File-Based Preservation of the BBC's Videotape Archive

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ABSTRACT

The BBC Archive now contains around 15 Petabytes (single copy) of uncompressed audio-visual files that have been created from videotapes since 2007. This process is still on-going, creating an ever growing file-based collection of the BBC's television history. This is of course in addition to the new content now being produced that begins life as files. This paper focuses on the technology aspects of the digital preservation of the file-based historical TV collection and looks at how this currently isolated collection may later interface with other systems and collections. Consideration is given to what has been achieved so far, some lessons learnt, and the future challenges.

Keywords

Television, Digitisation, Preservation, Migration, Archive, Library, MXF, OAIS, LTO

1. INTRODUCTION

The BBC Archive contains more than 12 million items including several million television items held on either film or videotape [1]. Migrating the content from physical carriers to files ensures the preservation of content previously held on obsolete carriers, reduces the physical storage space required for the collection, and brings about new opportunities for providing access to the archive. In 2007 the BBC began creating master media files from television content held on Panasonic D3 videotapes (a process known as 'ingesting') [1].

The systems have since been developed and are now in use at the BBC Archive Centre in Perivale (West London) for the ingest of Sony Digital Betacam (DigiBeta) videotapes. So far, around 100000 D3 and 125000 DigiBeta videotapes have been ingested representing about 15 Petabytes of content (single copy). It is these videotapes that are considered here. The processes that have been / might be applied to television content held on other videotapes, film, etc are not considered in this paper (e.g. the collection of U-Matic tapes that were migrated to MPEG-2 files stored on DVDs).

The digital preservation of this content is carried out by the BBC Information & Archives department, with many of the systems and processes developed in collaboration with BBC Research & Development and other partners. An overview of the current status is given in Section 2 with a description of the core processing systems, consideration of the 'level' of digital preservation that has been achieved, and some of the challenges faced and lessons learnt. With a large proportion of the content held on LTO3 data tape, action will soon be required to migrate this to a new storage technology before these tapes become difficult to read – the issues involved are considered in Section 3. The focus so far has principally been on preserving, as files, the content that was held on videotape. However, with more production facilities operating completely tapelessly, providing file-based access to the preserved content is an important area to address. With this in mind, the content migration from LTO3 data tape will need to be considered with regards to the wider context of file-based archives and production systems. A simple model is presented in Section 4 of how such systems are likely, in practice, to relate to the long-term preservation collection of historical TV content.

2. THE CURRENT STATUS

2.1 Core Processing Systems

Figure 1 provides an overview of the core systems involved in the ingest of videotape content to files and the subsequent preservation operations (databases, reporting systems etc are omitted). Further details of each of the systems are given below.

2.1.1 Preparation (DigiBeta Only)

Prior to ingest the videotapes are checked and prepared physically and checks are made on their metadata. Videotapes containing *content* that the system deems should not be ingested are rejected: this may be because the content has already been ingested successfully (from this, or another, videotape) or has not been selected for preservation. Videotapes to be ingested are rewound and any paperwork, barcodes, etc with the videotapes are corroborated with each other and with the system. Any videotapes requiring metadata correction or enhancement are removed to be dealt with separately. Those videotapes that remain are sorted by the number of content items that they hold and by video aspect ratio, ready for ingest.

This level of preparation ensures that the ingest process is as smooth as possible such that an efficient 'preservation factory' [2] is established.

2.1.2 Ingest

The ingest function is performed by the Ingex Archive system originally developed by BBC R&D [1][3]. For the transfer of D3 videotapes custom hardware was designed to convert the data on the tapes to a practical form at the highest quality [4]. For the transfer of DigiBeta videotapes custom software has been added to verify the performance of the Video Tape Recorders (VTRs) as well as to detect video faults specific to the DigiBeta format.

After a videotape has been recorded, 'chunking' is performed to split the data such that one master media file is produced for each content item. A brief review of each file then takes place, principally based on any errors or features that have been automatically detected during ingest. When enough master

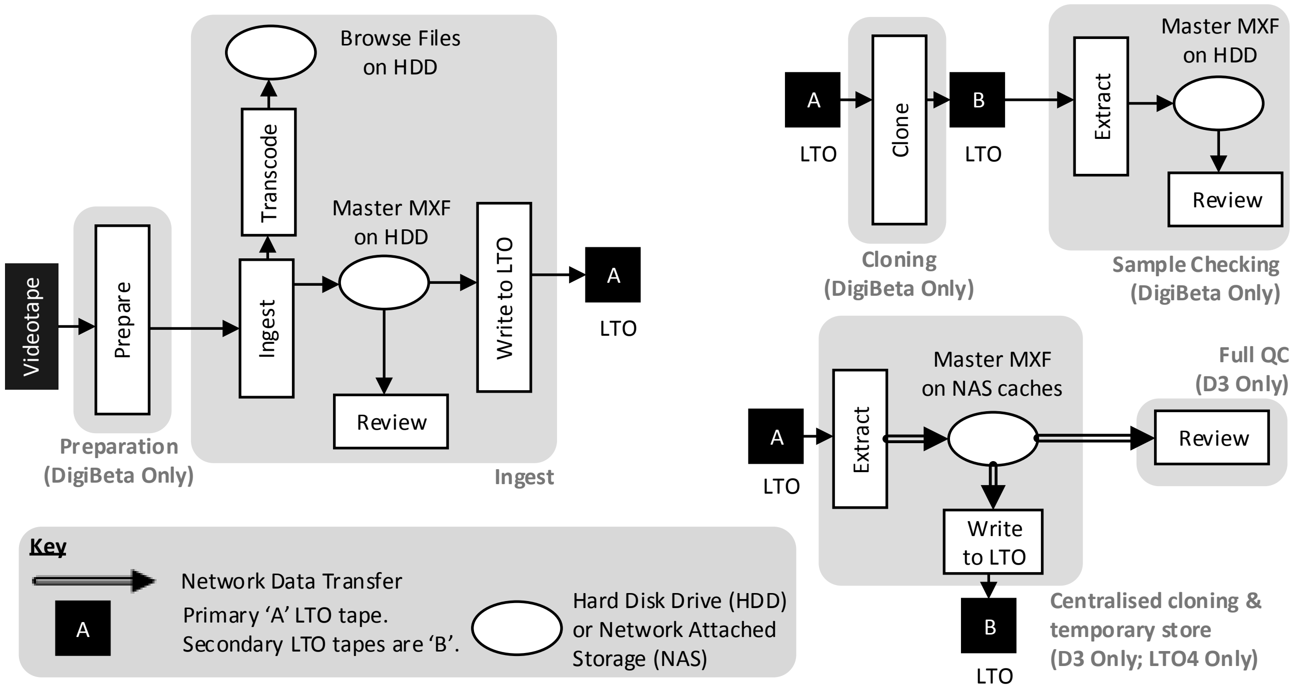

Figure 1. A simplified view of the core processing systems for D3 and DigiBeta videotape content preservation.

media files have accumulated they are written to LTO data tape (LTO3 originally; LTO4 currently). The MPEG-2 browse files are produced locally during ingest and later 'harvested' to a central location. They have been used to provide some access to the collection as well as to aid in Quality Control (QC).

2.1.3 Cloning (DigiBeta Only)

This LTO cloning system operates by cloning files directly from input LTO tape to output LTO tape. This avoids any need for a storage cache inside the cloning machines which simplifies the system, reduces the cost, and removes another source of possible errors and system failures. The supported LTO generations are governed purely by what the tape drives support, and the capacity of the system can be scaled simply by adding additional cloning machines. Although consideration was given to modifying the ingest system to produce an additional copy of each LTO tape, the present arrangement was chosen as it ensures that every 'A' LTO tape is fully read and independently verified.

2.1.4 Centralised Cloning & Temporary Store (D3 Only; LTO4 Only)

This system provides:

- *LTO tape extraction & writing.* Content from LTO tapes is extracted onto Network Attached Storage (NAS) hard drive caches and new LTO tapes are produced from this content. LTO tapes are out of the vault for the minimal amount of time and are only handled by the logistics staff.
- *File playback over network.* The master media files extracted from LTO tape can be played over the network from any machine allowing QC of the master media files by both the primary operators and their supervisors (who previously had to rely on the browse files).
- *Automated management.* The system itself and the processes it supports are automatically managed thereby simplifying workflows. QC operators are automatically allocated content to be reviewed rather than allowing them to choose – if the operator chooses content they are interested in then less attention is paid to the technical quality.

The centralised nature of this system naturally provides some disadvantages also. Principally, the workflows of the associated operations are less flexible, and the system component that manages its operation constitutes a single point of failure. Additionally, the need for NAS caches introduces the issues avoided for LTO cloning as described in Section 2.1.3.

2.1.5 Sample Checking / Full QC

A sample of DigiBeta content is checked by extracting from LTO tapes to a hard drive cache on the review machines. All D3 content is fully manually QCed either by playback over the network or by extracting from LTO tape onto the review machine as for DigiBeta content (latter case not shown in Figure 1). The review processes provide feedback on the integrity of the LTO tapes, metadata accuracy, master file technical details, errors introduced to the content by the ingest process, etc.

2.2 Archival Information Packages (AIPs)

It is instructive to assess the preservation outputs in relation to the OAIS concept of an Archival Information Package (AIP) where the LTO tapes constitute the Archival Storage [5] (only the newest format preservation outputs are considered). Firstly, it is useful to consider the elements that *delimit* and *describe* the AIPs:

- *Packaging Information.* The master media files are Material eXchange Format (MXF) OP1a adhering to a custom BBC Archive profile [1]. They are written to LTO tape (without compression) following a custom scheme using TAR archive files and plain-text index files. So, each

AIP is actually a combination of elements from the LTO scheme and MXF profile. Each AIP is identified by the MXF filename (held inside the TAR archive, the MXF file itself, and the LTO index file) and the MXF Unique Material IDs (UMIDs).
- *Descriptive Information.* This consists of: metadata from the AIP (such as Programme Title); content properties such as duration; browse files.

The AIPs themselves consist of:

- *Digital Object.* It is valuable to realise that the Content Data Object to be preserved consists of the bitstreams representing the audio, video, and timecode from the source videotape rather than the entire MXF file (which additionally contains many of the metadata items identified below). The audio and video are stored uncompressed, immediately achieving the migration end-state promoted by PrestoPRIME [6].
- *Representation Information.* The LTO scheme is described in the plain text index files on the tapes themselves. The MXF profile is fully described in PDF documents [1] – these depend on numerous other documents (e.g. MXF standards) and are not stored in the AIPs.
- *Reference Information.* Includes the programme title etc and content identifiers such as the BBC 'programme number'.
- *Provenance & Context Information.* Details are included of: the original content transmission date etc; the videotape the file was produced from; the ingest process.
- *Fixity Information.* Checksums of the MXF files and the LTO index files are stored on the LTO tape. The MXF files contain checksums per frame for each audio / video track.
- *Access Rights Information.* Any details that may be available are stored in completely separate systems.

2.3 Digital Preservation Assessment

The systems and processes setup to preserve content from videotape did not set out to establish a complete Trustworthy Digital Repository [7] – instead the BBC decided to "get on with it" [8] and focus on transferring content from videotape while the machines were still available (especially a concern for D3). Over time the systems have evolved and been added to in order to support additional videotape formats as well as to introduce improved digital preservation practices, and they will continue to evolve in the future. The concepts of "Levels of Digital Preservation" [9] and "Digital Archiving Maturity" [10] are quite useful in understanding how digital preservation systems can evolve through stages.

Table 1 shows *highlights* of digital preservation developments and gaps in relation to the BBC's historical TV archive. It is certainly not comprehensive (e.g. as in [7]), completely ignoring issues of funding, administration, preservation planning, etc (these are ignored not least because aspects of these elements are common to other areas of the BBC Archive including to collections that are not file-based). The main changes have been due to the introduction of fixity information and improved documentation (Section 2.2), the introduction of cloning (Sections 2.1.3 & 2.1.4), and additional work on database integrity and data reporting (Section 2.4.3). Possible future developments are discussed in Sections 3 and 4.

Table 1. Digital preservation development over time.

	2007	2013
Full AIPs	+	++++
Number of AIP copies	1	2
Regular object fixity checks	N/A	No
Provide access to content for re-use – on videotape	Yes (manually)	Yes (manually)
Provide access to content for re-use – as a file	No	No
Data Management	+	++

'+' indicates advancement towards an OAIS.

2.4 Main Challenges & Lessons Learnt

2.4.1 Custom Designed Systems

All the systems described in Section 2.1 were custom designed with custom schemes for writing the master media files and LTO tapes as described in Section 2.2. Using custom solutions has allowed the BBC Archive's precise requirements to be met which was not felt to be possible (at least in 2006 / 07) using solutions available in the industry. It has also meant that there is: complete transparency as to how the systems operate; no reliance on a third party solution provider; the option to add new features as required. However, a firm commitment is required to support and maintain the software (even today issues are being discovered with software first developed six years ago) and to produce tools (and new systems) to operate on the custom MXF / LTO schemes because they are not fully supported by industry solutions. The work required in testing and documenting the systems should also not be overlooked.

2.4.2 File Sizes, Data Rates & Storage

The main limiting factor in many of the systems is data input / output (and consequently data movement times) due to the master media files (MXF) being 75–100GB per hour of content and the fact that around 30TB of content can be produced per day by the current DigiBeta ingest process at Perivale (24 stations running simultaneously) – this is clearly one of the disadvantages of storing uncompressed content. Such data rates require a different approach compared with systems handling small files. For example, the only practical solution to producing checksums for the MXF files is to construct a processing pipeline that does this while simultaneously performing other operations (such as copying files from hard drive to LTO tape). Moving or playing-back these large files over a network (Section 2.1.4) requires careful consideration of the design of the network as well as the whole software stack on both the NAS and the access client. For example, the MXF player software built by BBC R&D and used for file review over the network had to be modified in order to prevent overzealous file caching that could use up all available network capacity. Inside the ingest system (Section 2.1.2) the data rates are also a major challenge. For example, 'chunking' involves reading back the recorded content while writing new files (one per content item). If LTO writing of other files is happening simultaneously then the system is obliged to severely limit the rate of chunking which introduces a large delay before the next videotape can be ingested. This situation could be dramatically improved by ingesting content items separately, an approach that is now enabled by the collection of item timecodes prior to ingest (an example of 'metadata enhancement' described in Section 2.1.1).

All the LTO tapes produced by the preservation systems are handled manually and stored on shelves / in crates with 'A' and 'B' tapes stored in different locations. This is a flexible solution (compared to storing tapes in robots) that fits well with the skills and facilities already present in the Archive for handling other physical assets such as videotapes. It also means that all the content is completely offline and can be moved at high speed around the Archive (consider the 'bandwidth' of a trolley full of LTO tapes!). However, it does mean that: there is no automatic management of tape locations; access requires human handling which introduces delays and exposes tapes to less than ideal conditions; tapes have to be treated as 'units' rather than being able to handle the contained files individually.

One observation of MXF file corruption highlights that while checksums are important it is critical to understand at what point in the file's life they were produced. In this case, a number of MXF files stored on LTO tape were found to be corrupted towards the end-of-file due to an issue with the hard drives in the ingest station while the files were being written to LTO tape. Given that the checksums are produced during the tape writing process the actual checksums of these corrupt files (as stored on LTO tape) matched the expected values. Alterations have since been made to detect such hard drive errors. An even more robust solution would involve verifying the internals of the MXF files as they are written to LTO tape including the per-frame checksums.

2.4.3 Metadata & Databases

No databases are shown in Figure 1 but they are of course a crucial element. Some of the main challenges & lessons include:

- *Many databases.* Metadata is distributed between numerous databases, most of them with different schemas. However, this is still preferable to data being stored in text files etc as long as a database with standard query interfaces is used.
- *Duplicated data.* Sometimes this is helpful but it can make correcting any metadata errors very difficult to do correctly.
- *Missing fields.* New metadata fields to aid in error diagnosis are continually being thought of but in many systems it is not straightforward to add them.
- *Data integrity.* As much as possible, integrity should be enforced by the database itself to avoid erroneous data.
- *Data access.* Mechanisms should be built-in as early as possible for reporting and summarising data for users.

2.4.4 Workflows & Processes

The digital preservation "three-legged stool" [11] is a useful reminder that successful preservation is not all about the technology. Some of the largest challenges have been related to the scale and complexity of the physical logistics operation and accommodating 24-hour working (at times) in order to ingest content at the required rate. The ways in which processes have evolved has certainly altered the preservation of content and tracking / recording these process changes, as well as trying to ensure consistency at such a scale, are real challenges. Work was conducted in the PrestoPRIME project to produce a simulation of the D3 preservation process [12]. Building even the simplified model took a number of months highlighting the complexity of the workflow when all factors are taken into account – even then, setting the model parameters realistically is challenging.

2.4.5 A Complicated & Varied Collection

The videotape collection being ingested contains content from as early as the 1930s (which originated on film), and content from the 1950s and later which may have originated on 2" tape and then been migrated to 1" tape then D3 and / or DigiBeta tape, perhaps with multiple videotape copies being made (which are unlikely to be 100% identical). An item of content may be ingested to file multiple times from the same or different videotapes, each of which may have a different provenance and different faults. This results in a very complex collection to manage and it is not always straightforward to derive the best possible copy of each content item from the ingests performed.

3. LTO3 MIGRATION

With a large proportion of the content held on LTO3 data tape action will soon be required to migrate this to a new storage technology before these tapes become difficult to read (due to lack of support by the latest drives). This migration process presents numerous challenges as well as opportunities to improve the preservation of this portion of the collection.

3.1 The LTO3 Tape Collection

Some key statistics for the collection:

- 14000 LTO3 tapes
- 5PB of data
- ~7.5 years of A/V content if played end-to-end
- Only one copy of each file MXF file is stored
- No Fixity Information

3.2 Designing a Migration Process

A custom solution is almost certainly required for the reasons discussed in Section 2.4.1. Some of the processes that it could potentially include are:

- *Validation of existing AIPs and Packaging Information.* The LTO scheme and MXF files could be validated against the relevant specifications, although without fixity information errors in the Digital Object itself would probably not be detected.
- *Migration of AIPs and Packaging Information.* New AIPs could be generated from the old with augmented content e.g. Fixity Information and additional Representation Information could be added.
- *Creation of additional Descriptive Information.* Some metadata items are held only inside the MXF files so it may be of benefit to extract this information and store more accessibly. Content analysis could be performed: even simple analysis could be very useful e.g. determining how many black frames of video each content item contains.
- *Creation of Dissemination Information Packages (DIPs).* While all of this content is being read from LTO tape it would be possible to create a complete collection of DIPs for ingest into another system. This would probably involve

transcoding the uncompressed content to a format more appropriate for re-use.

- *File audit, retention review, repair.* This may be an appropriate time to filter the collection to remove some of the complexities described in Section 2.4.5. However, this would be complex and perhaps involve some risk as it might involve discarding some MXF files.

3.3 Choice of Archival Storage

The type(s) of storage to use and the number of copies of each AIP to store will be affected by the issues discussed in Section 4. However, it seems likely that at least one copy will be stored on LTO tape, perhaps LTO6. Although LTO3 tape will become an 'obsolete' technology, given the popularity of LTO tape, drives will surely be available to read them for many years to come (although they may be scarce, expensive, and difficult to connect to). Therefore, it is worth considering whether the LTO3 tapes should be kept even after the migration: they would serve as an additional copy of the content for use only in extreme circumstances or if a fault with the migration process is later discovered.

3.4 Choice of AIP & Packaging Information

If it is possible to use standards (ideally commonly adopted and well-supported open standards) when defining the outputs of the migration process then this may mean that a custom solution is not required for the next migration process (although if open standards are adopted then it is not precluded). This is in addition to the benefits of increased interoperability with industry tools, other repositories, etc. Even if it is not possible to use such standards for all 'layers', the higher up the 'stack' that standards are used the more that should be possible with industry solutions. For the same reason there may be a benefit to clearly discrete 'layers' unlike the current situation where there is an overlap between elements of the AIP and the Packaging Information (Section 2.2). The principle 'layers' in the 'stack' are listed below along with possible standards (some not yet completed; note that some standards cover multiple layers) to consider – these are listed purely as examples rather than recommendations. The Presto4U project includes an element of work analysing and promoting standardisation for audiovisual digital preservation [13] and should be consulted for more information on this topic.

- *Archival Storage* e.g. LTO tape
- *Packaging Information* e.g. LTFS, AXF
- *AIP 'wrapper' or (virtual) 'container'* e.g. BagIt, METS, MPEG-A PA-AF, AXF
- *Metadata* e.g. PREMIS [14], METS, MPEG-A MP-AF [15]
- *Digital Object* e.g. AS-07 [16]

Those standards / formats not referenced above are described in [2] or [17].

3.5 On-going Preservation

Consideration also needs to be given to how the migrated content will be managed as a collection / repository and issues of regular fixity checking, data management, repository interfaces, access, etc.

4. THE WIDER CONTEXT

To answer all the questions raised in Section 3 requires an understanding of how this historical TV archive could relate to other archive and production systems in the BBC, and therefore how the content might be accessed. Figure 2 illustrates a possible practical model that appears to be developing for at least the short to medium term. In this very simple model only the historic TV digital preservation archive and a digital archive library are included: the latter represents systems used to manage production quality content (both historic and new) and perform day-to-day functions on it such as search and access for re-use, as well as interfacing to all the other systems required to import and export content (e.g. for television broadcast). This represents the shift of the archive to the heart of the content production and delivery processes.

The formats used in the archive library are those suitable for current processes and much of the content will not be in its final state (with new versions being created, and some content perhaps being reviewed and deleted after short periods e.g. one year). Conversely, the content held in the preservation archive will (principally) be in a final state, stored using an archival format (e.g. uncompressed) and selected for long-term retention. The vast majority of Descriptive Information could be held in the library. This arrangement allows the specific and rapidly changing needs of users to be met by the archive library while the preservation archive focuses on the long-term preservation of content. The preservation archive is able to be managed separately to ensure content security, and need only expose a simple (and fairly static) interface that is used by the library. Not least, the separation between the two systems means that the challenge of providing all the required digital archive functions is divided into smaller, more manageable 'modules'.

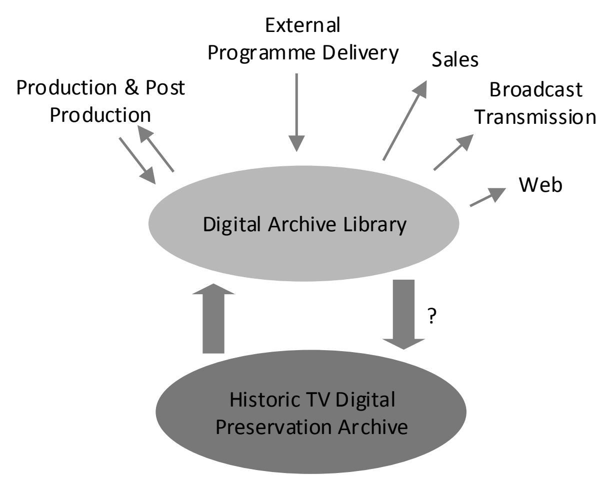

Figure 2. Possible model of a Digital Preservation Archive & a Digital Archive Library

Content in the preservation archive could be accessed on-demand by the library (with the content transcoded to any supported format). However, it may be preferable for DIPs to be delivered in bulk from the preservation archive to the library so that large amounts of content are immediately available to users (but without the same freedom of choice about the format). If content is later required in a different format then a new request can be submitted to the preservation archive. This approach (rather than transcoding from the format held in the library) avoids concatenated transcodes and so maximises the quality of the content over its lifetime.

It will be important to define the Service Level Agreement (SLA) for the preservation archive [18] as this will help to manage expectations as well as inform design decisions such as the type(s) of archival storage, the repository interfaces, network connectivity, repository management workflows and functions, etc. For example, if on-demand access requests to the preservation archive are to be handled rapidly then it could perhaps be a good option to store at least one copy of the content on (idle) hard drive arrays rather than LTO tape only.

The complete television archive system will be much more complicated than the simplified model presented here. In reality a number of library and preservation systems are likely to exist, each with different functions. These will be easier to manage (and potentially to federate to form a more cohesive archive) if common standards are adopted both for the elements highlighted in Section 3.4 and crucially for repository interfaces and unique identifiers. A central registry of all content may be a key enabler.

A key question to address will be how production quality (compressed) content will be handled e.g. content born-as-files or content ingested from videotape to a non-archival compressed format only. Will this content be delivered straight to the library (as indicated in Figure 2)? Presumably the library would be responsible for the preservation of this content in the short term but in the longer term would it be migrated to the preservation archive (perhaps migrating to an archival format e.g. uncompressed)? Such a decision would probably be required at the library's end-of-life, if not before then. Some preservation strategies and format migrations are explored in [6].

5. CONCLUSIONS

Progress has been made in creating a large quantity of master media files from videotapes with the 'level' of digital preservation developing as the systems and processes have evolved. There is still much work to do in order to improve this file-based collection and its data, both to ensure its preservation and to provide access as part of the wider archive landscape in the BBC: the systems will likely always continue to evolve. Evolution will soon be taking place as part of the LTO3 migration even before ingest of the current batch of videotapes is complete – the use of commonly adopted and well-supported open standards may ease future migrations of the collection.

This paper has only considered part of the videotape collection. The remaining videotapes and other carriers (e.g. film) around the organisation will eventually need to be processed, perhaps using different systems and file / storage schemes. Of course, the collections of radio programmes, photos, documents (contracts, scripts, etc) are all other challenges for the BBC, all at different 'levels' of digitisation and digital preservation.

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