVisual Preservation Solutions

avps

October 2010

Introduction: Authentication of the Digital Replica from Media-Based Origins

Cover Image: Barcode on paper surface and DV recording on metal evaporated tape.
Both represent digital information on susceptible surfaces and both contain parity data to enable assessment of accurate reads.

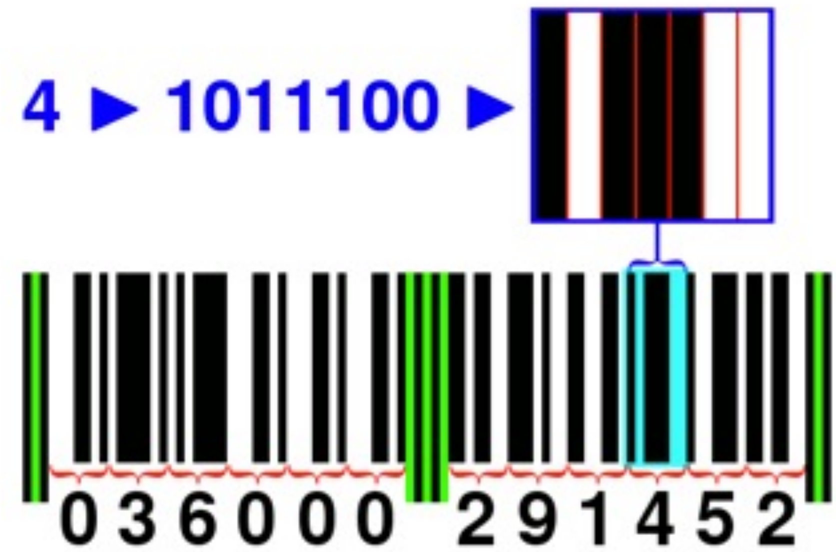
Due to the susceptibility and challenges of both digital and analog carriers, data must be periodically moved from one carrier to another within a preservation process. When analog data is migrated from its original carrier to a new digital carrier, the analog data is ultimately transformed through the process of sampling. Challenges are then posed to authenticating the accuracy of such a migration. Despite the perceptual exactness of an analog source to its digital copy, the analog data and the digital data are never exactly the same. However, in the realm of file-based digital-to-digital migration, exactness can be achieved and evaluated. Within the entirely file-based environment, checksums and data comparison tools can verify that two copies are exact matches or reveal their deviation in a way that is not feasible between analog and digital environments.
This report examines the evaluation of accurate replication of data within a third category of migration: digital tape to digital file. In this scenario, traditional video digitization sampling strategies are not necessary and digital authenticity tools such as checksums cannot be applied to digital tape. Furthermore, an exact digital migration from tape to file may be achieved.

To review the unique challenges and strategies in the migration of digital data from a physical object to a file-based system, the report examines the storage of data in UPC barcodes. Following this, the report will focus specifically on the preservation of digital DV videotapes. Based on this evaluation, the report will draw conclusions about authentication of digital tape-to-file migrations and provide recommendations on how to implement this practice in the context of audiovisual preservation.

Digital on Paper: The UPC Barcode, Parity Data, and Verified Scanning

We witness the reading of UPC Barcodes multiple times per day. The UPC Barcode stores data that enables the identification and management of items within and across systems. The UPC barcode also contains data that ensures correct operation of the barcode scanner. When barcodes are stored on unstable surfaces such as paper, plastic or cardboard, problems can occur in reading the data. For example, if a barcode is on a wrinkled, smudged, or stained surface and it is misinterpreted by the scanner, an inaccurate identifier should be prevented from passing through the system.

The reading of a barcode is verified for accuracy using a 'check digit'. The UPC barcode is 12 digits long. The last digit is the 'check digit' and serves as a redundancy check of the other 11 numbers. If a UPC barcode is read as '0 36000 29145 2', the accuracy can be evaluated using the following calculation:



UPC Barcodes: http://commons.wikimedia.org/wiki/File:UPC_EANUCC-12_barcode.png

Sample Barcode Value
0 3 6 0 0 0 2 9 1 4 5 2

Step 1: Add odd positions (digits 1,3,5,7,9 and 11)
0 + 6 + 0 + 2 + 1 + 5 = 14
Step 2: Add even positions, excluding the 12th (digits 2, 4, 6, 8 and 10)
3 + 0 + 0 + 9 + 4 = 16
Step 3: Take the result of Step 1 and multiply by 3, then add result of Step 2
(14 X 3) + 16 = 58
Step 4: Determine the difference between the result of step 3 and the next highest multiple of 10
58 + **2** = 60
The check digit (12th digit in the barcode) is 2.

This system allows for 100% detection of single-digit scan errors and 90% detection of multiple-digit scan errors. Additional specifications regarding the binary form and structure of the barcode digits further reduces the probability of error. Together the check digit and formatting rules of the barcode form a data integrity solution for the reading of data, encoded as UPC barcodes, from physical analog surfaces.

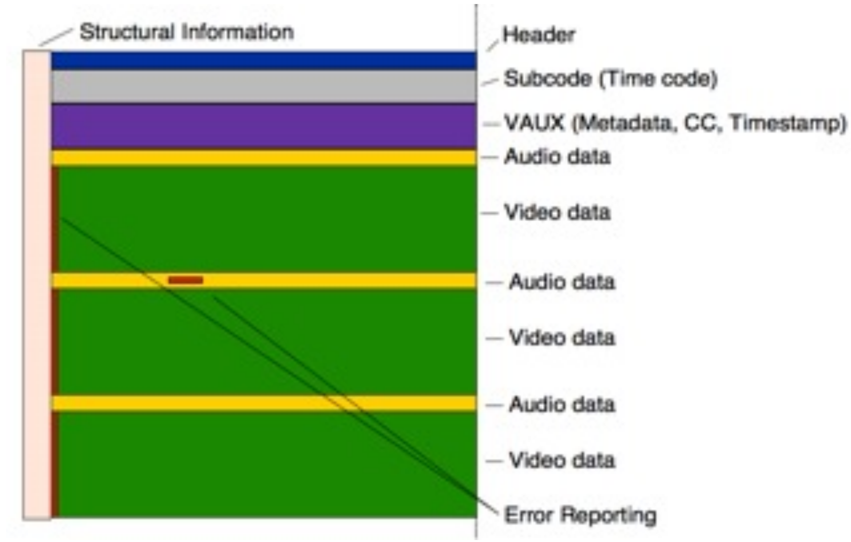
DV as Tape-Based Digital Video

Opened miniDV tape and decoded DV video, timecode and camera data.

Like barcode values on a piece of paper, DV tape stores digital information on a highly susceptible surface. This data represents video, audio, timecode, and technical metadata while potentially representing closed captioning, camera settings, and date and time of recording. Analogous to barcode verification, when DV data is recorded to tape, **check digits**, referred to as ‘parity data’, are included as a redundancy check. During the playback of a DV tape, the deck reads both the audiovisual data and the parity data from the surface of the tape. By evaluating these two data sets against each other, the deck determines if the data was read correctly or misread. Many factors can challenge an accurate read from digital tape, such as scratches, poorly aligned or dirty record or playback heads, deterioration, and damage. Whether the problems occur in the recording deck, playback deck or on the surface of the tape itself, the consequences of misread data from a DV tape are commonly recognized as dropped frames, audio dropouts, and video glitches. Additionally, one playback pass may yield differing results than the next with a likelihood of variance when transitioning from one deck to another.

The PAL DV frame is made of 12 DIF sequences. Each DIF Sequences is made of 150 DIF blocks: 135 for video, 9 for audio, 3 for video metadata, 2 for subcode or timecode, and 1 as a header to the DIF sequence. A full PAL DV frame thus contains 1,800 DIF blocks. SMPTE and IEC standards define how a playback deck should react to the identification of a misread DIF block. Rather than knowingly pass inaccurate data, the standard defines a methodology to both conceal and report the error in order to limit the visual or sonic effect of the inaccuracy while simultaneously documenting it in the outbound DV stream. Error concealment is detectable both quantitatively and qualitatively and its assessment is a meaningful aspect of the preservation process.

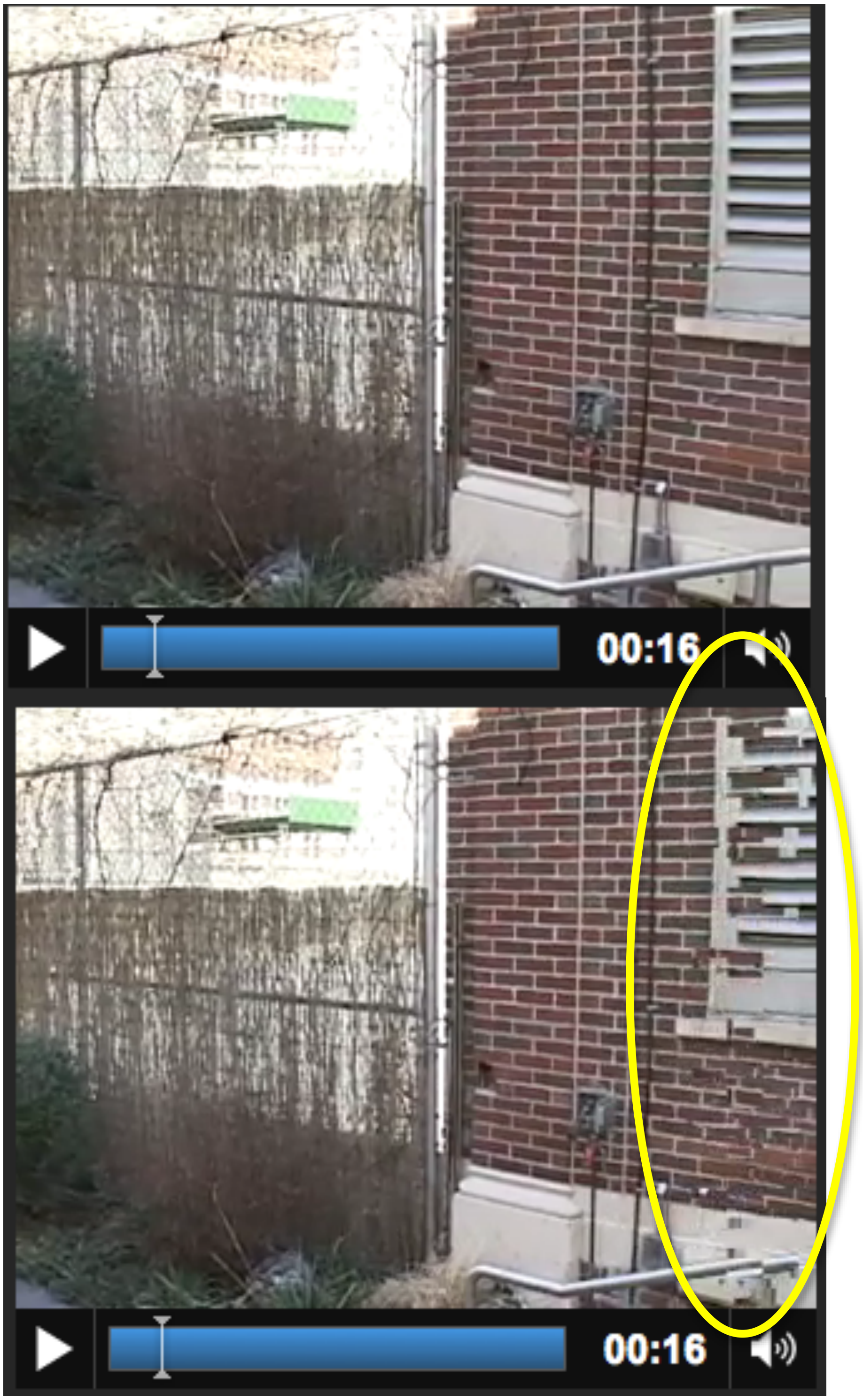
Demonstration of DIF block ordering.
1500 NTSC DIF blocks changed from an image of color bars to black in the order that the blocks occur in the file. Video available at:
http://ia311036.us.archive.org/3/items/DifBlockReplacement/dif_block_replacement_512kb.mp4



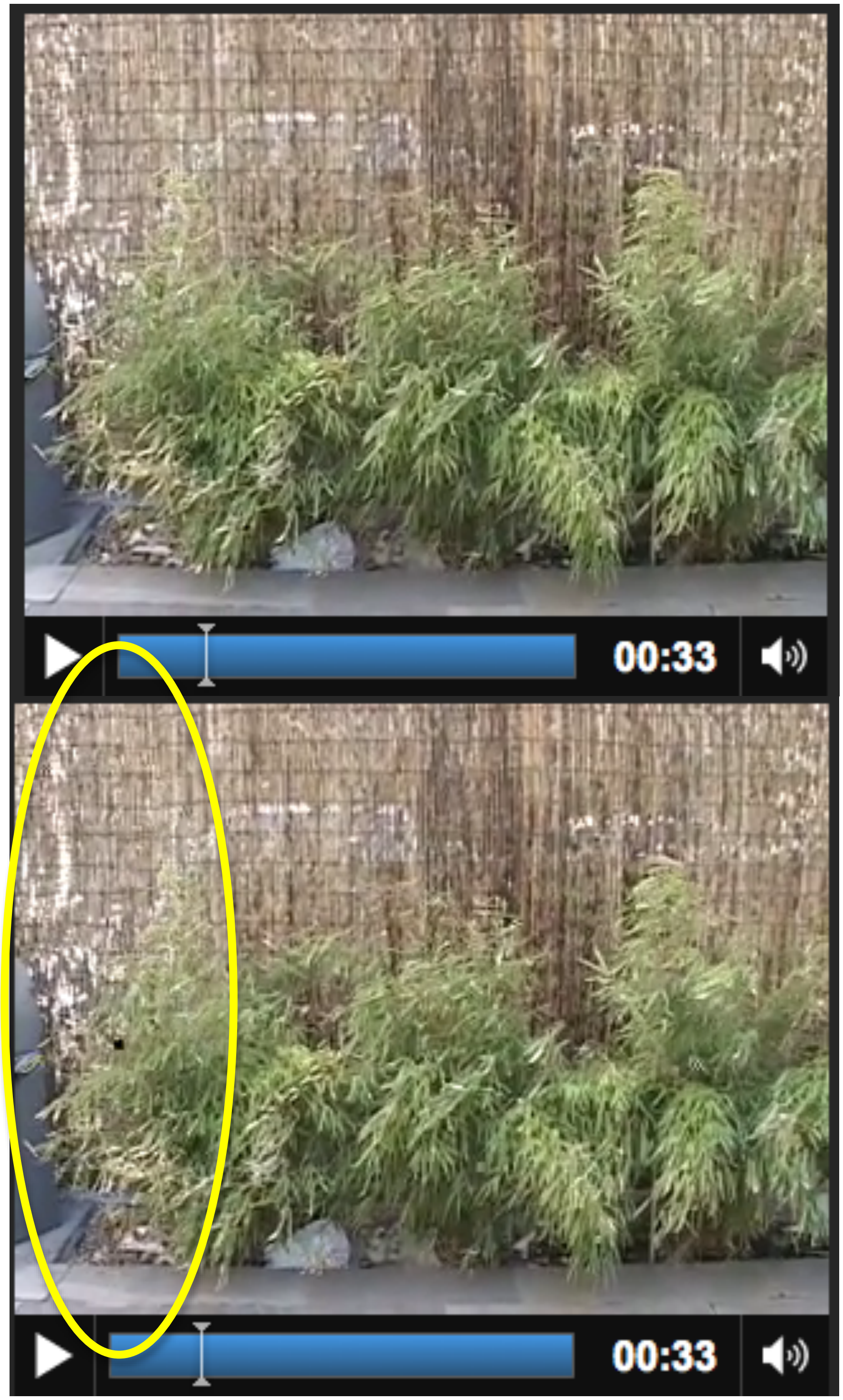
Interpretation of DV where each horizontal line represents an 80 byte DIF block.

In the case of misread video data, the most common strategy employed by the deck is to patch the misread DIF block with the corresponding block from the prior frame. This method allows for errors in static scenes with minimal action to go relatively unnoticed by the viewer; however, in scenes where the camera is moving, concealment may be evidenced by the presence of some blocks of pixels that do not move from one frame to the other, creating a visual artifact. Within the DV data stream that travels from the playback deck over FireWire, concealed DIF blocks are identified using a non-visual flag in order to declare that it is not part of the DV frame in which it is seen, but rather a digital patch to cover misread data.

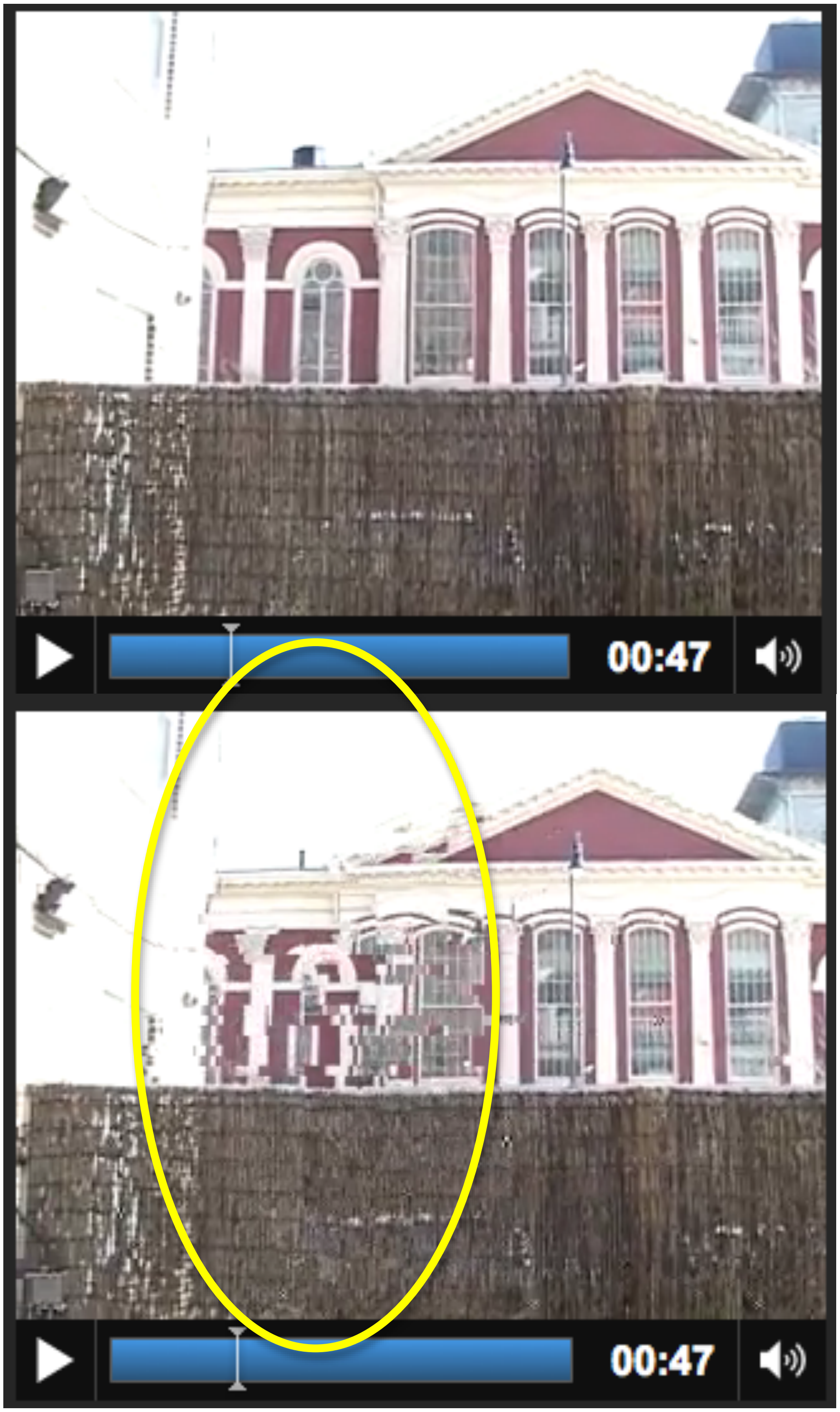
The following images are screenshots from two videos comparing playback of original DV recording and playback of original DV recording after extensive damage to the tape surface. Full video examples available at:
http://www.archive.org/download/avps_dv_damage_before_and_after/S-test-damage-1_cat_512kb.mp4
http://www.archive.org/download/avps_dv_damage_before_and_after/S-test-1-0_00_01_02_512kb.mp4



00:11-00:25 vertical scratches down the top of the tape (note replacement of pixels and distortion in right side of image)

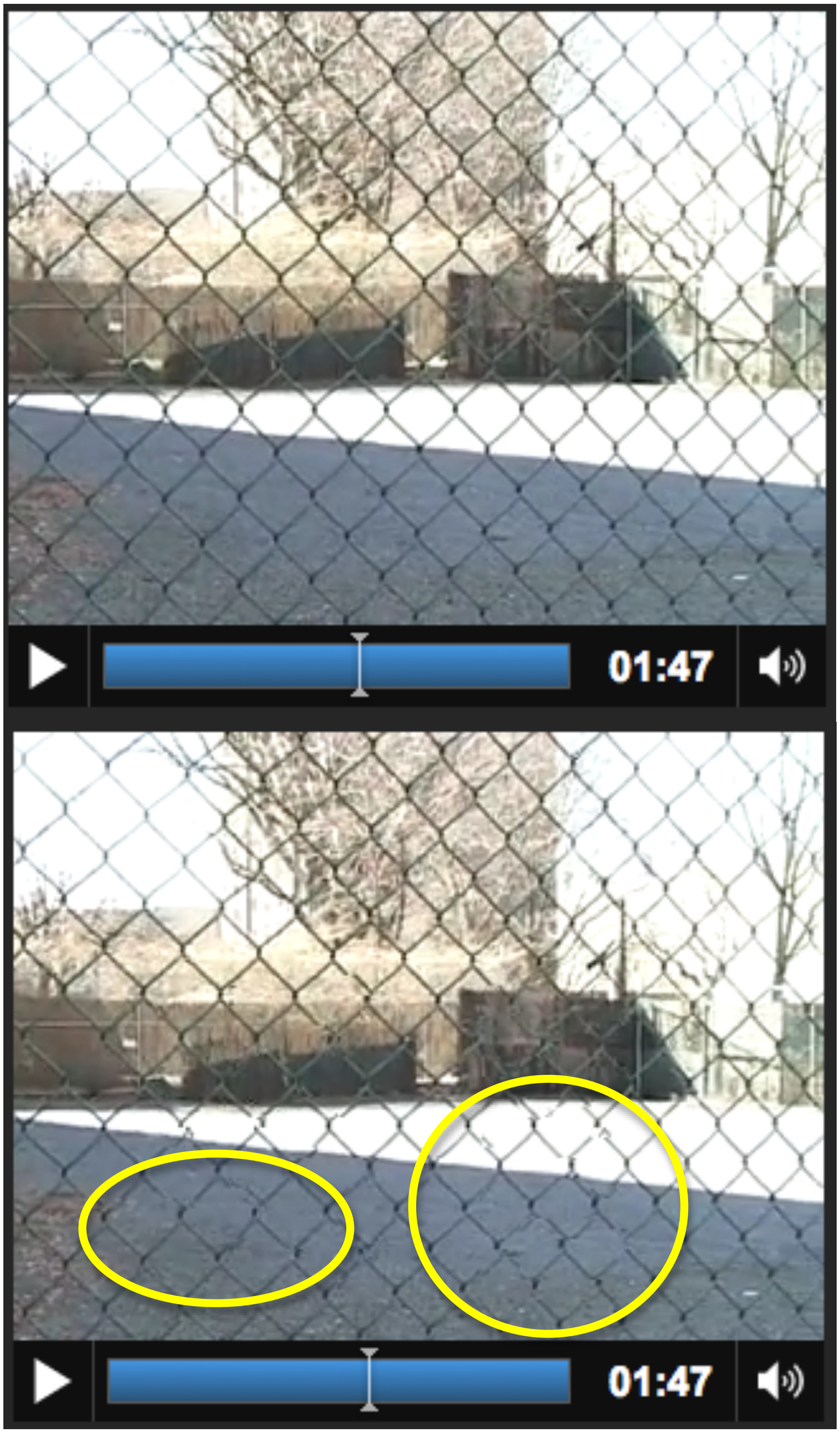


00:26-00:35 vertical scratches down the bottom of the tape (note missing pixel and distortion in left side of image)

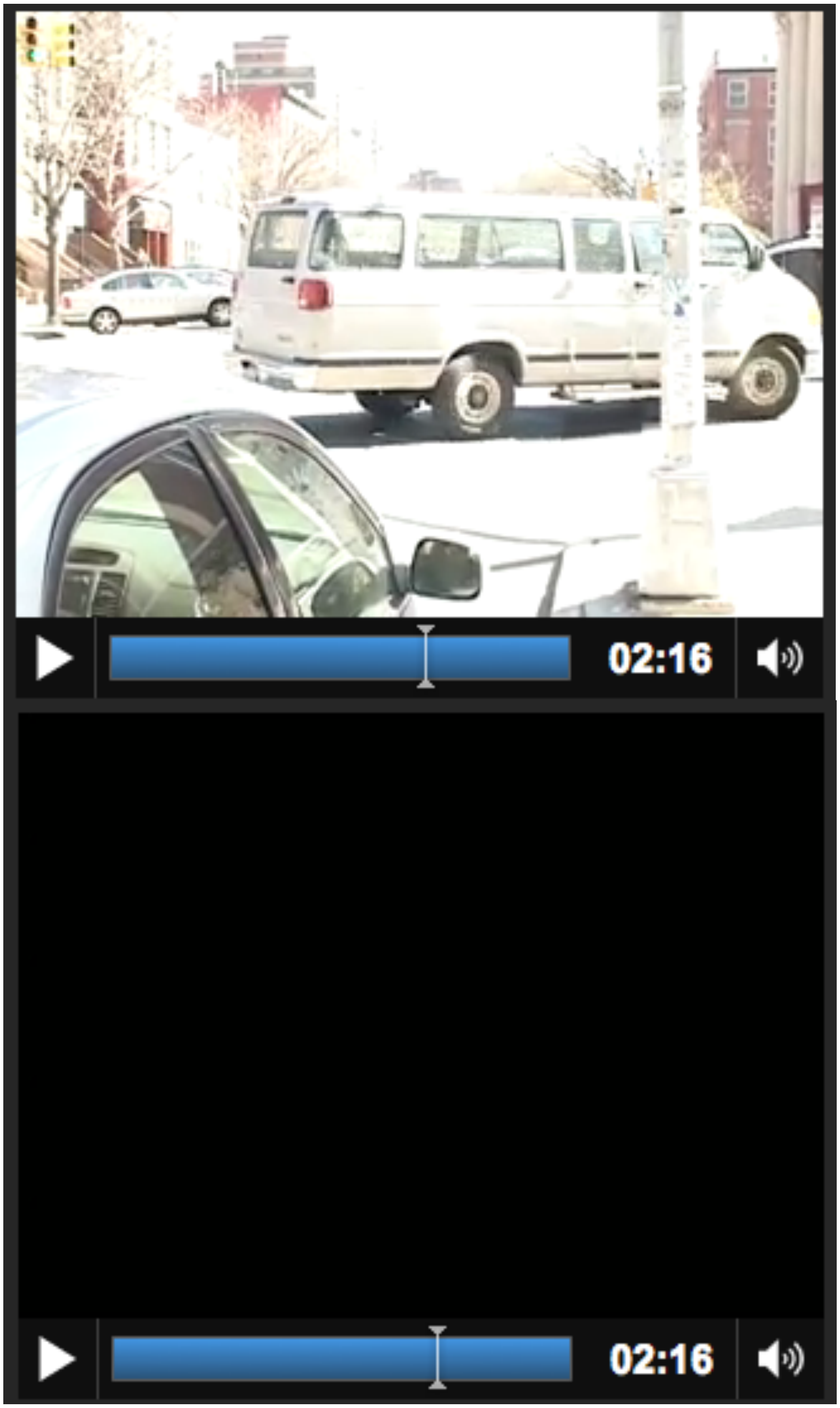


00:41-00:54 vertical scratches down the middle of the tape

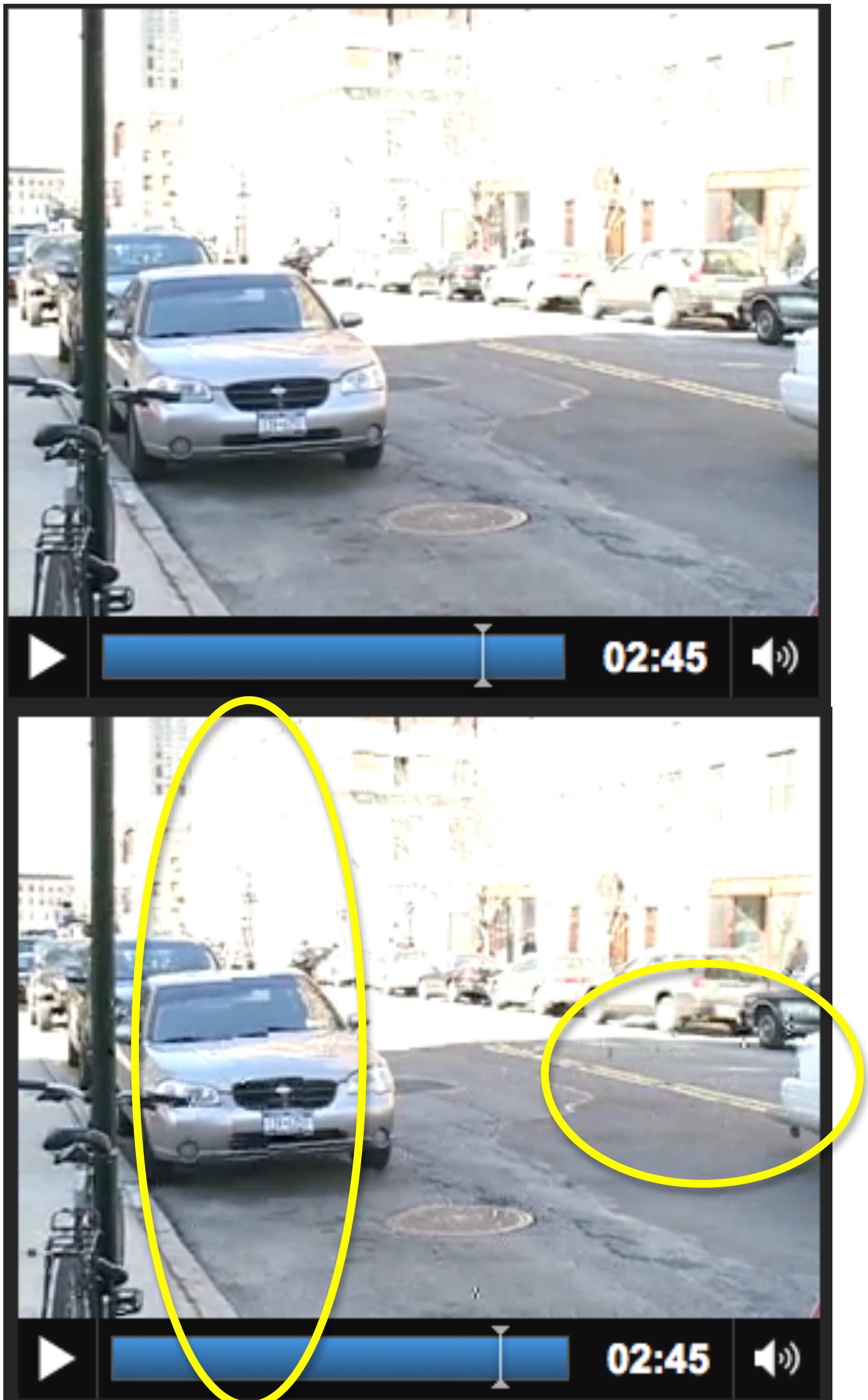
01:12-01:26 criss-cross scratches



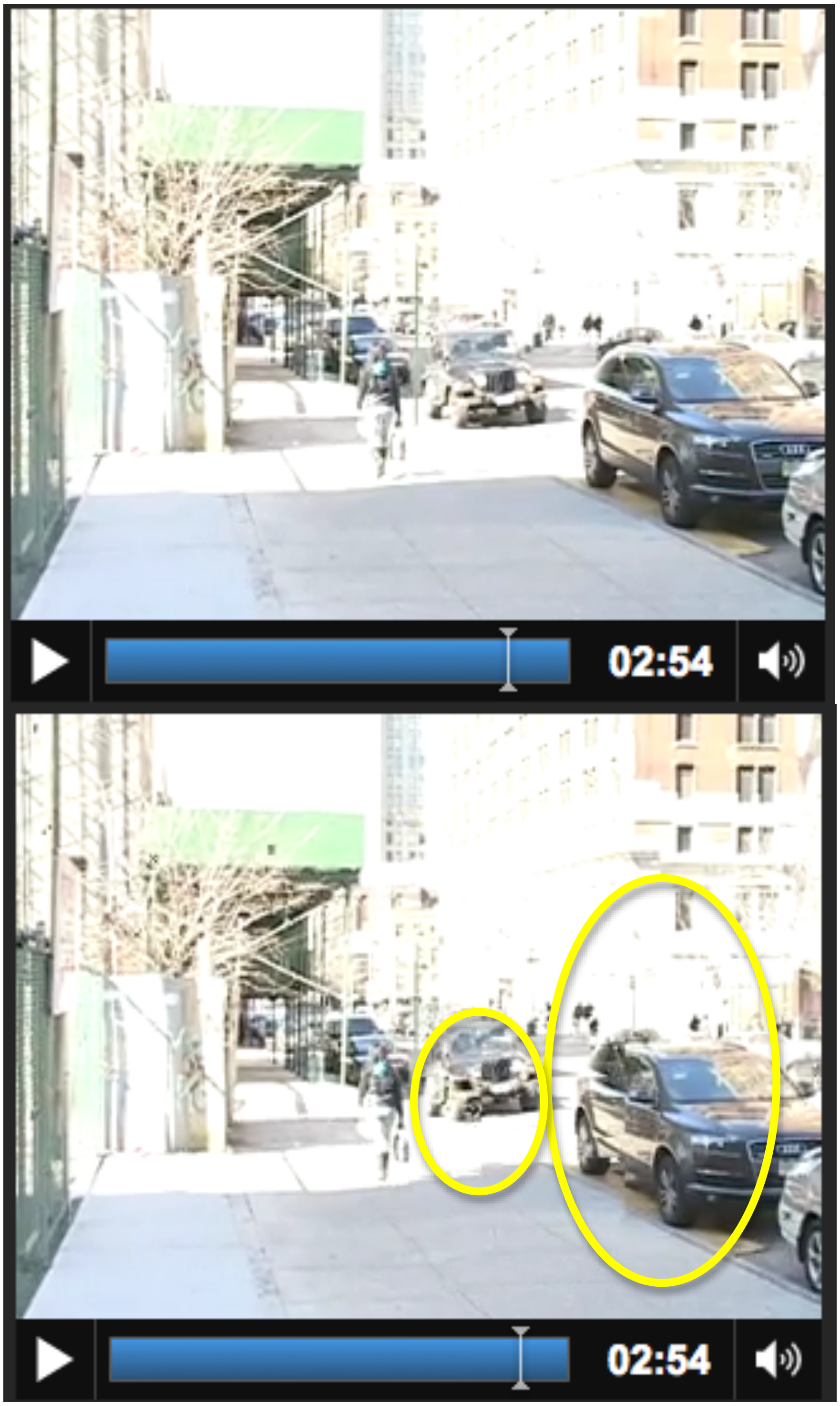
01:41-01:51 pin-pricks (note distortion in chain link fence)



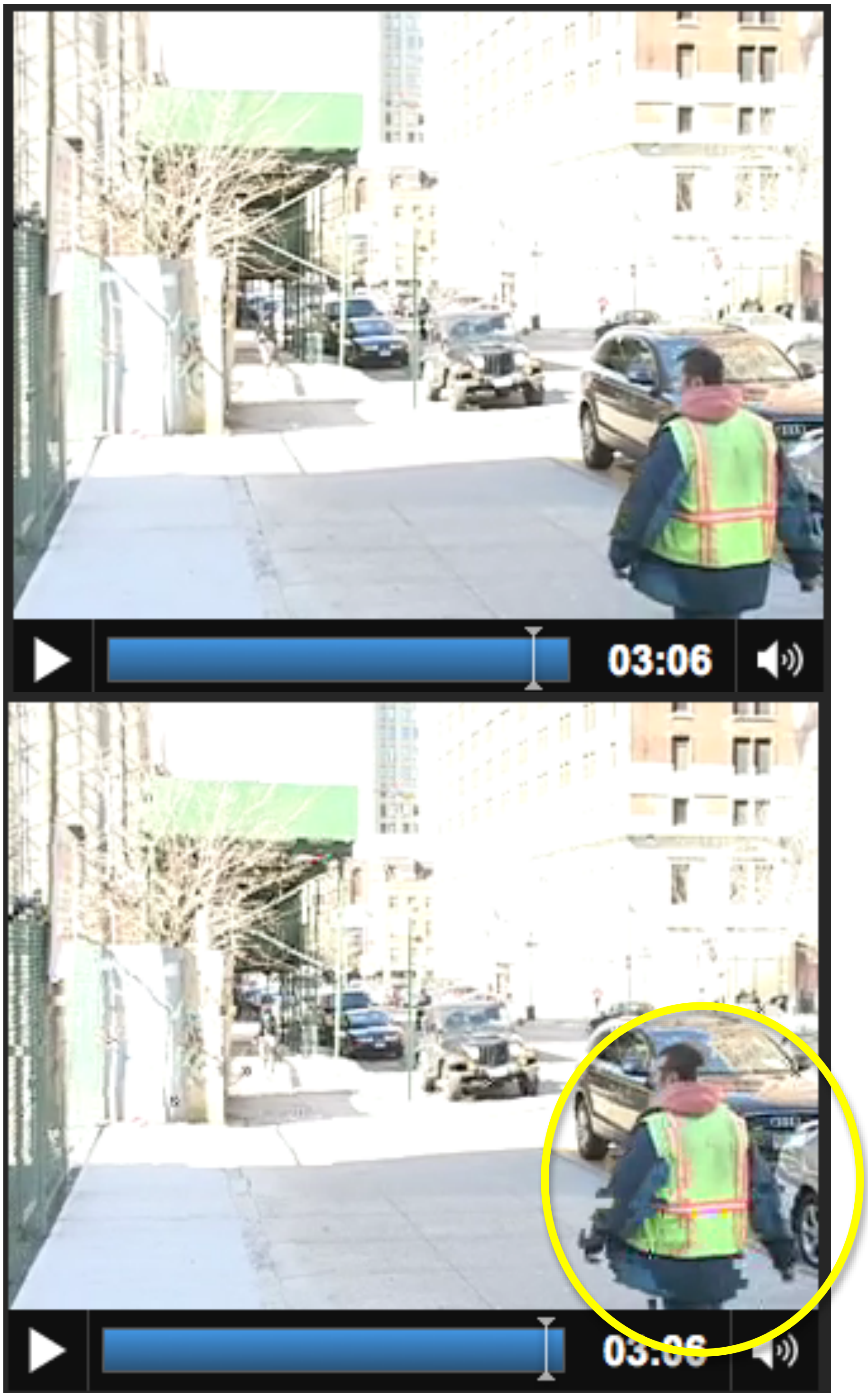
02:12-02:27 Demagnetization



02:42-02:52 creasing section (inside, outside)



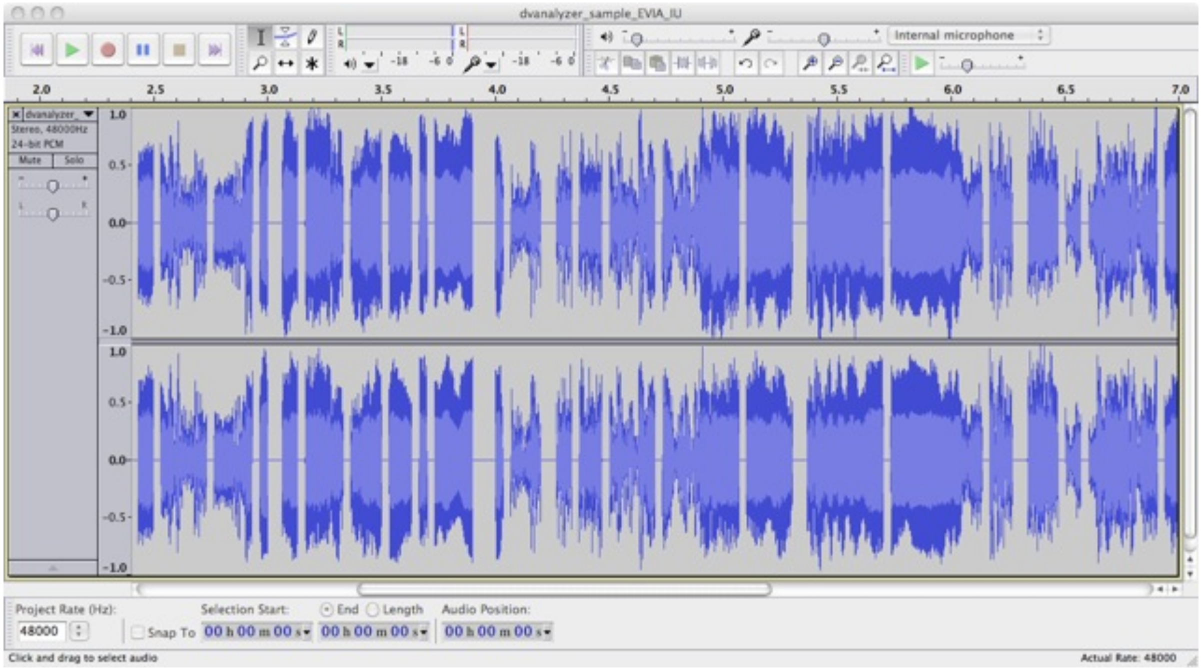
02:53-02:55 middle folding



03:04-03:07 crinkling

Playback of original DV recording after extensive damage to the tape surface
In this version all DIF blocks where the deck used video error concealment (digitally noted in the file coming over FireWire) were substituted with the color red. Full video available at http://www.archive.org/download/avps_dv_damage_before_and_after/S-test-damage-1_cat_red_512kb.mp4

In the case of misread audio data, the strategies for concealment are more limiting. While duplicating data from a prior frame to cover errors in the next can be an effective strategy for video error concealment, the same cannot be said for audio. For audio, a single audio sample value, the negative full-scale audio sample value, is reserved as the audio error code. Since this code is stored within the audio data payload, it will play back as silence (i.e., dropout).



Errors in reading the audio from the tape.
The deck outputs audio sample value 0×80 (which plays back as silence) as the audio error.

The **identification of video error concealment** and **audio errors** in the resulting file-based DV stream can aid in evaluating the quality of the tape-to-file migration process. When an audio dropout occurs in an otherwise silent portion of the recording, or video error concealment occurs in a static scene, the audiovisual result during playback may be difficult to detect. On the other hand, if audio dropout occurs during a key soundbite or video error concealment renders patches of glitchy video during an active scene, the result can compromise the integrity and authenticity of the data migration. Whatever the resulting aesthetic effect of error concealment, the resulting digital file represents a change from the original data on the digital tape.

Last year AudioVisual Preservation Solutions initiated a project to design and develop a free, open source application to exploit DV error documentation mechanisms and released **DVAnalyzer** (http://www.avpreserve.com/dvanalyzer/), a tool that reports the presence, location, extent and classification of errors at the frame level.

In addition to reporting on video error concealment and audio dropout, DVAnalyzer reports on frame-level temporal metadata including scene start and stop recording flags, continuity and gaps in recording date, time, and timecode. All of this metadata can be used to assess provenance, authenticity, and descriptive qualities of the content. Exploitation of this data enables a highly efficient and cost effective strategy to optimize expertise by allowing the focus of quality control to sections of DV files that are identified as having errors. This ultimately helps determine whether a second pass of the tape may provide an improvement, whether to service or change a deck, or whether to adjust the playback strategy for a more authentic digital copy.

It is important to note that the functionality of error identification and DVAnalyzer depends on the capturing method employed. Traditional AV outputs such as composite, component and SDI transform the original data and do not allow for comprehensive transfer of embedded metadata in the DV stream. Thus, DVAnalyzer depends on a capturing method that employs a FireWire interface, preserving the most accurate migration of DV data from tape to file.

Next Steps: The Testing Phase

Working with Stefan Elnabli, a graduate of New York University's Moving Image Archiving and Preservation program, we performed a controlled damage test to systematically analyze and report on the effect of various types of damage to DV tape.

To begin, 3 minutes of content were recorded to DV tape and captured. We then proceeded to open and unspool the tape, marking off sections of the tape for differing types of damage. The tape damage performed included scratching, folding, pinpricking, crinkling, and demagnetization. Each damage type and section was documented before spooling and closing the tape. The 3 minutes of unspooled DV tape was equal to the surface area of less than half a sheet of paper. We then captured the content multiple times using various combinations of hardware and software and used DVAnalyzer to generate extensive reports for further analysis and investigation. This gave us unique and precise data on the degree to which decisions regarding hardware and software selection impacts authenticity of DV migration.


Recording DV


Capturing DV

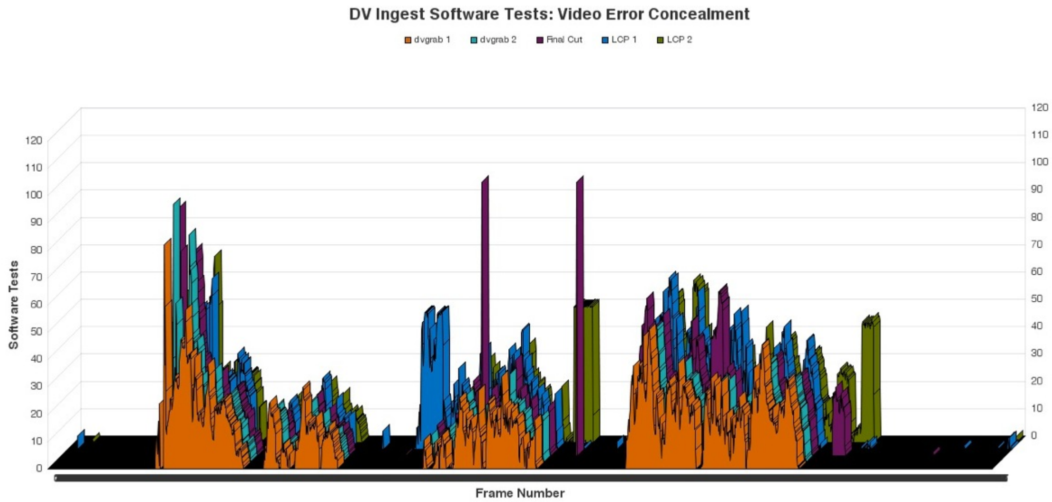

Damaging DV

All tests and strategies for DV tape-to-file preservation throughout this experiment were designed to migrate DV data from the tape domain to the file-based domain with careful attention to avoid unnecessary transcoding, digital manipulation, and generation loss to the greatest extent possible. To maintain this level of control, all captures were performed by migrating the data from various decks to the same computer via FireWire interface.

DV Ingest Software Tests

For DV ingest software, we selected Live Capture Plus, Final Cut Pro, and dvgrab. When attempting to capture a heavily damaged tape with these various tools, we identified a key workflow and the performance issues that distinguish each software.

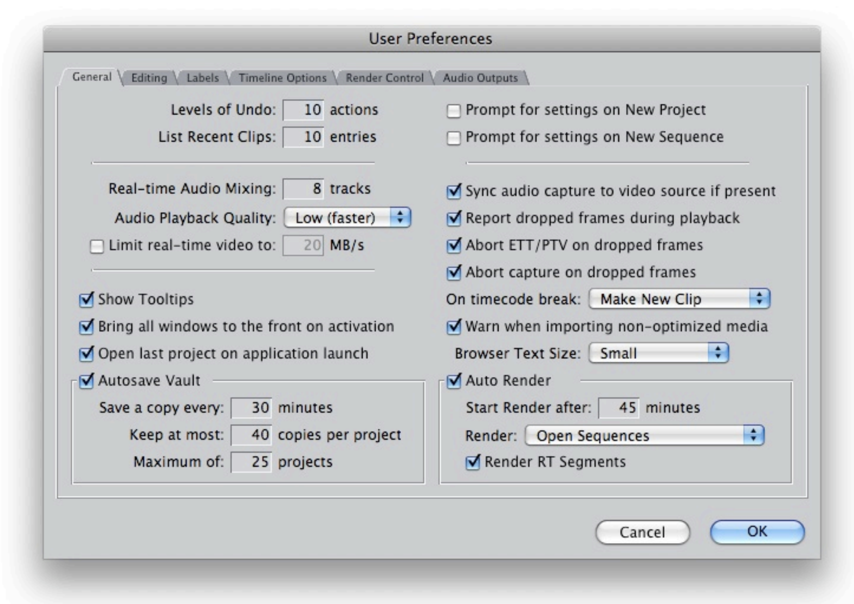
All software tests were performed using the same hardware setup, which included the original camera that shot the tape, a Sony DCR-VX2000, and the same MacBook Pro laptop running both the Mac and Ubuntu operating systems.



Charting of percentage of video error concealment per frame over the playback timeline for various software tests

DV Ingest Intention: Authenticity vs. Conformance

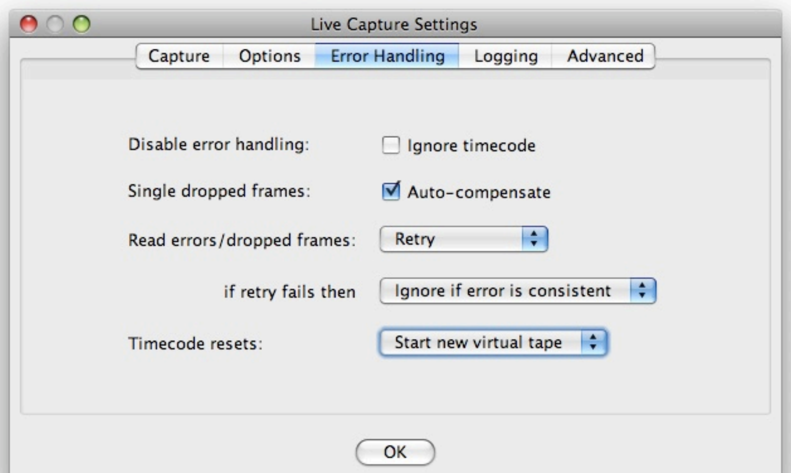
Both Live Capture Plus and dvgrab appeared to operate in a manner where the default action would be to migrate the DV stream from the tape as is without adjustments to frame size, audio sampling rate, frame rate, or color space. On the other hand, Final Cut Pro required greater user input as to what the intended result of capture would be. When using Final Cut Pro, we had to be careful to ensure that we matched the capture settings in the software to the technical specifications of the tape in order to ensure the most authentic copy possible.



Tolerance of Handling Damaged Media

During the migration process, each software reacted differently to extreme tape damage. Final Cut Pro frequently aborted the capture and generated a brief error message with each abort. Whenever Final Cut aborted the capture, we had to initiate a new capture from the current tape position.

Live Capture Plus provided options to set how the software would react to errors. Live Capture Plus pays particular attention to inconsistencies in DV's embedded timecode track. Under certain settings, when Live Capture Plus is capturing a tape and encounters timecode errors, it pauses the capture, rewinds the tape, and automatically requeues the capture for a second pass over a problematic area.



dvgrab did not abort at any point in the software capture tests and was able to ingest nearly every frame during the capture process.

By analyzing the resulting files with DVAnalyzer, one can see similarities among the ways that the software applications captured the files. We observed that peaks of video error concealment corresponded to controlled tape damage with a noticeable correlation between the severity of the damage and the level of video error concealment employed during playback.

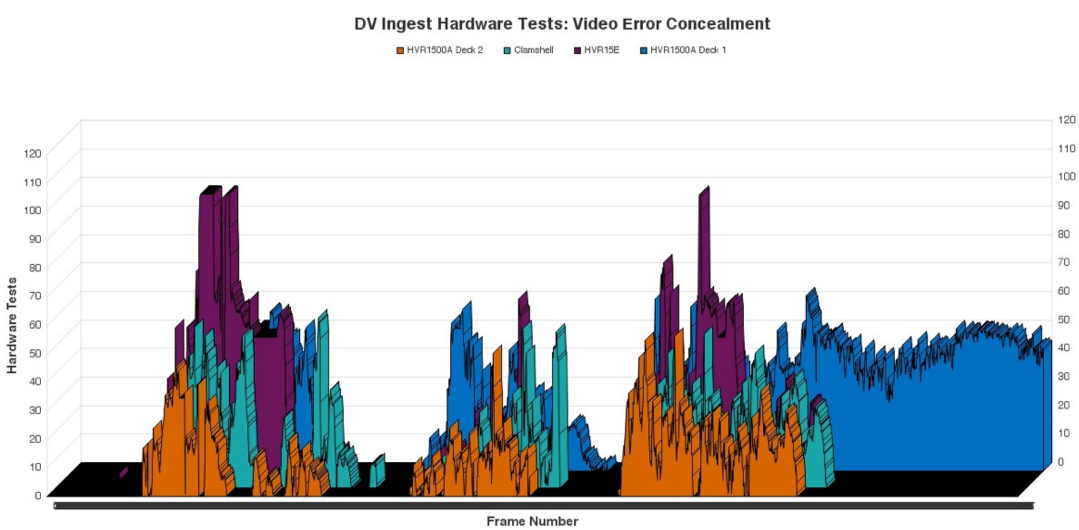
In the resulting files, we found that for each capture approximately 30.5% to 34.5% of the frames contained some degree of video error concealment. For audio, between 10.5% and 11.5% of frames contained audio errors. The results were such that we were not able to identify a correlation between accuracy and a given software application.

Regarding other aspects of the software tests, we noticed that Live Capture Plus provided the most comprehensive settings for error handling, while dvgrab provided the simplest workflow and highest success at handling dropped frames.

DV Ingest Hardware Tests

Similar to the design of the software tests, the hardware tests utilized a single software and capturing computer as controls in order to test DV ingest from a variety of DV decks, including newer and older models as well as high-end and low-end decks. Based on our experience in the software tests, we decided to use dvgrab as the capturing software for all the hardware tests due to its ability to capture the entire DV stream without stopping for damaged areas, allowing for the least amount of human intervention.

The hardware test utilized multiple passes on the DSR-11, DSR-1500A, HVR-15E, HVR-1500A, Sony Clamshell (Sony GV D1000), and the source camera that originally recorded the control tape, the Sony DCR-VX2000.



Charting of percentage of video error concealment per frame over the playback timeline for various hardware tests

As expected, the hardware tests revealed more notable variations between decks than the software tests. The total percentage of frames that included video error concealment ranged from 30.7% (roughly the same low-end range as the software tests) to 86%. Additionally we discovered that decks responded to errors in different ways, sometimes in manners inconsistent with SMPTE's DV standard documentation.

The highest-end deck we tested was the Sony HVR-1500A. The facility in which we tested had two of these decks, one in heavy daily use and the other as a backup deck. The playback from the first deck produced the most error-heavy file of the tests, probably due to head clog, effectively hiding half of the video data for a substantial section of playback. Additionally we found that on audio errors the HVR-1500A did not output the specified DV audio error code value from the standard, but used a repeated pattern of numerically close sample values. Instead of audio read errors represented as a dropout, the deck rendered them as a low frequency tone. The same playback on the second, less-used HVR-1500A produced the best results of all the decks with respect to video error concealment, but it also exhibited the same mishandling of the DV audio error code.

Excluding the outlier file from the heavily used HVR-1500A deck, where 86% of the file's total frames contained error concealment, the files resulting from each deck differed by only a range of 10%. Files resulting from the good HVR-1500A and the DSR-11 had 30.7% and 40.6% of total frames with error concealment respectively. Both the Clamshell and the HVR-15E tests resulted in files with 32% of total frames containing error concealment. These results did not allow us to identify a correlation between accuracy and a given hardware. However, the different performance between the two HVR-1500A machines, which were purchased new and at the same time, demonstrates the effects of wear and tear, or lack of deck cleaning and maintenance. For video error concealment, the good HVR-1500A deck produced the most authentic DV migration and the bad HVR-1500A deck produced the least authentic DV migration throughout all the tests.

Conclusion

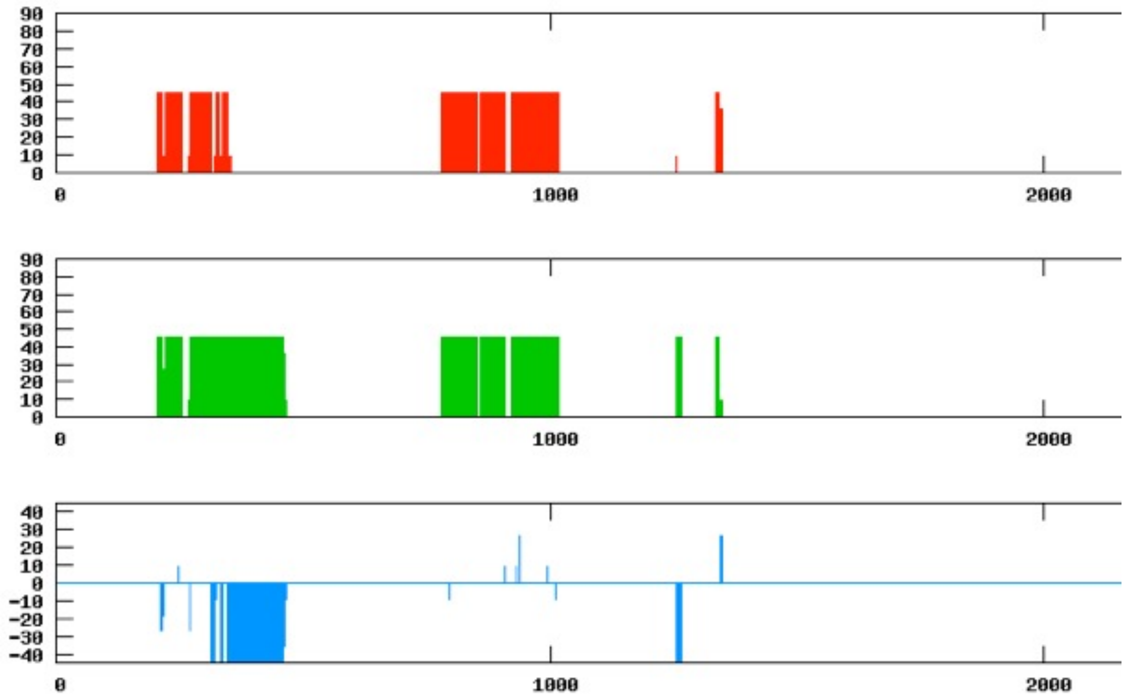
Using the results from these tests, we identified slight preferences for hardware and software, and a strong preference for well-maintained hardware. With respect to software, Live Capture Plus allowed the most user-control over handling of errors in the migration process but took longer than dvgrab due to Live Capture Plus' re-queuing process. While Live Capture Plus allowed the user to have more control over handling of errors in the DV stream, dvgrab allowed for the most streamlined process, taking less time. While there was no strong integrity advantage of a specific software application for tape-to-file migration, these observations are important to workflow considerations. With respect to hardware, the HVR-1500A performed the best, but extreme variations in the performance between the two HVR-1500A decks proved that deck maintenance is a much greater concern than selection of software if one is to weigh authenticity of tape-to-file migration.

These results lead us to the next step in the development of DVAnalyzer. Throughout the testing process we gathered detailed information that confirmed what we already know – that miniDV is an overall finicky format. In many cases, miniDV performs differently from one playback to the next. In areas of a tape where physical damage exists, consistency in errors among different migrations is generally observed. However, in cases where tapes are known to not have physical damage, DVAnalyzer has shown that captured files sometimes contain slightly different errors from one pass to the next. Because the DV format numbers each DIF block and each frame in a combination of sequential patterns, identification systems, and timecode, we theorize that two captures of a DV tape can be patched together through an automated process to generate a third copy that combines the preferred DIF blocks from each of the two passes, resulting in a best-effort restoration. We are in the midst of planning a feasibility study of this approach which would then inform extended development of the DVAnalyzer tool for performing comparative analyses on multiple files and managing combinatory derivative creation.

169	9.78	9.93	10.15	11.85	14.44	10.22	9.78
170	10.89	12.07	12.52	13.70	17.26	12.89	11.04
171	13.33	14.67	15.63	16.89	20.30	15.93	13.78
172	11.93	12.67	13.63	14.59	19.41	14.30	12.22
173	11.93	12.89	15.78	16.37	21.33	14.52	12.30
174	10.74	11.41	17.04	17.85	21.48	15.04	10.67
175	13.19	14.37	15.93	16.37	20.81	15.78	13.41
176	13.93	14.07	14.74	15.26	17.19	14.22	14.15
177	13.19	13.63	13.85	14.07	15.41	13.70	13.33
178	12.15	11.93	13.19	12.15	13.63	11.85	11.56
179	10.30	10.67	12.52	10.67	14.00	9.04	10.22
180	14.15	14.67	16.22	15.78	18.07	14.89	13.93
181	11.70	12.15	13.26	12.89	22.74	12.22	12.07
182	10.59	12.07	12.67	12.89	22.37	12.00	11.41
183	12.96	13.04	13.93	14.37	23.33	13.19	12.74
184	11.70	11.56	12.07	11.85	20.67	11.56	11.19
185	9.33	9.56	9.78	10.07	19.41	9.70	9.48
186	9.33	9.63	10.22	10.30	20.07	10.59	9.48
187	12.22	11.70	12.89	13.93	22.96	12.15	11.93
188	15.56	16.30	17.04	17.04	24.15	16.52	15.93
189	15.85	16.74	17.26	16.74	25.48	16.59	16.22
190	10.81	10.96	12.30	11.85	20.00	11.11	11.41
191	16.59	16.81	17.70	17.48	26.07	16.96	16.96
192	10.37	10.59	11.56	11.48	20.44	10.81	9.78
193	8.89	8.52	10.15	9.56	20.74	9.33	9.11
194	1.56	3.04	1.78	3.11	14.00	3.19	2.37
195	5.33	4.67	6.59	6.37	17.93	4.30	6.00
196	4.74	5.41	5.85	7.04	16.07	6.44	6.67
197	0.89	0	3.41	0.89	13.19	0.96	0
198	9.11	8.52	11.26	10.44	19.70	9.04	8.59
199	16.59	15.78	15.93	15.33	26.67	14.44	17.33
200	36.74	38.30	40.44	34.59	60.00	33.11	26.67

This table shows the percent of video error concealment per single frame for frames 169 through 200.
Each column represents an attempted ingest of the DV data.
Green cells show the best capture of the frame and red cells show the worst.
While it is clear that the fifth ingest was the least accurate, there is no ingest that is clearly the most accurate.
Theoretically, multiple ingests could be consolidated into a single DV stream based on the most accurate frames for each ingest, thereby making a better file.

Another challenge is to determine a methodology to effectively interpret such an analysis in order to choose an effective preservation strategy. When should the preservationist redigitize? Distinguishing the cause of the errors may enable a more effective response. If the DV tape is captured poorly because the tape is physically damaged, then there may be little that can be done to improve the capture. If the tape is captured poorly because of an issue with a deck, then this could be rectified.



Number of audio DIF blocks dropped per frame per head (from zero to 45).
Red represents audio dropouts from head 1.
Green represents audio dropouts from head 2.
Blue represents error differences between the 2 heads on the same frame.

By observing the amount of errors that the deck reports per frame, the archivist may focus their attention to areas where there are known errors. By further assessing these errors per playback head, the response can become more effective. When there is minimal difference between the amounts of errors of the two heads during a given frame, there is likely damage on the tape (which will be harder to improve with a subsequent recapture). When one head's errors per frame differ greatly from the other head's errors per frame, then there is likely a head clog or a read error. In this scenario, an improved ingest on a second pass may be achieved after cleaning the clogged heads.

Recognizing the physical variables in digital tape-to-file migration is an important step in evaluating the authenticity of the digital file in relation to its tape-based source. This process of evaluation not only considers the quantitative results of a file after migration, but the physical components of tape and playback machinery. Equally measuring these considerations informs the archivist about how to locate weaknesses in the migration process and conform the workflow to the realities of digitization projects. They inform the archivist on matters of provenance, authenticity and integrity. Questions thus arise: Does the ingest software provide error handling options and does it handle errors with or without human intervention? Does the process utilized facilitate or prevent opportunities for automated documentation and assessment of quality control data? Does the physical tape have damage and how can it be characterized? Have the playback decks been properly maintained? Utilizing tools like **DVAnalyzer** to measure quantitative results of DV migration does not give the answers to these questions, but provides critical evidence in support of the answers. The audiovisual archivist must recognize that tape-to-file migration is not solely a data process or solely a video process, but a process in which data, physical media, and componentry are intertwined. In such a light, digital audiovisual preservation tends toward a practice of practicality, and its mysterious inconsistencies no longer remain hidden in bits and bytes.

Special Thanks to:
Democracy Now!
WITNESS Media Archives