

# Improved Context-Based Adaptive Binary Arithmetic Coding in MPEG-4 AVC/H.264 Video Codec

**Abstract.** An improved Context-based Adaptive Binary Arithmetic Coding (CABAC) is presented for application in compression of high definition video. In comparison to standard CABAC, the improved CABAC codec works with proposed more sophisticated mechanism of data statistics estimation that is based on the Context-Tree Weighting (CTW) method. Compression performance of the improved CABAC was tested and confronted with coding efficiency of the state-of-the-art CABAC algorithm used in MPEG-4 AVC. Experimental results revealed that 1.5%-8% coding efficiency gain is possible after application of the improved CABAC in MPEG-4 AVC High Profile.

**Keywords:** entropy coding, adaptive arithmetic coding, CABAC, AVC, advanced video coding

## 1 Introduction

An important part of video encoder is the entropy encoder that is used for removing correlation that exists within coded data. Numerous techniques of entropy coding were elaborated, many of them have been applied in video compression. The state-of-the-art entropy coding technique used in video compression is the Context-based Adaptive Binary Arithmetic Coding (CABAC) [3, 5, 6, 14] that is used in the newest Advanced Video Coding (AVC) standard (ISO MPEG-4 AVC and ITU-T Rec. H.264) [1, 5, 6]. In comparison to other entropy coders used in video compression, CABAC encoder uses efficient arithmetic coding and far more sophisticated mechanisms of data statistics modeling which are extremely important from the compression performance point of view.

The goal of the paper is to show that it is possible to reasonably increase compression performance of adaptive entropy encoder by using more accurate techniques of conditional probabilities estimation. The paper presents the improved version of CABAC with more exact technique of data statistics modeling that is based on the well known from the literature Context-Tree Weighting (CTW) algorithm [7, 8, 9, 14, 15]. The older versions of improved CABAC codec have been already presented by authors in [10, 11, 12, 13]. Nevertheless, the older versions of improved CABAC were working only with 4x4 transform for residual coding. In the High Profile of MPEG-4 AVC the 8x8 transform is additionally used. When using 8x8 transform, independent set of statistical models is used in standard CABAC. The 8x8

transform coding mode was not supported by the previous versions of improved CABAC. Coding tools of High Profile significantly improve compression capability of encoder (especially for high definition (HD) sequences). This paper makes the continuation of previous research works and presents the newest version of improved CABAC codec that works with 4x4 and 8x8 transform. In this paper, the improved CABAC was tested in application to compression of high definition video. New not published yet experimental results on improved CABAC compression performance for 8x8 transform mode are presented in the paper.

## 2 CABAC algorithm

Detailed description of CABAC algorithm can be found in [1, 3, 6, 14]. Only short review of CABAC is presented here to show some features of the entropy codec that are important from the point of view of this paper. In general, CABAC consists of three functional blocks: binarizer, context modeler and arithmetic encoder core (see Fig. 1).

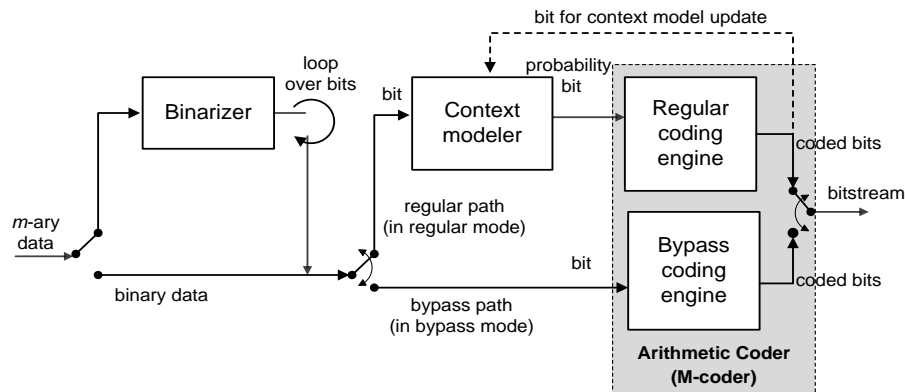


Fig. 1. Block diagram of standard CABAC encoder.

The main idea of CABAC algorithm is the following. In order to speed up processing of symbols, binary arithmetic codec (the so-called M-codec) was used in CABAC [1, 3, 4, 5, 6]. Due to application of binary arithmetic codec, all non-binary valued syntax elements must be mapped into string of binary symbols. This is realized by the binarizer at the first stage of coding. The binarizer has a huge impact on the number of bits that are put to arithmetic codec core. Therefore, CABAC exploits adaptive binarization by the application of several different binarization schemes for coded syntax elements. Results of binarization are put to arithmetic encoder core. The arithmetic encoder core allows to efficiently representing binary symbols with exploiting statistics of coded data estimated by the context modeler.

The way of data statistics estimation to a large extent determines compression performance of adaptive arithmetic encoder. Therefore, in order to obtain an accurate adaptation to the current signal statistic, total number of 460 finite-state machines (FSM) was defined in CABAC context modeler for all syntax elements. Individual

FSM is used to calculate the conditional probability of a binary symbol that appeared in a given context. By encoding a binary symbol, CABAC chooses the right FSM depending on type of syntax element and its values in two neighboring blocks. That is the context encoding and independent statistics estimation for individual syntax elements make the power of CABAC algorithm. The algorithm of data statistics estimation used in CABAC belongs to the most advanced used in adaptive entropy encoders.

### 3 Research problem

CABAC algorithm realizes advanced data statistics modeling, nevertheless some simplifications were done in the mechanism data statistics estimation. First of all, only one transition rule was defined for 460 FSMs that calculates the conditional probabilities of symbols. Secondly, the limited set of only 128 pre-defined quantized values of probabilities is used by arithmetic codec core. Both simplifications of CABAC negatively affect its compression performance.

An interesting research problem is to check the possibility of improving compression performance of CABAC by the use of even more exact method of data statistics estimation. This makes the subject of further part of the paper.

### 4 Improved CABAC algorithm

Authors proposed the original improvement of CABAC algorithm that increases compression performance of entropy codec. Modifications concern the context modeler functional block only. Other parts of CABAC algorithm (binarization and arithmetic codec core) were left unchanged (see Fig. 2).

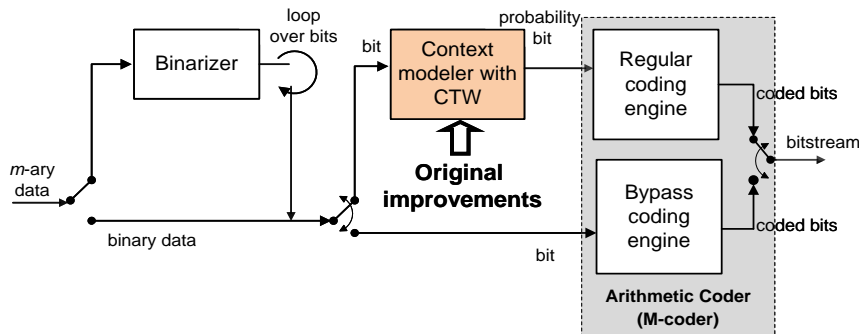
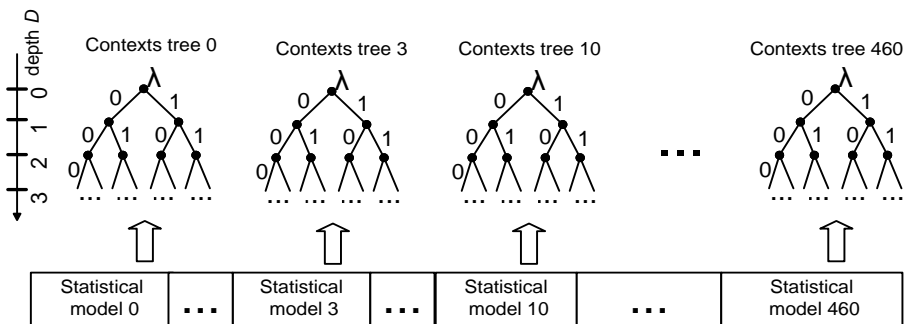


Fig. 2. Block diagram of improved CABAC encoder.

In the improved CABAC, the standard method of data statistics modeling (used in original CABAC) was replaced with more sophisticated mechanism of the conditional probabilities estimation that exploits the well known CTW method. To do this, the

460 FSMs were replaced with new 460 more accurate statistical models, each statistical model uses binary context tree of depth  $D$  (see Fig. 3). The binary context tree is a collection of nodes, each node keeps the information about the statistics of 0 and 1 symbols that appeared in a given context in video data stream. It is difficult to predict which context will be the best for encoding the current symbol. Therefore, the CTW method appropriately weights the statistics collected in individual nodes of context tree to produce the weighted conditional probability for symbol.



**Fig. 3.** Statistical models in improved CABAC.

In the proposed mechanism of data statistics gathering the depth  $D$  of context trees strongly influences the precision of estimated conditional probabilities. In the previous research works [10, 11, 14] authors tested the influence of this parameter on compression performance of entropy encoder. The improved CABAC was tested for depths  $D$  equal to 2, 4, 8, and 12. Obtained results proved, that the greater depth  $D$  of context trees the more accurate estimation of probabilities and better entropy encoder efficiency. The final conclusion of the research was that depth  $D=8$  is a good compromise between the efficiency and complexity of entropy codec. In the newest version of improved CABAC depth  $D=8$  is used for context trees. In comparison to the previous versions of improved CABAC codec, the current version was developed to work with both the 4x4 and the 8x8 transform mode.

## 5 Methodology of experiments

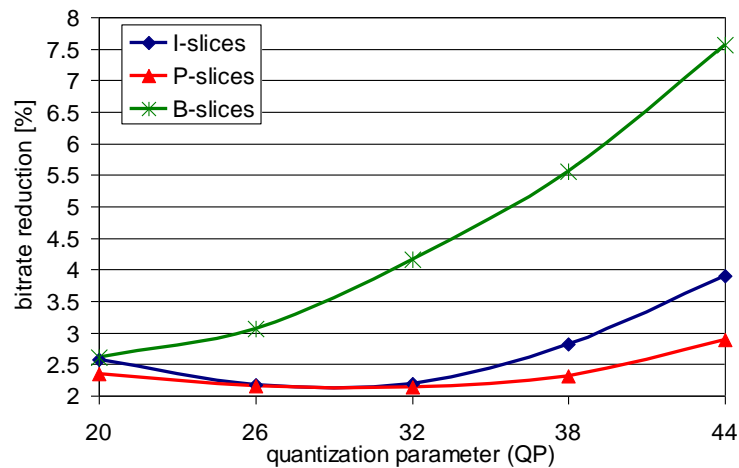
The proposed improved mechanism of data statistics estimation was implemented and embedded into the structure of CABAC entropy codec. The modified CABAC algorithm was successfully activated in the reference software JM 10.2 [2] of MPEG-4 AVC video codec. It must be emphasized that both video encoder and video decoder were prepared to obtain reliable experimental results. This phase of works was very difficult and time-consuming for the reason of JM 10.2 reference software implementation complexity (about 90 thousands lines of program code in C). The compression performance of the modified MPEG-4 AVC encoder was tested and confronted with coding efficiency of the original MPEG-4 AVC video encoder. This paper focuses on efficiency of the improved MPEG-4 AVC working in High Profile,

which distinguishes the paper from previous works [10, 11, 12, 13]. Experiments were done according to the following scenario:

- Full HD test video sequences were used: *Pedestrian Area*, *River Bed*, *Rush Hour* and *Station* (spatial resolution: 1920x1080, temporal resolution: 25 Hz);
- Test video sequences were encoded with JM 10.2 encoder forcing different values of bitrate at the output of video encoder. Different bitrates were obtained by setting different values of quantization parameter QP in video encoder (from QP=20 to QP=44 with step 6) that is responsible for the quality of decoded video sequence. Experiments were done for I-, P- and B-frames by setting the GOP structure on IBBPBBP...;
- The improved CABAC codec was tested for 8x8 transform mode used in High Profile of MPEG-4 AVC standard;
- Encoding tools were used in both the modified and the original MPEG-4 AVC encoder that guarantee identical quality of reconstructed sequences regardless of entropy encoder applied.
- Correctness of encoded bitstreams was checked in each experiment.

## 6 Experimental results

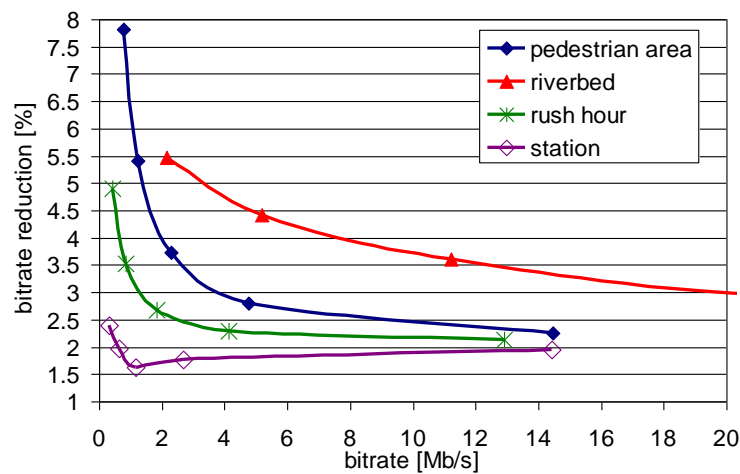
Obtained results revealed that the modified High Profile MPEG-4 AVC encoder with improved CABAC is characterized by higher compression performance relative to the original MPEG-4 AVC. In the first step of research, experiments were done for individual frame types (I, P and B). Detailed experimental results for this scenario were presented in Fig. 4. Results were averaged over 4 test video sequences.



**Fig. 4.** Average bitrate reduction due to application of improved MPEG-4 AVC encoder instead of the original MPEG-4 AVC (for I-, P-, and B-frames, 8x8 transform mode).

The improved CABAC outperforms the original CABAC for all types of frames (I, P and B). Nevertheless, different values of bitrate reduction were observed for I-, P-, and B-frames. Additionally, different results were obtained for individual QP values that determine the size of bitstream at the output of video encoder. Greater bitrate reduction was observed for smaller bitrates (bigger values of QP parameter). Best results were noticed for B-frames (2.5%-7.5% reduction of bitrate), the worst results were observed for P-frames (only 2.5%-3% bitrate reduction). In the case of I-frames 2.5%-4% bitrate reduction was observed.

In the second step of research, the efficiency of improved CABAC was tested for whole test sequences. Detailed experimental results were depicted in Fig. 5.



**Fig. 5.** Average bitrate reduction due to application of improved MPEG-4 AVC encoder instead of the original MPEG-4 AVC (for individual test video sequences, 8x8 transform mode).

After the application of improved CABAC within MPEG-4 AVC bitrate reduction of 1.5%-8% was noticed in comparison to standard MPEG-4 AVC encoder. Different results were obtained for individual test video sequences. Best results were obtained for *Pedestrian Area* (2.5%-8%), the smaller bitrate reduction was observed for *Station* sequence (1.5%-2.5%). In the case of each video sequence, better results were achieved for bigger values of QP parameter (which corresponds to smaller bitrates).

Experimental results revealed that gap in compression performance between improved and original CABAC strongly depends on: value of bitrate, content of sequence and frame type. The three mentioned above parameters affects statistical properties of residual signal that is finally encoded with entropy encoder. The improved CABAC algorithm is able to track changing statistics of coded data. In the original CABAC codec, context modeler takes advantage of predefined probability distribution of data which reduces the ability of entropy codec to track data statistics efficiently. When the real statistics of data differs from the assumed one, coding efficiency of standard CABAC decreases. It results in greater bitrate reduction when using the improved CABAC.

Higher coding efficiency of improved CABAC was obtained at the cost of computational complexity increase. The application of improved CABAC in the MPEG-4 AVC reference decoder increased total decoding time up to 25% (for the useful in high definition television range of bitrates below 8 Mb/s). The authors are fully aware that this result may be different for another implementation of MPEG-4 AVC.

## 7 Conclusions

The improved adaptive arithmetic codec CABAC was presented in application to high performance video coding. The improved CABAC exploits authors' more accurate mechanism of the conditional probabilities estimation. Experiments revealed superior coding efficiency of improved CABAC relative to the state-of-the-art CABAC algorithm. When comparing to the original CABAC encoder, improved CABAC allows for 1.5%-8% bitrate reduction when applied in MPEG-4 AVC High Profile.

The improved CABAC codec is more complex than the original CABAC. In comparison to original MPEG-4 AVC, improved MPEG-4 AVC video decoder is up to 25% more computationally complex for high definition sequences.

## Acknowledgment

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