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Preparing VVC for Streaming: A Fast Multi-Rate Encoding Approach

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Abstract—The integration of advanced video codecs into the streaming pipeline is growing in response to the increasing demand for high quality video content. However, the significant computational demand for advanced codecs like Versatile Video Coding (VVC) poses challenges for service providers, including longer encoding time and higher encoding cost. This challenge becomes even more pronounced in streaming, as the same content needs to be encoded at multiple bitrates (also known as representations) to accommodate different network conditions. To accelerate the encoding process of multiple representations of the same content in VVC, we employ the encoding map of a single representation, known as the reference representation, and utilize its partitioning structure to accelerate the encoding of the remaining representations, referred to as dependent representations. To ensure compatibility with parallel processing, we designate the lowest bitrate representation as the reference representation. The experimental results indicate a substantial improvement in the encoding time for the dependent representations, achieving an average reduction of 40%, while maintaining a minimal average quality drop of only 0.43 in Video Multi-method Assessment Fusion (VMAF). This improvement is observed when utilizing Versatile Video Encoder (VVenC), an open and optimized VVC encoder implementation.

Index Terms—VVC, multi-rate, VVenC, CTU, fast partitioning, random access.

I. INTRODUCTION

The demand for high quality video streaming is continuously rising, making the transition to more advanced video codecs inevitable. While H.264/Advanced Video Coding (AVC) [1] continues to maintain its dominance as the primary video codec in the industry, reports indicate a growing trend of adopting more advanced video codecs like High Efficiency Video Coding (HEVC) [2] and AOMedia Video 1 (AV1) [3]. Many companies are actively adding support for these codecs in their products. For instance, Google has incorporated HEVC support into Chrome, enabling users to experience the benefits of this advanced codec while streaming videos. In addition, Meta has introduced AV1 support for reel videos, enhancing the visual quality and efficiency of their video platform. These initiatives highlight adopting and leveraging the capabilities of cutting-edge video codecs for improved user experiences [4].

As the latest video codec, VVC [5] showcased a remarkable reduction in bitrate of around 50% for the same subjective video quality compared to its predecessor standard, HEVC [6], [7]. Wieckowski *et al.* [8] highlight the feasibility of employing VVC in a streaming application through a practical

workflow. The study presents the successful integration of VVenC, an open and optimized implementation [9] of the VVC encoder, into Bitmovin’s cloud-based encoding solution. The paper thoroughly examines the effects of VVC on practical considerations such as selection of the bitrate ladder, cost and performance compared to other codecs. Furthermore, it shows the utilization of Versatile Video Decoder (VVdeC) with WebAssembly, enabling seamless real-time playback of VVC directly within web browsers.

As we move towards more advanced video codecs to achieve higher-quality video delivery, one common trade-off is the increased computational time associated with these codecs. This aspect becomes even more critical in video streaming applications, where the encoding process involves multiple representations of the same content to accommodate varying network conditions for users. For instance, VVC demonstrates a 5x increase in complexity compared to HEVC when encoding the same content under LowDelay conditions [10]. This increase in complexity is mainly attributed to the utilization of more sophisticated tools, which inherently introduce complexity. The main contributor to the increase in complexity in HEVC and VVC is the Coding Tree Unit (CTU) partitioning [11], [12].

There are many approaches that have been introduced to reduce the complexity of VVC, in particular fast CTU partitioning algorithms for the VVC Test Model (VTM) encoder. Heuristic methods make full use of pixel-related statistics, such as gradient, variance, *etc.* Fan *et al.* in [13] developed a hybrid early termination mechanism based on pixel variance and gradient. Similarly, a gradient-based early termination was proposed in [14].

In streaming applications, where video content is encoded at multiple bitrates, fast multi-rate encoding methods are employed. These methods typically designate a single representation as the reference representation, encoding it first, and utilizing its information to expedite the encoding process for the remaining representations, known as dependent representations. Schroeder *et al.* [15] proposed a multi-rate encoding approach in which the video is first encoded at a high quality representation, and its information is reused to accelerate the encoding of lower quality representations. They leveraged the fact that each CTU achieves its highest partitioning depth in the highest quality representation. Consequently, by deter-

mining the partitioning depth of CTUs in the highest quality representation (d_m), it is possible to skip the partitioning of co-located CTUs in lower quality representations beyond d_m . This leads to significant time savings during the encoding process. Çetinkaya *et al.* [16], [17] proposed an approach in which the lower quality representation is initially encoded, and for each CTU with a partitioning depth of (d_m), depths lower than d_m are skipped during the Rate-Distortion Optimization (RDO) search. In this method, Convolutional Neural Networks (CNNs) is used to extract additional features, enhancing the performance of partitioning depth decisions. Amirpour *et al.* [18] investigate the trade-off between time savings and quality drop by considering different representations as reference representation. They concluded that utilizing a middle quality representation can effectively strike a balance between these factors, optimizing the trade-off. Menon *et al.* [19] presented an extensive investigation of various multi-rate schemes and introduced innovative heuristics aimed at constraining the RDO process across different representations. Building upon these heuristics, they proposed three multi-encoding schemes that leverage encoder analysis sharing across various representations. These schemes were designed to optimize: (i) highest compression efficiency, (ii) the optimal trade-off between compression efficiency and encoding time savings, and (iii) maximum encoding time savings.

While the aforementioned methods have demonstrated significant performance in the context of HEVC, the exploration of fast multi-rate encoding techniques in VVC remains relatively unexplored. In this paper, our aim is to bridge this gap by applying fast multi-rate encoding to VVenC, an optimized open-source software implementation of VVC. By leveraging this approach, we investigate the potential benefits and performance improvements of fast multi-rate encoding in the VVC domain. In the following section, we provide a concise overview of CTU partitioning in VVC. Section III outlines our proposed fast multi-rate encoding approach specifically tailored for VVC. The experimental results are presented in Section IV. Finally, Section V concludes the article, summarizing the key findings and contributions.

II. VVC PARTITIONING IN PRACTICE

A. Multi-Type (MTT) partitioning

VVC offers more efficient partitioning through larger and more flexible Coding Unit (CU) splits than HEVC [20]. To be precise, the largest and smallest CU in VVC are 128×128 and 4×4 for the luma samples, respectively. Six types of splits are also allowed, namely Non-Split (NS), QuadTree Split (QT) split, Horizontal Binary Tree (HBT) split, Vertical Binary Tree (VBT) split, Horizontal Ternary Tree (HTT) split, and Vertical Ternary Tree (VTT) split, as presented in Fig. 1. NS refers to encoding the entire CU without applying any split on it. Moreover, VVC is integrated with tools such as Intra Sub Partitioning (ISP) [21] or Geometric partitioning (GEO) [22] that are capable of further splitting CU into the smallest units to provide more accurate texture/motion modeling.

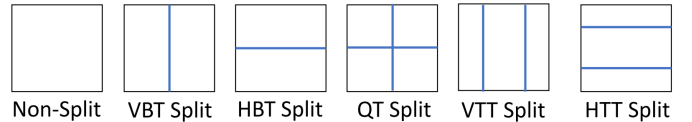


Fig. 1: Different split types in VVC.

B. The challenge of partitioning RDO search

Partitioning is in the heart of the RDO search; hence, it typically decides the overall encoder complexity. Precisely, the encoder is provided with such freedom of parameters, so that encoding a single video could be as fast as real-time (*e.g.* 60 frames per second) or as slow as days of encoding. Depending on the underlying use case, either one could be preferred. In particular, a slow encoding is popular in streaming services, where the video titles are typically transmitted to receivers on-demand, therefore, compression efficiency has priority to the encoding complexity. However, extremely long encoding could be costly, especially given that most encodings are performed on relatively expensive cloud servers. Therefore, even for streaming services, it is always preferred to deploy an encoder that is fast and efficient as much as possible.

Practical encoders deploy various early termination shortcuts to reduce the complexity of RDO. The aim of these shortcuts – typically applied on the partitioning search – is to avoid searches that are less likely to be optimal. Specifically, given the partitions checked in the past and the trend of their Rate-Distorsion Cost (RDcost)s, the shortcuts determine whether to check the size of each partition. The effectiveness of this approach depends on different aspects, including texture/motion complexity, the accuracy of the RDcost estimation, and last but not least, the encoded bitrate. In the last case, previous studies show that early termination shortcuts often skip more RD checks for lower bitrates. For instance, encoding JVET’s Common Test Condition (CTC) [23] sequences with Quantization Parameter (QP) 37 is about 80% faster than with QP 22 [24]. This is mainly due to the fact that at lower bitrates, large CUs often end up having lower RDcosts than smaller CUs, and this trend is usually identified early enough during the top-to-bottom partitioning search to trigger and early termination, which saves several partitioning checks.

A challenge in deploying effective partitioning acceleration lies in the concept of CU depth, which is defined as the number of times a CTU should split in order to reach a certain CU size at a certain position in the CTU. In HEVC, the depth of a CU is directly determined by the size of CU, since only quad split partitioning is available in HEVC. However, in VVC, binary and ternary splits are designed so that the depth of a rectangular leaf CU cannot be determined merely by its size and shape. For example, to obtain four 8×8 CUs from a 16×16 CU, one has the freedom to perform either a single QT, or a VBT followed by an HBT, or an HBT followed by a VBT. As a result, the use of CU depth in VVC to exploit partitioning size correlations is less evident than in HEVC.

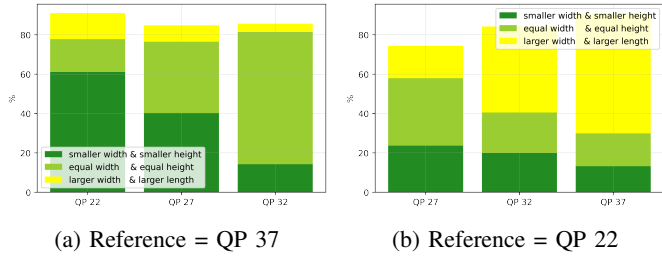


Fig. 2: Average percentage of the CUs with CU height and width larger, equal to, or smaller than the reference encoding.

C. Multi-rate encoding opportunities

Despite the above complications, multi-rate VVC encoded representations of a video content can still carry a significant level of redundancies. To demonstrate this, we encoded 18 sequences with RandomAccess (RA) coding configurations at QPs of 22, 27, 32, 37. These sequences include six from class A of the VVC CTC [23] and 12 from the Inter4K dataset [25]. To select 12 sequences out of the 1000 sequences available in the Inter4K dataset, we compared their spatial and temporal complexities using Video Complexity Analyzer (VCA) [26]. Based on this comparison, we divided them into four clusters as follows: low spatial and low temporal complexity, low spatial complexity and high temporal complexity, high spatial complexity and low temporal complexity, and high spatial complexity and high temporal complexity. From each cluster, we then randomly selected three sequences for further evaluation (sequences 10, 47, 56, 176, 186, 339, 497, 500, 606, 646, 666, 754). QP 22 and 37 were used as reference for comparisons of CU sizes in non-reference QPs. Fig. 2 (a) and (b) show, respectively, what percentage of encoded co-located CUs have *both* CU width and height smaller than QP 37 or larger than QP 22.

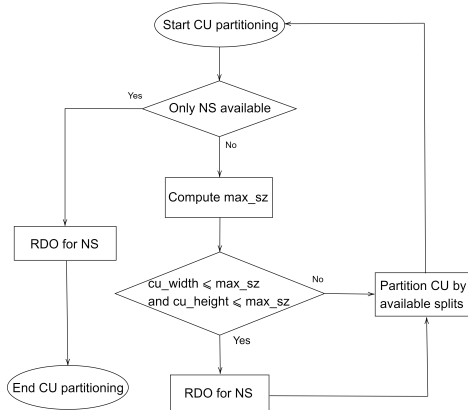


Fig. 3: Diagram of CU size based fast partitioning.

When the reference encoding is set to QP 37, it is observed that a smaller portion of CUs in the dependent encodings have larger width and height sizes compared to their co-located CUs in the reference encoding (yellow bars in Fig. 2a). The closer the QP of the dependent encoding to the reference encoding, the larger the portion of CUs that have the same size as the

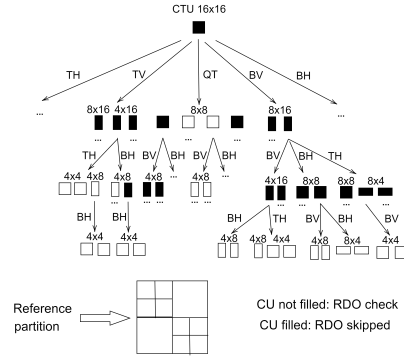


Fig. 4: Fast approach involved partition search.

co-located CU in the reference encoding. Therefore, when the reference encoding is set to QP 37, RDO can be skipped for co-located CUs that have a width and height larger than the reference CU. On the other hand, when the reference encoding is set to QP 22, a smaller portion of CUs in the dependent encoding have smaller width and height sizes compared to their co-located CUs in the reference encoding (dark green bars in Fig. 2b). Therefore, when the reference encoding is set to QP 22, RDO can be skipped for co-located CUs that have a smaller width and height than the reference CU. Please note that the cumulative percentages of CUs do not reach 100% because the cases where CUs have smaller widths but larger heights or larger widths but smaller heights have not been considered in the evaluations.

III. A FAST MULTI-RATE ENCODING SCHEME FOR VVC

Based on the experiments presented previously, a method is proposed to exploit the redundancy in the CU sizes with respect to a reference-coded bitrate. Selecting the appropriate reference encoding for reusing its information to accelerate the encoding of dependent representations is indeed a challenging task and can vary depending on the specific application. In the context of live video streaming, it is commonly observed that the highest quality representation requires the longest encoding time, followed by lower quality representations as the quality decreases. Given the significant impact of encoding time on the latency of live video streaming, it is advantageous to select a representation with a lower encoding time (lower quality) as a reference for accelerating the encoding of representations with higher encoding time (higher quality). By doing so, the maximum and overall encoding process can be expedited, reducing the latency and enhancing the potential for transitioning towards real-time streaming with VVC. Therefore, in this paper, we propose selecting the representation with the lowest encoding time (QP 37) as the reference encoding. By reusing its information, we aim to accelerate the encoding process of the dependent representations (QP 32, QP 27, and QP 22).

When a reference CTU of 128×128 is encoded at QP 37, its size map is calculated to contain the maximum width and height of CUs. Since the smallest CU size is 4×4 , each 4×4 sub-block is assigned the maximum width and height of the CU it belongs to. This process results in a map of size 32×32

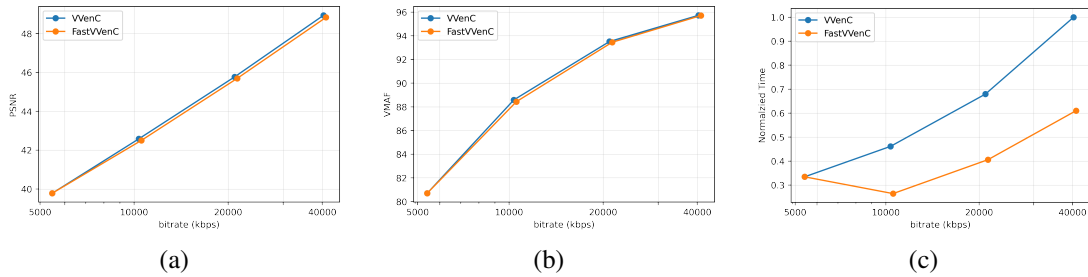


Fig. 5: The comparison between the standalone VVenC and the proposed fast multi-rate encoding.

for each CTU. With a reference encoding of QP 37 and a reference size map of 32×32 , the algorithm for accelerating the encoding of co-located dependent CUs is illustrated in Fig. 3.

Firstly, possible split types of current CU are investigated. If no split types other than NS are available, the fast partitioning approach will not be applied to current CU. The encoding of current CU is directly processed and the CU partitioning is terminated. If other split types are possible, we obtain max_sz in Fig. 3 by getting the maximum value of elements of the size map inside current CU. If the width and height of the current CU are both smaller or equal to max_sz , we do the RDO for current CU. Otherwise, the encoding of CU is skipped and the CU is further split to sub-CUs. A part of RDOs of CU is leaped by applying our fast partitioning method.

To better illustrate the effect of the acceleration achieved by our algorithm, we present the partition search results with our fast approach applied in Fig. 4. To simplify the partition tree, we have set the CTU size to 16×16 and the QT split is disabled for 8×8 CU. Meantime, the maximum partitioning depth is 3. For better visualization, repetitive branches are not presented in the figure. CUs with RDO skipped are filled with black. If we proceed with a larger CTU size, the proportion of skipped CUs would be larger.

IV. EXPERIMENTAL RESULTS

To evaluate the proposed algorithm, we performed encodings using the VVenC with both the standalone and modified versions of the encoder on the same set of sequences and with the same encoding configuration as mentioned in Section III. For each encoding, we recorded the bitrate, and encoding time, and computed objective metrics, including Peak Signal-to-Noise Ratio (PSNR) and VMAF. Fig. 5 shows the PSNR vs. bitrate, VMAF vs. bitrate, and normalized time vs. bitrate for the video sequence 754 from Inter4K dataset as an example. It is observed that the rate-distortion performance remains approximately the same while the encoding time is significantly reduced for the dependent representations. From Fig. 5-(c), it can be concluded that not only is the overall encoding time of all representations reduced, but also the maximum encoding time is decreased, which is equivalent to the encoding latency. This is highly beneficial in live video streaming as it ensures efficient and timely processing of the video data. In this example, using the proposed method, the maximum encoding time is reduced by 40%, as can be

seen in Fig. 5-(c). The average BD-PSNR and BD-VMAF are achieved at -0.21 and -0.43, respectively, indicating that the proposed fast multi-rate encoding method causes a slight decrease in video quality compared to the standalone VVenC at equivalent bitrates. At the same time, the average increase in bitrate in equivalent quality is 5.11% and 4.82% using PSNR and VMAF as objective metrics, respectively. However, the reduction in video quality is minimal, and the benefits of significantly reduced encoding time make the proposed method a valuable option for various applications, especially in live video streaming scenarios where real-time performance is crucial. The proposed fast multi-rate encoding results in an average encoding time reduction of 40% for all dependent representations. Additionally, it achieves an average maximum encoding time reduction of 39%, indicating that the encoding latency is reduced by 39% when using this approach.

V. CONCLUSIONS

This paper proposes a fast multi-rate encoding approach for VVC aimed at reducing the encoding time for video streaming applications. The approach involves encoding a reference representation using a standalone VVC encoder. The information obtained from the reference representation is then utilized to accelerate the encoding process for the dependent representations. To ensure compatibility with parallel processing, the representation with minimal encoding time is selected as the reference encoding. This reference representation is then utilized to reduce the encoding time of the longer encoding time representations, aiming not only to reduce the overall encoding time but also to minimize the maximum encoding time, which is equivalent to encoding latency. When a CTU is encoded in the reference representation, the RDO process is skipped in the co-located CTUs in dependent representations for CUs that have larger width and height compared to the reference CTU. The experimental results demonstrate that the proposed method achieves an average 40% encoding time reduction, while the quality drop, on average, is only 0.43 VMAF when using VVenC, an optimized VVC implementation.

VI. ACKNOWLEDGMENT

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