CREATING DCP WORKFLOW FOR DIGITAL CINEMA SYSTEM

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Abstract*: This paper describes in details analysis of Digital Cinema Package (DCP) file format structure, which is today widely used for distribution of digital movies for digital cinema. The whole process from creating source files, following by intermediate steps, to the final form of this format, is presented as well. Security principles are covered by Key Delivery Message (KDM). Some free software for creation DCP are mentioned at the end of this paper.*

1. INTRODUCTION

The cinema is the last entertainment industry to be embraced by the digital revolution. Until recently, movies were filmed and reproduced only on celluloid film for more than 100 years [1]. More or less, movies have been filmed in the same way after the launching of cinematography in the late 19th century. Even today, in some movie theaters, old machines rotate wheels of 35mm films, which is actually a century old media.

Over the last few decades, digital technology has transformed the music and home video industries, and has already a huge effect in the motion picture industry. It can be said that a new era has emerged for cinema. The transition to digital cinema has already changed cinema industry and will, undoubtedly continue to change, since its impact has just started being sensed.

Digital cinema refers to digital technology used in the production, post-production, distribution and projection of motion pictures on screen. However, this description does not include all aspects of digital cinema. Cinema can be defined as the art of presenting pictures on a “big screen” with a visual and audio quality not usually found in other media, e.g. television.

It should be pointed out that cinema includes visual and audio quality. By designated cinema as “digital”, it is implied that its quality is at least that of a 35mm celluloid film.

Until last few years, digital films could not achieve the level of quality similar to that of 35mm film. However, recent developments in areas such as digital projection, high-resolution film scanners, and advanced image compression techniques have enabled high quality digital cinema projection.

In digital cinema, motion pictures and sound are recorded digitally. Computers are used to process movies or even construct entire scenes from scratch to enhance color and to create visual effects, subtitles and titles.

The final movie version is compressed, encrypted and distributed on Digital Versatile Discs (DVD), smart phones, USB memories, via internet, or satellite communications to movie theaters. For movie projection, instead of using a conventional movie film projector, digital projectors with high luminosity, transfer rate, resolution and color quality can be used.

Digital cinema has many advantages in processing, transmitting and projecting cinematographic materials comparing to the old system. Digital information is much more suitable for processing than analog information. A computer can handle digital images easily, but cannot process an analog audio-visual stream in a simple way. Presentation quality is one of the main characteristics of digital cinema. It offers high quality image resolution and sharpness, excellent audio quality and visual effects that render viewer’s experience unique and exciting [2]. Digital data allow faster, easier and more economic digital movie distribution methods, such as internet, cable or satellite distribution. Digital technology makes motion picture distribution more robust against piracy, by allowing digital file encryption and subsequent decryption in the movie theater only by legitimate users, who have the appropriate decoding keys.

These technological advances were recognized by the movie industry. It was also recognized that these technological advances into commercially digital cinema use, industry-wide standards would need to be created. To establish such standards, Digital Cinema Initiatives (DCI) consortium was created in March 2002 [3]. DCI is a joint venture of seven the most important major Hollywood studios (Disney, Fox, MGM, Paramount, Universal, Sony Pictures Entertainment, and Warner Bros. Studios). The goal of DCI was to establish a standard with an open architecture for digital cinema. Such a standard would ensure the players in the movie industry that their final products and services will be compatible and interoperable with other industry members. The final version of the DCI specification was published online in July 2005 [3].

This paper is organized as follows. After description of the digital cinema system, including video, audio and subtitles, JPEG 2000 as a standards for image compression for digital cinema, is considered. The next section describes digital cinema package as a file format for the digital film. Some free software for digital cinema illustrate the process of DCP creation.

2. DIGITAL CINEMA SYSTEM

DCI has defined very detailed and comprehensive digital cinema standards as early as of 2005 and has updated those standards since then. DCI specifications are internationally used as digital cinema standards. Basic DCI standards cover image compression, audio, text, transmission and encryption.

The block-diagram of a digital cinema flow is illustrated in *figure 1*. As shown in the figure, a digital cinema system can be divided into four stages: Mastering, Transport, Storage and Playback, and Projection. At the mastering phase, the movie is compressed, encrypted and packaged for delivery to the movie theatres. The data is then transported to the projection site, where it is decrypted, uncompressed, and played back. The DCI standards discuss each of these stages.

Concerning transmission, the final composition is compressed, encrypted and packaged to form the Digital Cinema Package (DCP), using Material Exchange Format (MXF) and the Extensible Markup Language (XML). MXF is a container format, which supports separate information streams, encoded by a variety of codes [4]. Encryption is carried out by Advanced Encryption Standard (AES) 128 bits standard, which receives an 128 bit text for encoding and makes 128 bits encrypted text. AES 128 encoding uses a secret key. Keys are distributed by Key Delivery Message (KDM). The decoding algorithm is similar to encoding.

Creation of DCP format is carried out by using specific form of source files, which depends very much on the format of the stored data and the quality of the recording techniques. In fact, a normal user is not able to use of all the advantages of the DCP file format with available technical equipment. Today, images are used with four times higher resolution than the most widespread HD 1080p resolution, and double sampling rate and audio bit depth, which can be achieved with professional microphones.

In practice, the entire process of creating a complex package of files is controlled by experts for mastering or distribution companies. Resulting form of DCP depends on whether the files come from commercial or amateur production. Differences can be found in the input data, professional or amateur hardware and software in output files. This format is primarily used for movie projection in the cinema for commercial use, as well as for advertisements, trailers and spots that are designed for screening in digital cinemas [3].

3. DIGITAL CINEMA DISTRIBUTION MASTER

The DCP creation process consists of the following three basic steps:

- Digital Source Master (DSM);

- Digital Cinema Distribution Master (DCDM);
- Digital Cinema Package (DCP).

3.1 Digital Source Master (DSM)

A prerequisite for creating a digital cinema format is the existence of a data set, created in post-production. Post-production is the phase after filming, when the film is being edited to the final form. The format of these data and record parameters is not fixed. It depends on the provider, but also on the distributor and whether will be able to process this data format. The data format has an influence on the quality of the provided number of recording tracks, and the recording medium on which the data is stored. Input data can be in digital and analog form and it is edited to final forms of film. Today, the digital form of recording and storing data is used without exception [3].

DSM consists of:

- Video recording - video in analog or digital form;
- Audio tracks - audio in analogue or digital form;
- Subtitles - text usually in electronic form.

3.2 Digital Source Master (DSM)

The DCDM format was launched by DCI and its data formats are fixed and regulated by standards. Standardized format structure of DCDM was created by mastering companies from any of the DSM sources. It is important to ensure sufficient control of the output quality of the DCDM data. Also, the quality control of individual structures for both standalone playback and synchronization with other structures should be kept. Furthermore, it is also of importance to check the stored data for the presence of errors caused by transfer. For this purpose, DCDM files must be played on the device (projector, speaker set) for which they are designed. However, this is not possible on digital cinema systems. This is because the data is still uncompressed at this point and all data tracks have a very high bit rate. Therefore, there are high demands on the capabilities of the playback device, in particular the computing capability of a processor.

DCI computer assemblies were created for this verification and testing and they are capable for playing back these data structures. DCDM is not intended for distribution for two main reasons. First, it contains uncompressed data with too high bit rate and above all, data is not at all protected by encryption against tampering. To reduce the amount of data and playback device requirements they must be compressed. The compression rate is chosen so that the quality of signal is not significantly reduced. Ordinary viewers must not notice errors on projection due to compression [3].

The DCDM workflow is shown in *figure 2*. DCDM contains all digital material required

for playback and includes image and audio information, subtitles, comments, animation, optical and sound effects, etc. Audio, image and text conform to the DCI standards. DCDM files can be directly played by the media playback equipment (e.g. projector and sound system) for projection quality control, or for synchronization and composition integration. Composition refers to all content and metadata required for a movie, trailer or advertisement projection

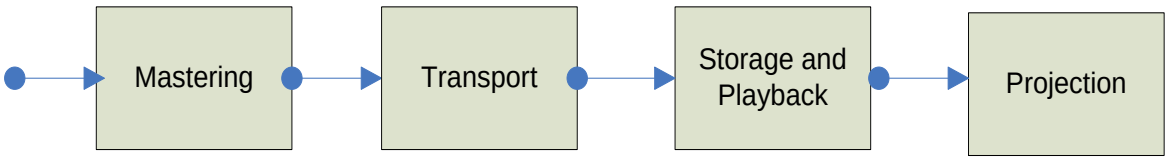

Fig. 1. Digital cinema system

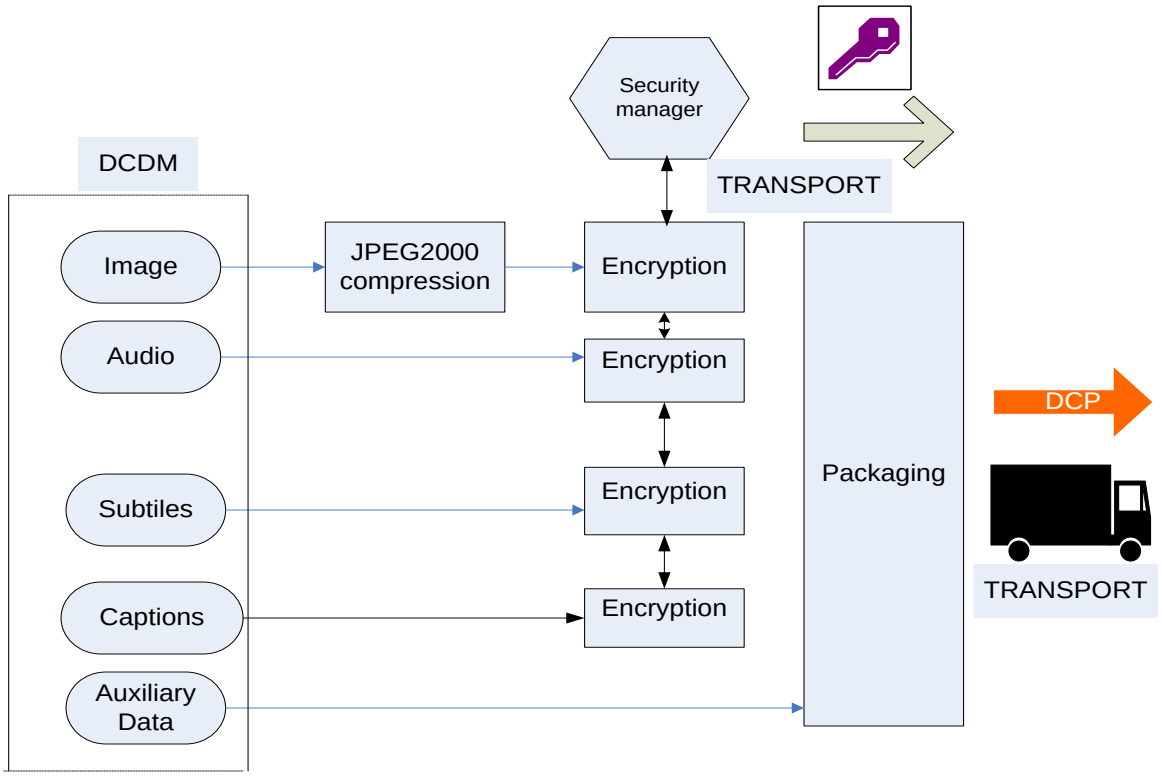

Fig. 2. Digital cinema mastering

DSM consists of:

- Image structure – J2C format;
- Sound structure - WAV format;
- Title structure - PNG or XML format;

3.3 Video

It is possible today to meet analog recording films that were shot before process of film digitization. At the start of digitization, the film strip is shot frame by frame by high-resolution

special film scanner and saved in TIFF (Tagged Image File Format) format. Furthermore, images are edited in graphics editors for color adjustment and removal of image defects. This is often caused by scanning errors, time degradation of the recording or incorrect handling of the film record.

Compared to the previous procedure, the processing of digital image recording is substantially simpler and the resulting image is much better. The recording quality depends very much on the used hardware and software, and the chosen file format chosen where the data is stored. It is understood that the best results can be achieved by use quality recording techniques, saving the file without using compression and with the highest possible quality. The sequence of TIFF images has a data volume of approximately 8TB for 4K resolution (for a film length of 200k frames).

3.4 Audio

As a video recording, audio has been recorded in analog form historically and stored on different carriers. Therefore, there is a need to digitize the audio. Various defects can exist on the recorded audio, caused very often by the aging of the recording medium or by mechanical means damage. For instance, tape cassettes were very often damaged in the sensing head or player mechanism. The tapes were not resistant to high temperatures nor exposure to dust. This can be reflected in the signal-to-noise ratio (SNR) or in a sound recording that negatively affects on its fidelity Resulting quality will also greatly affect on the quality of used analogue–digital (A/D) audio converters. Film studios use unquestionably high-quality digital converters and storing without the use of compression into a 96 kHz WAV file and a bit depth of 24 bits/sample [5]. Each sequence of images is always accompanied with a multi-channel audio track that physically represents one or more record carriers. Each audio track can contain a maximum of 18 channels for surround sound. Every sound channel contains different audio information and as many channels as possible must be present for perfect preservation of spatial information [3].

3.4 Subtitles

Subtitles are the last feature to be edited in a movie. Today, computer programs are used to create and edit subtitles. A template that is based on a scenario is available for a subtitle structure pattern. This template is formed by DCP - data format for digital cinemas. The corresponding software contains everything for creating subtitles in all languages. The template contains text and audio information in text form. The translations and scene notes for easy translation and orientation in subtitle timing are available. Final control, however, is still dependent on a person, and the native speaker of the language in which the subtitles are made. It is necessary to control a lot of aspects that the software is unable to do, such as accurate

timing, comfortable reading speed, or correct placement of subtitles in the image. Only a native speaker can make headlines to perfection so that every viewer can fully understand the story of the film in his language [3].

4. JPEG 2000 CODING FOR DIGITAL CINEMA

The recommended image compression standard for digital cinema is JPEG 2000 and the maximal data rate is 250 Mb/s [7]. JPEG 2000 has been standardized by the Joint photographic Expert Group (JPEG) of the International Organization for Standardization (ISO) and has been published as ISO 15444-1 standard [8]. JPEG 2000 uses a wavelet based image compression technique, which does not require image division in blocks, as the popular JPEG does. Therefore, it yields fewer blocking artifacts. Additionally, it conveys 20% better image compression, at significantly higher image quality. The main benefits of JPEG 2000 are the following:

- Support of lossless and lossy compression in a single codec;
- Multiple aspect ratios and resolutions;
- Intra-frame coding, which does not require motion estimation and compensation;
- Scalable image reproduction; a low resolution image version can be shown after the reception of a small part of the image file and can be enhanced progressively, after receiving more data. The first layer which can be transmitted and displayed, corresponds to the image background, which is, usually, its least important part.

With three color components, high bit-depth of 12 bits per pixel (bpp) and per color component, and 24 f/s, the total size of a three-hour feature film exceeds 9 TB. Such large sizes make the distribution of uncompressed digital movies impractical. Thus, the DCI specification includes data compression technique to decrease the size of the image data for economical storage and delivery. The compression technology chosen for digital cinema is JPEG 2000 [8]. It should be noted that JPEG 2000 was selected because of its tremendous flexibility, as well as its ability to deliver excellent picture quality. One important feature is its ability to compress both 2K and 4K pixel resolutions with one pass of 4096x2160 down the network. A second feature is that the JPEG 2000 compression engine is primary-set independent [7].

Another advantage is that separate signals simultaneously passing through can be selectively compressed or ignored and seamlessly passed along together. For example, accompanying metadata in MXF track files are not compressed, but are sent along in the output code streams, in sync with the compressed image representations. Among other features, JPEG 2000 has also the ability to extract sub-frame objects within full frames without any loss of quality [6].

In order to meet all the requirements, as well as those of using only standardized and non-proprietary formats, the standard JPEG 2000 was chosen for both lossless and lossy

compression, while MXF can be selected as a wrapper to package together all data streams and metadata in the *Master Archive Package* and *Intermediate Archive Package* [9]. DCI required a compression algorithm to be an open standard, so that multiple hardware manufactures would be able to build digital cinema systems. Significantly, the compression algorithm needed to support both 2K and 4K resolution projectors from the same file. JPEG 2000 satisfies these requirements and more [10].

The particular set of parameters (that will be used in digital cinema applications) is defined in JPEG 2000 profiles. A JPEG 2000 profile is a set of parameters that are designed to best serve the needs of a particular application. Currently, there are three profiles, defined as part of the JPEG 2000 standard. Two of these profiles, described a restricted set of parameters for use in particular applications, while the third profile is unrestricted. Two additional profiles are being developed for use in digital cinema applications by the JPEG 2000 committee.

The DCI specifications require a 4K decoder to decode all data for every frame in a 4K distribution. Similarly, a 2K decoder is required to decode all data in a 2K distribution. A 2K decoder is allowed to discard the highest resolution level of a 4K distribution [11]. No other data can be discarded. In other words, discarding data to keep up with peak decoding rates is not allowed.

5. DIGITAL CINEMA PACKAGE

This digital data format is referred to the classic film format wheels. The individual video and audio structures are packaged in separate files in MXF format and saved separately [12]. This is because subtitle tracks in the individual language could be separated to allow separate projection. MXF is the carrier format of all structures (tracks) together, intended for distribution, which is formed from DCDM. There is no change in the appearance of the tracks. The subtitles are saved in XML or PNG format and descriptive files in XML. Descriptive files include: Composition Playlist - CPL (list of all files in DCP), and Volume index file - VOLINDEX (volume information). The DCP designation includes all these files. The packing list is only added at the end of the process and can be used to verify that the DCP did not lose any stored data after decryption and whether all data is read properly and errors are eliminated [3]. The whole package is encrypted at the end against unauthorized playback, copying and further copyright infringement by KDM. Complete DCP includes also lot of trailers and advertisements. The exact structure of the DCP depends on the used software and may vary slightly in some respects (e.g. in directory structure). *Figure 3* shows the process of DCP delivering to a movie theater.

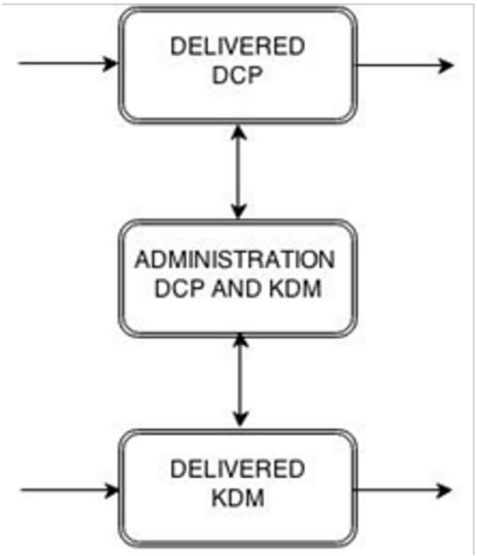

Fig. 3. Digital cinema package delivering

5.1 Key delivery message

This is a security mechanism that is used to prevent unauthorized access to DCP data [13]. When creating a DCP from DCDM, the video and audio tracks are encrypted with unique keys that allow the owner to decrypt encrypted data. These decryption keys must be securely delivered to all end customers, such
as cinemas, distributors or editorial companies. Each key is unique and it is used to decrypt only certain traces for which it is intended. It is not possible to have a key that decrypts all tracks on data medium [13].

KDM has three levels of security:

- 128-bit AES key for video and audio track security;
- RSA (*Rivest–Shamir–Adleman*) key used to encode content to level 1;
- RSA key for the final encryption of the content to level 2 by another type of key of the same kind.

KDM specifies the following [13]:

- Closer rights to CPL;
- Access rights to individual tracks;
- Key validity period - time of day, time interval;
- List of trusted devices - public key.

KDM takes the form of a very small digital XML file that the distributor sends to the cinema stored on a USB stick or simply as an electronic attachment. Usually an external company handles the issue of these keys. They can only decrypt the data devices that own a unique private key associated with a public key contained in KDM. The first decryption option is using a private key. This is a device description issued by a manufacturer or supplier. A model, serial number, device role in the distribution chain (mastering, playback…), as well as

proof that the private key comes from a trusted source, are shown. If an invalid (pirated) certificate is included in the database of certificates, it would mean financial losses for film production and mastering company. For this reason, when issuing certificates, greater attention is paid to credibility of the applicant.

The second option is to decrypt the data using the internet. If the device is certified for this server, it is capable of using protected data and it allows access to content. Device certification information for the server is listed in the CPL. If the device is certified for another generation of certificates KDM must be able to decrypt and extract the necessary data. The device creates its own KDM, for which it is certified and fully supported. This happens in practice very often, as a large number of KDM and playback systems are widely used throughout the world. The key issuer must anticipate this option in advance. A typical certificate database consists of a relatively small number of root and signed certificates, but with a large number of device certificates. Managing a certification database is a tough task. This is mainly because servers can move to repair or replace with newer models. Cinema server operators are therefore forced to constantly communicate with key distributors and provide them with up-to-date information, to receive the correct KDM for projection [3].

5.2 Projection

Within the DCI specification, the projection system converts the digital picture information into light which is projected on a screen. The DCI specification defines several aspects of the projection system including colorimetry, performance specifications and requirements, as well as physical connections to and from a projector.

A projection system can support many interfaces and various digital cinema architectures. In addition to the main image, a projection system may also project text and still images on a screen. This requires additional interfaces. Two major technologies are used in digital cinema projectors, namely Digital Light Processing (DLP) and Digital Image Light Amplifier (DILA).

DLP has three basic benefits, compared to alternative existing projection technologies:

- It allows high quality color or monochrome image projection without noise;
- It is more efficient than other alternatives (e.g. LCD technology), because it doesn’t require polarized light;
- The dense location of micromirrors produces images at the highest perceivable image resolution.

DILA technology has other benefits:

- It allows maximal pixel density and supports high image resolution;
- It allows powerful light emission, even at high resolution;
- It provides high image contrast.

Digital content can be stored on a local or central cinema server hard disk. The local disk is located right next to the cinema server. The central disk is common to the entire multiplex and is located at a central site that is connected via 1 Gb/s Ethernet projector. In practice, the best combination of both solutions is where the central disk is used for retention of all data and only digital content needed for the nearest is transferred to the local disk projection.

5.2 Transport

The DCI specification does not specify a particular mode of transport. It is envisioned that the transport can be via physical media or over a network. It is required that the content owners' encryption is not removed during transport. All of the data of the original movie files must be intact upon completion of the transport.

5. NON-COMMERCIAL SOFTWARE PRODUCTS

Creating DCP format using non-commercial products from source files is not a simple matter if legally free available programs are used. Still several years ago, no commercial software was available for this purpose. A large number of software companies, computer programmers and enthusiasts made a big step forward in developing software products that make this possible.

Nowadays, ordinary users interested in DCP encoding also have a choice from several available programs. However, the complete flawlessness of this software has yet to be discussed. The reason for this is largely the limited number of experts involved in their development.

Non-commercial software products can be used free of charge, where only registration on the product website is required. Main software requirements include:

- Freeware;
- Simple installation and operation;
- Encoding speed;
- No restrictions: time of coded recording, adding text or logo to the image;
- Possibility of basic output settings;
- A wide range of supported codecs.

Although these products are very specific, they are available for use in large amount. The main drawback of all programs is their unfinished and unverified development. It is occurred very often that while using applications instead of responding to a command or

execution it happens either an inadequate response, an incorrect execution of the command, or in worse case, unexpected crash or freezing of the application.

5.1 DCP Builder

This software makes use of multiple free available libraries. According to the appropriate page, the program is designed to be used by film professionals and not by an occasional user because of large number of options compared to other programs of the style. DCP Builder is a good alternative to commercial OpenDCP software.

The electronic application must be relatively detailed compared to other similar registrations; it must contain a detailed purpose for the use of the program, institution, etc. A shoot screen of this program is shown in *figure 4*. However, the use of the program has one drawback. Internet registration requires a detailed electronic application for serial issue keys to be completed on the web site of this program. Moreover, there is a request on the allocation of a key for study reasons. To unlock the necessary features of this program the serial key is necessary and therefore the alternative software should be found. A watermark should be embedded, but there is a free code to disable it.

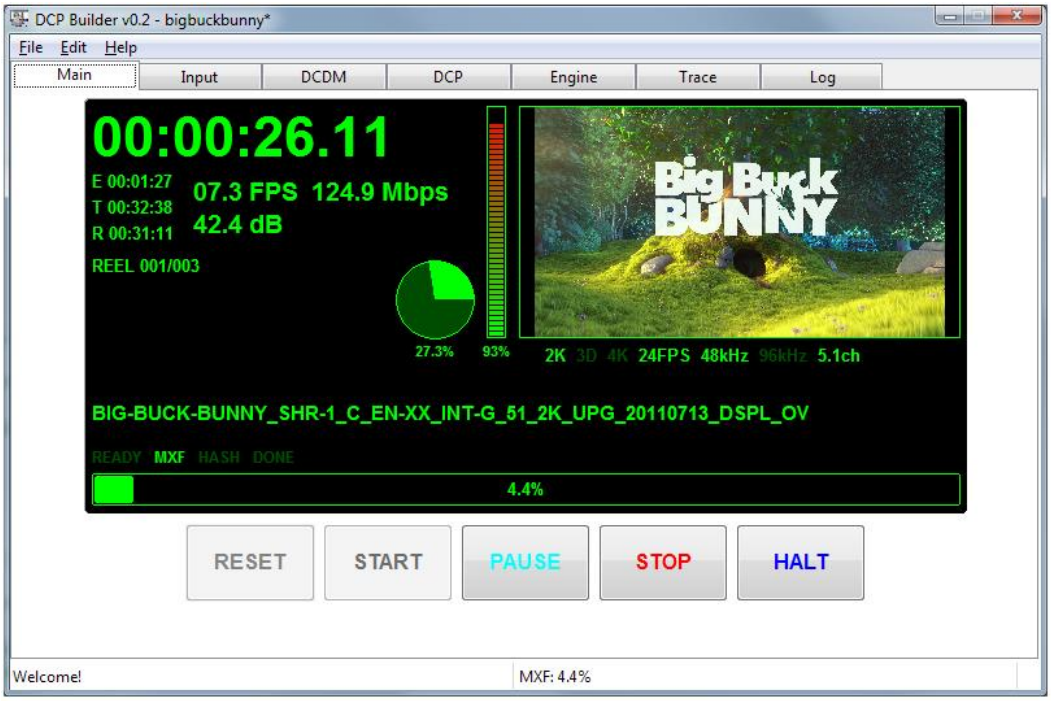

Fig. 4. DCP Builder

5.2 Digital Cinema Package Editor (DCPC)

This is a program that is available only on the platform Microsoft Windows. A shot screen of this program is presented in *figure 5*. It is available in non-commercial and

commercial versions. The price includes only the encoding program itself that is identical to the non-commercial version. To store multiple tracks into one DCP file, multiple audio channels at maximum, plug-ins are required for support encoding.

Program features include:

- 2D and 3D image tracks;
- 2K and 4K image resolution;
- 6-channel 24 bit/48 kHz audio.

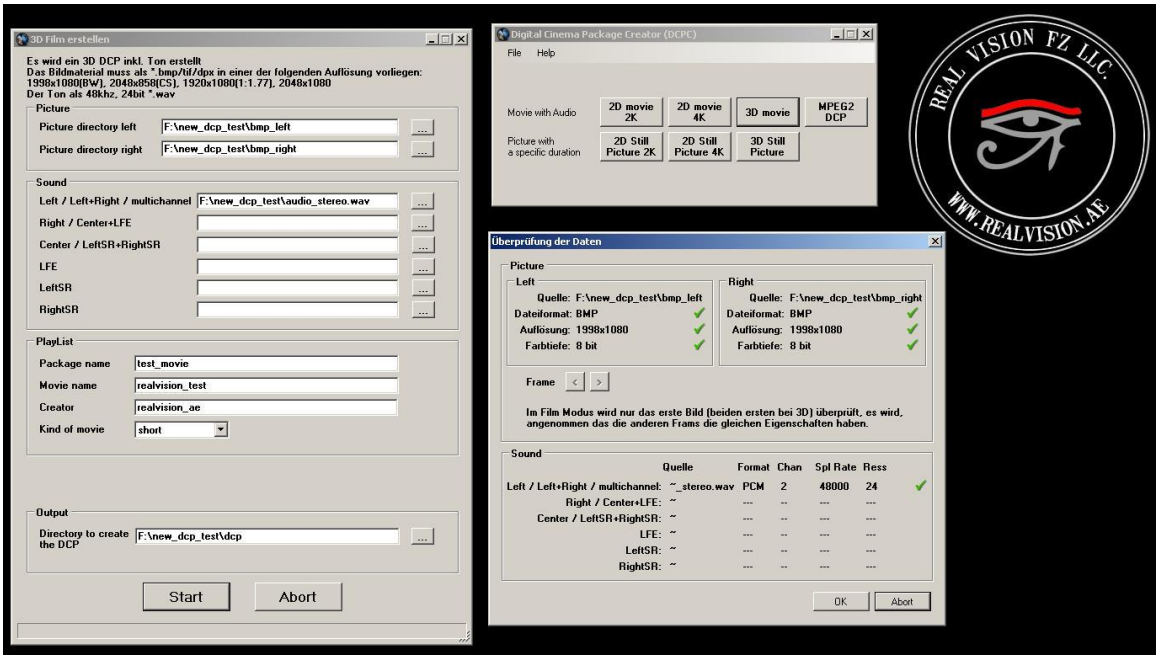

Fig. 5. Digital Cinema Package Editor

5.3 DVD-o-matic

It is a free and open source program and supports files in very different formats, including DVDs, Blu-ray, MP4, AVI, and many more. The last updated version includes a professional option such as sending the DCP to the Theater Management System. It includes a guide for the correct use of the software.

The program can use codecs that already exist in the installed system. The input file format can be any common type of video file formats, DCP data format, or still image. Software operation is very simple. Required time for encoding depends on the input file for codec.

The drawback is that it is a copy of another program and does not include enough new options that make us opt for this new program. Also, this software doesn't have a version for Mac OS system.

Figure 6 shows a simple initial form for setting conversion parameters. It is always performed before starting the transfer by filling the basic output parameters. It is essential to specify the address of the space on the input disk and output file, output file name, crop, and

default image frame. Other parameters that can be set are, for example, video image filters or audio sync with video using delay settings. The shortcoming of this program is that some file formats of the program don't recognize the frame rate and encoding would not be well performed.

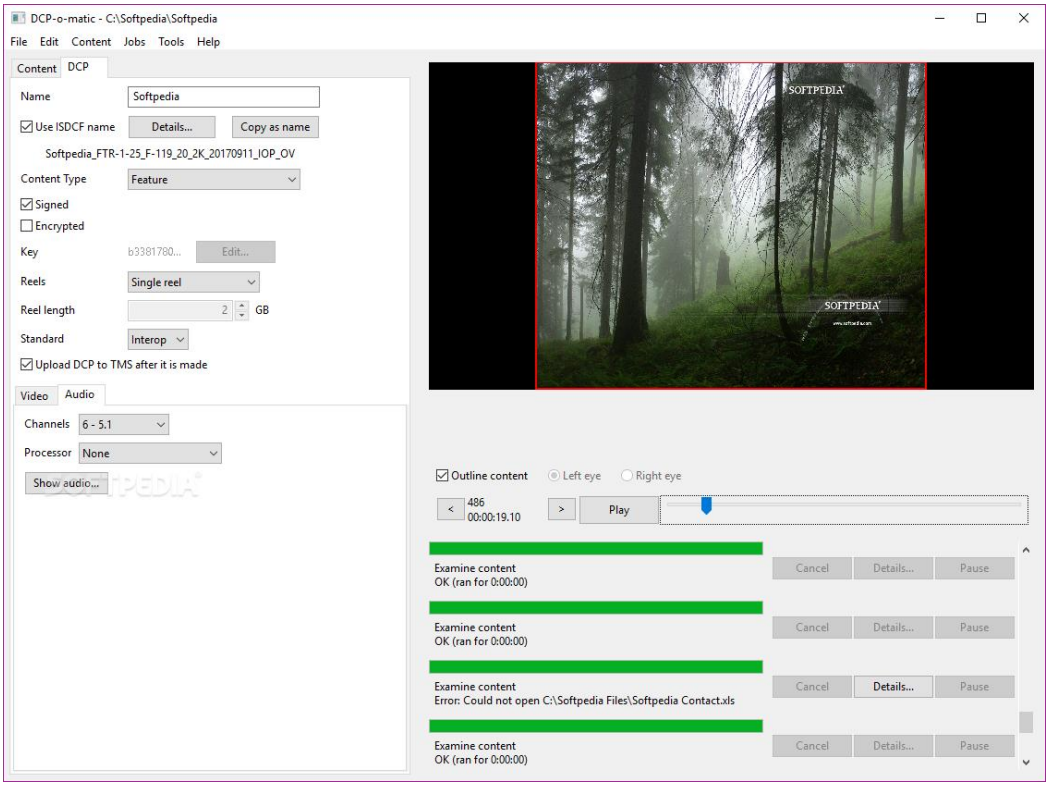

Fig. 6. DVD-o-matic

The main features of free software for digital cinema are presented in Table 1.

Table 1. Main properties of free software for digital cinema

Software	**Source file format**	**Output file format**	**Operating system**	**Licence**
DCP Builder	Image sequences, video with extern FFmpeg codec	JPEG 2000, MXF, XML, 3D	Windows, Mac OS X, Linux	Freeware, registration necessary
DCPC	Image and audio sequences	JPEG 2000, MXF, XML, 3D	Windows	Freeware
DVD-o-matic	Video	JPEG 2000, MXF, XML	Windows, Linux	GNU

6. CONCLUSION

Digital cinema became possible thanks to the major Hollywood film studios. We have presented the necessary information about the digital cinema technology and the steps to be followed to create the digital cinema package, from production to distribution. At first glance it may be somewhat complicated, but it is far from reality. To achieve a DCP a few simple steps should be followed, though, paying special attention is necessary in order to obtain the final result is as expected.

We emphasized the role of digital source master in DPCM development. When producing the DCP signal processing methods are necessary. The DCI System Specification represents an important step towards establishing an interoperable, secure digital cinema production and exhibition environment. It makes a broad use of the existing, well accepted cryptographic standards. As digital cinema has been built and deployed worldwide, standard organizations will further refine the functionality and interoperability requirements of various digital cinema components.

After seeing the pros and cons of each free program for creating DCP, choosing software depends on some variables. However, there are certain guidelines to be followed.

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