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| *Title:* | **On GOP-16 structures of the CTC** | | |
| *Status:* | Input document to JCT-VC | | |
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# Abstract

This contribution reports BD-rates on three GOP-16 configurations that are asserted to remove the use of a 7th frame in the DPB used by the current GOP-16 configuration.

# Introduction

It has been reported in JVET-P0133 the current GOP-16 structure used in the HM CTCs requires a 7th frame in the DPB. For the appropriate profile’s level, the DPB must only contain 5 old frames, and 1 frame being constructed.

In addition, as highlighted by JVET-P0133, the DPB must also contain frames that are waiting to be output – frames must be produced in sequence and regularly.

This is highlighted in the following table of the current GOP-16 structure, where:

* red coloured numbers indicate the frame being output after the decoding of a frame
* the light-coloured boxes indicate the frames currently being decoded
* the dark grey cells indicate the frames that are not used as reference frames but are just waiting in the DPB to be output.

As can be seen in the last column, the number of frames in the DPB is sometimes 7.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Decoding order | POC |  | POCs of Frames in DPB, other than current POC | | | | | | | | | | | | | | | | | | | | | Number in DPB |
|  | -16 | -8 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | 16 | -16 | -8 | **-3** | -2 | -1 | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 | 7 |
| 2 | 8 |  | -8 |  | **-2** | -1 | 0 |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 3 | 4 |  | -8 |  |  | **-1** | 0 |  |  |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 4 | 2 |  | -8 |  |  |  | **0** |  | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 5 | 1 |  |  |  |  |  | 0 | **1** | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 6 | 3 |  |  |  |  |  | 0 |  | **2** | 3 | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 7 | 6 |  |  |  |  |  | 0 |  |  | **3** | 4 |  | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 8 | 5 |  |  |  |  |  | 0 |  |  |  | **4** | 5 | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 9 | 7 |  |  |  |  |  | 0 |  |  |  | 4 | **5** | 6 | 7 | 8 |  |  |  |  |  |  |  | 16 | 7 |
| 10 | 12 |  |  |  |  |  | 0 |  |  |  |  |  | **6** | 7 | 8 |  |  |  | 12 |  |  |  | 16 | 6 |
| 11 | 10 |  |  |  |  |  | 0 |  |  |  |  |  |  | **7** | 8 |  | 10 |  | 12 |  |  |  | 16 | 6 |
| 12 | 9 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | **8** | 9 | 10 |  | 12 |  |  |  | 16 | 6 |
| 13 | 11 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | 8 | **9** | 10 | 11 | 12 |  |  |  | 16 | 7 |
| 14 | 14 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | 8 |  | **10** | 11 | 12 |  | 14 |  | 16 | 7 |
| 15 | 13 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | 8 |  |  | **11** | 12 | 13 | 14 |  | 16 | 7 |
| 16 | 15 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | 8 |  |  |  | **12** | 13 | 14 | 15 | 16 | 7 |

A number of alternatives GOP-16 structures have been explored, as described below.

## JVET-P0133

JVET-P0133 introduces the following GOP-16 structure, reproduced using the same tabular format as above:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Decoding order | POC |  | Frames in DPB, other than current POC | | | | | | | | | | | | | | | | | | | | | Number in DPB |
|  | -16 | -8 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | 16 |  | -8 | **-3** | -2 | -1 | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 | 6 |
| 2 | 8 |  | -8 |  | **-2** | -1 | 0 |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 3 | 4 |  | -8 |  |  | **-1** | 0 |  |  |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 4 | 2 |  | -8 |  |  |  | **0** |  | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 5 | 1 |  |  |  |  |  | 0 | **1** | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 6 | 3 |  |  |  |  |  | 0 |  | **2** | 3 | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 7 | 6 |  |  |  |  |  | 0 |  |  | **3** | 4 |  | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 8 | 5 |  |  |  |  |  | 0 |  |  |  | **4** | 5 | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 9 | 7 |  |  |  |  |  | 0 |  |  |  |  | **5** | 6 | 7 | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 10 | 12 |  |  |  |  |  | 0 |  |  |  |  |  | **6** | 7 | 8 |  |  |  | 12 |  |  |  | 16 | 6 |
| 11 | 10 |  |  |  |  |  | 0 |  |  |  |  |  |  | **7** | 8 |  | 10 |  | 12 |  |  |  | 16 | 6 |
| 12 | 9 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | **8** | 9 | 10 |  | 12 |  |  |  | 16 | 6 |
| 13 | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 | **9** | 10 | 11 | 12 |  |  |  | 16 | 6 |
| 14 | 14 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  | **10** | 11 | 12 |  | 14 |  | 16 | 6 |
| 15 | 13 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  | **11** | 12 | 13 | 14 |  | 16 | 6 |
| 16 | 15 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  | **12** | 13 | 14 | 15 | 16 | 6 |

## Alternative Arrangement 1

This document introduces alternative arrangement 1, described below:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Decoding order | POC |  | Frames in DPB, other than current POC | | | | | | | | | | | | | | | | | | | | | Number in DPB |
|  | -16 | -8 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | 16 |  | -8 | **-3** | -2 | -1 | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 | 6 |
| 2 | 8 |  | -8 |  | **-2** | -1 | 0 |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 3 | 4 |  | -8 |  |  | **-1** | 0 |  |  |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 4 | 2 |  | -8 |  |  |  | **0** |  | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 5 | 1 |  |  |  |  |  | 0 | **1** | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 6 | 3 |  |  |  |  |  | 0 |  | **2** | 3 | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 7 | 6 |  |  |  |  |  | 0 |  |  | **3** | 4 |  | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 8 | 5 |  |  |  |  |  | 0 |  |  |  | **4** | 5 | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 9 | 7 |  |  |  |  |  |  |  |  |  | 4 | **5** | 6 | 7 | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 10 | 12 |  |  |  |  |  |  |  |  |  |  |  | **6** | 7 | 8 |  |  |  | 12 |  |  |  | 16 | 5 |
| 11 | 10 |  |  |  |  |  |  |  |  |  |  |  |  | **7** | 8 |  | 10 |  | 12 |  |  |  | 16 | 5 |
| 12 | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  | **8** | 9 | 10 |  | 12 |  |  |  | 16 | 5 |
| 13 | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 | **9** | 10 | 11 | 12 |  |  |  | 16 | 6 |
| 14 | 14 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  | **10** | 11 | 12 |  | 14 |  | 16 | 6 |
| 15 | 13 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  | **11** | 12 | 13 | 14 |  | 16 | 6 |
| 16 | 15 |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  | **12** | 13 | 14 | 15 | 16 | 6 |

## Alternative arrangement 2

This document also introduces alternative arrangement 2, described below:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Decoding order | POC |  | Frames in DPB, other than current POC | | | | | | | | | | | | | | | | | | | | | Number in DPB |
|  | -16 | -8 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 1 | 16 | -16 |  | **-3** | -2 | -1 | 0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 16 | 6 |
| 2 | 8 | -16 |  |  | **-2** | -1 | 0 |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 3 | 4 | -16 |  |  |  | **-1** | 0 |  |  |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 4 | 2 | -16 |  |  |  |  | **0** |  | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 5 | 1 |  |  |  |  |  | 0 | **1** | 2 |  | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 6 | 3 |  |  |  |  |  | 0 |  | **2** | 3 | 4 |  |  |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 7 | 6 |  |  |  |  |  | 0 |  |  | **3** | 4 |  | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 8 | 5 |  |  |  |  |  | 0 |  |  |  | **4** | 5 | 6 |  | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 9 | 7 |  |  |  |  |  | 0 |  |  |  |  | **5** | 6 | 7 | 8 |  |  |  |  |  |  |  | 16 | 6 |
| 10 | 12 |  |  |  |  |  | 0 |  |  |  |  |  | **6** | 7 | 8 |  |  |  | 12 |  |  |  | 16 | 6 |
| 11 | 10 |  |  |  |  |  | 0 |  |  |  |  |  |  | **7** | 8 |  | 10 |  | 12 |  |  |  | 16 | 6 |
| 12 | 9 |  |  |  |  |  | 0 |  |  |  |  |  |  |  | **8** | 9 | 10 |  | 12 |  |  |  | 16 | 6 |
| 13 | 11 |  |  |  |  |  | 0 |  |  |  |  |  |  |  |  | **9** | 10 | 11 | 12 |  |  |  | 16 | 6 |
| 14 | 14 |  |  |  |  |  | 0 |  |  |  |  |  |  |  |  |  | **10** | 11 | 12 |  | 14 |  | 16 | 6 |
| 15 | 13 |  |  |  |  |  | 0 |  |  |  |  |  |  |  |  |  |  | **11** | 12 | 13 | 14 |  | 16 | 6 |
| 16 | 15 |  |  |  |  |  | 0 |  |  |  |  |  |  |  |  |  |  |  | **12** | 13 | 14 | 15 | 16 | 6 |

# Results

The random-access main10 results are described in the following tables, using HM 16.20.

## JVET-P0133

The results of JVET-P0133 were regenerated but match exactly those reported in JVET-P0133.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Random Access Main 10** | | |
|  | Y | U | V |
| Class A1 | 0.1% | 0.1% | 0.2% |
| Class A2 | 0.4% | 0.6% | 0.7% |
| Class B | 0.6% | 0.9% | 0.8% |
| Class C | 1.2% | 1.3% | 1.2% |
| Class E |  |  |  |
| **Overall** | 0.6% | 0.8% | 0.7% |
|  | 0.6% | 0.8% | 0.7% |
| Class D | 0.7% | 0.9% | 0.7% |
| Class F | 0.8% | 0.8% | 0.8% |
| Enc Time[%] | 101% | | |
| Dec Time[%] | 101% | | |

## Alternative arrangement 1

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Random Access Main 10** | | |
|  | Y | U | V |
| Class A1 | 0.4% | 0.4% | 0.6% |
| Class A2 | 0.9% | 1.0% | 1.1% |
| Class B | 1.1% | 1.3% | 1.2% |
| Class C | 1.6% | 1.7% | 1.7% |
| Class E |  |  |  |
| **Overall** | 1.1% | 1.2% | 1.2% |
|  | 1.1% | 1.2% | 1.2% |
| Class D | 1.0% | 1.1% | 1.0% |
| Class F | 1.1% | 1.1% | 1.0% |
| Enc Time[%] | 97% | | |
| Dec Time[%] | 102% | | |

## Alternative arrangement 2

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Random Access Main 10** | | |
|  | Y | U | V |
| Class A1 | 0.1% | 0.1% | 0.0% |
| Class A2 | 0.1% | 0.1% | 0.1% |
| Class B | 0.3% | 0.1% | 0.1% |
| Class C | 0.1% | 0.0% | 0.0% |
| Class E |  |  |  |
| **Overall** | 0.2% | 0.1% | 0.1% |
|  | 0.2% | 0.1% | 0.1% |
| Class D | 0.2% | 0.1% | 0.0% |
| Class F | 0.0% | -0.2% | -0.2% |
| Enc Time[%] | 109% | | |
| Dec Time[%] | 101% | | |

# Analysis

As can be seen from the results, the “alternative arrangement 2” has least BD-rate loss, but it also has a 9% impact on encoder run-time. The graphs below illustrate how these different structures are impacting the BD-rate, considering the first 19 frames of the BasketballDrill at QP 22. The penultimate data point corresponds to POC 32, the significant frame in the second GOP.

The first graph illustrates the change in bits, relative to the anchor, for each POC. At POC 32, the structure in JVET-P0133 and the “alternative arrangement 1” have a large increase in bits.

The second graph illustrates the change in PSNR, relative to the anchor, for each POC. At POC 32, the PSNR is lower for both the structure in JVET-P0133 and the “alternative arrangement 1”.

However, in both graphs, “alternative arrangement 2” is modified only slightly.





It is also apparent in the results that the run-time has increased.

This is because in the CTCs, the search range is adaptively adjusted (ASR), causing shorter search ranges when the reference frame is temporally nearer, and vice versa.

This can be seen in the graph below, for Campfire at QP22:

POCs 2, 4, 11, 13 and 14 are significantly slower that the default GOP, because they include the distant GOP 0 (or -16).

# Conclusion

It can be seen in the reported results that the “alternative arrangement 2” has significantly less BD-rate loss over the other two GOP-16 structures studied, however, it introduces ~9% encoder run time increase.

Any change to the GOP-16 structure would not require a release of new CTCs, as these structures are defined only in configuration files.