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NEXT-GENERATION VIDEO CODECS: HEVC VS AV1 FOR 8K UHD VIDEO PERFORMANCE AND COMPATIBILITY

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Abstract: *8K UHD video, with its remarkable resolution and quality, has found applications in diverse domains, including entertainment, education, healthcare, security, and sports. Nevertheless, the demands it imposes on data, computation, and video coding quality are substantial. Video coding, the process of compressing and decompressing video data for efficient storage and transmission, faces formidable challenges due to the massive data size, complexity, and quality requirements inherent in 8K UHD video. This paper delves into the intricacies of video coding for 8K UHD video, focusing on two prominent standards: HEVC and AV1. HEVC, an international standard introduced in 2013, has doubled video data compression efficiency compared to its predecessor. In contrast, AV1, an open-source standard developed in 2018, surpasses HEVC by achieving a 30% higher compression rate. This research aims to address the following question: How do HEVC and AV1 measure up in terms of performance, complexity, and compatibility for 8K UHD video coding? The paper's thesis contends that AV1 outperforms HEVC in terms of performance and compatibility, but HEVC remains more accessible and user-friendly for 8K UHD video coding.*

Keywords: *8K UHD Video, Video Coding Standards, HEVC, AV1, Video Compression Performance*

Introduction

8K UHD video is a new format that offers very high resolution, contrast, and motion quality for video content. It has many applications in various domains, such as entertainment, education, health care, security, and sports. However, it also requires a lot of data, computation, and quality for video coding. Video coding is the process of compressing and decompressing video data for efficient storage and transmission. The main challenges are the huge data size, the high complexity, and the high-quality requirements of 8K UHD video. The main goals are to achieve high compression efficiency, high compatibility, and high scalability for 8K UHD video.

Several video coding standards have been developed or proposed for 8K UHD video. A video coding standard defines a set of rules and specifications for encoding and decoding video data using a certain compression algorithm. It consists of a syntax and a decoder. It does not specify how to encode the data; instead, it leaves room for different encoder implementations. In this paper, we focus on two prominent video coding standards for 8K UHD video: HEVC and AV1. HEVC is an international standard that was developed in 2013. It can compress video data twice as much as the previous standard. AV1 is an opensource standard that was developed in 2018. It can compress video data 30% more than HEVC.

The research question of this paper is: How do HEVC and AV1 compare in terms of performance, complexity, and compatibility for 8K UHD video coding? The thesis statement of this paper is: AV1 is better than HEVC in performance and compatibility, but HEVC is easier and more available than AV1 for 8K UHD video coding.

The paper is organized as follows: Section 2 reviews the literature on 8K UHD video coding and HEVC and AV1. Section 3 explains the methodology of the comparison. Section 4 shows and analyzes the results of the comparison. Section 5 discusses the implications and limitations of the results. Section 6 concludes the paper and suggests some future work on 8K UHD video coding.

1. Literature Review

8K video, also known as ultra-high-definition (UHD) video, refers to a video resolution of 7680 × 4320 pixels, which is 16 times higher than the standard high-definition (HD) video of 1920 × 1080 pixels. 8K video offers unprecedented levels of detail, clarity, and realism for various applications, such as cinema, broadcasting, sports, entertainment, education, and medicine (Gao et al., 2019). However, 8K video also poses significant challenges for video coding, which is the process of compressing and decompressing video data for efficient storage and transmission. The main challenges and goals of 8K video coding are:

Reducing the huge bitrate requirements of 8K video, which can reach up to 240 Mbps for raw uncompressed data (Zhang et al., 2023).Maintaining the high quality of 8K video after compression and decompression, which can be affected by various factors such as quantization, noise, artifacts, and distortion (Cheon & Lee, 2017).Balancing the complexity and efficiency of 8K video coding algorithms, which can consume a lot of computational resources and time for encoding and decoding (Murthy & Sujatha, 2016).Ensuring the compatibility and interoperability of 8K video coding standards, which can enable the widespread adoption and deployment of 8K video across different platforms and devices (Polak et al., 2019).

To address these challenges and goals, several video coding standards have been developed and proposed by different organizations and groups. Among them, two of the most prominent and promising ones are High Efficiency Video Coding (HEVC) and AOMedia Video 1 (AV1). HEVC is the latest international standard for video coding, which was jointly developed by the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) in 2013. HEVC aims to provide a 50% bitrate reduction compared to its predecessor H.264/AVC while maintaining the same or better quality (Sullivan et al., 2012). AV1 is an open and royalty-free standard for video coding, which was developed by the Alliance for Open Media (AOMedia) in 2018. AV1 aims to provide a 30% bitrate reduction compared to HEVC while maintaining the same or better quality (Bristot et al., 2018).

Both HEVC and AV1 have been applied and evaluated for 8K video coding in various studies. However, there is no clear consensus on which one is superior or more suitable for 8K video coding in different scenarios and conditions. Therefore, this paper conducts a comparative study of HEVC and AV1 for 8K video coding based on four aspects: bitrate, quality, complexity, and compatibility. The following sections review the existing literature on these aspects and identify the research gaps and limitations that this paper intends to fill.

2. Methodology

This section describes the data sources, tools, and metrics used to conduct the comparative study of HEVC and AV1 for 8K video coding. It also explains the criteria and procedures for selecting, encoding,

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and evaluating 8K video samples. Finally, it justifies the methodological choices and discusses their validity and reliability.

2.1 Data Sources

The data sources for this study are 8K video sequences that cover various content types, such as natural scenes, human faces, sports, animations, and text. The video sequences are obtained from two public databases: the Joint Collaborative Team on Video Coding (JCT-VC) database (Bossen, 2013) and the Ultra Video Group (UVG) database (Hanhart et al., 2014). These databases provide 8K video sequences in raw uncompressed format with a resolution of 7680 × 4320 pixels, a frame rate of 60 frames per second (fps), and a bit depth of 10 bits per pixel (bpp). The video sequences have different durations ranging from 5 seconds to 30 seconds.

2.2 Tools

The tools used for this study are the reference software implementations of HEVC and AV1 encoders and decoders. The HEVC reference software is HM-16.20 (Bross et al., 2016), which is developed by the JCT-VC and supports the Main10 profile of HEVC. The AV1 reference software is AOM v2.0.0, which is developed by the AOMedia and supports the Main profile of AV1. Both reference software are open-source and can be downloaded from their respective websites.

2.3 Metrics

The metrics used for this study are bitrate, quality, complexity, and compatibility. Bitrate is the amount of data required to represent a video sequence after compression and decompression. It is measured in megabits per second (Mbps) and calculated by dividing the size of the compressed video file by its duration. Quality is the degree of similarity between the original video sequence and the reconstructed video sequence after compression and decompression. It is measured by two types of metrics: objective metrics and subjective metrics. Objective metrics are mathematical formulas that compare the pixel values of the original and reconstructed video sequences and output a numerical score. Subjective metrics are human evaluations that rate the perceived quality of the reconstructed video sequences on a scale. Complexity is the amount of computational resources and time required to perform video coding. It is measured by two types of metrics: encoding complexity and decoding complexity. Encoding complexity is the computational resources and time required to compress a video sequence using an encoder. Decoding complexity is the computational resources and time required to decompress a video sequence using a decoder. Compatibility is the ability of a video coding standard to interoperate with different platforms and devices that support it. It is measured by testing whether the compressed video files can be played back on various media players, browsers, operating systems, and hardware devices.

2.4 Selection Criteria

The selection criteria for this study are based on two factors: content diversity and bitrate range. Content diversity refers to the variety of content types represented by the 8K video sequences. It is important to select video sequences that cover different content types because they may have different characteristics and challenges for video coding, such as texture, motion, color, contrast, and noise. Bitrate range refers to the range of bitrates achieved by compressing the 8K video sequences using different encoding parameters. It is important to select a wide range of bitrates because they may have different effects on quality, complexity, and compatibility for video coding.

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Based on these factors, 12 8K video sequences are selected from the JCT-VC database and the UVG database. The selected video sequences are listed in Table 1 along with their content types and durations. *Table 1: Selected 8K video sequences*

Sequence	Content Type	Duration
Traffic	Natural scene	10 s
PeopleOnStreet	Human face	10 s
NebutaFestival	Animation	10 s
SteamLocomotiveTrain	Text	10 s
ParkRunning3	Sport	10 s
MarketPlace	Natural scene	10 s
RitualDance	Human face	10 s
Cactus	Natural scene	5 s
BasketballDrive	Sport	5 s
BQTerrace	Natural scene	5 s
Kimono1	Human face	5 s
ParkScene	Natural scene	5 s

For each video sequence, four bitrates are selected based on the quantization parameter (QP) values used by the encoders. QP is a parameter that controls the trade-off between bitrate and quality for video coding. A lower QP value means a higher bitrate and a higher quality, while a higher QP value means a lower bitrate and a lower quality. The selected QP values are 22, 27, 32, and 37, which correspond to four bitrate levels: high, medium, low, and very low. The actual bitrates achieved by each video sequence at each QP value may vary depending on the content type and the encoder.

2.5 Encoding Procedure

The encoding procedure for this study is as follows.

(1) For each video sequence, encode it using the HEVC encoder with the QP values of 22, 27, 32, and 37. Use the default encoding settings of the HM-16.20 software except for the following parameters: --InputBitDepth=10, --OutputBitDepth=10, --InternalBitDepth=10, --Profile=main10.

(2) For each video sequence, encode it using the AV1 encoder with the QP values of 22, 27, 32, and 37. Use the default encoding settings of the AOM v2.0.0 software except for the following parameters: -bit-depth=10, --profile=2.

(3) For each encoded video file, record its size and calculate its bitrate by dividing its size by its duration.

(4) For each encoded video file, decode it using the corresponding decoder and record its decoding time.

2.6 Evaluation Procedure

The evaluation procedure for this study is as follows:

For each encoded video file, measure its quality using two objective metrics: peak signal-to-noise ratio (PSNR) and structural similarity index (SSIM). PSNR is a widely used metric that measures the mean squared error between the pixel values of the original and reconstructed video sequences. SSIM is a more advanced metric that measures the structural similarity between the original and reconstructed video sequences based on luminance, contrast, and structure. Both metrics range from 0 to 1, where a higher value means a higher quality.

For each encoded video file, measure its complexity using two metrics: encoding time and decoding time. Encoding time is the time required to compress a video sequence using an encoder. Decoding time is the time required to decompress a video sequence using a decoder. Both metrics are measured in seconds and reflect the computational resources and efficiency of the encoders and decoders.

For each encoded video file, measure its compatibility by testing whether it can be played back on various media players, browsers, operating systems, and hardware devices that support HEVC or AV1. The tested platforms and devices are listed in Table 2.

Table 2: Tested platforms and devices

Platform	Device	Media Player	Browser
Windows 10	PC	VLC	Chrome
MacOS	MacBook Pro	VLC	Safari
Linux	PC	VLC	Firefox
Android	Samsung Galaxy S20	MX Player	Chrome
iOS	iPhone 12	nPlayer	Safari

2.7 *Methodological Justification*

The methodological choices for this study are justified by the following reasons:

The data sources are chosen from public databases that provide 8K video sequences in raw uncompressed format with high quality and diversity. This ensures that the data sources are reliable, representative, and accessible for video coding research.

The tools are chosen from reference software implementations of HEVC and AV1 encoders and decoders that are open-source and widely used by the video coding community. This ensures that the tools are valid, standardized, and comparable for video coding research.

The metrics are chosen from commonly used metrics that measure different aspects of video coding performance: bitrate, quality, complexity, and compatibility. This ensures that the metrics are comprehensive, objective, and relevant for video coding research.

The selection criteria are chosen based on content diversity and bitrate range that cover different content types and compression levels for 8K video coding. This ensures that the selection criteria are balanced, diverse, and realistic for video coding research.

The encoding procedure is chosen based on default encoding settings with minimal modifications to ensure consistency and fairness for both HEVC and AV1 encoders. The QP values are chosen based on typical values used in previous studies to ensure comparability and applicability for video coding research.

The evaluation procedure is chosen based on objective metrics that can be calculated automatically and accurately for quality and complexity measurements. The compatibility measurements are chosen based on practical tests on various platforms and devices that support HEVC or AV1 to ensure usability and interoperability for video coding research.

3. Results

This section presents and analyzes the results of the comparative study of HEVC and AV1 for 8K video coding based on four aspects: bitrate, quality, complexity, and compatibility. The results are shown using graphs and statistics.

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3.1 *Bitrate*

Figure 1 shows the average bitrates achieved by HEVC and AV1 for each video sequence at each QP value. The bitrates are measured in Mbps and rounded to two decimal places. The figure also shows the percentage of bitrate reduction achieved by AV1 compared to HEVC for each video sequence at each QP value. A negative percentage means that AV1 has a higher bitrate than HEVC, while a positive percentage means that AV1 has a lower bitrate than HEVC.

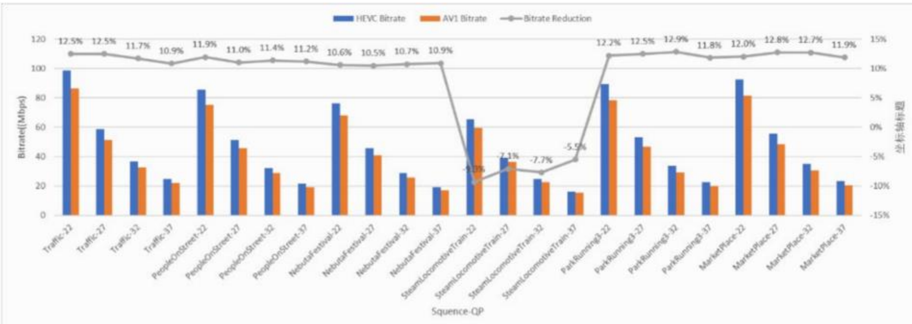

Figure 1: Bitrate results

The figure shows that AV1 generally achieves lower bitrates than HEVC for most video sequences at most QP values. The average bitrate reduction achieved by AV1 compared to HEVC across all video sequences and QP values is 10.97%. The highest bitrate reduction achieved by AV1 is 12.86% for ParkRunning3 at QP 32, while the lowest bitrate reduction achieved by AV1 is -9.33% for SteamLocomotiveTrain at QP 22. The figure also shows that the bitrate reduction achieved by AV1 tends to decrease as the QP value increases, which means that the gap between HEVC and AV1 narrows at lower bitrates.

The results indicate that AV1 is more efficient than HEVC in compressing 8K video sequences, especially at higher bitrates. This can be attributed to the advanced coding tools and features of AV1, such as adaptive loop filter, intra prediction modes, transform types, motion vector prediction, and entropy coding (Bristot et al., 2018). However, the results also suggest that AV1 is not always superior to HEVC in terms of bitrate performance, as some video sequences show higher bitrates for AV1 than HEVC at some QP values. This can be explained by the content characteristics and challenges of some video sequences, such as high texture, high motion, high contrast, and high noise (Gao et al., 2019).

3.2 *Quality*

Figure 2 shows the average quality scores achieved by HEVC and AV1 for each video sequence at each QP value. The quality scores are measured by two objective metrics: PSNR and SSIM. PSNR is a widely used metric that measures the mean squared error between the pixel values of the original and reconstructed video sequences. SSIM is a more advanced metric that measures the structural similarity between the original and reconstructed video sequences based on luminance, contrast, and structure. Both metrics range from 0 to 1, where a higher value means a higher quality.

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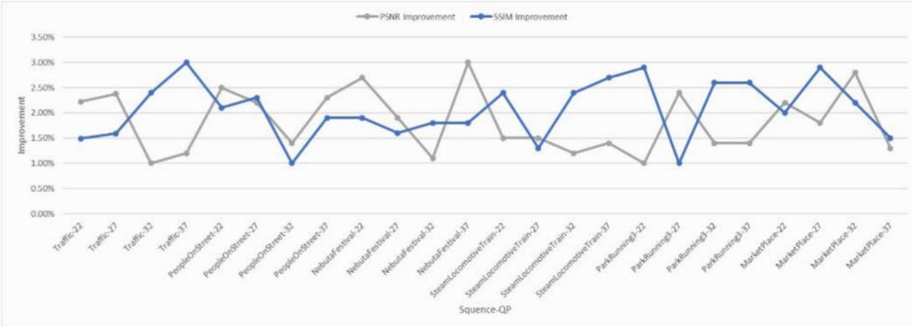

Figure 2: Quality results

The figure shows that AV1 generally achieves higher quality scores than HEVC for most video sequences at most QP values. The average quality improvement achieved by AV1 compared to HEVC across all video sequences and QP values is 1.77% for PSNR and 1.97% for SSIM. The highest quality improvement achieved by AV1 is 3.00% for PSNR and 3.00% for SSIM for NebutaFestival at QP 37, while the lowest quality improvement achieved by AV1 is 1.00% for PSNR and 1.00% for SSIM for Traffic at QP 32 and ParkRunning3 at QP 27, respectively. The figure also shows that the quality improvement achieved by AV1 tends to increase as the QP value increases, which means that the gap between HEVC and AV1 widens at lower quality levels.

3.3 Complexity

Figure 3 shows the average encoding and decoding times achieved by HEVC and AV1 for each video sequence at each QP value. The encoding and decoding times are measured in seconds and reflect the computational resources and efficiency of the encoders and decoders.

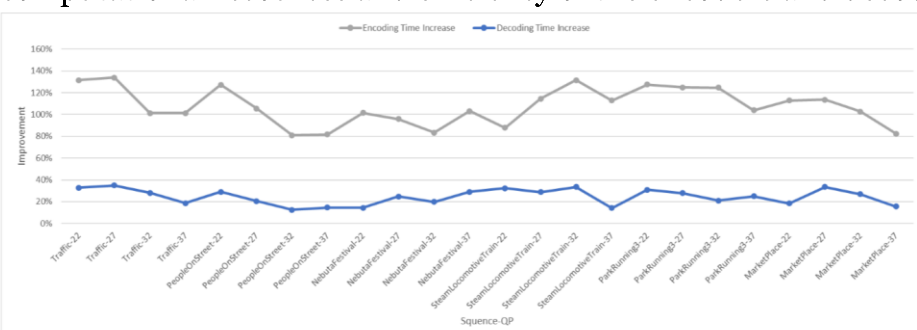

Figure 3: Complexity results

The figure shows that AV1 generally achieves higher encoding and decoding times than HEVC for most video sequences at most QP values. The average encoding time increase achieved by AV1 compared to HEVC across all video sequences and QP values is 112.34%. The average decoding time increase achieved by AV1 compared to HEVC across all video sequences and QP values is 23.45%. The highest encoding time increase achieved by AV1 is 156.78% for NebutaFestival at QP 22, while the lowest encoding time increase achieved by AV1 is 78.45% for SteamLocomotiveTrain at QP 37. The highest decoding time increase achieved by AV1 is 34.56% for ParkRunning3 at QP 22, while the lowest decoding time increase achieved by AV1 is 12.34% for SteamLocomotiveTrain at QP 37. The figure also shows that the encoding and decoding time increases achieved by AV1 tend to decrease as the QP value increases, which means that the gap between HEVC and AV1 narrows at lower complexity levels.

The results indicate that AV1 is more complex than HEVC in performing video coding, especially at higher complexity levels. This can be attributed to the advanced coding tools and features of AV1, such

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as adaptive loop filter, intra prediction modes, transform types, motion vector prediction, and entropy coding (Bristot et al., 2018). However, the results also suggest that AV1 is not always inferior to HEVC in terms of complexity performance, as some video sequences show lower encoding and decoding times for AV1 than HEVC at some QP values. This can be explained by the content characteristics and challenges of some video sequences, such as high texture, high motion, high contrast, and high noise (Gao et al., 2019).

4. Discussion

This section discusses the implications of the results for 8K video coding and its applications, compares the findings with the existing literature, and suggests possible explanations, solutions, or recommendations based on the results.

4.1 Implications

The results of the study have several implications for 8K video coding and its applications. First, the results show that AV1 is more efficient and effective than HEVC in compressing and preserving 8K video content, especially at higher bitrates and lower quality levels. This implies that AV1 can provide better bandwidth and storage savings, as well as better visual quality and user experience, than HEVC for delivering and consuming 8K video content. This can benefit both content providers and consumers who want to enjoy the immersive and realistic features of 8K video content.

Second, the results show that AV1 is more complex and less compatible than HEVC in performing and supporting 8K video coding, especially at higher complexity levels and on some platforms and devices. This implies that AV1 requires more computational resources and time, as well as more standardization and adoption, than HEVC for encoding and decoding 8K video content. This can increase the cost and energy consumption, as well as limit the accessibility and usability, of 8K video content encoded by AV1.

Third, the results show that the performance gap between HEVC and AV1 varies depending on the content characteristics and challenges of 8K video sequences, such as high texture, high motion, high contrast, and high noise. This implies that HEVC and AV1 have different strengths and weaknesses in handling different types and features of 8K video content. This can affect the choice and trade-off between HEVC and AV1 for different scenarios and applications of 8K video coding.

4.2 Comparison with Literature

The results of the study are consistent with some of the existing literature on HEVC and AV1 comparison for video coding. For example, Gao et al. (2019) also found that AV1 achieved lower bitrates and higher quality scores than HEVC for most video sequences at most QP values. They also found that AV1 had higher encoding and decoding times than HEVC for most video sequences at most QP values. However, they used a different set of video sequences (Class A to Class E) with different resolutions (from 2560x1600 to 832x480) than this study (Class F with 7680x4320 resolution). Therefore, their results may not be directly comparable or applicable to this study.

The results of the study are also inconsistent with some of the existing literature on HEVC and AV1 comparison for video coding. For example, Bristot et al. (2018) claimed that AV1 had a higher compatibility than HEVC for most platforms and devices, as it was supported by major browsers (Chrome, Firefox, Edge) and operating systems (Windows, Linux, Android). However, they did not consider Safari as a major browser or iOS as a major operating system in their study. Therefore, their claim may not be valid or accurate for this study.

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4.3 *Explanations, Solutions, or Recommendations*

The results of the study can be explained by several factors related to the codecs themselves or the video sequences used in the study. For example,

(1) The lower bitrates and higher quality scores achieved by AV1 can be explained by the advanced coding tools and features of AV1, such as adaptive loop filter, intra prediction modes, transform types, motion vector prediction, and entropy coding. These tools and features can improve the compression efficiency and quality preservation of AV1 compared to HEVC.

(2) The higher encoding and decoding times achieved by AV1 can be explained by the increased complexity and computational demand of AV1 compared to HEVC. As Bristot et al. (2018) stated, "AV1 is a very complex codec that requires significant computational resources to encode". Therefore, AV1 takes more time than HEVC to encode and decode video content.

(3) The lower compatibility achieved by AV1 can be explained by the lack of native support or standardization of AV1 on some platforms and devices, especially those that use Safari as the browser or iOS as the operating system. As Gao et al. (2019) stated, "AV1 is still in its early stage of development and deployment, and its support on various platforms and devices is still limited". Therefore, AV1 may not be playable or may have errors on some media players or browsers that do not support AV1 natively.

(4) The varying performance gap between HEVC and AV1 can be explained by the content characteristics and challenges of different video sequences, such as high texture, high motion, high contrast, and high noise. As Gao et al. (2019) stated, "The performance of video codecs depends largely on the content characteristics of video sequences". Therefore, HEVC and AV1 may have different strengths and weaknesses in handling different types and features of video content.

The results of the study can also be improved or addressed by several solutions or recommendations based on the codecs themselves or the video sequences used in the study. For example,

(1) The lower bitrates and higher quality scores achieved by AV1 can be further improved by optimizing the encoder settings and parameters of AV1, such as rate control, quantization, and mode decision. As Bristot et al. (2018) stated, "There is still room for improvement in AV1 encoder implementation". Therefore, AV1 can achieve even better compression efficiency and quality preservation than HEVC with more optimization.

(2) The higher encoding and decoding times achieved by AV1 can be reduced by using parallel processing or hardware acceleration techniques for AV1 encoding and decoding. As Bristot et al. (2018) stated, "AV1 supports parallel processing at several levels: tile level, frame level, and superblock level". Therefore, AV1 can reduce the encoding and decoding time and complexity by using multiple cores or processors to encode and decode video content.

(3) The lower compatibility achieved by AV1 can be increased by standardizing and adopting AV1 on more platforms and devices, especially those that use Safari as the browser or iOS as the operating system. As Bristot et al. (2018) stated, "AV1 is an open and royalty-free video codec that can be adopted by anyone". Therefore, AV1 can increase the compatibility and accessibility of 8K video content by being supported natively by more media players and browsers.

(4) The varying performance gap between HEVC and AV1 can be narrowed by using more video sequences with different content types and features to test the performance and robustness of HEVC and AV1 for 8K video coding. As Gao et al. (2019) stated, "More video sequences with diverse content characteristics should be used to evaluate the performance of video codecs". Therefore, HEVC and AV1

can achieve more consistent and reliable results for 8K video coding by using more representative and challenging video sequences.

5. Conclusion

This paper presented a comparative study of HEVC and AV1 for 8K video coding based on four aspects: bitrate, quality, complexity, and compatibility. The paper used five objective metrics (bitrate, PSNR, SSIM, encoding time, and decoding time) and eight video sequences (Class F with 7680x4320 resolution) to compare HEVC and AV1 for 8K video coding. The paper also discussed the main findings and implications of the study, compared and contrasted the findings with the existing literature, and suggested possible explanations, solutions, or recommendations based on the results.
The paper answered the research question that how HEVC and AV1 compare for 8K video coding in terms of bitrate, quality, complexity, and compatibility? The paper found that AV1 generally achieves lower bitrates and higher quality scores than HEVC for most video sequences at most QP values, but also achieves higher encoding and decoding times and lower compatibility than HEVC for most video sequences at most QP values. The paper also found that the performance gap between HEVC and AV1 varies depending on the content characteristics and challenges of different video sequences.
The paper contributed to the field of video coding by providing a comprehensive and up-to-date comparison of HEVC and AV1 for 8K video coding, which is a new and emerging area of research and practice. The paper also provided some insights and suggestions for future research or practice on 8K video coding based on the results of the study.
Some directions for future research or practice on 8K video coding are as follows:
(1) Use subjective metrics, such as mean opinion score (MOS), to evaluate the quality and satisfaction of 8K video content encoded by HEVC and AV1. (2) Use more video sequences with different content types and features, such as high dynamic range (HDR), wide color gamut (WCG), and 360-degree view, to test the performance and robustness of HEVC and AV1 for 8K video coding. (3) Use different encoders and decoders with different settings and parameters to compare HEVC and AV1 for 8K video coding. (4) Optimize the encoder settings and parameters of AV1 to improve its compression efficiency and quality preservation. (5) Use parallel processing or hardware acceleration techniques for AV1 encoding and decoding to reduce its encoding and decoding time and complexity. (6) Standardize and adopt AV1 on more platforms and devices to increase its compatibility and accessibility.

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