JPEG 2000 Applications

Foreword

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Peter Schelkens (Editor), Athanassios Skodras (Co-Editor), Touradj Ebrahimi (Co-Editor)
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1 JPEG 2000 for Digital Cinema

Dr. Ing. Siegfried Fößel

1.1 Introduction

Digital media content is widely used today. With DVD, DVB and Internet a broad acceptance of digital content distribution took place. Digital Cinema is one of the latest steps in the digitization of media content. It encompasses not only the replacement of film reels by digital data packages, but in a broader sense the complete digitization of the production- and utilization chain for high-quality moving images. For a clear differentiation the digital cinema distribution to theatres is called in this chapter “D-Cinema”.

In former times the theatres were the main refinancing instrument for movie producers. Nowadays, movies will be shown not only in theatres or on TV, but also in many other different formats. Today the DVD is the main revenue source. Nonetheless, consuming markets still are changing rapidly. And analysts claim that this will shift in future to Internet and Video-On-Demand markets. The expected worldwide market for Video-On-Demand shall change from 281M US$ in 2006 to 4.4B US$ in 2010 (Hohenauer, 2007). However this shall only inhibit the revenues of the TV and DVD market.

An example for the western world changeover is the comparison of the market share between cinema and video in Germany in between the years 1999 and 2006. While the turnover in the theatres kept nearly constant with 808M Euro in 1999 and 814M Euro in 2006, new markets in the digital media area could be opened. In the meantime these new markets have overrun the values of the cinema market considerably (see **Fig. 1.1**).

This demonstrates that multiple digital utilization of content is the key element for digital movie distribution in the future. The process has started just now. In the future, movies will be consumed not only in theatres or by TV at home, but anytime anywhere. In the meantime the quality of home entertainment has been improved by digital HDTV and Blu-Ray DVD, so that cinema came under pressure. One way out of this dilemma is D-Cinema, which allows better quality, reduced distribution costs, improved viewing experiences and a seamless integration into a complete digital production chain.

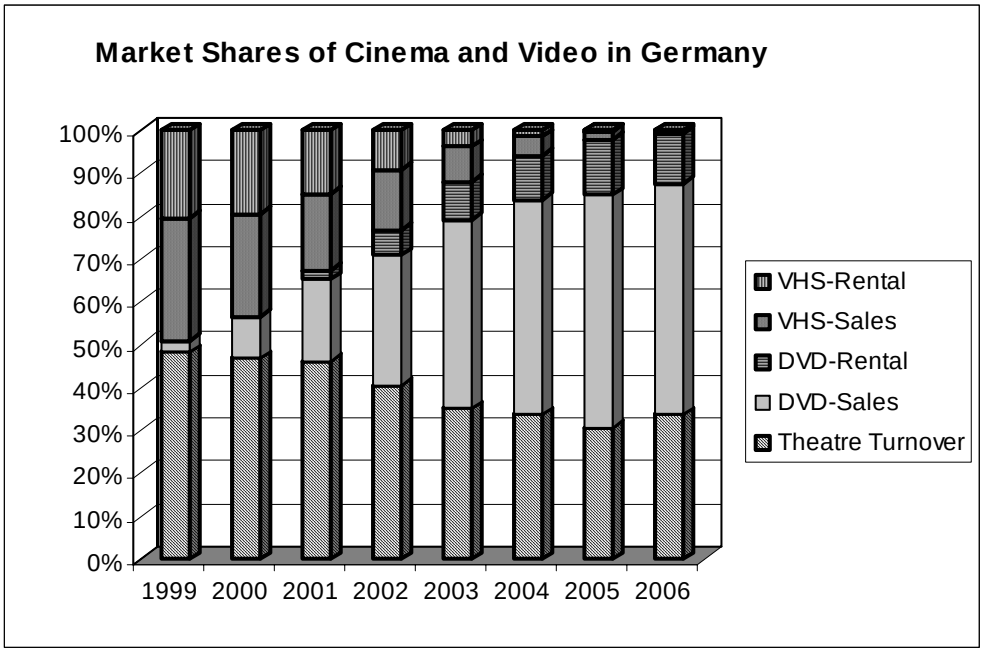


Fig. 1.1 *Market Shares of Cinema and Video in Germany,*
Source: Bundesverband Audiovisuelle Medien, 2007 (BVV, 2007)

For very high quality requirements JPEG 2000 with its intra frame coding and new features like scalability is a good option for producing, archiving and distribution of moving images. As shown on the simplified diagram of the production chain (**Fig. 1.2**), the only remaining market actors using film are the existing film archives. The encircled items indicate the main standardized or proposed areas for JPEG 2000. Especially areas that require the preservation of very high quality are well suited for JPEG 2000.

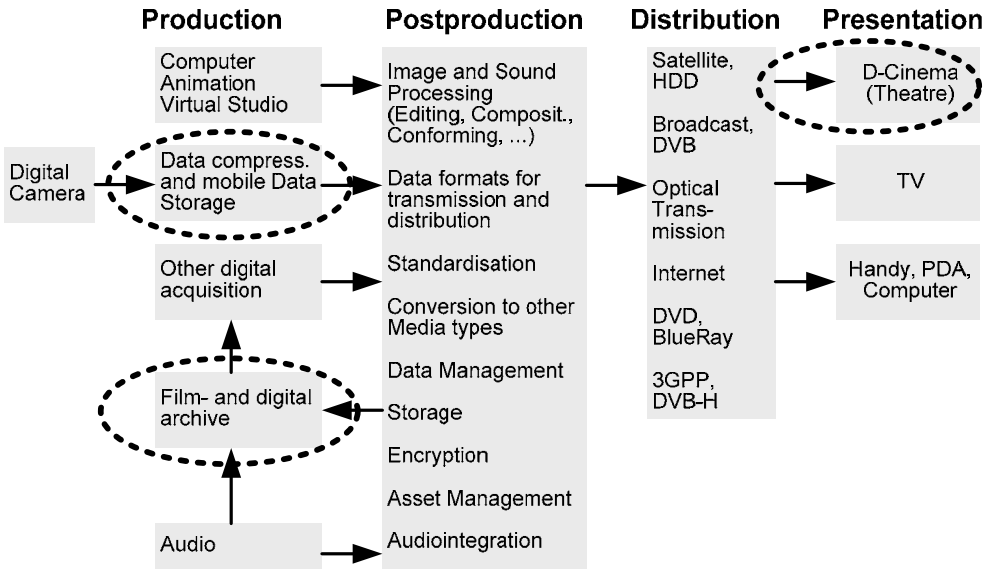


Fig. 1.2 *Digital Movie Production Chain (Fraunhofer IIS)*

While moving images used for TV and Internet have been processed and played back digitally for a long time, this was not the case for the high-end area of cinema movies, because of the huge amount of data and the very high requirements to the image quality. This caused a separate film processing chain for cinema moving images. The first steps into digitization were taken in the post-production, where special effects and animations in movies like Star Wars resulted in new viewing experiences.

Because of the permanently increasing processing power of computers and the increasing capacity of storage media also cinema movie production is subject to a new evolution. Similar like in other application areas, analogue technology is being replaced in the cinema production and distribution by digital processing (**Fig. 1.3**).

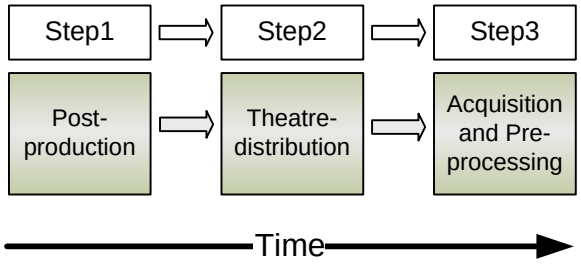


Fig. 1.3 *Temporal order of the transition from analogue to digital technology*

1.2 General Requirements for Digital Cinema

General requirements

The main benefit of a cinema presentation is - in parallel with the social aspects - the immersive viewing experience. For the industry this is the most important feature, as this brings people from home to theatres. Otherwise the people would not pay a high ticket price for a single presentation. An immersive viewing experience includes that the projection should have a high resolution, high contrast and dynamic range, a very good color reproduction and an outstanding sound. For this reason theatres have a big screen, low ambient light conditions and excellent loudspeaker systems. To take though full advantage of these benefits the content has to be presented from a high quality distribution format.

In former times the carrier for distribution was a 35mm film print. Tests within ITU-R (ITU-R, 2001) (Morton, 2002) have demonstrated that typical 35mm film answer prints for theatres have a vertical resolution of less than 800 lines. The 35 mm film during acquisition however can have a vertical resolution of up to 2000 lines. The main losses in the chain are due to the duplication and copy processing steps. Based on these results two formats were selected by the industry, one format with 2048 by 1080 Pixel (“2k format”) and the other with 4096 by 2160 Pixel (“4k format”). To allow the use of only one distribution master, a scalable compression format was requested. This allows producing only one distribution format for both projection sizes, and the playback system can extract the requested size from one codestream.

For the successive contrast in a scene, a nominal ratio of 2000:1 was requested. This allows for the perception of fine details in different scene conditions (e.g. dark scenes vs. sun bright scenes). Within one single frame the contrast can be lower. This correlates to the adaptation behavior of the human eye. A bit depth of equal or more than 12 bits per component is the consequence. This high contrast ratio is the real big difference to home presentations based on 8 bits per component transmission formats and allows for immersive experiences.

Color reproduction is also an important aspect in cinema. Film has a very high color gamut, whereas TV in former times had a color gamut limited by the cathode-ray tube (CRT) phosphors. With the invention of new projection technologies like DLP®[1] and LCOS, more suitable digital projection systems are currently available. To restrict color reproduction in D-Cinema systems not to actual technology or devices the XYZ color space was chosen. This color space is a mathematical model already defined in 1931 by the CIE (Commission internationale de l'Eclairage) that can represent all human visible colors. So future projection systems like laser projectors will not request a new color space (Kennel, 2006).

A movie will be shown in many countries all over the world. Because of country specific movie rating restrictions, scenes within the movie will need to be cut off or replaced by less offensive content. Hence, country specific reassembly is an additional requirement. A frame accurate reassembling is possible by using country specific composition play lists. These play lists define in and out-points for the movie, so that only one distribution package has to be used. The reassembling is effectuated during playback in real-time.

[1] DLP® is a trademark of Texas Instruments

A typical movie with a playtime of 100 minutes has an uncompressed size of about 1.5 TB in the 2k format and 6 TB in the 4k format. Even with today's increasing storage capacities this is too much for distribution. Therefore compression is still necessary. As discussed before the special requirements for a compression format in D-Cinema are scalability, high resolution capabilities of at least 4k, high bit depths of at least 12 bit per component, the use of special color spaces and frame accurate reassembling of play lists. The visibility of compression artifacts is not acceptable. Hence, even with compression the data rates remain high. Based on these requirements JPEG 2000 as intra-frame compression format was chosen for D-Cinema and special profiles were created. With enough flexibility and headroom JPEG 2000 is not solely suitable for D-Cinema, but also for the complete Digital Cinema chain.

Additional requirements in the acquisition area

Image quality in the acquisition of movies is the most important requirement since similar like with the analog film process all following processing steps will reduce the image quality. Hence, the compression has to be lossless or near lossless. However, the required processing power for compression will be even higher than for D-Cinema, as variable frame rates up to 150 fps for slow motion capturing will be recorded and the compression has to be carried out in real-time before storing the data. On the other side the use of scalable compression formats would allow an easy extraction of "dailies" (previews for quality control at the end of the day), An additional copy and processing step for the dailies after recording would require a multiple of the recording time.

Additional requirements in the post-production area

The huge amount of data in cinema movie production requires special processing systems. Even with today's technology most 4k productions will be processed first with smaller representation copies of the movie (proxies). This allows a faster editing and color correction. With JPEG 2000 these proxies can be extracted directly from a lower resolution level of the bit-stream. When producing the final master copy, all processing steps will be reapplied to the original data at maximal resolution. The processing steps will be stored e. g. in metadata like EDL (Editing Decision List) and CDL (Color Decision List) (ASC, 2008).

Additional requirements in the archive area

For archiving of movies two main, contradictory requirements exist. On one hand side the image shall be preserved in its original quality, which implies lossless compression or uncompressed storage with huge amounts of data. This requirement is necessary to give future audience an authentic impression of the artistic intention of the director. It preserves the cultural heritage of movie makers. Furthermore, as soon as better distribution media are available (e.g. BlueRay DVD), the movie can be remastered and released in a better image quality. On the other hand fast browsing and retrieval of content in a large archive system is desired. With uncompressed or lossless compressed images one movie will exceed a data amount of one or more TB. To read the data from media alone requires too much time and is not appropriate for browsing and searching. A higher compression ratio is therefore necessary for such applications.

Summary

Digital Cinema imposes the handling of big images with very high quality requirements leading to a huge amount of data to be processed and stored. Because of the aforementioned quality and accessibility constraints, compression is though limited to intra-frame processing and very low compression ratios. Hence, for browsing, editing and retrieval, a scalable compression algorithm with the option of efficiently extracting lower resolution representations is helpful to reduce processing power. JPEG 2000 fulfils these requirements. **Fig. 1.4** gives an overview of the main interesting features of JPEG 2000 for the Digital Cinema chain.

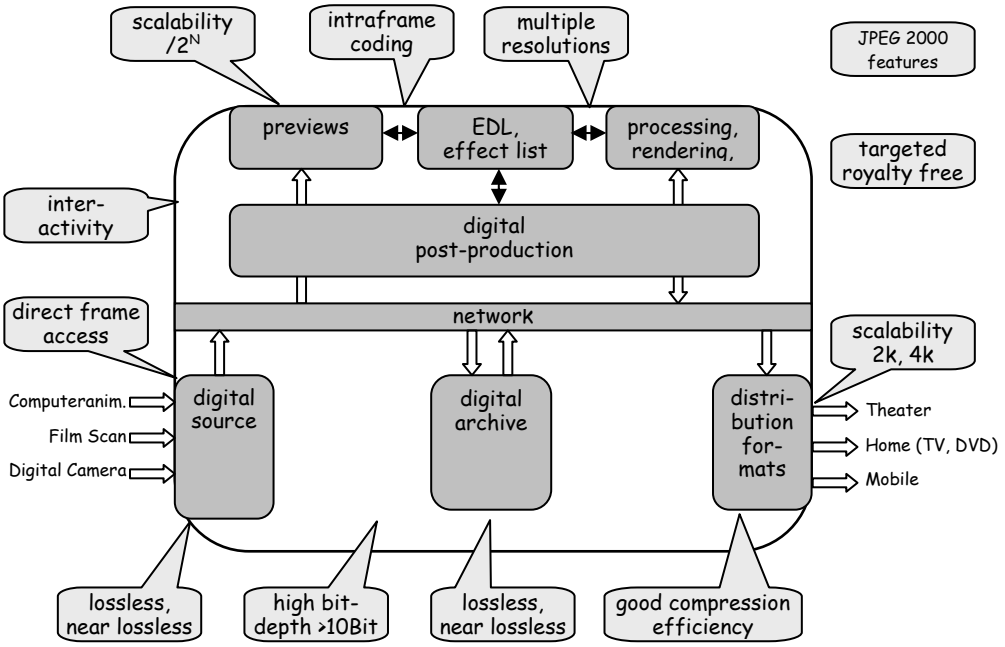


Fig. 1.4 Features of JPEG 2000 useful for Digital Cinema (Edwards, 2001)

1.3 Distribution of Digital Cinema Content

Whereas digital movie post-production can and will be done in many different ways and with a multiplicity of different systems, the output of these systems has to be standardized, such that the content can be presented on all screens without further processing. The film reel with its standardized 35mm film fulfilled this requirement in a perfect way. Film could be shown on projectors in America, Europe or Asia. To allow this worldwide interchangeability a large effort was made to standardize digital cinema distribution. The Digital Cinema Initiative

stepped of this effort, and it was supported additionally by the Society of Motion Picture and Television Engineers (SMPTE) and ISO/IEC (and ITU-T).

1.3.1 Digital Cinema Initiatives, LLC (DCI)

When it became obvious that cinema had to take the digital highway, the big Hollywood studios started in 2002 with the DCI project to define specifications for digital cinema distribution. The mission statement on the DCI website (http://www.dcimovies.com) states:

> *"DCI's primary purpose is to establish and document voluntary specifications for an open architecture for digital cinema that ensures a uniform and high level of technical performance, reliability and quality control. "*

During this still ongoing effort many evaluation and comparison tests were done to ensure highest quality and security. A mini-movie (StEM = Standard Evaluation Material) was produced to allow for quality tests. System architecture was developed that enables the replacement of film reels by digital movies in form of Digital Cinema Packages (DCP), which were encrypted and can be unlocked by a key contained by a Key Delivery Message (KDM).

After extensive compression tests at the Digital Cinema Lab of the Entertainment Technology Center (http://www.etcenter.org/digital-cinema-lab) JPEG 2000 was chosen in 2004 as the compression algorithm, because of its scalability, the quality and some other features. It has to be noted that quality comparisons were done between JPEG 2000 and other coding standards. For high quality applications, where the noise level of the image or the grain in scanned films becomes relevant, JPEG 2000 is a very good solution (see also chapter 1.5). In these circumstances, inter-frame coding algorithms like MPEG cannot benefit from the temporal redundancy of successive images. In addition, JPEG 2000 can be used to integrate several resolution levels inside the codestream. For D-Cinema distribution the quality scalability in JPEG 2000 was not used, means only one quality layer is present.

The main results of the DCI are:

- StEM Mini-Movie (DCI, 2006)
- Digital Cinema System Specification V1.2 (DCI, 2008)
- Digital Cinema System Specification Compliance Test Plan V1.0 (DCI, 2007)
- Reference DCP and KDM

Since, industry immediately supported this effort by developing devices, the DCI Digital Cinema System Specification soon became a de facto standard.

1.3.2 System Concepts and Processing Steps

Below is the principal workflow of the D-Cinema content distribution (**Fig. 1.5**):

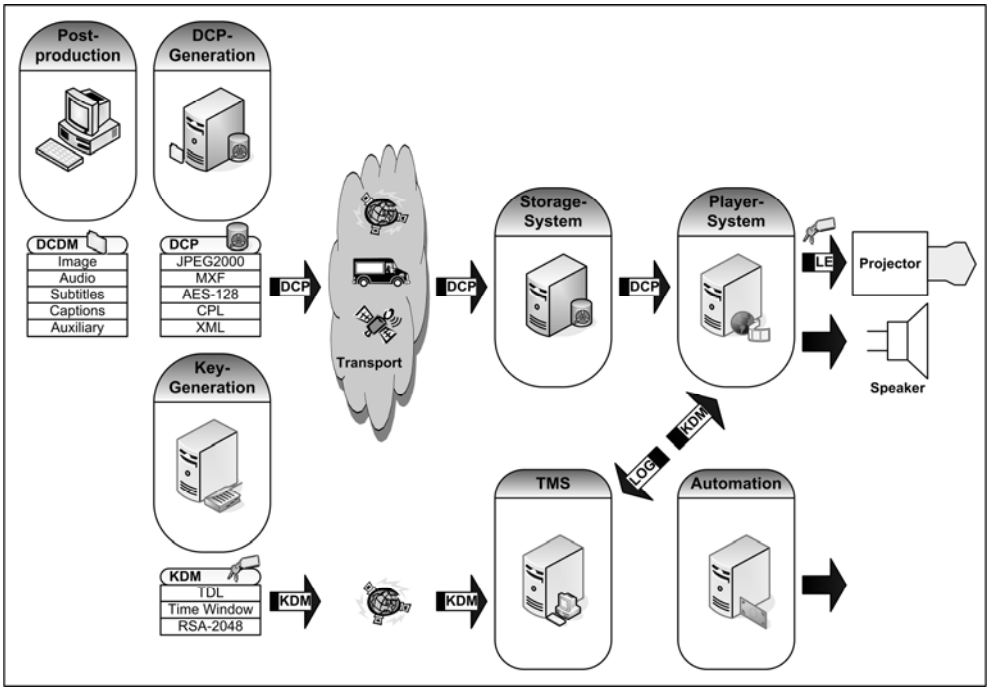


Fig. 1.5 Distribution workflow for D-Cinema (Foessel, 2008-1)

- During post-production a D-Cinema Distribution Master (**DCDM**) will be created. The DCDM has specific format constraints to enable efficient standardized processing for the distribution format packaging (see SMPTE standard family 428-x, section 1.3.4). The packaging format enables the embedding of image, audio, subtitle and caption content.
- The Digital Cinema Package (DCP) is derived from the DCDM. It consists out of MXF and XML files. The MXF files are created by wrapping audio, subtitles, captions and JPEG 2000 compressed images into these files. The images are typically encrypted with AES128 before wrapping, so that unauthorized access is prevented. Additional information for the package (Packaging List and Asset Map) and the playback procedure (Composition Package List) are included the XML-files.
- To enable the presentation of the movie the AES128 key is enclosed in a Key Delivery Message (KDM). The AES128 key again is encrypted by a public-private key pair encryption technology, called RSA-2048 (see **Fig. 1.6**). The KDM uses a public key to encrypt parts of the message and only the corresponding private key of the player/presentation device can decrypt the KDM. In addition, messages within the theatre and to the outside are defined (see SMPTE standard family 430-x, section 1.3.4). (for further information see also (Bilgin, 2006) (Bloom, 2006))

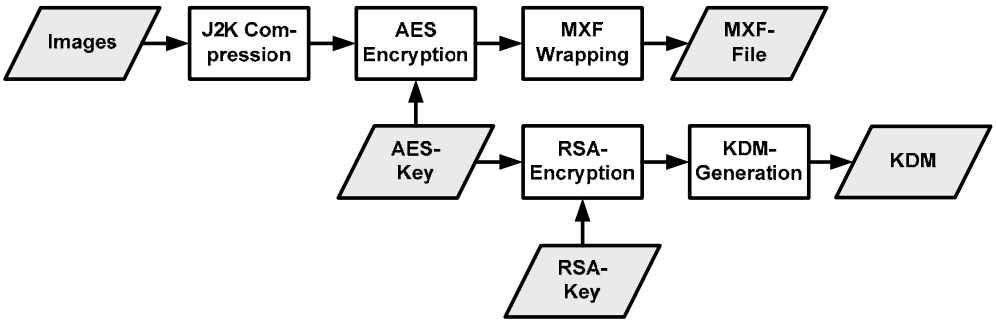


Fig. 1.6 Encryption Process for Images

- Both DCP and KDM are required for playback of a movie. The DCP contains the movie, whereas the KDM is the activation key for the playback. The DCP has a size of 100 to 300 GBytes. The KDM has a size of only a few kBytes. Today DCP distribution is done by mailing hard disk drives. At a later stage satellite or Internet distribution is planned. The KDMs are send by email, USB-Sticks or can be acquired over Internet.
- In the theatre, the DCP will be ingested into a central storage system or directly into a player system. The KDM is valid for only one specific player system. A media block inside the player system can decrypt the KDM, access the AES key and decrypt the DCP. If the media block is not in the projector a separate encryption has to be used between the media block and the projector. A Theater Management System (TMS) can control multiple player and projector systems.

Requirements and derived processing steps

Several requirements were imposed for the introduction of D-Cinema distribution. The first set of requirements considers the replacement of an old proven technology by a new one:

- Traditional film reels shall be replaced by digital data packages with all the advantages of film and digital.
- The movie shall be able to play back worldwide and the systems shall be interoperable.
- The same organizational distribution channels shall be used for a seamless exchange.
- The visual quality shall be the same or even higher than 35mm film.
- The digital playback system shall be as robust as film projectors with the same amount of low number of failures.

For IT-equipment, the latter requirement is of certainly a challenge. The second set of requirements considers the new advantages of a digital system:

- The access to the market shall be faster, because hybrid systems (film and digital) are no longer required.
- The digital data distribution shall be much cheaper than the film distribution, mainly because of the lower cost of the digital copy in relationship to the film print.
- The production of digital cinema movies shall fit seamless to the rest of digital movie production (DVD, TV, ..).

- And what is very important, especially in the last years new, technologies like digital 3D-movies shall be possible now.

Of course also some disadvantages exist. Piracy of a digital copy is much easier than for a film print. Therefore more than half of the DCI specification covers security and watermarking items.

The distribution of D-Cinema content requires many new processing steps, which are derived from other post-production, coding and encryption technologies. The concatenation of processing steps can be shown in a simplified way in **Fig. 1.7**. Subtitles and captions are neglected.

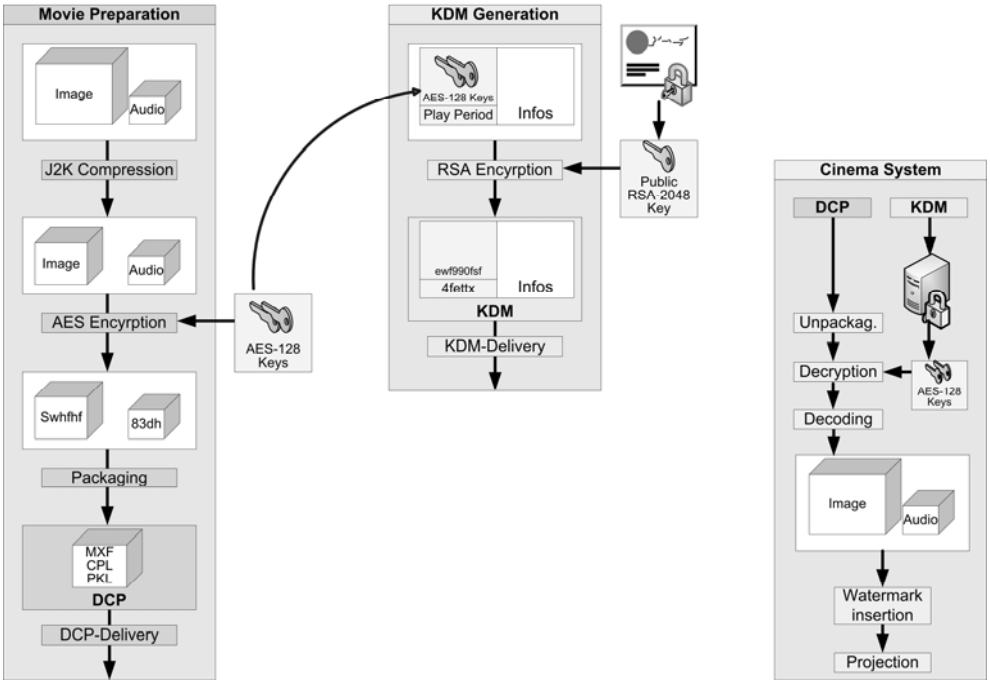


Fig. 1.7 *Processing Steps for D-Cinema (Foessel, 2008-1)*

This led to the following specifications reflecting the aforementioned requirements:

- To reduce the amount of data JPEG 2000 compression for the images was chosen. Each frame is compressed individually. Only Part 1 of the JPEG 2000 standard 15444-1 is used. DCI did not adopt JPEG 2000 Part 3, i.e. the Motion JPEG 2000 file format, but preferred to adopt the more suitable MXF specification of SMPTE. The JPEG 2000 Profiles for Digital Cinema distribution defined the maximum bit-rate for 2K/4K distribution at 250 Mbit per second. This reduces the amount of data for 2k images by a factor of more than 8 and for 4k images by a factor of more than 30.
- Two resolutions are selectable from the codestream, one for big screens, one for smaller. This resulted in two image containers: 2048x1080 pixels and 4096x2160 pixels. The scalability feature of JPEG 2000 was used to create only one data stream for both screen

sizes. For feature films with an aspect ration of 2.39:1 this results in a resolution of 2048x858 pixels or 4096x1716 pixels.

- The selected bit-depth is 12 bits per color component to allow enough headroom for dynamic range and contrast. An XYZ color space was introduced, which allows for a device-independent coding. Future projectors can benefit from this color space without additional color grading.
- For security purposes the JPEG 2000 codestreams are AES-128 encrypted. The key is only known during the post-production or inside the playback devices in a specially secured environment (Media Block). No decrypted image data is available outside these devices.
- The audio information is uncompressed (PCM format). The DCP allows the integration of up to 16 audio channels.
- The frame-rate is currently 24 frames per second. This is sufficient to avoid flicker problems under the low ambient light conditions of the theatres. An extension to other frame-rates is tough under consideration.

1.3.3 Digital Cinema Package (DCP)

The Digital Cinema Package replaces the traditional film reel and contains all movie essence like images, soundtrack and subtitles. It is a set of files with the following structure (see **Fig. 1.8**):

- The most basic element is a track file and that contains essence and/or metadata. It is a MXF wrapped file format and holds JPEG 2000 compressed images, audio and/or subtitles. Analogue to film the digital track files will be split into reels. This allows the use of different encryption keys throughout the movie. Typically three reels are used for D-Cinema.
- A Composition Playlist (CPL) is created in the Digital Cinema mastering process to assemble a complete Composition. This Composition consists of all of the essence and metadata required for a single presentation of a movie, a trailer, an advertisement, or a logo. A single Composition Playlist contains all of the information on how the files are to be played, at the time of a presentation, along with the information required to synchronize the track files.
- The Packing List (PKL) contains information and identification about each of the individual files that will be delivered in a Digital Cinema Package (DCP).

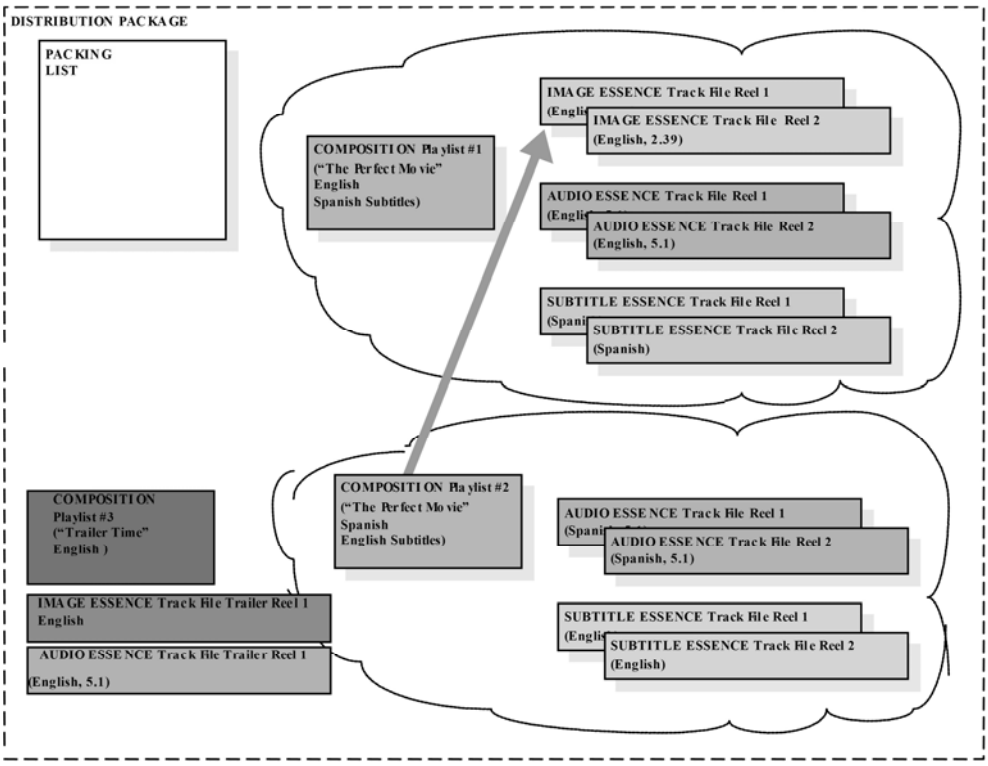


Fig. 1.8 *Structure of Distribution Package (DCI, 2008)*

1.3.4 Standardization of D-Cinema Distribution

Society of Motion Pictures and Television Engineers (SMPTE)

To achieve a broader acceptance the DCI specifications were fed to SMPTE and ISO/IEC for standardization. Based on the specifications a complete set of new standards is under development. Below is an extract of the most important standards:

427		Link Encryption for 1.5 Gb/s Serial Digital Interface
428	428-1	D-Cinema Distribution Master: Image Characteristics
	428-2	D-Cinema Distribution Master: Audio Characteristics
	428-3	D-Cinema Distribution Master: Audio Channel Mapping and Channel Labeling
	428-4	D-Cinema Distribution Master: Audio File Format/Constraints
	428-5	D-Cinema Distribution Master: Image Mapping into TIFF
	428-6	D-Cinema Distribution Master: PCM Format
	428-7	D-Cinema Distribution Master: Subtitle
	428-8	D-Cinema Distribution Master: Image Metadata
	428-9	D-Cinema Distribution Master: SDI Mapping
429	429-1	D-Cinema Packaging: Packaging Guideline
	429-2	D-Cinema Packaging: Operational Constraints
	429-3	D-Cinema Packaging: Sound and Picture Track File
	429-4	D-Cinema Packaging: MXF JPEG 2000 Application
	429-5	D-Cinema Packaging: Timed-Text Track File
	429-6	D-Cinema Packaging: MXF Track File Essence Encryption
	429-7	D-Cinema Packaging: Composition Playlist
	429-8	D-Cinema Packaging: Packing List
	429-9	D-Cinema Packaging: Asset Mapping and File Segmentation
	429-10	D-Cinema Packaging: Stereoscopic Picture Track File
	429-11	D-Cinema Packaging: Auxiliary Sound for CPL
430	430-1	D-Cinema Operations: Key Delivery Message
	430-2	D-Cinema Operations: Digital Certificate
	430-3	D-Cinema Operations: Generic Extra-Theater Message Format
	430-4	D-Cinema Operations: Log Record Format Specification
	430-5	D-Cinema Operations: Security Log Event Class and Constraints
	430-6	D-Cinema Operations: Auditorium Security Messages for Intra-Theater Communications
	430-7	D-Cinema Operations: Facility List
	430-8	D-Cinema Operations: Show PlayList
	430-9	D-Cinema Operations: Key Delivery Bundle
431	431-1	D-Cinema Quality: Screen Luminance Level, Chromaticity and Uniformity
	431-2	D-Cinema Quality: Reference Projector
433		XML Data Types

Table 1: SMPTE D-Cinema Standards (SMPTE, 2007)

ISO/IEC SC29 WG1

The JPEG 2000 profiles, which are referenced in the SMPTE 429-4 standard and used for D-Cinema distribution, are defined in ISO/IEC 15444-1:2004/AMD1:2006, Profiles for Digital Cinema Applications (ISO/IEC, 2006).

ISO TC36 Cinematography

For a worldwide standardization of the D-Cinema distribution the SMPTE standards are now under standardization within ISO TC36. The standards are in a so called fast-track procedure, which allows a faster standardization. Mid 2008 about 27 documents of table 1 are in the ISO standardization process.

1.3.5 JPEG 2000 D-Cinema Distribution Profiles

For D-Cinema distribution codestream restrictions two new profiles were introduced. The two profiles correspond to a 2k (2048x1080) pixel profile and a 4k (4096x2160) pixel profile. Below are the most important parameters. A complete set can be found in ISO/IEC 15444-1:2004/Amd 1:2006, Profiles for Digital Cinema Applications (ISO/IEC, 2006).

	2K digital cinema profile	**4K digital cinema profile**
SIZ marker segment		
Profile Indication	Rsiz=3	Rsiz=4
Image size	Xsiz <= 2048, Ysiz <= 1080	Xsiz <= 4096, Ysiz <= 2160
Tiles	one tile for the whole image:	Same
Sub-sampling	No subsampling	Same
Number of components	3	Same
Bitdepth	12 bit unsigned	Same
Marker locations		
Packed headers (PPM, PPT)	Disallowed	Same
COD, COC, QCD, QCC	Main header only	Same
COD/COC marker segments		
Number of decomposition levels	N_L <= 5	1<= N_L <= 6
Number of layers	Shall be exactly 1	Same
Code-block size	32x32	Same
Code-block style	SPcod, SPcoc = 0000 0000	Same
Precinct size	PPx = PPy = 7 for N_LLL band, else 8	Same
Progression order	CPRL, POC marker disallowed	There shall be exactly one POC marker segment in the main header. …
Tile-parts	Each compressed image shall have exactly 3 tile parts. Each tile part shall contain all data from one color component	Each compressed image shall have exactly 6 tile parts. Each of the first 3 tile parts shall contain all data necessary to decompress one 2K color component. Each of the next 3 tile parts shall contain all additional data necessary to decompress one 4K color component.
Application specific restrictions		
Max compressed bytes for any image frame (aggregate of all 3 color components)	1302083 bytes for 24 fps 651041 bytes for 48 fps	1302083 bytes (for 24 fps)
Max compressed bytes for any single color component of an image frame	1041666 bytes for 24 fps 520833 bytes for 48 fps	1041666 bytes for 2K portion of each component (for 24 fps)

Table 2: Important parameters of JPEG 2000 Profiles for D-Cinema distribution

The main reason for the codestream restrictions was to constrain the codec flexibility, such that manufacturers can create systems more easily. A detailed explanation of the parameters can be found in (Bilgin, 2006). The main restrictions are: defining a 2k and 4k format, using maximally up to 5 or 6 resolution levels, using only one quality layer, using fixed codeblock size of 32x32, using 12 bit per color component, restricting the bit-rate to 250Mbit/s.

1.4 Archiving of Digital Movies

With the introduction of D-Cinema distribution and the continued growing of digital post-production and digital movie acquisition, archiving of digital cinema movies in its original format is requested by the industry. Film is certainly today's the best physical long term archiving media for movies. Nonetheless, since the film substrate is still prone to long-term deterioration, other carriers have to be looked for imposing the need for redundant storage architectures and standardized archive formats, such that long term digital preservation becomes acceptable. Additionally, as more and more content is digitally born, the transfer back to film (e.g. as YCM Separation Archival Master) costs a lot of efforts, money and potentially quality.

Traditional film archives therefore have to look carefully, in which way the preservation of movies as cultural heritage can be done in the digital age. On one hand the content has to be preserved for a long term, on the other hand with the change of utilization of movies (see introduction) a direct short term access for reusing of digital movie data is necessary to help refinancing the archival costs.

1.4.1 EDCine

To address the problem of digital movie archiving an initiative was started in 2006 by the Cinémathèque Royale de Belgique (CRB), the Fraunhofer IIS and MOG Solutions as part of the European funded project called EDCine (EDCINE, 2008). The project started with the collection of requirements for digital movie archives and intends to meet all requirements by presenting a two-tier storage model that provides both a long-term preservation file format at the best quality, called Master Archive Package (MAP) and an simple access format, called Intermediate Access Package (IAP) (Read, 2008). As the ideal physical storage media for digital long term data storage today is still not identified, EDCine concentrates its effort in defining digital storage formats independent from the physical media.

As digital preservation strategy data migration is recommended.

> *"Data migration involves the transfer of data from old physical media to new physical media, a process that often (but not always) includes updating file formats for currency with the latest-generation operating system and/or software application" (A.M.P.A.S., 2007)*

The main goal in the project is to define JPEG 2000 and MXF based file formats as open standards with long term lifetime, so that the migration process is limited to the data transfer from old to new physical media. With the scalability features of JPEG 2000 a high flexibility for data access in browsing, searching and retrieval applications shall be achieved.

1.4.2 Requirements for digital movie archives

All moving image film, video and digital archives need a procedure that stores their images (and related sound) in their highest quality and provides access to them in an increasing variety of formats and qualities. For search and retrieval purposes additional metadata for categorizing and indexing of the archive items are necessary.

With the transition of film movies to D-Cinema distribution packages the storage of digital movie data has to be taken into account. To avoid quality loss and additional processing steps archiving of DCI/SMPTE compliant DCPs has to be supported as well.

Film for cinema has always generated its own unique experience in the audience, which has varied with time, location and technology for over 100 years. Archives, movie libraries and specialist cinemas require that the cinema projection of heritage films (best defined as films shot and released prior to digital projection becoming used or standardized) be authentic and bring as faithful as possible a representation of the projected original film (a requirement already observed in the restoration of old films). Hence, it should respect the rendering intend.

The following list (an excerpt of the details provided by the Cinémathèque Royale de Belgique in consultation with the FIAF Technical Commission to the research partners) records some of the characters that provide this authenticity, but is not exhaustive. A complete list and a white paper can be downloaded from the EDCine Website (http://www.edcine.org):

- The resolution of the projected screen image should not be visually lower than that of the original film/movie image (it is anticipated that this requirement is difficult to quantify).
- The frame rate of a digital cinema projection should be the same as that of the original film.
- The aspect ratio of the image should be that of the original film

In brief, the basic requirements of a digital storage system for film are as proposed:

- Ingest should be from all available essence: film images, film sound, and any analogue, digital video or data version of a programme, images or sound.
- For purposes of access, the intermediate access package IAP must be capable of producing a wide range of current formats and media output (from D-Cinema quality to HD and standard definition television, to Internet-browsable versions).
- The MAP, the long term digital storage format, must store data in a lossless format.
- D-Cinema output versions, film output versions and any other high quality output versions of the future that are generated from long term digital storage formats should be as close to the original film or digital version, as possible.

1.4.3 System Concepts and Archival Workflows

The EDCine Digital Film Archive System Architecture presents two different file formats to store images, audio and metadata (see **Fig. 1.9**). Each is able to store archived items in the best possible quality (at this time), and to facilitate the access to the archived items into many different distribution formats. The proposed architecture consists of two packages, the Master Archive Package (MAP) for long-term preservation, and an Intermediate Access Package (IAP) designed to make the access to the stored items faster and simpler. Both MAP and IAP are designed as information packages where the content (image, sound, texts, etc.) is stored jointly to its cataloguing information and technical metadata to ensure that the content is correctly displayed when accessed. This is in accordance with the Open Archival Information System (OAIS) Reference Model standardized as ISO 14721:2003. Archived material may be stored in either one of the two formats or in both formats simultaneously depending on the usage scenarios.

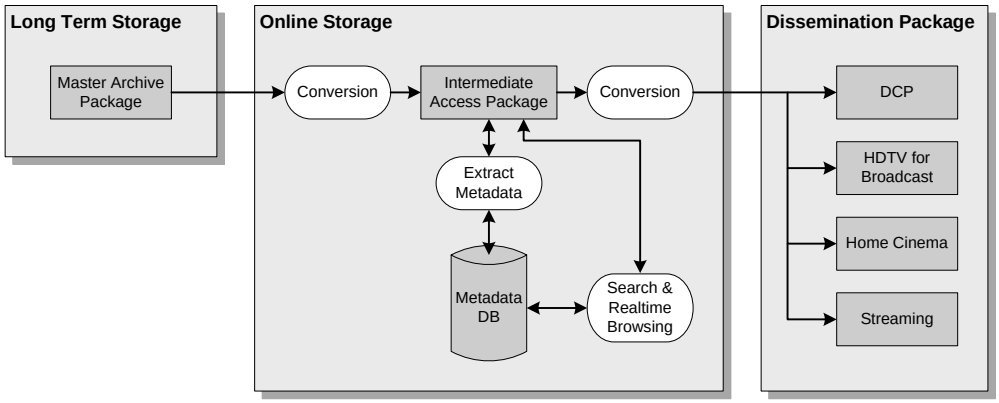


Fig. 1.9 *Two-tier approach for digital movie archives (Fraunhofer IIS)*

The main design goal for the MAP is to store the source images and sound without any loss of information in order to preserve the original viewing experience. This practice usually requires lossless compression and results in large amounts of data. For the MAP a JPEG 2000 lossless profile is recommended.

The main design goal for the IAP is to allow frequent access to archived items. This usually does not require the original lossless quality of the source images and data. Instead the focus lies on easy and standardized access through local and remote channels. This results in the requirement for a significant (and often extreme) reduction of the original amount of data and the restriction of certain coding parameters to ensure maximum compatibility with a wide range of decoding and playback equipment.

1.4.4 Archive Packages MAP and IAP

The key specifications of the **Master Archive Package** are within the limitations of JPEG 2000 and AES (Audio Engineering Society) recommended practices:

- Image resolutions up to 16K (16384 x 8640 pixels)
- Any image frame aspect ratio
- Any image bit depth (only limited by JPEG 2000 maximum bit depth, which is for practical implementations 32 bits per component)
- Any color space
- Any frame rate
- Image components up to 8
- Mathematically lossless compression for image content (can also be lossy if required, e.g. when archiving an already compressed DCP)
- Audio data in RAW format (optional MPEG-4 SLS)
- No audio sampling restrictions (at least support of recommended values as in AES-5)
- No restrictions for word length in audio (at least 16 bit or 24 bit)
- Discrete (i.e. no matrix encoding) audio channels (unrestricted number)
- MXF wrapper (implementation currently limited to Operational patterns Op1a and Op1b or Op2a) . For more information on MXF format specifications see (Devlin, 2006)

Within the limitations of JPEG 2000 and AES recommended practices, the key specifications of this **Intermediate Access Package** are:

- Image resolution up to 2k (2048 x 1080) or 4k (4096 x 2160) (depending on adopted profile)
- Any image frame aspect ratio
- Image bit depth up to 12 bits
- Any frame rate
- Image components up to 8
- Compression aimed at producing a bit-rate up to 250Mbits/sec for 2k images with 24fps, 500Mbit/s for 2k images with 48 fps or 500Mbits/sec for 4k images (this level set at a current practical level that allows real time presentation with current technology).
- Audio data in RAW format (optional MPEG-4 SLS)
- 48kHz or 96kHz audio sampling frequencies
- 16 bit or 24 bit word length for audio
- Discrete (i.e. no matrix encoding) audio channels (up to 16 channels)
- MXF wrapper (implementation currently limited to Operational patterns Op1a and Op1b or Op2a)

1.4.5 Standardization of Archive Profiles

The EDCine consortium started a standardization effort within ISO SC29 WG1 in liaison with the Association des Cinémathèques Européennes (ACE), Fédération Internationale des Archives du Film (FIAF) and SMPTE to define and standardize the new profiles for JPEG 2000. It is known as ISO 15444-1: AMD2 Extended profiles for digital cinema applications (ISO/IEC, 2007). Further recommendations are planned for the integration of the JPEG 2000 codestreams into the MAP and IAP data packages, similar to the D-Cinema distribution package (DCP).

1.4.6 JPEG 2000 Archive Profiles

For Digital Cinema Archive applications three new profiles are proposed within ISO: one profile for *Lossless Long Term Archiving*, and two other profiles as intermediate access formats with higher flexibility than the D-Cinema distribution profiles: *Scalable 2K Digital Cinema* and *Scalable 4K Digital Cinema*. The profiles are being standardized as ISO 15444-1: AMD2 Extended profiles for digital cinema applications (ISO/IEC, 2007)

	Scalable 2k digital cinema profile	**Scalable 4k digital cinema profile**	**Long-term storage profile**
SIZ marker segment			
Profile Indication	Rsiz=5	Rsiz=6	Rsiz=7
Image size	Xsiz <= 2048, Ysiz <= 1080	Xsiz <= 4096, Ysiz <= 2160	Xsiz <= 16384, Ysiz <= 8640
Tiles	one tile for the whole image	one tile for the whole image	One tile for the whole image or minimum tile size YTsiz + YTOsiz >= 1024 XTsiz + XTOsiz >= 1024
Sub-sampling	No subsampling	No subsampling	No restriction
Number of components	Csiz = 3	Csiz = 3	Csiz<=8
Bitdepth	$Ssiz^i$ = 11 (i.e., 12 bit unsigned)	$Ssiz^i$ = 11 (i.e., 12 bit unsigned)	No restriction
Progression order	CPRL	CPRL	CPRL
Number of layers	L=2	L=2	L<=5
Multiple component transform	No restriction	No restriction	No restriction
Number of decomposition levels	N_L <= 5 Every component of every image of a distribution shall have the same number of wavelet transform levels.	1<= N_L <= 6 Every component of every image of a distribution shall have the same number of wavelet transform levels.	No restriction, with respect to: (Xsiz-XOsiz)/D(*I*) <= 64 (Ysiz-YOsiz)/D(*I*) <= 64 and D(*I*)=pow(2,N_L) for each component *I*
Code-block size	xcb = ycb = 5	xcb = ycb = 5	xcb <= 6, ycb <= 6
Transformation	9-7 irreversible filter	9-7 irreversible filter	No restriction
Application specific restrictions			
Max compressed bytes for any image frame (aggregate of all 3 color components)	1302083 bytes	2604166 bytes	No restrictions
Max compressed bytes for any single color component of an image frame	1041666 bytes	2083332 bytes	No restrictions
Max compressed bytes for quality layer 0 of any image frame (aggregate of all 3 color components)	1302083 bytes for 24 fps 651041 bytes for 48 fps	1302083 bytes (for 24 fps)	No restrictions
Max compressed bytes for layer 0 of any single color component of an image frame	1041666 bytes for 24 fps 520833 bytes for 48 fps	1041666 bytes for 24 fps for 2K portion of each component.	No restrictions
Purpose	**Used as IAP**	**Used as IAP**	**Used as MAP**

Table 3: Important parameters of JPEG 2000 Profiles for Digital Movie Archives

The two scalable profiles contain DCP compliant tile parts, meaning that by only properly parsing the codestream a D-Cinema distribution codestream (15444-1:Amd1) can be created without decompression and recompression. With the additional layer 1 a bit-rate up to 500 Mbit/s can be achieved for 4k image movies and 2k image movies at 48 fps. The long term

storage profile has very flexible parameter ranges, such that the original format can be preserved.

1.5 Future use of JPEG 2000 within Digital Cinema

1.5.1 Acquisition

During the acquisition of digital feature movies preservation of high quality is required. Whereas in HDTV applications, broadcast cameras compress the images down to 100-200MBit/s, this is not acceptable for feature movies. Consequently, either an uncompressed recording is used or a lighter compression, which results in data rates of 400 to 800Mbit/s. Next generation digital cameras will have higher resolutions (up to 4k) and higher frame rates (up to 150 frames per second), hence also the necessary data rate will increase. Feature movies run through a complex post-production process with many image processing steps (pan and scan, zoom, contrast enhancement ...), where compression artifacts can become visible. Tests within the project WorldScreen (Worldscreen, 2003) have demonstrated that compression factors of 4:1 to 8:1 are acceptable as a maximum; otherwise post-production is limited to specific operations.

First cameras based on JPEG 2000 algorithms have been implemented. Cameras developed for movie and medical purposes, which use this technique, are e.g. the Thomson Infinity camera series or the RED camera. In the future more cameras are expected. However, high quality and high bit-depth are the basic requirements for its use.

1.5.2 Post-production

Post-production is a very data intensive process. Today 2k real-time post-production is possible. However in many cases, especially for movies with 4k images, the standard process is to generate proxies, meaning a copy of the captured images with a smaller resolution, and to work with these proxies. Hence, editing can be done faster and more easily. Typically CDLs (Color Decision Lists) and EDLs (Editing Decision Lists) will be generated as metadata and later used in the conforming process. In this process the decisions will be applied to the original captured data to generate the final version.

JPEG 2000 would ideally eliminate the need for proxies, as several resolutions are inherently present inside the JPEG 2000 codestream. Several projects like WMP (Tools for Media Production) (WMP, 2008) demonstrated that the use of JPEG 2000 from acquisition to distribution is a good approach for future post-production systems. Today, it is hampered by the high processing complexity of the JPEG 2000 algorithm. In the future however with higher computational power and/or better JPEG 2000 ASICs this seems to be a good option.

1.5.3 Mastering with JPEG 20000

In the past a scanned film master was the starting point for different distribution formats. However the number of distribution formats increased in the last years (more than 30) and will increase more, so that the handling of the original uncompressed high data volumes became a bottleneck in the creation of these formats. With the DCP as highest quality distribution format, a new workflow is possible. Tests have demonstrated that the creation of lower quality distribution formats directly from a DCP have no quality loss in comparison to the original workflow, where the distribution formats are processed directly from the uncompressed master. The only workflow restriction is the limited scalability and metadata information of the DCP. Metadata in this case means information about the processing steps from one distribution format to the other. This problem can be solved by defining a more flexible JPEG2000 package called DVP (Digital Video Package) (Lukk, 2008) (Foessel, 2008) or to use the scalable 2k or 4k profiles of the Digital Cinema Archive profiles (see chapter 1.4.6) in conjunction with XML metadata files.

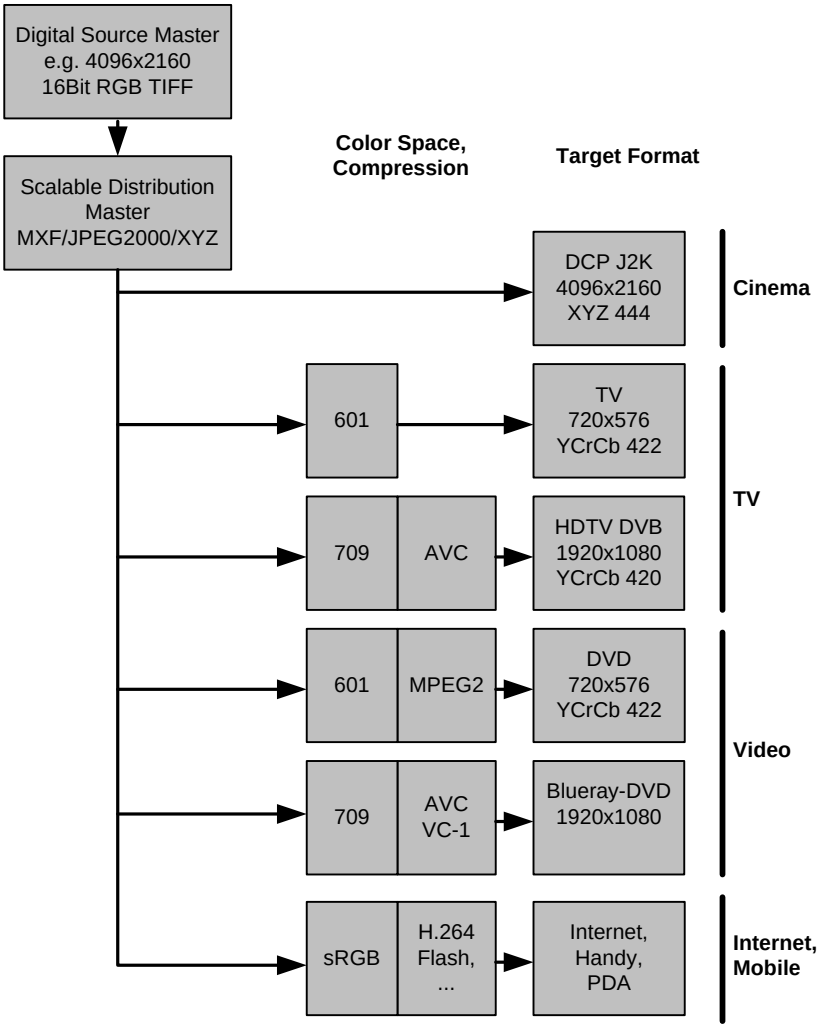


Fig. 1.10 *Mastering with JPEG 2000 (Fraunhofer IIS)*

1.5.4 Enhanced Distribution Profiles

During visual tests it could be demonstrated, that extremely high quality feature movies can not be presented in their original acquisition quality when limiting the data rate to 250MBit/s as specified in the D-Cinema distribution profile (DCP). To reach this quality, it is necessary to use exclusive lenses and a scanned 65mm film or computer generated images. For scanned 35mm film or today's digital cameras this is not the case. Therefore DCI and SMPTE have restricted the parameters in the DCP to avoid higher costs due to the complexity of the systems.

However, it can be expected that future digital cameras will be improved and that 3D movies will receive a higher acceptance. In this case, profiles with higher data rates are useful. The

scalable 2k and 4k profiles in the archive section seem suitable for these applications. Further investigations are needed to verify this and a guideline for the use of JPEG 2000 in Digital Cinema applications is in progress. The guideline will be published in the future as

"ISO/IEC 15444-1:2004/AMD3, Guidelines for digital cinema applications" (ISO/IEC, 2008)

It will contain information's about visual weighting factors for frequency bands, wireless transmission and enhanced profile coding for digital cinema.

1.6 Conclusions

With JPEG 2000 an excellent solution for high quality digital cinema movie compression was found. The intra-frame codec is ideal for editing and for frame accurate access during playback and browsing. Bit-depths of 12 or more bits per component allow for coding of high dynamic range images, which are typical for digital cinema environments. The scalability of JPEG 2000 enables the generation of one compressed image track which can be used simultaneously for 2k and 4k screens. In addition the scalability of JPEG 2000 offers future possibilities for fast editing and browsing in post-production and archive applications.

1.7 Addendum

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- The text and tables from amendments to ISO/IEC 15444-1:2004 Information technology – JPEG 2000 image coding system: Core coding system, are reproduced with the permission of the International Organization for Standardization, ISO. This standard can be obtained from any ISO member and from the Web site of ISO Central Secretariat at the following address: www.iso.org. Copyright remains with ISO.
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1.7.2 Glossary

ACE	Association des Cinémathèques Européennes, http://www.acefilm.de
AES	Audio Engineering Society
AES	Advanced Encryption Standard
ASC	American Society of Cinematographers
DCDM	Digital Cinema Distribution Master
DCI	Digital Cinema Initiatives LLC
DCP	Digital Cinema Package
DSM	Digital Source Master
DVP	Digital Video Package
FFA	Filmförderanstalt (http://www.ffa.de)
FIAF	Fédération Internationale des Archives du Film (http://www.fiafnet.org)
HDTV	High Definition Television
ISO	International Standardisation Organisation
KDM	Key Delivery Message
SMPTE	Society of Motion Pictures and Television Engineers

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