DivX: DVD quality movies on a CD-R?

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Abstract

DivX compresses high quality video into files up to 10% smaller than other formats. Potentially a threat to DVD sales, DivX copies are easily distributed, a phenomenon that has attracted much media interest. This paper explores the uses of DivX, focusing on the issue of high-quality DVD backups.

Keywords

DivX, DVD, MPEG, CSS, DeCSS, MPAA, "ripping", SmartRipper, FlasKMPEG, Xmpeg, mpeg2avi, MP3, LAME, VirtualDub, Nandub

Introduction

This paper investigates the task of creating a high quality copy of a DVD using DivX technology for backup or archival purposes. Comparing different implementations of DivX and the methods used in the copying process, differences in quality between the DivX copy and the original DVD are assessed. The problem of presenting DVD quality video on a single CD-R is also examined.

Background

The movie data on DVDs is encrypted using the CSS[1] system. According to the MPAA[2], this is done:

"...to provide security to copyrighted content of DVDs and to prevent unauthorized (sic.) copying of that content." [MPAA-faq]

In October 1999, source code for a software tool called DeCSS was released onto the Internet. Written by Jon Johansen, a Norwegian programmer, the tool is able to decrypt CSS and write the movie data to the computer's harddrive. [CRYPTOME]

At the time, it was impractical to store the decrypted DVD in its original format. The average harddrive size in 1999 was 10GB. Most DVD movies total between 5 and 8 GB. [PAGE-history] This meant that only one movie could be stored on a user's harddrive, and that it could not be easily moved to other locations for playback.

Jerome Rota (known on the Internet as 'Gej') was a French video enthusiast and video engineer who modified some early beta versions of Microsoft's MPEG-4[3] encoding codecs[4]. Gej named his codecs "DivX ;-)", a satirical reference to the failed DVD rental scheme: DIVX[5] [PAGE-history].

[1] CSS: Content Scrambling System - encryption designed to prevent DVD from being copied.

[2] MPAA: Motion Pictures Association of America - a body comprising of the major American movie studios and distributors. [MPAA-faq]

[3] see "DVDs, MPEG, and DivX", page 2

[4] Codec - a piece of software for coding/encoding video streams. [DOOM9-glossary]

[5] DIVX: DIgital Video eXpress (DIVX) - a restrictive

Using suitable software utilities with the DivX codec, a DVD's video and audio streams can be re-compressed, without a noticeable loss in quality. The DivX movie can be written onto a standard CD-R, making it as versatile and transportable as the original DVD disk.

At the time of writing, standalone DivX playback hardware is unavailable. The copy can only be watched on a modern PC with the appropriate audio and video codecs installed.

DVDs, MPEG, and DivX

DVDs are stored in the MPEG-2 video format, usually with 5.1^6 channel AC-3[7] audio.

MPEG[8] formats specify how video and audio streams are combined for transmission or storage. Video is stored as I-, B-, and P-frames. A complete I-frame is followed by a series of B- and P-frames that describe the spatial difference between I-frames. Since B- and P- frames are not complete images, they require less storage data than I-frames, making the format highly compressible.

MPEG-2 is designed for digital TV transmission and DVD storage while MPEG-4 is designed for delivery of content in low bandwidth applications such as mobile and Internet connections. [QUANTEL 2000]

The original "DivX ;-)" was an unlicensed modification of Microsoft's MPEG-4 codec, a codec that could only create ASF[9] files. (ASF files are unusable on platforms other than Windows due to restrictive patents.) "DivX ;-)" removed these restrictions, allowing movies to be created in the open AVI[10] file format. "DivX ;-)" was distributed with an unlicensed version of Fraunhofer's professional MP3 audio codec, the "Radium" MP3 codec. [BENNETT 2000]

There are two versions of "DivX ;-)": the high motion and low motion codecs, based on Microsoft's v2 and v3 codecs respectively. Other similar codecs, such as AngelPotion, nAvi and SMR, are also based on Microsoft's MPEG-4 v3 codec. [DOOM9-codec]

To legitimise the DivX format, open-source versions are being developed. DivX4 has been developed from the ground up by DivXNetworks and does not use any of Microsoft's patented code, instead being based on the official MPEG-4 specification. DivX4 is backward compatible "DivX ;-)", such that all DivX content can be played using the DivX4 codec. By porting DivX4 code, DivX movies can now be played on alternative[11] operating systems. [BENNETT 2000]

DivX is a Variable Bitrate (VBR) codec: the codec automatically adjusts the bitrate at which it encodes, depending on the complexity of the scene encoded. The

DVD rental scheme devised by the Los Angeles law firm, Ziffren, Brittenham, Branca & Fischer. [PAGE-history]

[6] 5.1 - 5 main speakers (left, front, right, and two rear speakers), and a subwoofer for low frequency output.

[7] AC-3 - Dolby Surround sound.

[8] MPEG: Moving Picture Coding Experts Group - A body that develops standards for digitally encoding video. [MPEG-about]

[9] ASF: Active Streaming Format - Microsoft's patented proprietary video file format.

[10] AVI: Audio Video Interleave - a file format describing how video and audio are combined. AVI places no restriction on audio or video codecs used. [DOOM9-glossary]

[11] "Alternative" operating systems - Apple Macintosh, BeOS, or Linux. (ie, not Windows)

desired average bitrate is specified before encoding and the codec attempts to stay close to this average. The high motion "DivX ;-)" codec is often described as "more VBR" than the low motion codec because it adheres less tightly to the specified bitrate, resulting in larger and less predictable file sizes.

In DivX, the MPEG-4 I-frames are usually referred to as "keyframes." Because keyframes are a complete compressed frame, they are used as reference points by playback software during fast-forward and rewind operations. [DOOM9-glossary]. The "DivX ;-)" codecs insers keyframes at specified intervals. DivX4 is able to automatically insert keyframes when it detects a scene change in the movie, a method referred to as Variable Keyframe Interval (VKI). VKI optimises the use of the B- and P-frames, resulting in higher quality output.

Two-pass encoding is a key feature of the DivX4 codec. On the first pass, the codec analyses and records statistics about the input video. The video data is encoded on the second pass with the bitrate automatically adjusted for each scene based on the complexity statistics obtained during the first pass. Two pass encoding results in higher picture quality at the expense of increased encoding times. [DOOM9-glossary]

Smart Bitrate Control (SBC) can achieve higher picture quality with "DivX ;-)" than two-pass DivX4 encoding by giving the user control over the codec's internal parameters. SBC is a complex two-pass process, taking many weeks to master. Incorrectly chosen parameters will result in low quality output. [DOOM9-sbc]

Legal Implications

The "DivX ;-)" codec utilises code patented by Microsoft and is therefore not licensed for use or distribution, regardless of the encoded video's ownership. The newer DivX codecs, such as DivX4 or 3ivx[12], resolve this licensing issue, allowing users to archive or distribute their own video footage in the DivX format, without fear of prosecution by Microsoft.

However, the majority of DivX users utilise the technology to duplicate copyright material. Copies are often distributed, either on CD-Rs or over the Internet. This theft of intellectual property is a violation of the applicable copyright laws.

Under current US law, the distribution of software that enables copyright material to be duplicated violates the DMCA[13], and therefore punishable under this Act. The MPAA has issued threats of legal action and has filed lawsuits against those involved with the creation and distribution of DeCSS. It can be argued that the MPAA are in violation of the First Amendment, an Act that protects the right to the freedom of speech.

DVD to DivX conversion

Nicky Page, Doom9, and Jaspov have been writing on this subject since its infancy. They are now major figures in the field, and much of their work has been quoted, translated, and plagiarised by other websites.

DVD to DivX conversions are typically carried out in the following stages [JASPOV-main]:

- "Rip" (copy) the DVD movie data to the

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[12] 3ivx - a less widely used open-source DivX implementation.

[13] DMCA: The Digital Millennium Copyright Act - an Act passed by Congress on 12th October 1998, designed to protect the copyright of digital material. [MPAA-faq]

hard drive.

- Convert the MPEG-2 video data to DivX.

- Convert the AC-3 audio to MP3.

- Multiplex[14] the DivX video and MP3 audio into one output AVI file.

Once the output file has been created, it can be split into suitably sized sections and written onto CD-Rs for storage convenience.

For the purposes of this paper, I have copied only one chapter from my chosen DVD[15]. This will allow me to demonstrate and evaluate the conversion process using both "Divx ;-)" and DivX4, without having to encode the entire movie. Due to its complexity, I will not cover SBC.

Due to the range of scenes present, I have selected chapter six from the DVD. At the start, a group of soldiers dressed in camouflage crawl covertly through dense undergrowth. A sequence of close-ups of the actors is followed by an assault on a guerrilla emplacement, resulting in fast moving action and explosions. These complex scenes should stretch DivX to its limits and expose its shortcomings.

Ripping

Often incorrectly used to summarise the entire conversion process, the term "ripping" describes process of decrypting the DVD and placed the data onto a harddrive. [DOOM9-glossary]

The most comprehensive ripping tool currently available is SmartRipper.

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[14] Multiplexing - the process of combining audio and video into one output file.

[15] The 20th Centry Fox movie: "Predator" (1987), starring Arnold Schwarzenegger

[DOOM9-ripper, JASPOV-nandub, PAGE-dvd2hd]

Utilising decryption methods from both DeCSS and VobDec[16], SmartRipper can rip either an entire DVD or a selection of chapters, enabling the removal unwanted features such as studio logos and disclaimer notices.

SmartRipper took 2:47 minutes to extract the 6:42 minute DVD chapter. The chapter occupies 352MB on the DVD. During the ripping process, CPU usage reached a maximum of 5%.[17],

Video encoding tools: Xmpeg and mpeg2avi

Many encoding tools are currently available, two of which are Xmpeg and mpeg2avi.

The GUI based FlaskMPEG was the simplest and most popular tool available for DivX encoding. [DOOM9-divx3, JASPOV-main, PAGE-flask]

Xmpeg is an updated version of FlasKMPEG, incorporating support for DivX4's features. It automatically multiplexes the video and audio streams. Xmpeg is able to encode directly from the DVD, eliminating the ripping stage. However, according to [DOOM9-dvd2mpg], this should not be attempted as it stresses and potentially damages the DVD drive.

mpeg2avi is the fastest encoding tool currently available, but is harder to set up than Xmpeg. Although mpeg2avi is a command-line interface tool, a powerful GUI which improves usability is available. Only video is encoded, the audio stream being de-multiplexed for processing

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[16] VobDec - a CSS decryption tool, similar to DeCSS

[17] see, Appendix A: Hardware specification, page 11

separately. [DOOM9-divx3, PAGE-mpeg2avi]

Bitrate

The bitrate at which the DivX codecs encode the video stream affects the output quality and filesize. Increasing the bitrate improves picture quality, but increases filesize. For the purposes of backing up a DVD movie, a bitrate is chosen that will produce a movie of 700MB[18], or a multiple of 700MB if the DivX copy is to span more than one CD-R.

A calculator tool is used to identify the required bitrate, the most flexible being "DivX4 BitRate Calculator" by Boris Kiradjiev which supports both "DivX ;-)" and DivX4.

The total movie length is 101 minutes, 23 seconds. The calculator suggests a bitrate of 818 Kbps[19] for the "Divx ;-)" video if "CD quality" MP3[20] audio is used (see Figure 1).
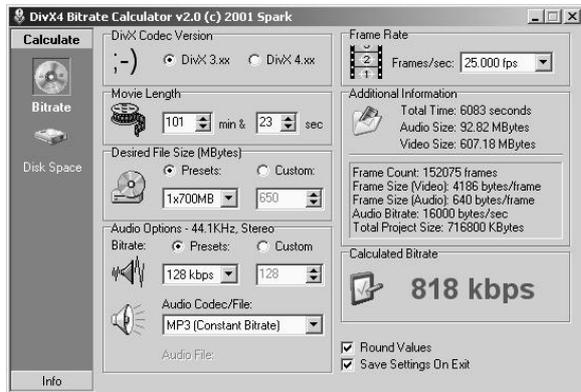

Figure 1: DivX4 BitRate Calculator

Re-sizing and Cropping

The MPEG-2 video on a DVD has a

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[18] 700MB - the capacity of a 80 minute CD-R.

[19] "DivX ;-)" expresses the size of a kilobit as 1024 bits, while DivX4 specifies 1000 bits.

[20] "CD quality" MP3 - 44KHz sample rate, 128 Kbps bitrate.

resolution of 720x576 pixels which is re-sized by decoding hardware to fill the screen during playback. DivX video is re-sized to a standard full-screen resolution during the encoding process to minimise CPU power required at playback. The closest screen resolutions to 720x576 are 640x480 and 800x600 pixels. No picture quality increase will be achieved by scaling up to a width of 800 pixels, and a lower resolution video requires fewer bits per video frame resulting in a smaller file. Therefore, DivX video is normally 640 pixels wide.

A DivX copy of a DVD with a resolution of 640x480 pixels would include black areas above and below the image[21]. The dotted frame in Figure 2 is the boundary of the output video.

Figure 2: Uncropped output in Xmpeg

Figure 3 shows the same source video, cropped to remove the black borders above and below the image. Preserving the original aspect ratio, the source video has been scaled to eliminate the narrow borders from the left and right of the image. The loss of a few pixels from the edges of the image is preferable to leaving borders to

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[21] This assumes that the DVD has an aspect ratio of 16:9.

preserve bits which could otherwise be used to describe the actual image.

Figure 3: Cropped output in Xmpeg

"DivX ;-)" encoding results

Table 1 shows times and filesizes for encoding with the "DixV ;-)" low motion codec using Xmpeg.

CD-Rs	Bitrate (Kbps)	Time to encode (minutes)	File size (MB)
1	818	14:34	46.7
2	1760	14:50	93.4
3	2655	15:08	133

Table 1: Xmpeg "DivX ;-)" encoding

At 818 Kbps (Figure 4), blocking[22] was evident in the moving footage, often leaving much detail from the picture. The entire movie will fit onto one 700MB CD-R, a compact backup of the DVD with a noticeable loss in quality.

Figure 4: "DivX ;-)" at 818 Kbps

At 1760 Kbps (Figure 5), blocking is less pronounced, only noticeable during scenes containing large amounts of detail, such as this explosion. The movie will occupy two CD-Rs. At the sacrifice of having to change the CD-R halfway through viewing, the quality is kept close to that of the original DVD.

Figure 5: "DivX ;-)" at 1760 Kbps

At 2655 Kbps (Figure 6), the picture is very clear and comparable to DVD quality, even in the most complex scenes. Blocking is almost undetectable. However, the small increase in picture quality gained by using three CD-Rs means swapping disks at every third of the movie, impractical for a DVD backup.

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[22] blocking - defects in MPEG video, caused by insufficiently low bitrates. [QUANTEL 2000]

Figure 6: "DivX ;-)" at 2655 Kbps

Using mpeg2avi, the tests were repeated (see Table 2).

CD-Rs	Bitrate (Kbps)	Time to encode (minutes)	File size (MB)
1	818	9:01	40.5
2	1760	9:29	87.2
3	2655	9:51	127

Table 2: mpeg2avi "DivX ;-)" encoding

The output video quality is indistinguishable from that produced by Xmpeg. However, mpeg2avi is up to 35% faster than Xmpeg.

Since mpeg2avi does not encode audio, a closer performance comparison is shown in Table 3. With Xmpeg's audio encoding disabled, mpeg2avi still shows a 20% speed advantage.

Encoder	Time to encode (minutes)
Xmpeg (no audio)	11:22
mpeg2avi	9:01

Table 3: Xmpeg and mpeg2avi compared

DivX4 encoding results

Encoding times for DivX4 using mpeg2avi are shown in Table 4. Compared to the "DivX ;-)" (Table 2), there is little difference in encoding times and filesize.

CD-Rs	Bitrate (Kbps)	Time to encode (minutes)	File size (MB)
1	837	9:14	43.9
2	1809	9:35	86.9
3	2768	9:47	125

Table 4: mpeg2avi DivX4 encoding

At 817 Kbps (Figure 7), DivX4 clearly outperforms "DixX ;-)" (Figure 4). Although the quality is not as high as the original DVD, blocking is less apparent as the codec blurs lacking detail.

Figure 7: DivX4 at 837 Kbps

At both 1803 Kbps (Figure 8) and 2768 Kbps (Figure 9), the DivX4 copy is extremely close to the quality of the original DVD. The higher bitrate produces a slightly sharper image at the expense of spanning three CD-Rs. Both are comparable to "DivX ;-)" at 2644 Kbps (Figure 6).

Figure 8: DivX4 at 1803 Kbps

Figure 9: DivX4 at 2768 Kbps

Although encoding times are longer than for "DivX ;-)", the DivX4 "slow" setting was used for a higher output quality. If quality is sacrificed, DivX4 will encode more quickly than "DivX ;-)".

Two-pass DivX4 encoding results

Two-pass 837 Kbps encoding produces a higher quality than one-pass encoding at the same bitrate (Figure 10).

Figure 10: Two-pass DivX4 at 837 Kbps

When increasing the two-pass bitrate to 1803 Kbps, the quality is almost indistinguishable from the original DVD. (Figure 11)

Figure 11: Two-pass DivX4 at 837 Kbps

With output so close to DVD quality at 1803 Kbps, there is no requirement to increase bitrate further. 1803 Kbps will produce a DVD quality backup that spans two CD-Rs. Table 5 shows the encoding times.

CD-Rs	Bitrate (Kbps)	Time to encode (minutes)	File size (MB)
1	837	9:12 + 9:08 = 18:40	40.8
2	1809	9:31 + 9:28 = 18:58	84.0

Table 5: mpeg2avi two-pass DivX4 encoding

Audio encoding

The most popular MP3 encoding software available today is LAME[23]. A test conducted by [MEYER] concluded that LAME MP3s were indistinguishable from the original source. The command-line options `--r3mix -b128` will give optimum sound quality. [R3MIX]

The simplest way to extract the sound from a DVD is to use Xmpeg's audio extraction function. This will create a WAV audio file that can be encoded with LAME. Alternatively, the AC-3 stream that mpeg2avi de-multiplexes can be converted to WAV with AZID, and then to MP3 with LAME, providing control over the process of down-mixing Dolby Surround to stereo.

Table 6 shows the file size differences between the different audio streams.

Audio format	Sound file size (MB)
AC-3	18.8
MP3 / Xmpeg	6.13
VBR MP3 / LAME	8.05

Table 6: Audio format sizes

Using a standard stereo playback system, the difference in sound quality between the

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[23] LAME: LAME Ain't an MP3 Encoder - an open source MP3 codec available under the GPL licence.

original AC-3 sound and the MP3 produced by LAME is not detectable. LAME's VBR output was far superior to that produced by Xmpeg.

The quality of the sound output produced by Xmpeg is very unsatisfactory, even though Xmpeg utilises the LAME codec. Xmpeg's audio sounded like it was being played underwater, normally a problem found in low bitrate MP3s. Encoding at the same quality used in Xmpeg with the standalone LAME tool provided far better results. This anomaly may to be due to a bug in Xmpeg.

Multiplexing and splitting

Nandub, the SBC tool, must be used to multiplex the audio stream with the DivX video to create the complete movie. VitualDub, the tool on which Nandub is based, cannot multiplex AC-3 or VBR MP3 streams.

For "DivX ;-)" encoding, the time advantage gained using mpeg2avi over Xmpeg is clear (Table 7). mpeg2avi and LAME produce a video clip with superior sound output in 25% less time - the same process in Xmpeg took 14:50 minutes.

Time to encode video (1760 Kbps)	9:29
Time to encode audio (--r3mix -b128)	1:34
Time to multiplex	0:08
Total time taken	11:11 minutes

Table 7: mpeg2avi "DivX ;-)" and LAME MP3 total time

With DivX4, the entire process takes 1% (6 seconds) longer than "DivX ;-)" (Table 8).

Time to encode video (1803 Kbps)	9:35
Time to encode audio (--r3mix -b128)	1:34
Time to multiplex	0:08
Total time taken	11:17 minutes

Table 8: mpeg2avi DivX4 and LAME MP3 total time

Producing a two-pass DivX4 copy, complete with sound, takes more than 50% longer than with "DivX ;-)" at the same bitrate (Table 9). However, the quality is almost indistinguishable from the DVD. Once multiplexed, the AVI file is 92.1MB.

Time to encode video (two-pass 1803 Kbps)	18:59
Time to encode audio (--r3mix -b128)	1:34
Time to multiplex	0:10
Total time taken	20:43 minutes

Table 9: mpeg2avi two-pass DivX4 and LAME MP3 total time

The chapter used in the demonstration was 6:42 minutes long. This is about 7% of the total movie length of 1:42:32 hours. Producing a DVD quality backup takes 20:43 minutes with two-pass DivX4 encoding. Projecting this time to the full length of the movie gives a total processing time of almost 5½ hours. At all times during the encoding processes, the CPU under 100% usage.

Conclusion

I have demonstrated that DivX can produce DVD quality output using approximately 25% of the space occupied by DVD. Although a DVD movie can be compressed with DivX to fit onto a single CD-R, the quality is not as high as the original DVD. However, a copy can span two CD-Rs and retain DVD quality.

Applications providing video content over low bandwidth connections could benefit from DivX technology.

DivXNetworks have announced partnerships with to provide video-on-demand services and preview trailers of movies, putting DivX technology to a legitimate use for commercial gain. [DIVX]

In the past, when VHS video copies were commonplace, the MPAA argued that taped copies were inferior in quality to the original version. Today, however, experienced DivX users can produce copies that are indistinguishable from the original DVD. This is potentially a large threat to DVD sales.

DVDs provide additional "extra features" including animated menu systems, multiple language soundtracks, and subtitles, as well as biographical information about the actors in the movie. Many titles are distributed in "special edition" box-sets, with two or more DVD disks, providing hours of additional content. Although it is possible to capture all of the separate programmes from the DVD and convert them into the DivX format, it is not possible to capture the dynamic menuing systems. This means that backups are linear, losing this valuable feature of the original DVD format.

Currently, the MPAA loses the revenue generated from DVD sales when DivX copies are distributed. Rather than rather than dismissing it as a method of piracy, I believe that the MPAA could pursue DivX as a distribution technology for feature films. Official movie releases to be sold on DivX CD-ROMS or made available for Internet download at a fee. Consumers may wish to purchase DivX releases rather than VHS or DVD versions if the pricing was correct within the marketplace.

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Appendix A: Hardware specification

Motherboard	Iwill KK266plus-R
CPU	AMD Athlon TBird 1.4GHz
RAM	256MB Crucial PC133 CAS2
Harddrive	2 x IBM 60GXP 40GB, RAID-0
DVD-ROM	Pioneer DVD-104F
OS	Windows 2000 Pro SP2