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A Comparative Study between two Video Compression Standards: the H.264 and the High Efficiency Video Coding

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Abstract: Video compression techniques are used to reduce the number of bits required to represent video data. These techniques are standardized to allow inter-operability between different devices. Many video compression standards have been developed over the last few decades. This article presents an overview of the two latest video compression standards, the H.264 and the High Efficiency Video Coding (HEVC). The major features and strengths and weaknesses of the two standards are particularly discussed. It is found that while H.264 provides faster encoding than HEVC, HEVC provides much better compression performance compared to H.264. The performance gains of HEVC are more prominent in case of lossy compression. Moreover, it is found that despite better compression performance, due to its complicated royalty structure, HEVC lags significantly behind H.264 in terms of deployment. Lastly, it is concluded that, in future, research in video compression techniques will focus on developing low-complexity encoding solutions and on leveraging artificial intelligence techniques for fast and efficient video compression.

Keywords: Video Compression, Compression Efficiency, Encoding Speed, Time Complexity, H.264, High Efficiency Video Coding.

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دراسة للمقارنة بين معياري ضغط الفيديو: H.264 وترميز الفيديو عالي الكفاءة

محمد عبدالمنان بار

(قدم للنشر في 1440/05/13هـ ؛ وقبل للنشر في 1442/01/15هـ)

ملخص: تُستخدم تقنيات ضغط الفيديو لتقليل عدد وحدات البت المطلوبة لوصف بيانات الفيديو. هذه التقنيات تم تعييرها لتسمح بالتشغيل البيني، الداخلي، بين الأجهزة المختلفة. لقد تم تطوير العديد من معايير ضغط الفيديو على مدار العقود القليلة الماضية. يقدم هذا البحث دراسة عامة على أحدث معيارين لضغط الفيديو وهما (H.264) ونظام ترميز الفيديو عالي الكفاءة.(HEVC) تناقش هذه الدراسة بشكل خاص السمات الرئيسية والاختلافات في تقنيات الضغط المستخدمة من قبل المعيارين. تتوصل هذه الدراسة الى انه في حين يوفر H.264 ترميزًا أسرع من HEVC، يوفر HEVC أداء ضغط أفضل بكثير مقارنة بـ H.264 وخاصة في حالة الضغط المفقود (Lossy compression). ومن المتوقع أن تركز ابحاث تقنيات ضغط الفيديو مستقبلا على تطوير حلول ترميز منخفضة التعقيد وعلى الاستفادة من تقنيات الذكاء الاصطناعي لضغط الفيديو بشكل أسرع وأكثر كفاءة.

كلمات مفتاحية: ضغط الفيديو، كفاءة الضغط، سرعة الترميز، تعقيد الوقت، H.264، ترميز الفيديو عالي الكفاءة.

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INTRODUCTION

Communication is an important aspect of human life. Humans have always found a way to communicate with each other. Among the forms of communication, visual communication has always been a popular mode of communication for humans. One reason for this could be that it allows human beings to understand the context of communication in a better way compared to speech communication only. The rapid advancements in telecommunication technologies have given birth to newer means of visual communication. For example, today, millions of people use their mobile phones to capture and share videos. There are over 170 million mobile video users in the USA alone (Statista, 2019). Similarly, a number of online video sharing and broadcasting services have emerged (e.g. YouTube, Netflix, and Facebook etc.). All these developments have made video communication more interesting for users and, hence, the number of users who use online video sharing or broadcasting services is rising with every passing day. For example, it is estimated that the number of viewers who watch online videos will grow from over 2.6 billion in 2019 to over 3.1 billion in 2023 (Verna, 2019) . While video is one of the most interesting mediums of online communication, it is also the most data-intensive medium. For example, it is estimated that, currently, around 80% of all internet traffic is based on video (Roesler, 2019). For example, storing a one-minute raw High Definition (HD) video requires more than 8 GB of storage space (DR, 2019). If the same video is required to be transmitted in real-time, it would require a substantially high bandwidth which may not be available in many scenarios. Hence, most of the times, when a video is captured, it is compressed before storage or transmission (Segall, Katsaggelos, Molina, & Mateos, 2004). At the receiver side, the compressed bit-stream is decompressed to view the video. So, almost all the digital videos that we see online today, are the compressed and decompressed versions of the raw videos. The video compression phenomenon is illustrated in Figure 1.

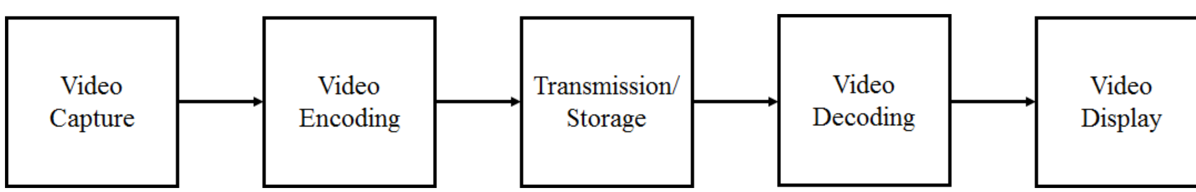


Figure 1: The video compression and decompression process (Richardson, 2010).

Video compression technologies are reducing and eliminating redundant video data so that a digital video file can be efficiently sent over a network and stored on computer disks. With efficient compression techniques, a significant reduction in file size can be achieved with little or no adverse effects on visual quality (Shi & Sun, 2008). The quality of the video, however, may be affected if the file size is further lowered by increasing the compression level for a given compression technique (Hernández & Schwarz, 2018).

Many different techniques can be used to compress videos. Since many different vendors of video technology (e.g., camera and television manufacturers etc.) exist, it is important that there exists a standard which defines the compression technique. In such a way, a video captured using a device from one vendor will be able to be played on a device from another vendor since both the capture (and encoding) device and display (and decoding) device will conform to one compression scheme. Without standardization, video captured using device from one manufacturer would not be able to play on a device from another manufacturer (Bhaskaran & Konstantinides, 1997). Hence, many video compression standards have been developed over the years. In this respect, the two main standardization bodies are the Motion Picture Experts Group (MPEG) of the International Standardization Organization/International Electro-Technical Commission (ISO/IEC) and Video Coding Experts Group (VCEG) of the International Telecommunication Union – Telecommunication (ITU-T). While in the beginning, both these groups competed each other by working on competing standards, lately, the two groups have joined resources and combined efforts in order to develop joint video compression standards. A pictorial depiction of the history of video compression standards developed by the two organizations is shown in Figure 2 (Khattak, 2014).

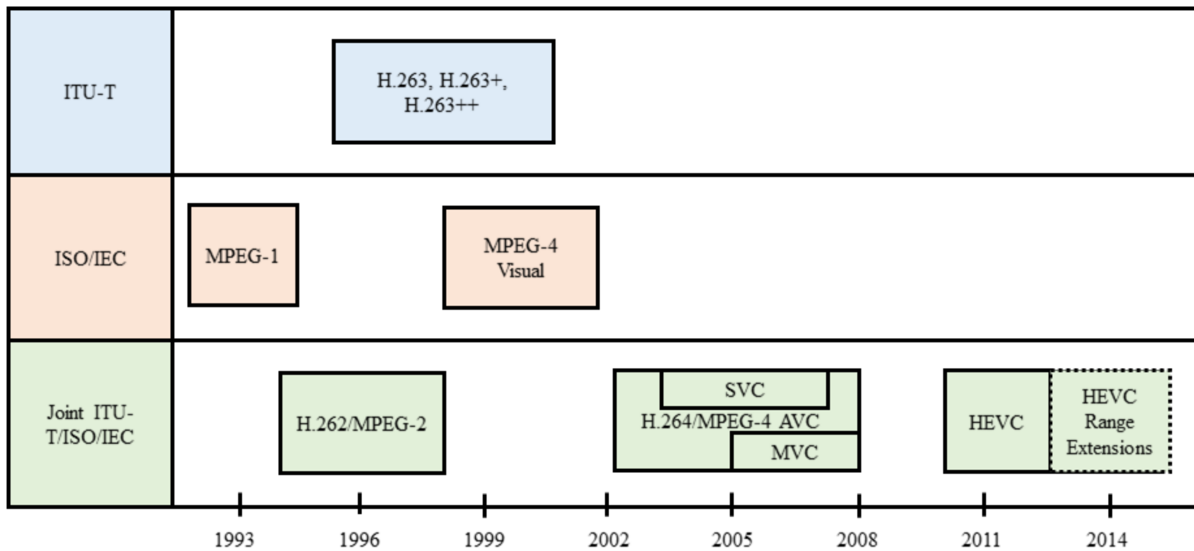


Figure 2: A history of video compression standards (Khattak, 2014).

It can be seen from Figure 2 that in the last two decades, the two standardization bodies of ISO/IEC and ITU-T have combined their efforts in developing joint standards. The last two of their jointly developed standards are the H.264 (Wiegand, Sullivan, Bjontegaard, & Luthra, 2003) and the High Efficiency Video Coding (HEVC) (Sullivan, Ohm, Han, & Wiegand, 2012) standards. Advanced Video Coding (MPEG-4 AVC) or H.264 is a video compression standard based on block-oriented motion compensation (Dominguez & Villegas, 2014). It is widely used in Blu-ray discs, Internet sources such as videos on iTunes Store and YouTube, Web software, as well as HDTV terrestrial, cable and satellite broadcasts (Diehl & Karmasin, 2013). On the other hand, the High-Efficiency Video Coding (HEVC) combines original technologies with advanced techniques to significantly improve bit flow, establish a better connection between delay and complexity of the algorithm and improve coding quality, leading to better optimizations considerably (Jiang & Nooshabadi, 2017).

Both the H264-AVC and HEVC compression standards implement a hybrid video coding approach based on spatial redundancies and temporal redundancies contained in a video sequence (Kovács & Nagy, 2014; Pastuszak & Abramowski, 2016). In hybrid video coding, two video compression techniques, predictive coding and transform coding, are combined. A generic hybrid video encoder is shown in Figure 3 (Kuo, Chung, & Shih, 2006). The idea behind predictive coding is that there is spatial redundancy within a video frame and temporal redundancy between the frames of a video. Hence, instead of coding each video block separately, information from already coded blocks of the same frame should be used to predict information in a current block (Richardson, 2010). Similarly, instead of coding each frame separately, information from one frame should be used to predict information in another frame (Richardson, 2010). A simple technique to achieve this is based on block differences and frame differences. That is, only the block or frame differences are encoded. This way, the amount of information, which is encoded, is reduced. Modern video compression standards achieve predictive coding using techniques such as motion estimation and motion compensation as shown in Figure 3. On the other hand, the idea behind transform coding is to reduce any existing psychovisual and coding redundancy while compressing videos (Richardson, 2010). The three main techniques which achieve this in successive steps are: transform, quantization, and entropy coding. Among these, transform is used to represent the frame/block differences (received after the predictive coding stage), in such a way that the energy is compacted in only a few transform coefficients. These transform coefficients are later quantized using a quantization technique. The quantization step allows to discard many of the transform coefficients and hence leaving only a small number of coefficients to encode (Richardson, 2010). Finally, an entropy coder is used to code the transformed and quantized coefficient (Richardson, 2010). The idea behind entropy coding is to use reduce the overall number of bits by allocating smaller codes to more probable symbols and larger codes to fewer probable symbols (Richardson, 2010). Context Adaptive Binary Arithmetic Coding (CABAC) and Context Adaptive Variable Length Coding (CAVLC) are two widely used entropy coders for video compression.

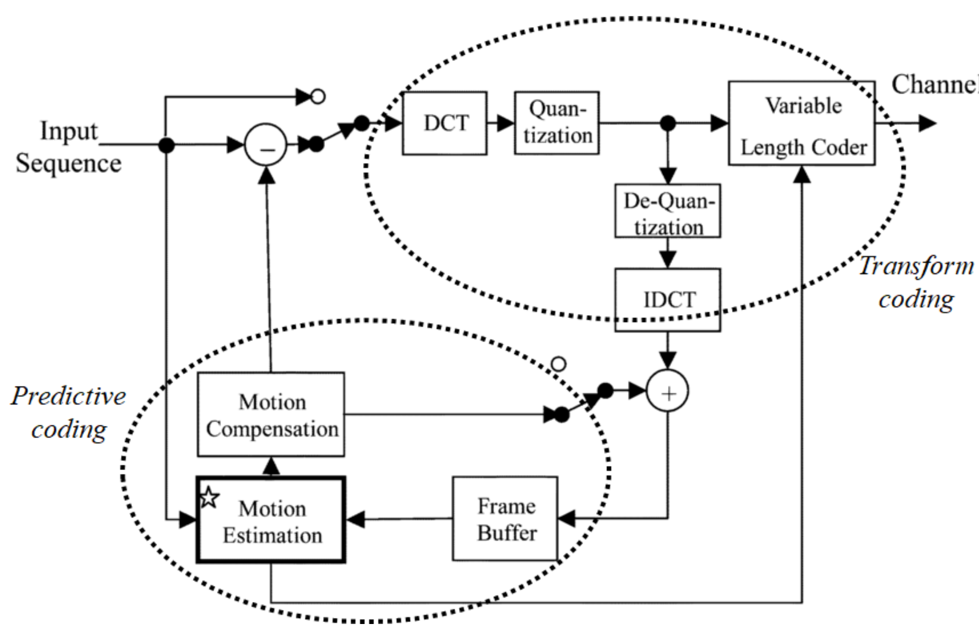


Figure 3: A generic hybrid video encoder (Kuo, Chung, & Shih, 2006).

The main contribution of this paper is that it provides a comparison of the H.264 and HEVC video compression standards from a unique perspective i.e., it reviews both the technical aspects as well as the deployment aspects of both H.264 and HEVC. Among the technical aspects, it reviews the encoding tools/features and the compression performance for the case of still images. Among the deployment aspects, it reviews the licensing strategies as well as the market penetration of both H.264 and HEVC.

The rest of the paper is organized as follows: in Section 2, related work is reviewed. In Section 3, a discussion of the comparison of both H.264 and HEVC is presented. The discussion is divided into several subsections, including technical comparison, image compression performance, market adoption, licensing structure, and upcoming video compression standards. Finally, conclusions are presented in Section 4.

2. RELATED WORK

The H.264 and High Efficiency Video Coding (HEVC) are among the most popular video compression standards (Zhang & Mao, 2019). Encoders conforming to each of these standards offer unique advantages over the other. For example, Pourazad, Doutre, Azimi, & Nasiopoulos (Pourazad, Doutre, Azimi, & Nasiopoulos, 2012) found that while compressing videos, HEVC provides 30 – 50% more compression efficiency compared to H.264. Xu et al. (Xu et al., 2015) found that the main reason for the better compression performance of HEVC over H.264 is the enhanced and improved coding tools (such as the quad-tree block structure) used by HEVC. Nguyen and Marpe (Nguyen & Marpe, 2012) found that for still images, HEVC provides, on average, 30% more compression efficiency compared to H.264. One of the reasons for such improved performance could be the use of larger block sizes by HEVC. Similarly, in terms of computational complexity, Yan et al. (Yan et al., 2013) found that the HEVC encoder is several times more complex compared to H.264. Again, this can be attributed to the exhaustive use of efficient coding tools by HEVC. Video encoders which are capable of high compression efficiency are generally very slow. Much of the research in the field of video compression has focused on finding a solution to this problem. Many fast encoding solutions have been proposed for H.264 (e.g., (Yang, Po,, & Lam, 2004; Yin, Tourapis, & Boyce, 2003; Kim, Shih, & Kuo, 2006; Pan, Lim, Rahardja, Lim, Li, Wu, & Wu, 2005)), H.264/MVC (Ho & Oh, 2007) (e.g., (Khattak, 2013; Gul & Khattak, 2018)), H.264/SVC (Vetro, Wiegand, & Sullivan, 2011) (e.g., (Yeh, Fan, Chen, & Li, 2010; Lu & Martin, 2013; Jung, Baek, Park, & Ko, 2010)), HEVC (e.g., (Tan, Ko, & Rahardja, 2016; Belghith, Kibeya, Loukil, Ayed, & Masmoudi, 2016; Jou, Chang, & Chang, 2015; Lee, Hang, Kim, Jeong, & Choi, 2015)), MV-HEVC (Hannuksela, Yan, Huang, & Li, 2015) (e.g., (Khan & Khattak, 2017), and 3D-HEVC (Tech, Chen, Müller, Ohm, Vetro, & Wang, 2016) (e.g., (Chiang, Peng, Wu, Deng, & Lie, 2019; Zhang, Yang, Chang, Zhang, & Gan, 2017; Shen, An, Zhang, Hu, & Chen, 2015; Fu, Zhang, Su, Tsang, & Chan, 2015)). However, with the development of each new standard, new challenges related to the issue of computational complexity arise. Hence, research in low-complexity video coding is expected to continue until a radical new and computationally less complex approach is taken for video coding.

In the literature, some studies can be found which compare different video compression standards. For example, Pourazad et al. (Pourazad et al., 2012) compared the performance of H.264 and HEVC. Similarly, Grois, Marpe, Mulayoff, Itzhaky, & Hadar (Grois, Marpe, Mulayoff, Itzhaky, & Hadar, 2013) compare the performance of H.264, HEVC, and VP9 (which is an opensource video codec). However, these studies are limited to either reviewing the technical features available in each video compression standard or reviewing the compression performance of each compression standard. Similarly, Koumaras, Kourtis, & Martakos (Koumaras, Kourtis, & Martakos, 2012) confirm that HEVC can achieve twice the compression efficiency of H.264. In terms of comparison of the H.264 and HEVC, some works in the literature compare specific features offered by both the compression standards. For example, Lv, Wang, Xie, Jia & Gao (Lv, Wang, Xie, Jia & Gao, 2012) compare the sub-pixel interpolation filters available in both H.264 and HEVC. Similarly, some works in the literature compare the performance of H.264 and HEVC under different operating environments. For example, Garcia & Kalva (Garcia & Kalva, 2014) evaluate the performance of the two video compression standards in mobile environments and find that the gains of HEVC against H.264 are less impressive in mobile environments with lower video bitrates and resolutions.

While the above studies provide an insight into the compression and complexity performances of HEVC and H.264, the two standards need to be compared in a broader sense. For example, even though HEVC outperforms H.264 in terms of compression efficiency, it has not been able to penetrate the market as successfully as H.264 has (Liu, 2019). The reason for this cannot be explained by only considering the compression efficiency of the two standards. Hence, in this paper, a more comprehensive comparison of the two video compression standards in presented which takes into consideration both the technical and non-technical aspects of the two video compression standards.

3. DISCUSSION

3.1.Technical Comparison

In the following subsections, the major technical features of both H.264 and HEVC compression standards are reviewed.

3.1.1 Block Structure

The basic coding unit in the H.264 video compression standard is a macroblock (MB). An MB has a fixed size of 16x16 pixels. On the other hand, the basic coding unit in HEVC is called a Coding Tree Unit (CTU). The size of a CTU can be configured to 16x16, 32x32, or 64x64. The block structures of H.264 and HEVC are shown in Figure 4. A CTU contains a luma Coding Tree Block (CTB) and two chroma CTBs. Each sized CTB can be either used as the same size Coding Block (CB) or it can be broken down into square shaped smaller CBs using a quadtree structure (Figure 4c). For example, for , the possible CB sizes are: . In fact, is the smallest allowable size for a CB in HEVC. The H.264 and HEVC block structures are shown in Figure 4 (Sullivan et al., 2012). An MB has a fixed size while a CTB can be broken down into smaller CBs using a quadtree structure. This gives HEVC more flexibility over H.264 but evaluating the extra number of CBs adds to the computational complexity of HEVC and it slows down the encoding process of HEVC.

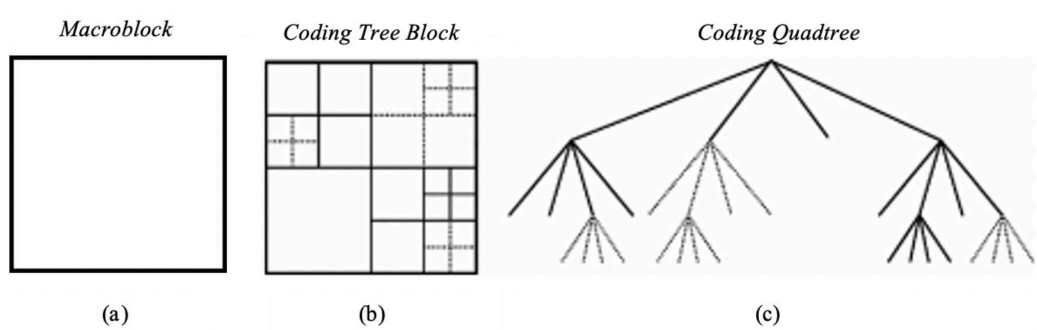


Figure 4: (a) An H.264 macroblock, (b) an HEVC Coding Tree Block subdivided into Coding Blocks. (c) Quadtree corre

From Figure 4, it is clear that an MB has a fixed size while a CTB can be broken down into smaller CBs using a quadtree structure. This gives HEVC more flexibility over H.264 but evaluating the extra number of CBs adds to the computational complexity of HEVC and it slows down the encoding process of HEVC. As shown in Figure 5 (Hruska, 2013), on the left side, the traditional H.264 standard is used, and each macroblock size is fixed. On the right side, the HEVC standard, the size of the code unit is determined by the regional information. From the contrast of the image, we can see the improvement of the video quality and the skin of the more delicate character HEVC presents, which is much better than H. 264.

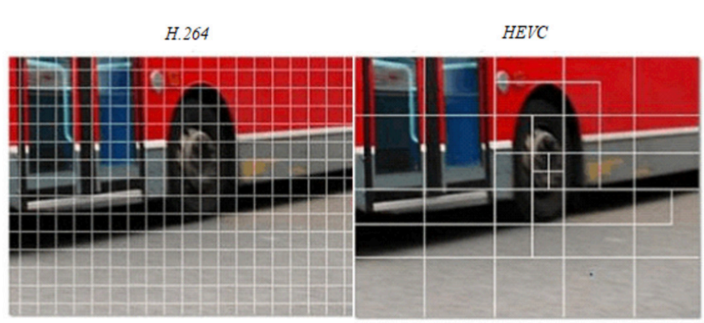
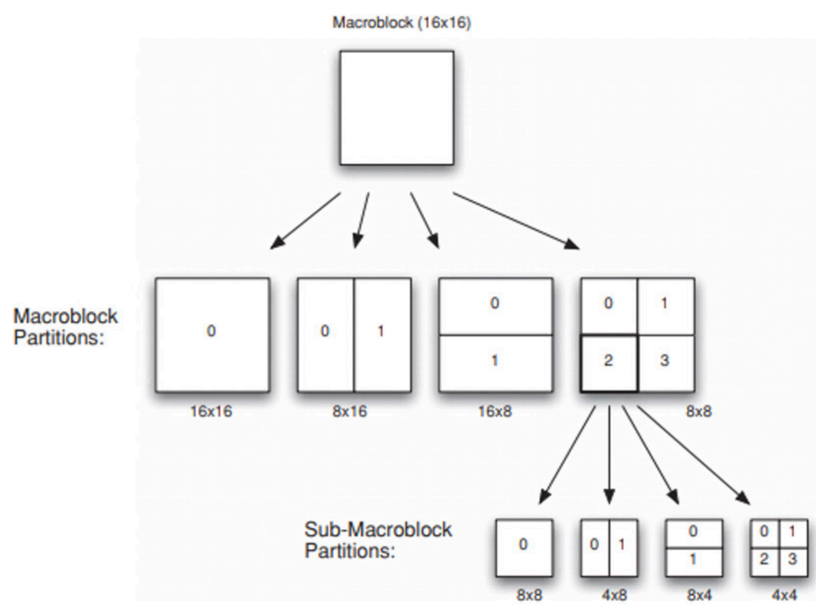


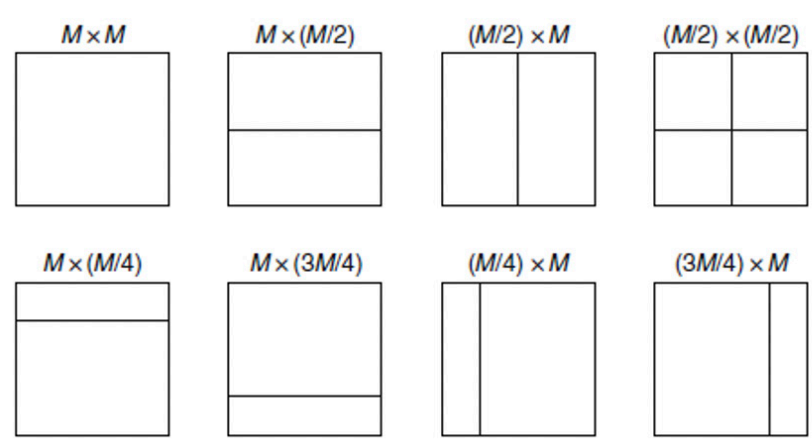
Figure 5: Illustration of block structure of H.264 vs HEVC (Hruska, 2013).

3.1.2 Predictive Coding

Both H.264 and HEVC employ Inter Prediction technique to exploit temporal redundancy between the blocks of different frames and Intra Prediction technique to exploit spatial redundancy between the blocks of the same frame. However, for inter prediction, H.264 can split an MB into six different partitions to achieve this while HEVC allows the splitting of a CB into many different partitions. The partition sizes allowed in H.264 and HEVC are shown in Figure 6 (Richardson, 2010; Sze, Budagavi, & Sullivan, 2014).



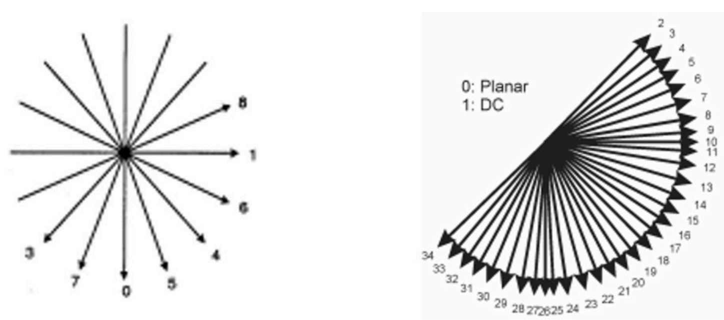
(a) Allowed macroblock partition sizes for Inter prediction in H.264.



(b) Allowed splitting of coding blocks of M × M size into prediction blocks in HEVC.

Figure 6: Available block partition sizes in H.264 and HEVC (Richardson, 2010; Sze et al., 2014).

Similarly, for Intra prediction, H.264 uses a maximum of 9 modes including eight directional modes (Figure 7a) and one DC mode. On the other hand, HEVC uses a total of 35 modes. Among these, 33 are directional modes (Figure 6b) while the remaining two are Planar and DC modes. The Intra prediction modes of H.264 and HEVC are shown in Figure 7 (Wiegand *et al.*, 2003; Sullivan *et al.*, 2012).



The 8 directional prediction modes in H.264
(a)

The 33 directional prediction modes in HEVC
(b)

Figure 7: The intra prediction modes available in H.264 and HEVC (Wiegand et al., 2003; Sullivan

3.1.3 Transform Coding

As discussed in Section 2, transform coding is based on three steps. In the first step, a transform like Discrete Cosine Transform (DCT), Discrete Sine Transform (DST) etc. is applied so that information is compacted in only a few transform coefficients. In the next stage, a quantization technique is used to discard the visually less-important coefficients while an entropy coding technique is then used to finally assign more bits to less frequent symbols and less bits to the more frequent ones.
In terms of transform, there are two considerations. The transform block size and the transform type. As for transform block size, the H.264 uses a fixed size of . On the other hand, in HEVC, the transform block also follows a quadtree structure and the size of a transform block can be either of the following: , , , or . Hence, HEVC allows for a more flexible transformation of data. However, again, the flexibility of HEVC comes at the cost of additional computational complexity. In terms of the transform type, H.264 use a DCT type integer transform while HEVC uses integer types of both DCT and DST transforms. However, the use of the DST style integer transform in HEVC is restricted to block size.
For quantization, both H.264 and HEVC use the same Uniform Reconstruction Quantization (URQ) (Gupta, Khanna, & Chaudhry, 2013) technique which uses a Quantization Parameter (QP) value for controlling the amount of quantization. The range of QP values in both H.264 and HEVC fall between 0 and 51. Increasing the QP value by 6 nearly doubles the quantization step size in both H.264 and HEVC. Moreover, HEVC also allows the uses of fixed quantization tables. Hence, the quantization process in both H.264 and HEVC is very similar and its impact on the compression efficiency and computational complexity of the two standards is also similar.
For entropy coding, H.264 uses two types of coders: CABAC and CAVLC. On the other hand, HEVC only allows the use of CABAC. However, the CABAC algorithm in HEVC is better than that in H.264. The CABAC used by HEVC provides better throughput speed compared to HEVC and is more suitable for parallel processing architectures. Similarly, in terms of compression efficiency, the CABAC algorithm used HEVC is better than that of H.264. Finally, in terms of context memory requirement, the CABAC algorithm in HEVC requires less context memory compared to the CABAC algorithm used in H.264. Hence, it can be concluded that the entropy coding mechanism in HEVC is better than that of H.264.

HEVC was developed with the aim of providing twice the compression efficiency of the previous standard, H.264. Although the compression efficiency results vary depending on the content type and encoder parameters, at consumer-typical video distribution bit rates, HEVC is generally able to compress the video twice as efficiently as H.264.

At an identical level of visual quality, HEVC can compress video to a file that is about half the size (or half the bit rate) of H.264, or when compressed to the same file size or bitrate that stroke, HEVC offers a much better visual quality.

3.2 Image Compression Performance

In this section, the performances of H.264 and HEVC standards are compared for compression still images under two scenarios: lossless compression and lossy compression. While comparing the performances of H.264 and HEVC, it is important to understand the evaluation criteria which has been used to compare the two standards. Performance under lossless image compression is evaluated with using compression ratio as a metric. Compression ratio can be defined as the ratio between the uncompressed image size and the compression image size i.e.

$$\textit{Compression Rato} = \frac{\textit{uncompressed image size}}{\textit{compressed image size}} \tag{1}$$

For lossy image and video compression, it is important to evaluate both the quality of video and the data rate. While the quality is evaluated using the Peak Signal-to-Noise Ratio (PSNR) (Equation (2)), the data rate is generally represented using bits per second (bps).

$$PSNR = 10\log_{10}\frac{R^2}{MSE} \tag{2}$$

In Equation (2), R represents the maximum fluctuation in the image. For an 8-bit image, $R = 255$. Mean Squared Error (MSE) can be computed between two images (or frames, in case of videos) I_1 and I_2 of resolution $M \times N$ pixels, using Equation (3).

$$MSE = \frac{\sum_{M,N}[I_1(m,n)-I_2(m,n)]^2}{M\times N} \tag{3}$$

In a typical RD curve, the vertical axis represents the quality (PSNR) while the horizontal axis represents the bitrate. When comparing the performance of two encoders, RD curves representing the two encoders are plotted first. Then, there are two ways of comparing the performance of the two encoders. Either by fixing the data rate and then comparing the quality of the two encoders or by fixing the quality and then comparing the data rate for the two encoders. The encoder which provides better quality for a given data rate or less data rate for a given quality is considered more efficient.

The results of lossless image compression using H.264 and HEVC are shown in Table 1 (Cai et al., 2012).

Table 1: Performance of H.264 and HEVC for lossless compression of still images (Cai et al., 2012)

Video	Resolution	Compression ratio	
H.264			HEVC
Traffic	2560x1600	2.28	2.16
PeopleOnStreet	2560x1600	2.29	2.21
Kimono	1920x1080	2.35	2.32
ParkScene	1920x1080	1.93	1.96
FourPeople	1280x720	2.64	2.55
Johnny	1280x720	2.85	2.78
RaceHorses	832x480	1.82	2.00
BQMall	832x480	2.05	2.08
BQSquare	416x240	1.42	1.69
BlowingBubbles	416x240	1.33	1.59
Average		**2.10**	**2.13**

From Table 1, several trends can be observed. Overall, HEVC achieves a compression ratio of 2.13 which is slightly better than the compression ratio of 2.10 achieved by H.264. This slight improvement in performance can be attributed to the more flexible intra-prediction technique used in HEVC. In terms of resolution, HEVC compresses smaller resolution images much better compared to H.264. For example, for the resolution images BQSquare and BlowingBubbles, HEVC achieves compression ratios of 1.69 and 1.59 compared to 1.42 and 1.33 achieved by H.264. On the other hand, higher resolution images are much better compressed using H.264. For example, for the 2560x1600 resolution images Traffic and PeopleOnSreet, H.264 achieves compression ratios of 2.28 and 2.29 compared to 2.16 and 2.21 achieved by HEVC.

The performance comparison of H.264 and HEVC for the lossy image compression scenario is shown in Figure 8. Unlike the lossless image compression scenario, for lossy image compression, HEVC outperforms H.264 for test images of all resolutions.

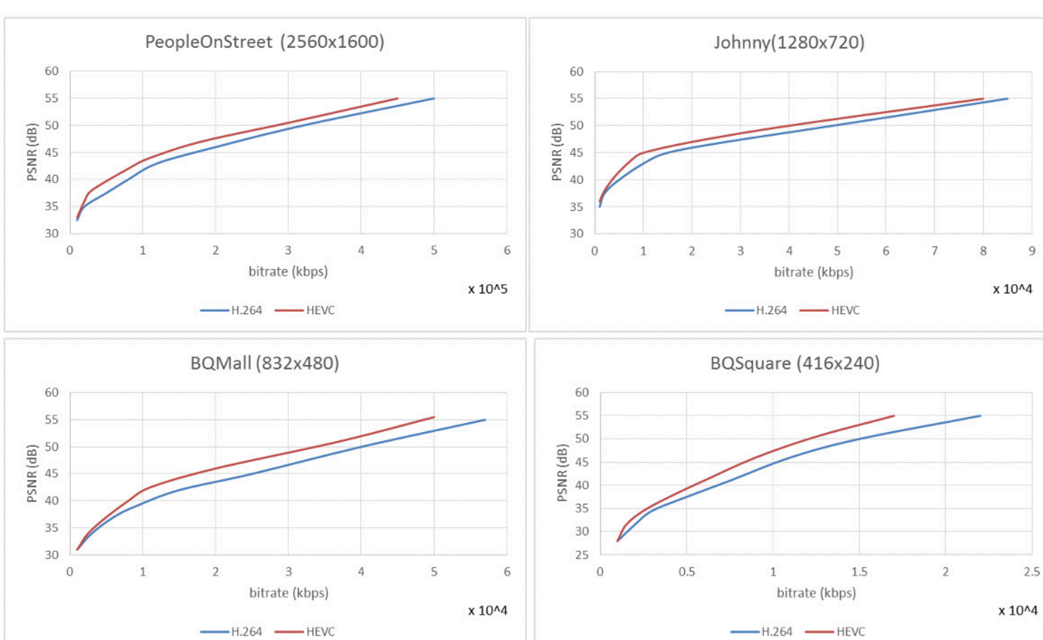


Figure 8: RD performance of HEVC and H.264 for PeopleOnStreet, Johnny, BQMall, and BQSquare test sequences.

3.3 Market Adoption

In terms of market penetration, HEVC has not yet gained as much success as H.264. As can be seen in Figure 9 (Liu, 2019).

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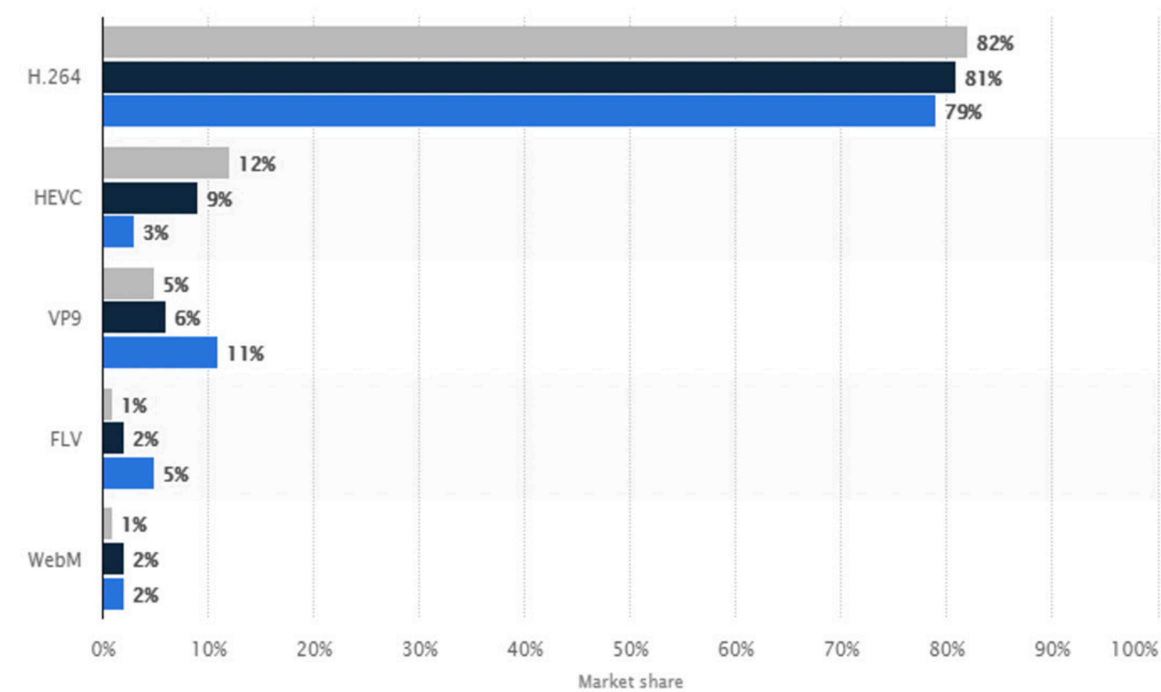

Figure 9: Market adoption of different video codecs by the years 2016, 2017, and 2018 (Liu, 2019).

From Figure 9, many trends can be observed. Firstly, over the years, H.264 has been the most popular video compression standard. Secondly, although inferior to HEVC in terms of compression efficiency, H.264 captured 82% market share in 2018 compared to the 12% market share of HEVC. Another important observation is that the market share of both H.264 and HEVC has increased over the years. One of the major reasons to which the widespread adoption of H.264 can be possibly attributed is its simple licensing structure compared to the more complex licensing structure of HEVC as discussed in the previous subsection.

3.4 Licensing Strategy

While the technical features of a video compression standard allow it to achieve a certain level of performance, its deployment strategy is an important factor in ensuring the market penetration of a video compression standard. In this regard, the cases of the deployment strategies of H.264 and HEVC present an interesting comparison. For example, as discussed in the previous subsections that despite HEVC's richer features compared to H.264, HEVC still has not been able to penetrate the market nearly as well as H.264. One of the reasons for this could be the differences in the licensing strategies of H.264 and HEVC. The licensing/royalty structures of both H.264 and HEVC are summarized in Table 2.

Table 2: Royalty structure of H.264 and HEVC (Rutz, 2016; Ozer, 2019)

Codec	Licensing Organization	Per device royalties	
		Royalty (per unit)	Yearly Cap (Millions)
H.264/AVC	MPEG-LA	\$0.1-\$0.2 depending on volume. No royalties for volumes less than 100,000 units	\$9.75
HEVC	MPEG-LA	\$0.20	\$25
	HEVC Advance	\$0.866	\$25
	Velos Media	\$1.00-2.50	None
	Others	+	+

From Table 2, it can be seen that H.264's license is owned by a single organization (Rutz, 2016). On the other hand, HEVC's license is owned by at least three patent pools. These include MPEG-LA, HEVC Advance, and Velos Media. Each of these organizations have a different royalty structure which makes it difficult to understand the royalty structure of HEVC (Rayburn, 2015). What complicates the HEVC royalty structure even further is that apart from these three licensing organizations, there may be individual patent holders who can claim royalties for using HEVC based products. Hence, unlike H.264, where the cost of deployment can be estimated in advance, with HEVC, it is difficult to estimate the total cost of deployment of HEVC due to its complex royalty structure (Rayburn, 2015).

3.5 Beyond H.264 and HEVC

As discussed in the previous sections, while HEVC is technologically superior to H.264, due to its complicated licensing strategy, it has not been as popular as H.264. Hence, there is a need for a video compression standard which combines the strengths of both H.264 (i.e., simple licensing structure) and HEVC (i.e., efficient compression performance). In this regard, currently, there are many video coding standardization activities taking place. This section presents an overview of the recent advances and expected future developments in the field of video compression research.

In terms of standardization work, MPEG and VCEG are currently working on developing a new video compression standard. This activity is called video compression with capability beyond HEVC (Segall, Baroncini, Boyce, Chen, & Suzuki, 2017). The new activity is expected to result in the development of a new video compression standard which has better compression efficiency compared to HEVC. The standard is expected to be finalized by the end of 2020. Hence, a lot of the video coding research in future is expected to be based on this new standard. The Alliance of Open Media (AOM) is a consortium of industries including Facebook, Google, Microsoft, Apple, IBM, Intel, and Netflix, etc. The alliance has recently combined efforts to develop a royalty-free video compression standard. Their new standard is called the AOM Audio Video 1 (AOM AV1) (Grois, Nguyen, & Marpe, 2016). AOM AV1 achieves around 30% better compression efficiency compared to HEVC. However, the current version of the encoder is very slow. Research is currently being performed to speed up the AOM AV1 encoder.

4. CONCLUSIONS

In this paper, the two most recent video compression standards of H.264 and HEVC were reviewed. It can be concluded from the review that both the standards are based on the well-known principle of hybrid video coding. Moreover, HEVC employs more efficient techniques such as allowing more flexible and finer partitioning of blocks compared to

HEVC. This feature is more useful for higher resolution videos. It also allows HEVC to achieve much better lossy compression performance compared to H.264. However, the flexibility of HEVC comes at the cost of higher computational complexity. Despite this, in terms of market penetration, H.264 has been a more successful codec compared to HEVC, largely due to its simple licensing structure. From the comparison of H.264 and HEVC, it can be learned that the popularity of a video compression standard depends on both its compression performance as well as its simple licensing structure. It is expected that while developing future video coding standards, both these aspects will be considered.

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