Design Approaches for Mode Decision in HEVC Encoder
Exploiting Parallelism at CTB Level

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Abstract: As CPU technology trend is strongly moving towards multi-core architectures, HEVC tried to embrace the parallel processing trend to possible extent. Hence, HEVC exploits some of the parallel processing capabilities like tiles, slices and WPP at frame level (Sullivan et al., 2012). Although slices, tiles and WPP can be used to achieve parallelism, they might end-up degrading either visual quality or compression efficiency. To address this problem, this paper tries to summarize/exploit the possible parallel processing capabilities of HEVC at Coding Tree Block (CTB) level with insignificant compromise in video quality and compression.

1 INTRODUCTION

The emerging video coding standard, High Efficiency Video Coding (HEVC/H.265) (Bross et al., 2013), which is also a part of MPEG-H, tries to achieve up to 50% better compression when compared to the Advanced Video Coding (AVC/H.264) standard, while maintaining similar video quality levels (Sullivan et al., 2012). Although HEVC uses the same “hybrid” approach and coding tools similar to prior standards, there are key differences that enable the enhanced compression. The higher gains in the compression are the result of using various high efficiency coding tools available in HEVC namely - large and variable size coding blocks, larger and variable size transforms, Advanced Motion Vector Prediction(AMVP), Merge prediction blocks and Band Offset Filters & Edge Offset Filters collectively named as Sample Adaptive Offset (SAO) filter.

Most of these high efficiency coding tools in the HEVC encoder are computationally intensive. Also, since HEVC provides more options to encode a picture, the challenge at the encoder side is to decide the “most suitable combination” of the coding tools for encoding such that both rate and distortion are minimized to the best possible levels (Bossen et al., 2012). The “most suitable combination” of blocks and modes is decided by the mode decision process of an encoder. Main focus of this paper will be on understanding the impact of mode decision flow of an encoder on computatonal complexity and resulting compression efficiency.

The rest of the paper is organized as follows. Section 2 briefs the encode mode decision details that have been considered for the proposed approaches implementation. In section 3, we brief the proposed approaches and in section 4, we carry out comparative study and analysis of proposed two approaches. Finally, section 5 concludes the paper.

2 OVERVIEW

The ultimate goal of any video coding standard has been to achieve maximum compression without compromising on the quality of encoded video. Mode decision in an encoder is responsible for making optimal decisions to achieve the said encoder goals with respect to complexity and video compression. For a Coded Tree Block (CTB), mode decision in HEVC encoder comprises of making the following set of decisions:

- Intra prediction Direction for intra prediction block(PB)
- Motion Vector (MV) for inter PB
- Merge Decision for Inter PB
- Best Part Mode for Intra CB – 2Nx2N/NxN
- Best Part Mode for Inter CB 2Nx2N/2NxN/Nx2N/NxN/2NxnU/2NxnD/nLx2N/nRx2N

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- Intra CB versus Inter CB decision at all depths
- Skip Decision for CB
- Depth of a Coding Block (CB)

The above decisions may lead to a CTB as shown in Fig.1.

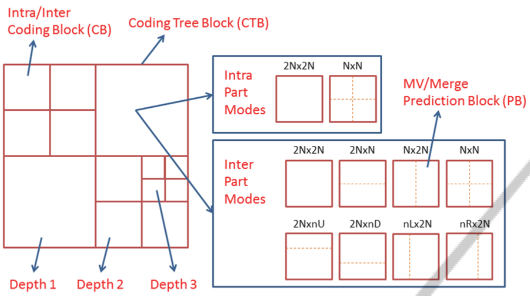


Figure 1: CTB splitting.

Mathematically, mode decision process has to minimize cost of the CTB by optimizing rate and distortion of a CTB so that video compression is better. According to Lagrangian cost minimization technique (Sullivan et al., 1998), cost of a block (CTB/CB/PB) is calculated as

$$\text{Cost} = D + \lambda * B \quad (1)$$

where, D is the distortion of a block, B is the bits required for encoding a block and λ is the Lagrangian Multiplier whose value majorly depends on the quantization parameter(QP). Whenever a decision is to be made between two choices, the option with lower cost is chosen for coding.

2.1 Inter Mode Decision

For each CB/PB, the process shown in Fig.2 is applied to take a decision between Inter, Merge and Skip by comparing their costs. Also, decision is made to select the best part mode for a CB. Skip can be coded for a CB only when part mode is equal to 2Nx2N, unlike MV and merge which can be coded for every part mode. MVCost of a PB is the sum of MVD bits and prediction error bits. MergeCost of a PB is the sum of merge index bits and prediction error bits. SkipCost is the penalty for the distortion introduced by coding a skip CB.

MV coding cost (MVCost) of a PB is estimated by Motion Estimation (ME) and Advanced Motion Vector Prediction (AMVP) technique. Merge cost (MergeCost) is estimated by using the merge candidates list. Skip coding decision also depends on the merge candidate list. Note that, all three calculations, merge MV, skip MV and AMVP calculation use the neighbouring coding blocks' MV information (Bross et al., 2013). Neighbouring MV information is used to estimate the coding cost (bits) of a CB and prediction error is used for estimating distortion. Output of Fig.2 is Inter Cost of a CB, featuring a combination of inter and merge PBs or a skip CB and their corresponding MVs.

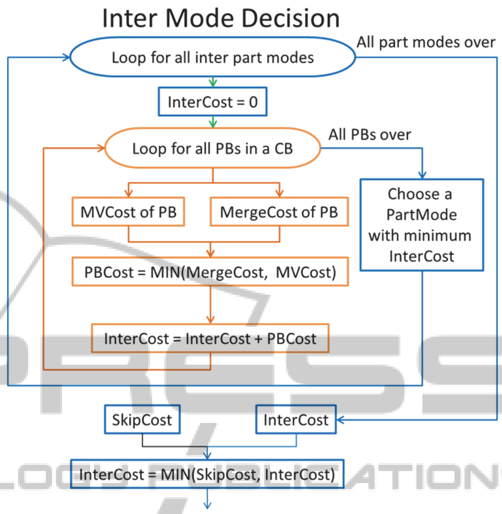


Figure 2: Inter coded block mode decision.

Inner loop runs for all PBs in a CB and makes a decision between Merge PB and Inter PB for all PBs of a part mode. Outcome of this decision is PBCost, which is the best of MergeCost and MVCost. InterCost of a CB is the sum of all PB costs of a given part mode.

Outer loop runs for all possible part modes and selects a best part mode having minimum cost. Best part mode is the one which has minimum cost according to Eq. 1. After deciding a best part mode for a CB, its cost is compared with the skip cost to decide between skip and inter. The final cost of inter CB is InterCost.

2.2 Intra Mode Decision

Process used for intra CB mode decision is similar to inter CB mode decision flow and is shown in Fig.3. There are 35 different intra coding modes for a PB. The process involves selecting a Rate-Distortion (RD) optimal part mode for a CB (Choose PartMode in Fig.3) and an RD optimal intra coding mode for each PB within a CB (PBCost = Best Intra Mode Cost in Fig.3). In estimating intra mode cost Most Probable Mode (MPM) list is used for estimating coding bits and prediction error is used for estimating distortion, which depends on the spatial neighbors of the block. Thus, the output of intra mode decision process is IntraCost comprising of best part mode of the CB and intra mode for each PB within a CB.

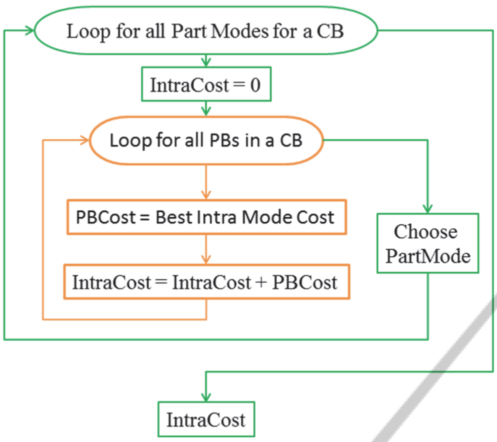


Figure 3: Intra coded block mode decision.

2.3 Intra-Inter Decision

Intra-Inter mode decision process happens for every CB. Before entering into this process, IntraCost and InterCost are computed for a CB.

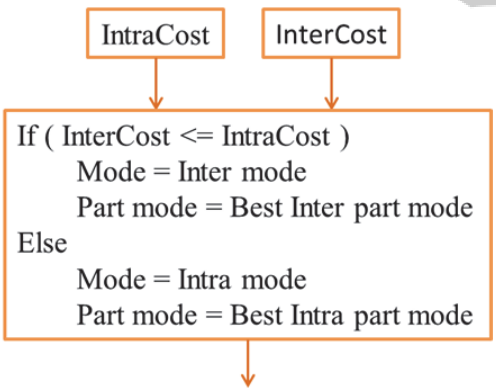


Figure 4: Intra-Inter decision.

InterCost estimate consists of selecting the part mode of CB and MV/Merge/Skip information of PB. IntraCost estimate consists of part mode of CB and selection of intra prediction direction for each PB within a CB. The decision process involves selecting the mode with minimum cost as the best mode as shown in Fig.4.

2.4 Depth Decision

CB can be coded as a single CB or it can be further split in to a quad tree (4 CBs). Decision has to be made whether a CB is to split or not. This is done by comparing the cost of a CB (C) with the sum of individual sub-CBs cost after the split. If the split sub-CB cost (C0+C1+C2+C3) is better than the non-split CB, then the CB is split in to a quad tree. In this process each CB can be Inter or Intra. Any CB resulted out of the split CBs can be further split into in to 4 CBs as seen in Fig.1.

3 APPROACHES TO MODE DECISION

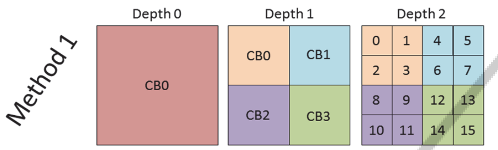
This section discusses two different approaches for CTB mode decision. In each approach there are trade-offs between Video Quality (VQ) and performance. Each CTB in a frame passes through the mode decision phase before encoding the H.265 video stream. The two methods discussed below make an assumption that the encoder processes all the CTBs one-by-one. Following convention is used below during discussions - DxCBy refers to Depth x and CB y, where x = {0, 1, 2, 3} and y = {0, 1, 2 … 64}. For simplicity, in sections 3.1 & 3.2 discussion is limited to x = {0, 1, 2} and y = {0, 1 …15}

3.1 Method 1 (Ideal VQ)

This method is the one used in reference software, called the HEVC Test Model (HM10.0, 2013).The whole process is divided into stages and in each stage decision is made between two CU depths. The approach is shown in Fig.5. Each stage is represented with different color. The numbers within the CTB or CB indicate the index of a CB at respective depth. The table shows the processing method for mode decision.

In the example shown below, 3 depths (D0, D1 and D2) are possible for a CTB of size 32x32. Each depth has 4^{depth} CBs. For each of the CB, at every depth, Inter Mode Decision, Intra Mode Decision and Intra-Inter Decision is performed as discussed earlier in sections 2.1, 2.2 and 2.3 respectively. At each stage, decision is made whether the CB has to be split into 4-CBs or it's to be coded as a single CB as discussed in Depth Decision.

Stage 1 computes and compares depth-1 cost for index-0 (D1CB0) and sum of depth-2 cost for indices 0, 1, 2 and 3 (D2CB0 + D2CB1 + D2CB2 + D2CB3). Decision is made whether the block is to be coded as split (depth2) or non-split (depth1) based on the cost and the resulted best cost is updated to D1CB0. Stage 1 execution ends here. In stage 2, similar process is carried out for taking the split decision for D1CB1. Here cost of depth 1 index 1 (D1CB1) is compared with the sum of cost of depth 2 indices 4, 5, 6 and 7(D2CB4 + D2CB5 + D2CB6 + D2CB7). The cost is updated in D1CB1. Similarly in stage 3 and stage 4 split decisions are taken and the best cost is updated in D1CB2 and D1CB3. Once stage 4 is completed, stage 5 compares the cost of depth-0 DOCB0 and total cost of split CTB (D1CB0 + D1CB1 + D1CB2 + D1CB3). Note that the cost at depth 1 can be sum of costs at depth 2. Decision is made whether the depth 0 CB is split or not split.



	Depth 0 (32x32)	Depth 1 (16x16)	Depth 2 (8x8)
Stage 1 D1 vs D2	x	D1CB0	D2CB0 + D2CB1 + D2CB2 + D2CB3
Stage 2 D1 vs D2	x	D1CB1	D2CB4 + D2CB5 + D2CB6 + D2CB7
Stage 3 D1 vs D2	x	D1CB2	D2CB8 + D2CB9 + D2CB10 + D2CB11
Stage 4 D1 vs D2	x	D1CB3	D2CB12 + D2CB13 + D2CB14 + D2CB15
Stage 5 D0 vs D1	D0CB0	x	x

Figure 5: Different stages in Method-1 flow.

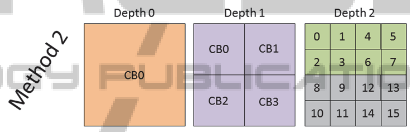
In this method, execution of all stages is sequential. The sequential flow has an advantage that the neighbor blocks' (Left, Top, Top Left, Top Right and Bottom Left) "accurate" information is available to the CB being processed. Accurate neighbor information refers to the to-be-coded mode information of the neighbors. Since accurate neighbor information is available to CB, it is possible to generate exact AMVP list and Merge list for Inter Mode Decision and MPM list for Intra Mode Decision, which helps to estimate the bits required for coding in a more precise manner. Thus, it is possible to estimate the rate during cost computation with greater accuracy or rather exactly. This decision process is able to choose the RD optimal MVP index, Merge index and MPM index for inter, merge and intra blocks, respectively.

The approach used in this method is more suitable for an encoder which has to achieve very good compression at lower bitrates, which is a high quality encoder. Also, it is suitable for encoders which perform the full rate distortion optimization (RDO) using Lagrangian Optimization or using Viterbi algorithms. Although this method delivers good results in compression and quality, this method is computationally expensive and unfriendly to multi-processor/parallel-programmable system. This method's sequential nature makes each succeeding stage to wait for the current stage to get completed.

3.2 Method 2 (Performance Friendly)

The approach used in this method is more suitable for an encoder which has to achieve good performance (in multi-processor scenario) with a little compromise on quality. Although, slight compromise is made w.r.t. neighbor information availability to the current CB during cost estimation. Method 2 achieves better performance by taking advantage of parallel processing. The approach used in Method 2 is shown in Fig.6.

The example discussed here assumes that a maximum of 3 depths are allowed and 4 processors are available for processing. The color in the figure indicates that the processor on which the block of data is being processed. The entire mode decision process is divided into three stages. Each stage is executed by one or more processors depending on the stage or on the availability of the processors.



	Processor 1	Processor 2	Processor 3	Processor 4
Stage 1	D0CB0	D1CB0 + D1CB1 + D1CB2 + D1CB3	D2CB0 + D2CB1 + D2CB2 + D2CB3 + D2CB4 + D2CB5 + D2CB6 + D2CB7	D2CB8 + D2CB9 + D2CB10 + D2CB11 + D2CB12 + D2CB13 + D2CB14 + D2CB15
Stage 2	D1CB0 vs D2(0+1+2+3)	D1CB1 vs D2(4+5+6+7)	D1CB2 vs D2(8+9+10+11)	D1CB3 vs D2(12+13+14+15)
Stage 3	D0CB0 vs D1(0+1+2+3)			

Figure 6: Different stages in Method-2 flow.

In the first stage, each processor operates on one depth. Processor 1, processor 2, processor 3 and processor 4 operate on depth 0, depth 1, depth 2 (top) and depth 2 (bottom), respectively. To balance the processing load, cost computation process in depth2 is split between processor 3 and processor 4. At the end of stage 1, the cost of each CB is available at all depths. All the processors need to sync after stage 1. In stage 2, decision is made whether each CB of depth 1 (D1CB0, D1CB1, D1CB2 and D1CB3) needs to be split to depth 2 or to be coded at depth 1. The decision process for each of the 4 CBs can be parallelized across the 4 processors. Again all the processors need to sync after stage 2 is completed. In stage 3, decision is made whether the depth 0 is to be coded or the output of stage 2 is to be retained.

Approach used in method 2 makes good use of multi-core processing environment. Method two can be modified easily to work on different number of cores or even a single core. Since method 2 does not use accurate neighbor information for estimating the cost, there is a possibility of selecting a suboptimal mode for coding.

4 COMPARISON OF TWO APPROACHES

Both the methods have their own pros and cons. Method 1 is more useful in scenarios where high quality and greater compression is primary objective. Method 2 is more useful in scenarios where parallel-processing is possible and performance is of prime importance.

In method 1, all CBs at a given depth cannot be processed in parallel. Each CB has to wait until the intra-inter decision process and reconstruction of the previous CB is completed. Intra prediction uses reconstructed neighbor samples during intra prediction direction selection. Inter prediction uses the actual neighbor mode information for AMVP/Merge/Skip decisions, which helps achieving better RD cost. In method 2, since coding blocks are processed in parallel, intra mode decision process cannot use reconstructed pixels for prediction. Also intra mode decision and inter mode decision process does not have access to the neighbor mode information and have to function assuming the neighbor mode information for decisions. Hence the modes selected in method 2 are with some approximations which affect the compression efficiency.

Method 1 is more suitable for encoders which perform full RD during mode decisions as accurate neighbor information is available to all CBs which contribute in achieving better compression when compared to method 2. Although Method 1 tries to deliver better quality, it cannot take greater advantage of multi core processing when compared to Method 2.

5 CONCLUSIONS

In this paper, we proposed a novel method to exploit the parallelism at CTU level in multi-core/multi-processor scenario. We described both the traditional and proposed design approaches for mode decision and compared them for performance and video quality/compression. Also, briefed the details of applications in which each method can be adopted for better results.

Since the experiment of proposed method is preliminary, we have only presented the ideas and approaches to exploit parallelism at the lowest possible granularity. So, our future work will include evaluating the performance gain & trade off in coding quality gain compared to the traditional approach. As well, future work can consider the proposed approach in hardware realization.

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