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(54) **CONTEXT ADAPTIVE VARIABLE LENGTH DECODING SYSTEM AND METHOD**

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(52) **U.S. Cl.** **341/67**; 382/246; 371/37.01
(58) **Field of Search** 341/67, 106, 143, 341/60, 63; 382/246; 348/403

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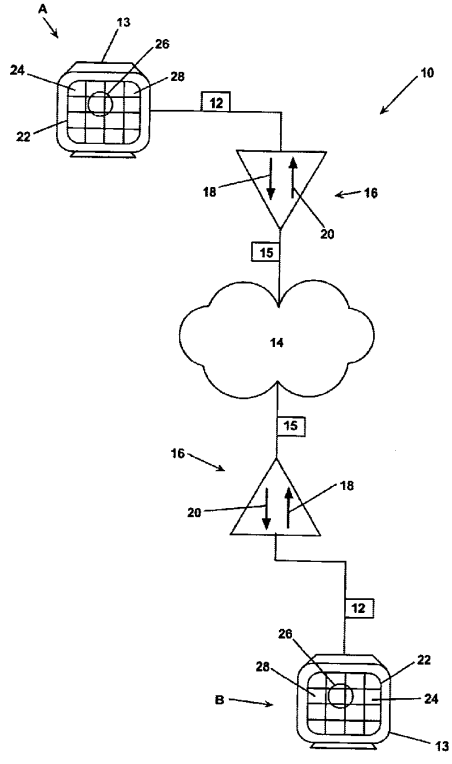
(57) **ABSTRACT**

A system and method to perform context-adaptive variable length decoding (CAVLC) of transform coefficient levels for block-based motion-compensated decoding of moving pictures, corresponding to transform coefficients. The system and method includes complexity-reduction improvements in the coefficient level decoding process, such as simplified and extended range of Lev-VLC tables. Specifically, the number of Lev-VLC tables is extended from 5 to 7 and only 1 escape code (28-bit escape code) is used for tables Lev-VLC1to Lev-VLC6. The system and method also includes a simplified and improved table selection process. The table selection for the first Coefficient_level after trailing ones depends on total number of non-zero coefficients and number of trailing ones which are local variables within the CAVLC module. The table selection process for subsequent Coefficient_level's has been re-designed in such a way that the same logic path can be used to select Lev-VLC table for the next coefficient regardless of block modes and quantization parameters.

23 Claims, 7 Drawing Sheets



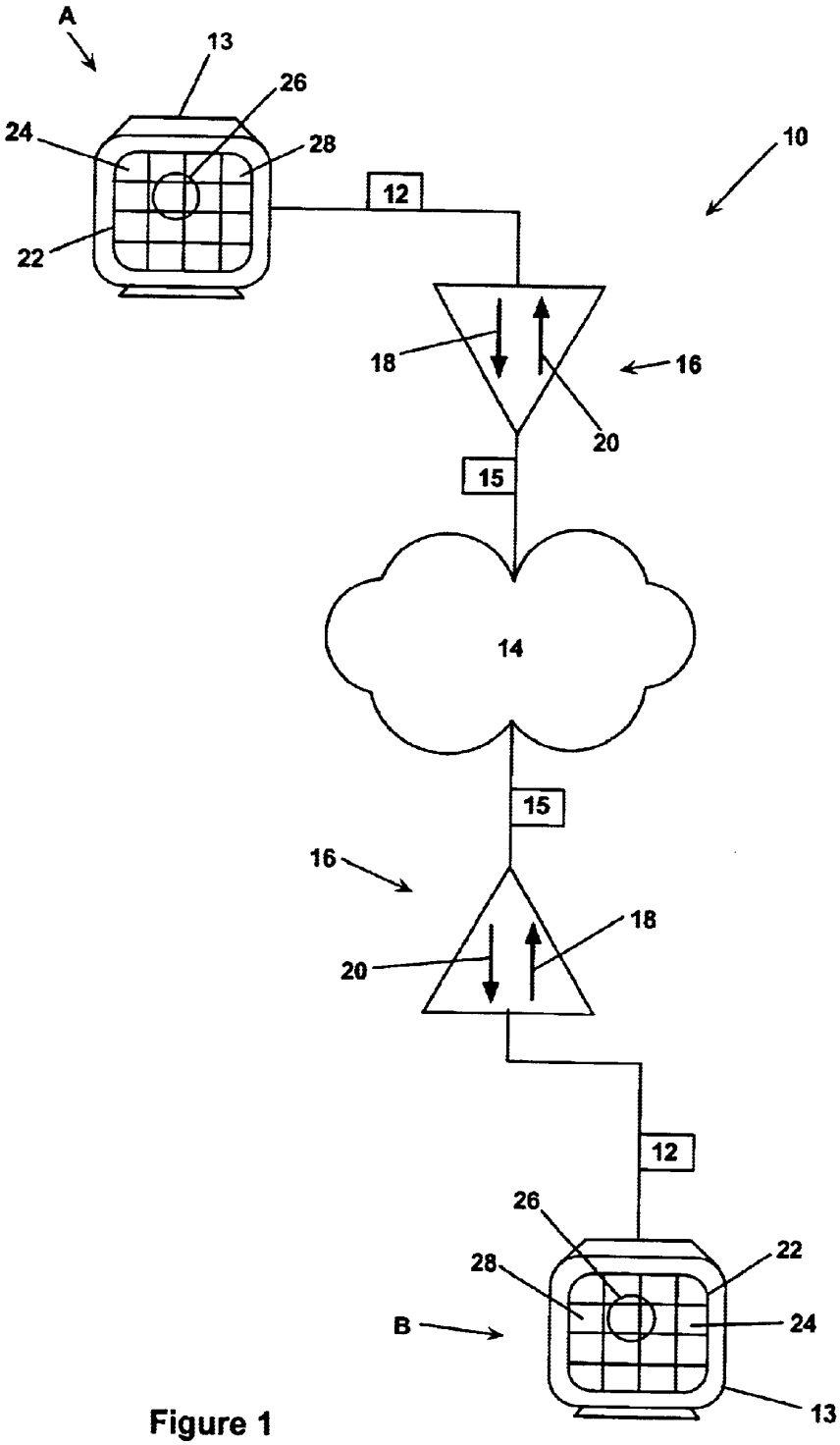


Figure 1

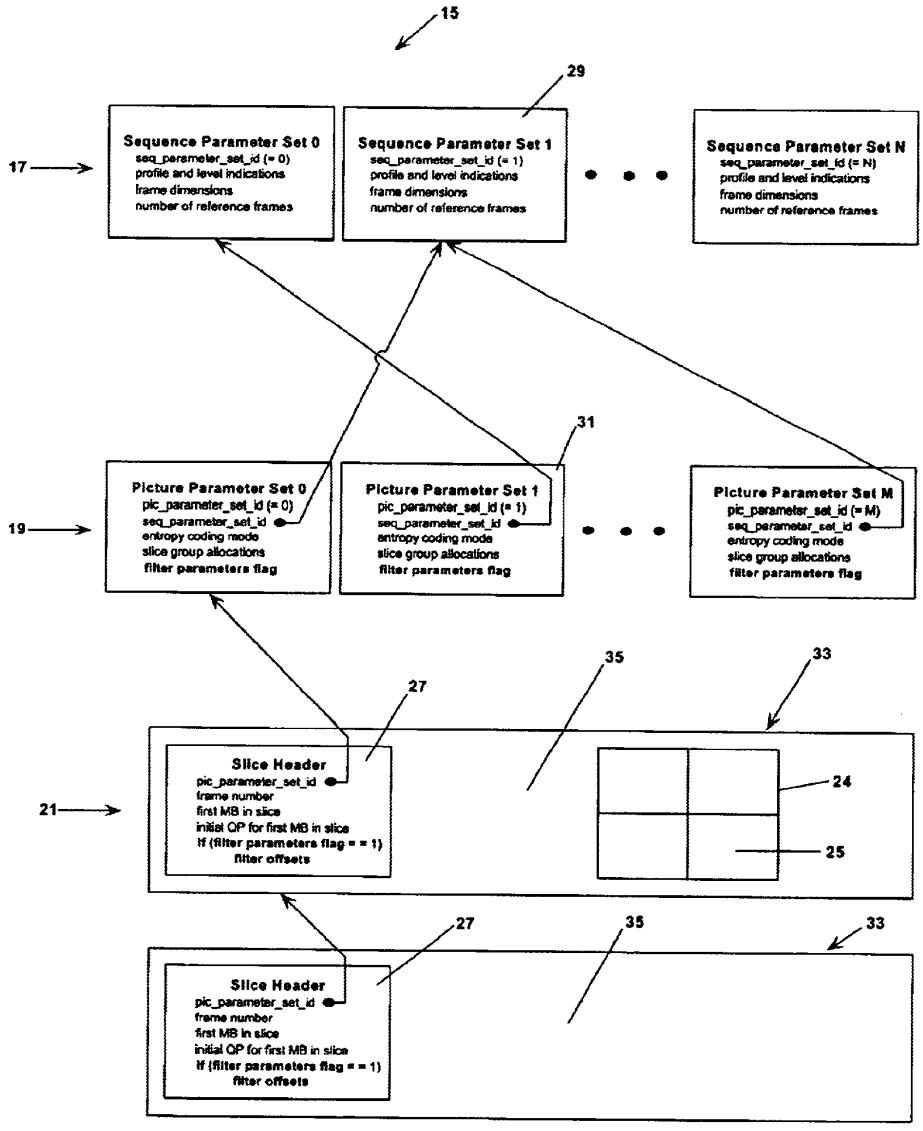

15
29
17
Sequence Parameter Set 0
seq_parameter_set_id (= 0)
profile and level indications
frame dimensions
number of reference frames
Sequence Parameter Set 1
seq_parameter_set_id (= 1)
profile and level indications
frame dimensions
number of reference frames
Sequence Parameter Set N
seq_parameter_set_id (= N)
profile and level indications
frame dimensions
number of reference frames
31
19
Picture Parameter Set 0
pic_parameter_set_id (= 0)
seq_parameter_set_id
entropy coding mode
slice group allocations
filter parameters flag
Picture Parameter Set 1
pic_parameter_set_id (= 1)
seq_parameter_set_id
entropy coding mode
slice group allocations
filter parameters flag
Picture Parameter Set M
pic_parameter_set_id (= M)
seq_parameter_set_id
entropy coding mode
slice group allocations
filter parameters flag
35
33
27
21
Slice Header
pic_parameter_set_id
frame number
first MB in slice
initial QP for first MB in slice
If (filter parameters flag = = 1)
filter offsets
24
25
27
35
33
Slice Header
pic_parameter_set_id
frame number
first MB in slice
initial QP for first MB in slice
If (filter parameters flag = = 1)
filter offsets

Figure 2

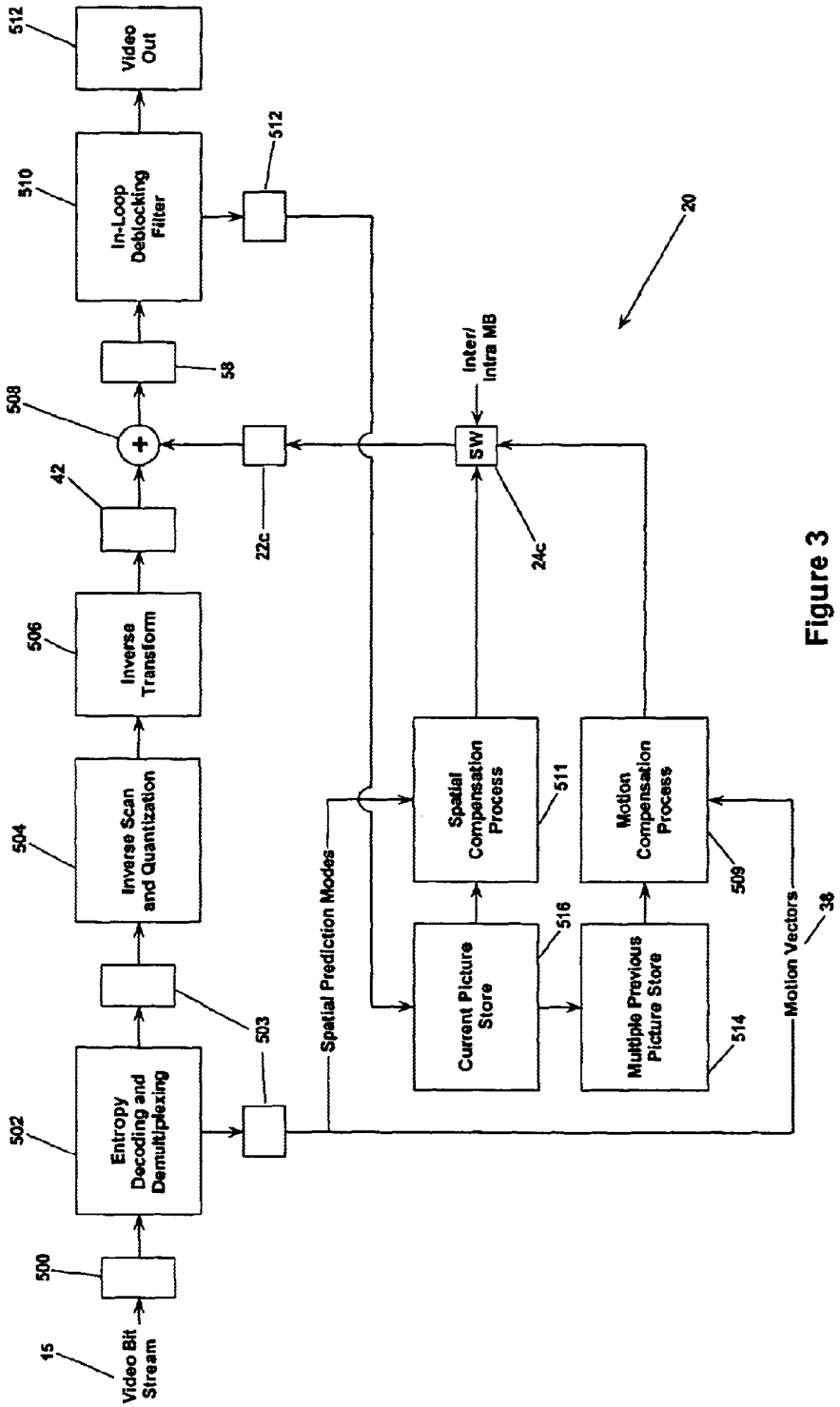

Video Bit Stream
15
500
Entropy Decoding and Demultiplexing
502
503
Inverse Scan and Quantization
504
Inverse Transform
506
42
508
58
In-Loop Deblocking Filter
510
512
Video Out
512
20
Inter/ Intra MB
SW
24c
22c
Spatial Compensation Process
511
Motion Compensation Process
509
Current Picture Store
516
Multiple Previous Picture Store
514
Spatial Prediction Modes
Motion Vectors
38

Figure 3

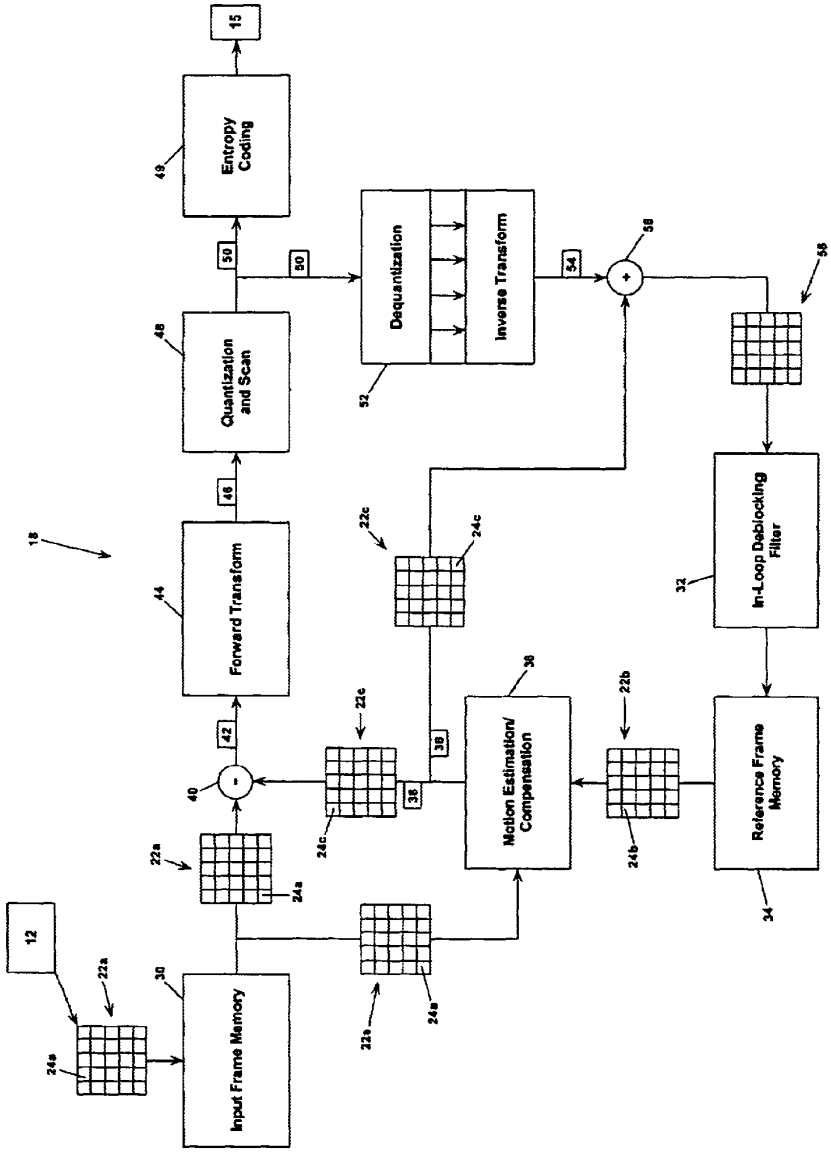

15
Entropy Coding
48
50
50
Dequantization
Inverse Transform
54
58
56
Quantization and Scan
46
52
22c
24c
In-Loop Deblocking Filter
32
18
Forward Transform
44
30
22b
42
22c
38
Motion Estimation/ Compensation
40
24c
24b
Reference Frame Memory
34
22a
24a
12
22a
30
24a
22a
24a
Input Frame Memory

Figure 4

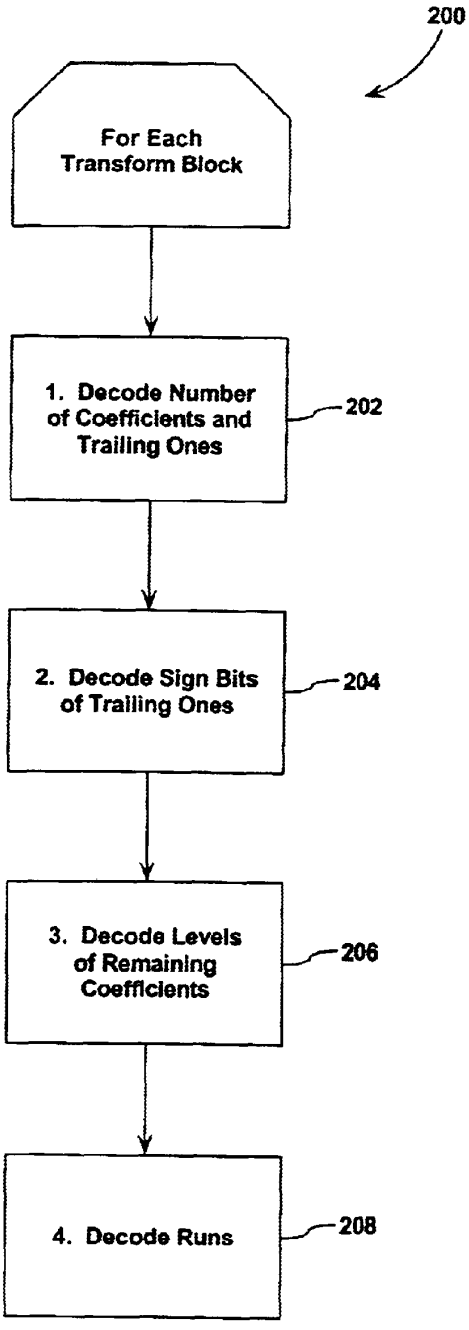

200
For Each Transform Block
1. Decode Number of Coefficients and Trailing Ones
202
2. Decode Sign Bits of Trailing Ones
204
3. Decode Levels of Remaining Coefficients
206
4. Decode Runs
208

Figure 5

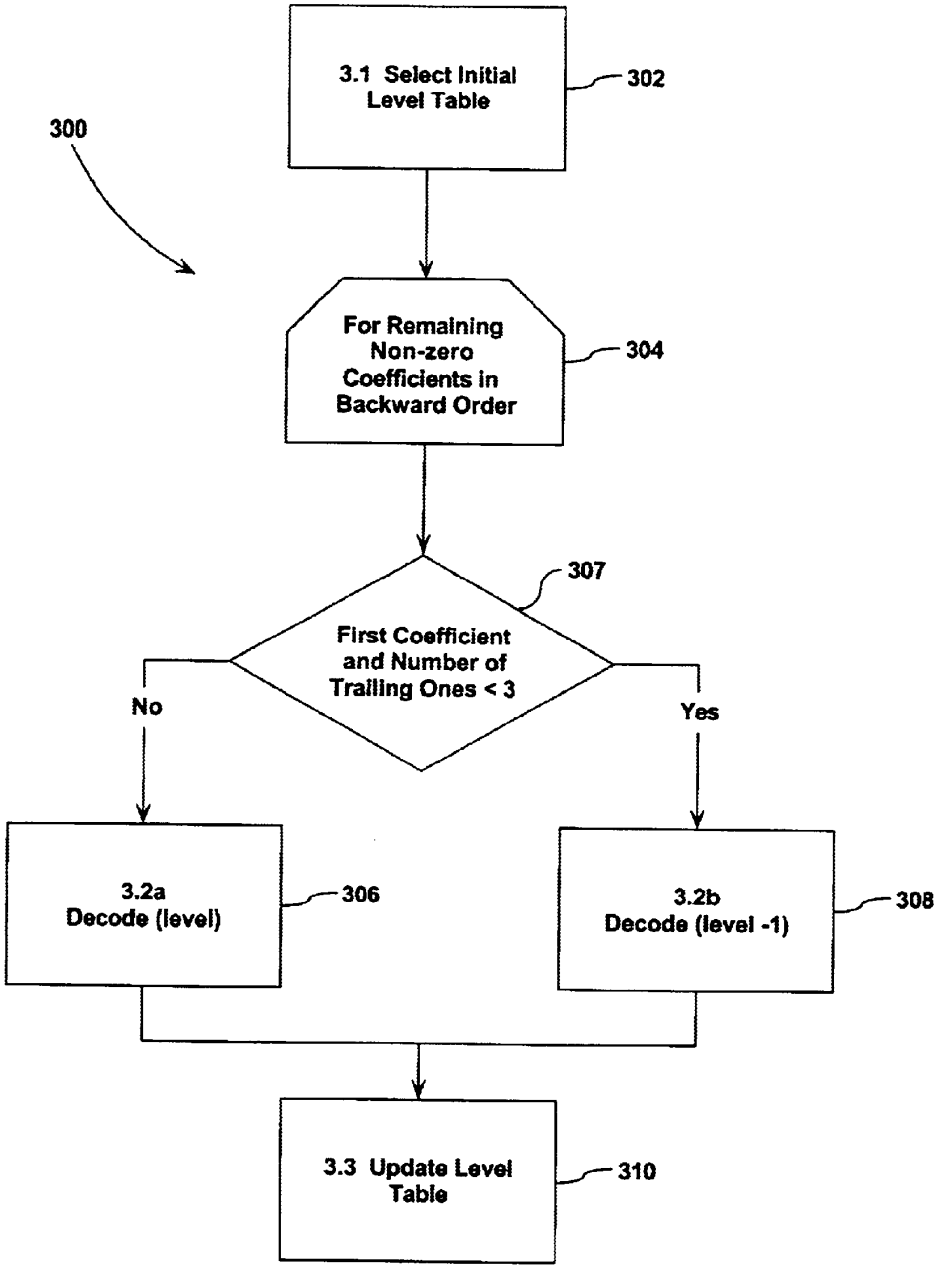

300
3.1 Select Initial Level Table
302
For Remaining Non-zero Coefficients in Backward Order
304
307
First Coefficient and Number of Trailing Ones < 3
No
Yes
3.2a Decode (level)
306
3.2b Decode (level -1)
308
3.3 Update Level Table
310

Figure 6

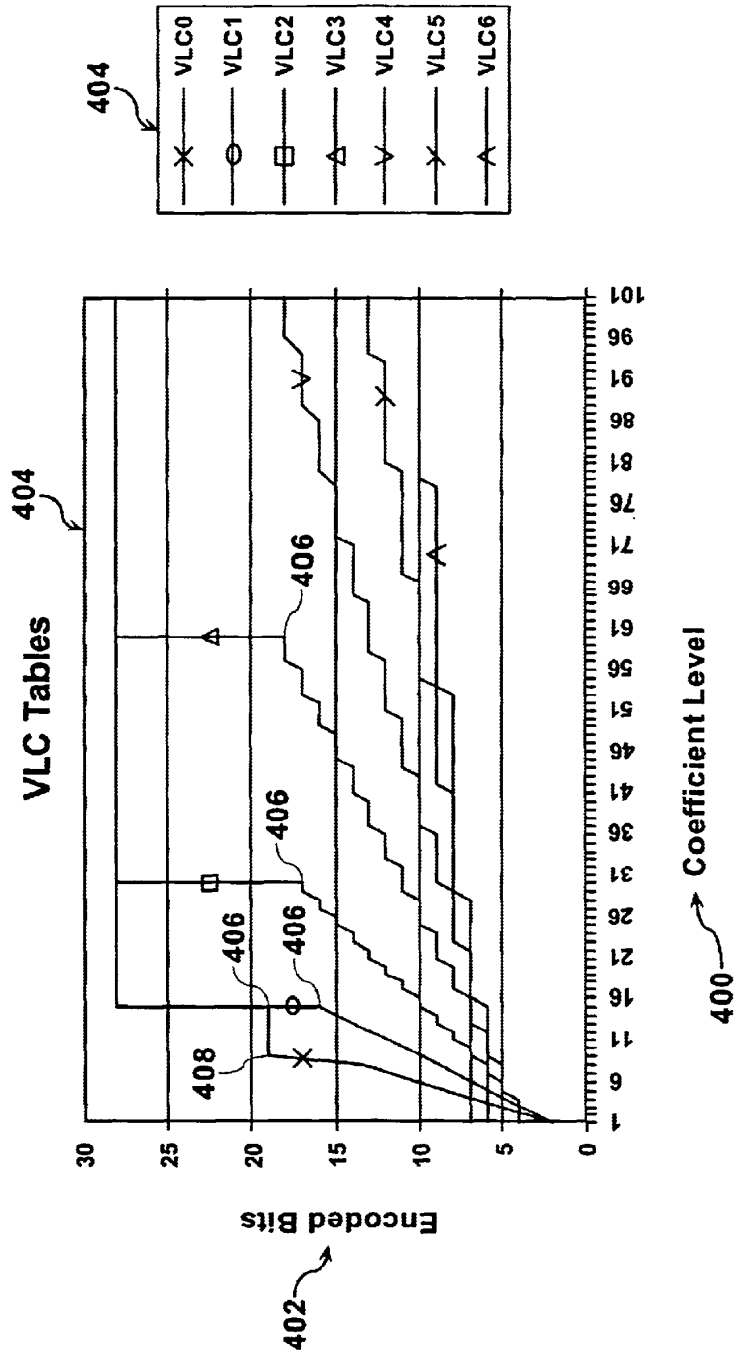

404
VLC0
VLC1
VLC2
VLC3
VLC4
VLC5
VLC6
VLC Tables
404
406
406
406
406
408
Encoded Bits
402
30
25
20
15
10
5
0
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
76
81
86
91
96
101
Coefficient Level
400

Figure 7

CONTEXT ADAPTIVE VARIABLE LENGTH DECODING SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a system and method for context adaptive entropy decoding of transform coefficients in compressed video images.

2. Description of the Prior Art

There is an increasing reliance on video data in rich media applications running on devices or systems such as personal computers, wireless devices, surveillance systems, video conferencing system and set-top boxes. Video data compression system play a key role in increasing the efficiency of video data transmission. Video data is compressed or coded for transmission by taking advantage of the spatial redundancies within a given frame and the temporal redundancies between successive frames. Intraframe compression operates on single frames independently of other frames to exploit spatial redundancies within the frame, whereas interframe compression exploits both spatial and temporal redundancies.

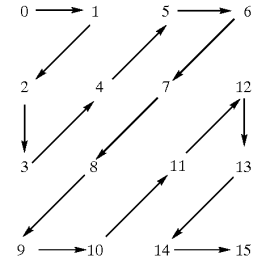
Video compression systems exploit temporal redundancies using interframe prediction coding. Interframe coding is based on predicting the current source frame using the previously coded frame, and coding only the prediction error between the source frame and the predicted frame. Approximations are done in the prediction process, by assuming the motion is uniform across all pixels of each motion estimation block in each frame. It is noted that intercoding can be done for both uni-directional and bidirectional prediction. Transmission efficiencies are realised in intercoding by transmitting the prediction error, as the amount of information present in the prediction error is generally less than that in the actual pixel values. The resulting prediction residuals from inter coding are processed through a frequency domain transform and a quantizer that sets the values of the transform coefficients to discrete values within a pre-specified range. Further compression of the video information is realized by entropy coding the resulting quantized transform coefficients before transmission or storage of the encoded bit stream. The entropy coder is used to represent the resulting information from the quantizer, the motion vector information, and other encoder information using short code words to code the information with the highest likely probability of occurrence, and long code words to code the information with the least likely probability of occurrence. The general approach to code the information with the highest likely probability of occurrence using short code words and the information with the least likely probability of occurrence using long code words is referred to as Variable Length Coding.

Since the video data is transmitted or stored in the form of a compressed bitstream, a decoder is needed to decode the bitstream to reconstruct the video data. First the decoder performs entropy variable-length-decoding of the quantized coefficients, then performs inverse quantization and inverse transform operations to form the image difference pixel values. Finally the image difference values are added to the image prediction pixel values to form the final reconstructed image pixels values.

As an example of entropy coding and decoding of transform coefficients, consider the case of entropy coding/decoding specified in the H.264 video coding standard. In H.264, entropy decoding of coefficients is done on a 4×4 block basis. As an illustrative example, consider the following 4×4 block of quantized transform coefficients at the encoder.

6	0	0	0
5	−4	0	0
0	3	0	0
0	−1	1	0

The first step in the encoding process for the above 4×4 quantized transform coefficients is to apply a zigzag scan to the above quantized transform coefficient block to produce a sequence of coefficients. The zigzag scan is performed according to the following diagram:



The resulting series of coefficients is then 6, 0, 5, 0, −4, 0, 0, 0, 3, 0, −1, 0, 0, 0, 1, 0. The coefficients are typically grouped into (Run_before, Coefficient_level) pairs where Run_before is the number of consecutive zero coefficients preceding a non-zero coefficients in the resulting zigzag order from low frequency coefficients to high frequency coefficients, and Coefficient_level is the value of the non-zero coefficients. The resulting (Run_before, Coefficient_level) pairs are then (0,6) (1,5), (1,−4), (3,3), (1,−1) and (3,1). In H.264, the Run_before information is separated from the Coefficient_level information and each is placed in a separate sequence. The resulting Run_before and Coefficient_level sequences are then:

Run_before: 6, 5, −4, 3,−1, 1

Coefficient_level: 0, 1, 1, 3, 1, 3

The second step in the coding process is to encode the Run_before information and the Coefficient_level information to produce the bit stream corresponding to the original quantized 4×4 transform coefficient data.

At the decoder side, the step in the entropy decoding process for the coded quantized transform coefficient data is to decode the bitstream generated by the encoder to produce the Run_before information and the Coefficient_level information. For the example discussed above, this first step in the decoding process results in the following two sequences:

Run_before: 6, 5, −4, 3, −1, 1

Coefficient_level: 0, 1, 1, 3, 1, 3

The second step in the decoding process is to use the zigzag scan order described above to recover the 4×4 block of quantized transform coefficients based on the above two sequences.

When the video data is transmitted at medium to high bit rates, the bits used to represent Run_before and Coefficient_levels dominate the compressed bit stream. It is therefore desirable to compress the Run_before and Coefficient_level information in the most efficient way. In a typical variable-length decoding system, each Run_before symbol and Coefficient_level symbol would be associated

with a unique variable-length codeword such that frequently-occurring symbols have shorter lengths and rarely-occurring symbols have longer lengths. However, since different types of video content and different bit rates usually lead to different statistics of the 4×4 transform coefficient data, a fixed mapping of Run_before and Coefficient_level symbols and variable legth codewords may not always provide optimal entropy compression. To solve this problem, context-adaptive variable length coding (CAVLC) schemes were developed so that the entropy coding process can adapt to different data statistics and always produce good entropy compression.

One of the known prior art CAVLC methods is described in a document "Committee Draft" by the Joint Video Team (JVT) of ISO/IEC MPEG and ITU-T VCEG. The H.264 standard specifies the use of context-adaptive variable length coding (CAVLC) in order to entropy decode the quantized transform coefficients information. Briefly, the method decodes the Coefficient_levels and Run_before using multiple variable-length decoding tables where a table is selected to decode each symbol based on the context of previously decoded symbols. One important aspect of the method is that the Coefficient_level and Run_before sequences are decoded in backward order, i.e. from coefficients corresponding to high frequencies to coefficients corresponding to low frequencies. For the example described above, the original scan order (from low frequency to high frequency) is given by

Coefficient_level: 6, 5, −4, 3, −1, 1

Run_before: 0, 1, 1, 3, 1, 3

whereas the CAVLC bitstream's order is given by:

Coefficient_level: 1, −1, 3, −4, 5, 6

Run_before: 3, 1, 3, 0, 1, 1

It was observed that the CAVLC ordering of the coefficient values the coefficient_level sequences often results in a number of coefficients at the beginning of the sequence with absolute value equal to 1. Consecutive coefficients starting with the first coefficient in the sequence and with absolute value of 1 are called trailing ones (T1s). At most 3 trailing ones could be considered. The presence of the T1s in the Coefficient_level sequence is used to further enhance the compression efficiency in the CAVLC method, as described in the sections below.

CAVLC decoding of transform coefficients is based on 4 main steps. In the first step, the total number of non-zero coefficients and the number of trailing ones (T1s) are decoded from the bit stream, where the total number of trailing ones indicates the number of consecutive Coefficient_levels with absolute values of one at the end of the Coefficient_level sequence within the last three Coefficient_levels.

In the second step, the sign bits of the trailing ones (up to 3) are decoded using 1 bit each. The sign bits are enough to decode the Coefficient_levels of the trailing ones.

In the third step, the rest of the Coefficient_levels are decoded using 5 different VLC tables with names Lev-VLC**0**, Lev-VLC**1**, Lev-VLC**2**, Lev-VLC**3**, and Lev-VLC**4**, and an adaptive table selection scheme. Each x in the tables below can take the value of either 0 or 1.

Code no	Bit stream codeword	Coefficient Level
	Lev-VLC0	
0	1	1
01	01	−1

-continued

Code no	Bit stream codeword	Coefficient Level
2	001	2
3	0001	−2
. . .	. . .	. . .
13	00000000000001	−7
14–29	000000000000001xxxx	±8 to ±15
30—>	0000000000000001xxxxxxxxxxxx	±16—>
	Lev-VLC1	
0–1	1x	±1
2–3	01x	±2
. . .	. . .	. . .
26–27	00000000000001x	±14
28–43	000000000000001xxxx	±15 to ±22
44—>	0000000000000001xxxxxxxxxxx	±23—>
	Lev-VLC2	
0–3	1xx	±1 to ±2
4–7	01xx	±3 to ±4
. . .	. . .	. . .
52–55	00000000000001xx	±27 to ±28
56–71	000000000000001xxxx	±29 to ±36
72—>	0000000000000001xxxxxxxxxxx	±37—>
	Lev-VLC3	
0–7	1xxx	±1 to ±4
8–16	01xxx	±5 to ±8
. . .	. . .	. . .
104–111	00000000000001xxx	±53 to ±56
112–127	000000000000001xxxx	±57 to ±64
128—>	0000000000000001xxxxxxxxxxx	±66—>
	Lev-VLC4	
0–15	1xxxx	±1 to ±8
16–31	01xxxx	±9 to ±16
. . .	. . .	. . .
224–239	000000000000001xxxx	±113 to ±120
240—>	0000000000000001xxxxxxxxxxx	±121—>

The third step is called the Coefficient_level decoding process. Accordingly, for the first Coefficient_level in the Coefficient_level sequence, a Lev-VLC table is selected based on the block type (inter-coded or intra-coded), quantization parameter (QP), and total number of non-zero coefficients. For the rest of the Coefficient_levels, a table is selected to decode each Coefficient_level based on the block type, quantization parameters, and the Coefficient_level of the previously decoded Coefficient_level. The exact algorithm is as follows:

If block is Inter-coded or (Intra-coded with QP>=21):
  Decode the first coefficient after trailing ones with Lev-VLC**0** table. Decode the
  next coefficient with Lev-VLC**1**.
  if previous Coefficient_level|>3
    Increase Lev-VLCN by one (up to Lev-VLC**2**)
If block is Intra-coded with QP<21:
  if (number of coefficients>10)
    Decode the first coefficient after trailing ones with Lev-VLC**1** table.
    Decode the next coefficient with Lev-VLC**2** table.
  else
    Decode the first coefficient after trailing ones with Lev-VLC**0** table.
    Decode the next coefficient with the Lev-VLC**1** table.
  if current table is Lev-VLC**1** and |decoded Coefficient_level|>3
    use Lev-VLC**2** for next Coefficient_level
  if current table is>=Lev-VLC**2** and |decoded Coefficient_level|>5
    Increase Lev-VLCN by one (up to Lev-VLC**4**)

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In other words, the most recently decoded Coefficient_level is used to predict what the next coefficient level may be and the most appropriate VLC table is selected based on the prediction. When decoding the first Coefficient_level (after trailing ones) and the number of trailing ones is less than three,the decoded Coefficient_level is the received level plus one.

In the fourth step, first the sum of Run_before is decoded, then multiple tables are used to decode each Run_before.

The major disadvantage of the existing method is that its complexity is high. Notice that there are two discontinuities (19-bit and 28-bit escape code sequences) in each of the Lev-VLC tables. The two discontinuities correspond to conditional execution branching and creates complexity for both software and hardware implementations. Furthermore, depending on the current block coding mode, quantization parameter, and total number of coefficients, three separate logic paths or circuits (Intercoded blocks and Intracoded blocks with QP>=21; Intracoded blocks with QP<21 and more than 10 nonzero coefficients; Intracoded blocks with QP<21 and the number of nonzero coefficients less than or equal to 10) are required to implement the table selection process. The discontinuities in the Lev-VLC tables and the multiple logic paths in the table selection process introduce a relatively large number of conditional instructions or branches that can significantly reduce the amount of parallelism in a typical processor or circuit. When there are many coefficients to be decoded (at medium to high bit rates), this can cause a significant slowdown in the speed of a decoder. For most DSP platforms, it is important that there be minimal or no branches inside the entropy decoding loop so that a software pipelining schedule can be utilized to exploit the parallel processing power of the DSPs.

Further, existing context adaptive variable length coding compression systems also select the decoding table for the first coefficient level after the trailing ones based on whether the current block is Inter mode or Intra mode, as well as what quantization parameter was used. Both of these parameters are external to the entropy decoding module, and therefore introduce inefficient data dependencies and increased data loading times. Further, the existing systems use different processing of Inter mode blocks and Intra mode blocks, which can increase code size and function set-up time, further impacting processing speed and memory requirements.

It is an object of the present invention to provide an entropy decoding system and method to obviate or mitigate some of the above-presented disadvantages.

SUMMARY OF THE INVENTION

According to the present invention there is provided a Context Adaptive Variable Length Coding (CAVLC) system and method to decode Coefficient level information corresponding to quantized transform coefficients. The system and method include complexity-reduction improvements in the coefficient level decoding process, such as:

1. Simplified and extended the range of Lev-VLC tables. Specifically, the number of Lev-VLC tables is extended from 5 to 7 and only 1 escape code (28-bit escape code) is used for tables Lev-VLC**1** to Lev-VLC**6**; and
2. Simplified and improved table selection process. The table selection for the first Coefficient_level depends only on number of non-zero coefficients and number of trailing ones which are local variables within the CAVLC module. The table selection process for subsequent Coefficient_levels has been re-designed in such a way that the same logic path can be used to select Lev-VLC table for the next coefficient regardless of block modes and quantization parameters.

According to a further aspect of the present invention there is provided a Context-Adaptive Variable Length Coding (CAVLC) system for decoding quantized transform coefficient levels. The system comprises: an input for a bitstream including context-adaptive variable-length-encoded Run_before and Coefficient_level data corresponding to quantized transform coefficients; an entropy decoding section for decoding the Run_before and Coefficient_level data; and a plurality of decoding tables used by the entropy decoding section for decoding the data, wherein at least two of the decoding tables have a single escape sequence and are generated by a common function.

According to a further aspect of the present invention there is provided a Context-Adaptive Variable Length Coding (CAVLC) method for decoding quantized transform coefficient levels. The method comprises the steps of: receiving a bitstream including context-adaptive variable-length-encoded Run_before and Coefficient_level data corresponding to quantized transform coefficients; accessing a plurality of decoding tables for decoding the data, wherein at least two of the decoding tables have a single escape sequence and are generated by a common function; and selecting one of the plurality of tables for decoding the Run_before and Coefficient_level data.

According to a still further aspect of the present invention there is provided a Context-Adaptive Variable Length Coding (CAVLC) system for decoding quantised transform coefficient levels. The system comprises: an input for a bitstream including context-adaptive variable-length-encoded Run_before and Coefficient_level data corresponding to quantized transform coefficients; an entropy decoding section for decoding the Run_before and Coefficient_level data; and a plurality of decoding tables used by the entropy coding section for decoding Coefficient_levels, at least two of the decoding tables have a single escape sequence and are generated by a common function; wherein selection from the plurality of decoding tables for the first Coefficient_level is determined solely by local variables representing a total number of non-zero coefficients and a number of trailing ones in the sequence of Coefficient_levels and selection from the plurality of decoding tables for subsequent Coefficient_levels is determined solely by a previous decoded coefficient_level and an experimentally pre-determined table.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features of the preferred embodiments of the invention will become more apparent in the following detailed description in which reference is made to the appended drawings wherein:

FIG. **1** is a diagram of an encoding/decoding system;

FIG. **2** is a bit stream of the system of FIG. **1**;

FIG. **3** shows further details of a decoder of the system of FIG. **1**;

FIG. **4** is shows further details of an encoder from the system of FIG. **1**;

FIG. **5** shows a coding process for the decoder of FIG. **3**;

FIG. **6** shows a flowchart for the decoding scheme for the decoder of FIG. **3**; and

FIG. **7** shows a graphical representation of tables used by the decoder of FIG. **3**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, such as but not limited to, a video conferencing system **10** has participants A and B that

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exchange video data **12** between monitors **13**, formatted as a compressed bit stream **15** over a network **14** (such as but not limited to the Internet). Each participants A and B that exchange video data **12** between monitors **13**, formatted as a data **12** and a decoder **20** for decoding the received bit stream **15**. Each image frame **22** displayed on the monitors **13** is made of a series of macroblocks **24**, such as but not limited to a block of 16×16 pixels, representing an object **26** which move over a background **28** (for example a person giving a presentation while standing in front of a backdrop). Accordingly, the processors **16** coordinate the display of successive frames **22** on the monitors **13**, as the video data **12** is communicated between the participants A, B during a video conference. It is processors **16** coordinate the display of successive frames **22** on the monitors **13**, as the video exchange of video data **12** in the compressed bit stream **15**. It will be recognised that the system **10** may also involve the exchange of video data **12** in the compressed bit stream **15** in either one direction or both and on peer to peer basis or broadcast, as well as used in personal computers, wireless devices, surveillance systems, video conferencing systems and set-top boxes. In addition, the transfer of the compressed bit stream **15** through the encoder **18** and decoder **20** could be to a storage device (not shown) for later usage.

Referring again to FIG. **1**, the video data **12** is a temporal sequence of pictures, each referred to as the frame (or field) **22**. Each picture is organized as a matrix of the macroblocks **24**. Each macroblock **24** can have a size of 16×6 pixels and the macroblocks **24** are stored from left to right and from top to bottom and consecutive macroblocks **24** are combined in a slice **80** (see FIG. **3**). Generally, a slice **33** contains the macroblocks **24** and one macroblock **24** consists of sub-blocks **25**. Each macroblock **24** is composed of three images; one red (R), one green (G), and one blue (B). However, for compatibility with non-coloured media, the RGB model is represented as an equivalent YCbCr model, where Y is a luminance (luma) component, and Cb and Cr are chrominance (chroma) components, such that typically $Y=0.299R+0.587G+0.114B$, $Cb=B-Y$, and $Cr=R-Y$. Therefore, each frame **22** of the video data **12** is generically referred to as containing one luma image, one Cb chroma image, and one Cr chroma image. Standard formats have 8 bits per pixel to digitally represent each of the three components, where Cb and Cr images are typically down-sampled by 2 in each dimension due to the sensitivity of human vision. Generally, each block **25** consists of four pixels for the luma components and one pixel for each chroma component of the 4:2:0 color data. The blocks **25** are processed and compressed for transmission as the bit stream **15** over the network **14** or stored for later decompression or transmission.

Generally, one of three fundamental coding modes can be selected for each macroblock **24**, with the choice of coding mode determining how the prediction of the macroblock **24** is formed. Intra-coded (I) macroblocks **24** make use of intra-prediction, in which the prediction is formed using only the current picture **22**. In predictive (P), or inter-coded, macroblocks **24** the prediction of each sample is formed by referring to one block in the set of previously decoded and stored reference pictures **22**. In bi-predictive (B) macroblocks **24**, predictions can be formed in this way, but can also be formed by computing a weighted average prediction can be formed in this way, but can also be formed by computing a weghted average of two different blocks in the set of previously decoded reference picture **22**. Note that some of the previously decoded pictures **22** are typically temporally subsequent to the current picture **22** in terms of their intended display order when bi-predictive coding is used. Referring to FIG. **2**, depending on the mode of each slice **33**, which is indicated in a slice header 27, P- and B-macroblocks **24** may not be permitted within certain slices **33**.

Referring again to FIG. **2**, the bitstream **15** is organizing into a hierarchy of syntax levels, with the 3 main levels being a sequence level **17**, a picture (or frame) level **19**, and slice level **21**. A concept know as "parameter sets" allows efficient transmission of infrequently changing data at the sequence **17** and picture level **19** in the H.264 standard. A sequence parameter set **29** in the first level **17** includes values of parameters that will remain unchanged for an entire video sequence, or from one instantaneous decoder refresh (IDR) picture to the next. (IDR pictures are used to provide points of random access into the bitstream **15**). Examples of parameters in a sequence parameter set **29** include frame dimensions and the maximum number of reference frames. A unique ID number "N" identifies each sequence parameter set **29**.

A picture parameter set **31** in the second level **21** includes values of parameters that will remain unchanged within a coded representation of a picture (frame or field) **22**. Examples of parameters in the picture parameter set **31** include the entropy coding mode and a flag that specifies whether deblocking filter parameters will be transmitted in the slice headers **27** of the picture **22** (see FIG. **1**). Each picture parameter set **31**, labeled as "M" refers to the unique ID of a valid sequence parameter set **29**, which selects the active sequence parameters that are used picture **22** (see FIG. **1**). Each picture parameter set **31**, labeled as "M", refers to the unique ID of a valid sequence parameter set **29**, which selects the active sequence parameters that are used when decoding coded pictures **22** that use the particular picture parameter set 3 1. The unique ID number "M" identifies each picture parameter set **31**.

The slice **33** in the bit stream **15** contains a picture data **35** representing a sub-set of the macroblocks **24** of the complete picture **22**. The macroblocks **24** in a slice **33** are ordered in raster scan order. The coded slice **33** includes the slice header **27** and the slice data **35** (coded macroblocks **24**). The slice header **27** contains a coded representation of data elements **35** that pertain to the decoding of the slice data that follow the slice header **27**. One of these data elements contains a reference to a valid picture parameter set **31**, which specifies the picture parameter values (and indirectly the sequence parameter values) to be used when decoding the elements contains a reference to a valid picture parameter set **31**, which specifies the picture parameter set **31**. Other data elements in the slice header **27** include the initial quantization parameter for the first macroblock **24** in the slice **33**. The macroblocks **24** can each consist of a grouping of pixels, such as a 16×16 luma block **25** with the two associated 8×8 chroma blocks **25**. However, it is recognized that other sizes of blocks **24** could be used to represent the frames **22**, if desired. The data corresponding to a coded macroblock **24** consists of: a skip count indicating the number of skipped macroblocks before the current macroblock, the MB_mode indicating Intracoded, Intercoded, or Bipredictive-Intercoded, the prediction_mode (Intra-prediction modes for Intracoded macroblocks, motion vectors for Intercoded and Bipredictive-Intercoded macroblocks), the Coded Block Pattern indicating which sub-partitions have nonzero coefficients, the Delta Quantization Parameter indicating the current macroblock's QP, and the residual pixel data as coded by the CAVLC process.

Referring again to FIG. **2**, each slice **33** of the frame **22** is encoded by the encoder **18** (see FIG. **1**), independently

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from the other slices **33** in the frame **22**. Each of the slices **33** has the slice header **27** that provides information, such as but not limited to the position of the respective slice **33** in the frame **22** as well as the initial quantization parameter; and the slice data which provides information for reconstructing the macroblocks of a slice, such as but not limited to the prediction modes and quantised coefficients for each of the respective macroblocks **24**. Further, each picture parameter set **31**contains parameter values that pertain to the decoding of the pictures **22** for which the particular parameter set **31** is active (i.e. selected in the slice headers **27** of the picture **22**). The parameter sets **31** also contain a reference to the sequence parameter sets **29**, which are active for decoding of the pictures **22**. The choice of sequence parameter sets **29** and picture parameter sets **31** can be chosen by the encoder **18** (see FIG. **1**), or set at the time of system **10** setup for sequential operation of the encoder **18**, decoder **20** pair.

Referring to FIG. **4**, the encoder **18** of the system **10** has an input frame memory **30**, for receiving an Nth or source frame **22***a* (a sequence of source blocks **24***a*) in the video data **12** from the participants A,B (see FIG. **1**). A reference frame memory **34** stores an (N−1)th or reference frame **22***b*, typically as a sequence of blocks **24***b*. Each block **22***a* of the source frame **22***a* is first input into a motion estimation/compensation section **36**, which produces predicted blocks **24***c* of a predicted frame **22***c*. The source frame **22***a* and the reference frame **22***b* are used **22***a* is first input into a motion estimation/compensation section **36**, which produces predicted **22***c*, a best matching block taken from the blocks **24***b* in the reference frame **22***b*, such that temporal redundancies in the video data **12** are exploited for compression purposes. The matching block can be defined as the reference block **24***b* that minimises a prediction error **42** within a search area of the reference frame **22***b*. This matching process is done by the motion section **36** by determining movement of the object **26** (and of the background **28** if present, see FIG. **1**) for a selected prediction block **24***c*, with respect to each reference block **24***b* from the frame **22***b*, by means of a block matching method as is known in the art. The predicted frame **22***c* is assembled by the motion section **36** as block **24***c* by block **24***c* to consist of matched blocks taken from the reference frame **22***b*, which correspond to the blocks **24***a* obtained from the source blocks **24***a*.

The motion section **36** also computes a displacement/motion vector **38** for representing temporal differences corresponding to each block **24***c*. A subtractor **40** computes the prediction error **42** between the source blocks **24***a* and the predicted blocks **24***c*, and passes the prediction error **42** to a transform section **44** for applying a forward transform. It is noted for intracoded blocks **22***a* that; the predicted frame **22***c* would be the reference frame **22***b*, no displacement/motion vectors **38** would be produced by the motion section **36**, and therefore the error **42** would physically represent the difference between each block **22***a*, **22***b* pair.

The transform section **44** applies a frequency domain transform to the error **42** to produce a set of transform coefficients **46** representing the error **42**. A quantization section **48** quantizes the set of transform coefficients **46** to produce a set of quantized coefficients **50**, which helps to eliminate any video information that would be least detected by the human eye. Furthermore, the quantized coefficients **50** are reordered in zigzag fashion from low frequency to high frequency, which allows for more efficient coding of the quantized coefficients by an entropy coding section **49** as more zero values (typically high frequency coefficients) will be packed together (further described below). It is recognised that the motion section **36**, the subtractor **40**, and the transform section **44** could be collectively referred to as the processing packed together (further described below). It is recognised that the motion section **36**, the subtractor **40**, and the transform section **44** could be collectively referred to as the processing section for producing the transform coefficients **46** representing the source frame **22***a*.

The entropy coding section **49** combines the quantised coefficients with the motion vectors **38** and other encoder information to produce the compressed or encoded bit stream **15**. In particular, the coefficients **50** usually are coded by the section **49** using Run_before and Coefficient_level symbols, instead of coding each coefficient **50** individually to increase compression efficiency. In such a scheme, zero coefficients **50** are not coded explicitly but are coded implicitly with non-zero coefficients. Each non-zero coefficient **50** is coded by; a Run_before symbol indicating the number of consecutive zero coefficients before the current coefficient **50**, and a Coefficient_level symbol indicating the current non-zero coefficient **50** value. Further, the Coefficient_levels and Run_before are transmitted in two separate sequences which are entropy encoded.

For both interceded and intracoded blocks, the quantized coefficients **50** are sent to a dequantization-inverse transform section **52** of the encoder **18**, to produce the reconstructed prediction error **54**, based on the inverse quantization operation and an inverse transform operation which takes as input the transform coefficients produced by the inverse quantization block and produces a block or pixel luminance values based on the inverse transform operation. An adder **56** then adds the predicted frame **22***c* with the error **54** to produce a new Nth reference frame **58** to be stored in the memory **32** for subsequent encoding of the next (N+1)th source frame (not shown). The encoder **18** (see FIG. **1**) emulates the behaviour of the decoder **20** for coded blocks **22** to make sure the encoder **18** of the transmitting participant A,B and the decoder **20** of the receiving participant A,B work from the same reference frames **22***b*. Further, a deblocking filter **32** may be applied on the reconstructed frame **58** block boundaries, which helps to reduce the visibility of coding artifacts that can be introduced at those boundaries.

The decoder **20** (see FIG. **3**) of the receiving participant A,B processes the received bit stream **15** and then reconstructs the coded frame, using a stored copy of the reference frame **22***b*, the transmitted motion vectors **38**, and the decompressed or reassembled prediction error **54** contained in the bit stream **15**. It is recognised that the motion vectors **38** are not operated on by the transform **44** and quantization **48** sections, but are included by the coding section **49** with the quantized coefficients **50** to assemble the bit stream **15**.

Referring to FIG. **3**, the bit stream **15** is then processed by the decoder **20** to produce reconstructed video images **512**, which correspond to the reconstructed frames **58** of the encoder **18**. An example H.264 decoder **20** is fully specified in the H.264 standard. The decoder **20** is base on functional units or components. These functional units include a buffering unit **500** that receives the compressed bitstream **15**, an entropy decoder **502** which decodes the received bit stream **15** to produce syntax elements **503** used in subsequent processing by the other decoder components, a motion compensated prediction unit **509** to produce the predicted frame **22***c* on a block **24***c* by block **24***c* basis (or a spatial compensation unit **511** in the case of intracoding), an inverse scanning and quantization unit **504**, and a transform unit **506** to reproduce the prediction error **42**, a reconstruction unit **508** that adds the prediction error **42** to the predicted frame **22***c* to produce the reconstructed frame **58**, and a deblocking filter **510** that smoothes the edges of sub-blocks **25** (see FIG.

2) within the reconstructed frame **58** to produce the filtered reconstructed frame **512**. The filtered frame **512** is stored in a current picture store **516**. Each of the above mentioned components is discussed in more detail in the following.

The incoming video bitstream **15** is stored in the buffer **500** at the input to the decoder **20**. The first stage in the decoding process includes the parsing and decoding of the entropy coded bitstream **15** symbols that are stored in the buffer **500** to produce the syntax elements **503** used by the other decoder components. For example, in the H.264 standard, two different entropy-coding modes are supported. The first method is based on using a context adaptive variable length coding (CAVLC) method to entropy decode the transform coefficients and a universal variable length coding (UVLC) which makes use of a single code-table for all syntax elements to entropy decode the rest of the information from the encoder **18**. The second method is based on context-adaptive binary arithmetic coding (CABAC), is more complex and compression efficient. The complexity of the CABAC method derives from the need to continually update a large set of context models throughout the decoding process, and the arithmetic decoding of symbols. The CAVLC/UVLC method can be implemented with a relatively small number of operations, requiring the parsing of each symbol and table lookups.

The various syntax elements in the bitstream **15** are de-multiplexed for use in different processes within the decoder **20**. High-level syntax elements **503** include temporal information for each frame **22**, and frame coding types and frame dimensions. H.264 coding, as with earlier standards, is based primarily on macroblocks **24** (see FIG. **1**) consisting of 16×16 luminance-pixel blocks **25** and 2 8×8 chrominance pixel blocks **25**. On the macroblock **24** level, syntax elements **503** include the coding mode of the macroblock **24**, information required for forming the prediction, such as motion vectors **38** and spatial prediction modes, and the coded information of the residual (difference) blocks **42**, such as the coded block pattern (CBP) for each macroblock **24** and quantized transform coefficients for each of the underlying blocks **25**.

Depending on the coding mode of each macroblock **24**, the predicted macroblock **24***c* can be generated either temporally (inter coding) or spatially (intra coding). The prediction for an inter coded macroblock **24***c* is determined by the motion vectors **38** that are associated with that macroblock **24***c*. The motion vectors **38** indicate the position within the set of previously decoded frames **22** from which each block of pixels will be predicted. Each inter coded macroblock **24***c* can be partitioned in one of seven ways, with luminance block sizes ranging from 16×16 pixels to 4×4 pixels. Also, a special SKIP mode exists in which no motion vectors **38** (or coded residual blocks) are transmitted and the prediction is based on the motion vector derived from neighbouring macroblocks' motion vectors. Thus, 0 to 16 motion vectors can be transmitted for each inter coded macroblock **24***c*. Additional predictive modes are supported when B-pictures are employed.

Motion vectors **38** are coded using either median or directional prediction, depending on the partition that is used for the luminance component of the macroblock **24***c*. For each motion vector **38**, the predicted block **25** must be computed by the decoder **20** and then arranged with other blocks **25** to form the predicted macroblock **24***c*. Motion vectors **38** in H.264 are specified generally with quarter-pixel accuracy. Interpolation of the reference video frames **22***b* is necessary to determine the predicted macroblock **24***c* using sub-pixel accurate motion vectors **38**. The complexity of the required interpolation filter varies as follows. To generate the predicted macroblock **24***c* using half-pixel accurate motion vectors **38**, an interpolation filter can be employed that is based on a 6-tap windowed sinc function. In the case of prediction using quarter-pixel accurate motion vector **38**, filtering can consist simply of averaging two integer- or half-pixel values (i.e., two pixels from the interpolated reference frame **22***b* that is used to generate the half-pixel accurate motion vector **38**), although one of every 12 quarter-pixel values (a.k.a. the "funny position") is replaced by the average the four surrounding integer-pixel values, providing more low-pass filtering than the remaining positions. A bilinear filter is used to interpolate the chrominance frames when sub-pixel motion vectors **38** are used to predict the underlying chrominance blocks **25**.

The H.264 standard also supports the use of multiple (previous for P-pictures) reference frames **22***b* for prediction. Selection of the particular reference frame **22***b* is made on a macroblock **24** basis. This feature can improve both coding efficiency and error resilience. However, this feature also requires that the decoder buffer **500** store several previously decoded and reconstructed frames **58**, rather than just the most recent reconstructed frame **58**, increasing substantially the decoder's **20** memory requirements.

Two different modes are supported in intra coding of macroblocks **24**. In the 4×4 Intra mode, each 4×4 block **25** within the macroblock **24** can use a different prediction mode. There are **9** possible modes one DC and **8**directional prediction modes. The complexity of the prediction mode varies, with the DC, vertical and horizontal modes being the least complex, and the diagonal modes being the most complex. In the 16×16 Intra mode, which is generally used in smooth areas, there are **4** modes available: DC, vertical, horizontal and planar, with the latter being the most complex. The prediction of intra-coded blocks **24**, **25** is always based on neighboring pixel values that have already been decoded and reconstructed.

The decoding of the residual (difference) macroblock requires that a number of inverse transforms be performed, along with associated inverse scanning and quantization operations. The decoding of the difference macroblock is based primarily on the transformation of 4×4 blocks **25** of both the luminance and chrominance pixels, although in some circumstances, a second-level transform must be performed on the DC coefficients of a group of 4×4 blocks **25**. More specifically, a special 2×2 transform is applied to the 4 DC coefficients of the blocks **25** of the chrominance pixels. For macroblocks **24** that are being coded in the 16×16 Intra mode, an additional scan and transform are applied to the DC values of each of the 16 4×4 luminance blocks of the macroblock **24**.

The inverse transforms that are required for each macroblock **24** are determined based on the coding mode and the coded block pattern (CBP) of the macroblock **24**. The input data are the Run_before-Coefficient_level codes that are parsed by the entropy decoder **502**. These are put into their correct order based on the Run_before values through the inverse scanning **504** process and then the Coefficient_ levels, which represent quantized transform coefficients, are inverse quantized via multiplication by a scaling factor. Finally, the necessary integer-specified inverse transform **506** is performed on the inverse quantized coefficients. The inverse transformed result for each macroblock **24** is added to the predicted macroblock **24***c* and stored in the reconstructed frame buffer **514**.

In the final stage of the decoding process, the decoder **20** applies the normative de-blocking filtering process **510**,

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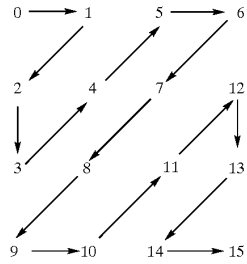
which reduces blocking artifacts that can be introduced by the coding process. The filter **510** is applied within the motion compensation loop.

The entropy decoding of quantized transform coefficients is currently done in the context of an H.264 standard, where entropy encoding/decoding of coefficients is performed on a 4×4 block basis, and involves two major steps. The Run_before and Coefficient_level are first entropy decoded from the bitstream, then the coefficients are reconstructed using the Run_before and Coefficient_level information in an zig-zag scan. Run_before is the number of consecutive zero coefficients preceding a non-zero coefficients in zigzag order from low frequency coefficients to high frequency coefficients, and Coefficient_level is the value of the non-zero coefficients. The following example is used to illustrate the major two steps used in the entropy encoding/decoding process.

As an example, consider the following 4×4 block of quantized transform coefficients at the encoder

6	0	0	0
5	−4	0	0
0	3	0	0
0	−1	1	0

The first step in the encoding process for the above 4×4 quantized transform coefficients is to apply a zigzag scan to the above quantized transform coefficient block to produce a series of coefficients. The zigzag scan is performed according to the following diagram:



The resulting series of coefficients is then 6, 0, 5, 0, −4, 0, 0, 0, 3, 0, −1, 0, 0, 0, 1, 0. The coefficients are typically grouped into (Run_before, Coefficient_level) pairs where Run_before is the number of consecutive zero coefficients preceding a non-zero coefficients in the resulting zigzag order from low frequency coefficients to high frequency coefficients, and coefficient_level is the value of the non-zero coefficients. The resulting (Run_before, Coefficient_level) pairs are then (0,6) (1,5), (1,−4), (3,3), (1,−1) and (3,1). The Run_before information is then separated from the Coefficient_level information and each is placed in a separate sequence. The resulting Run_before and Coefficient_level sequences are then:

Run_before: 6, 5, −4, 3, −1, 1

Coefficient_level: 0, 1, 1, 3, 1, 3

The second step in the coding process is to encode the Run_before information and the Coefficient_level information to produce the bit stream corresponding to the original quantized 4×4 transform coefficient data.

At the decoder side, the first step in the entropy decoding process for the coded quantized transform coefficient data is to decode the bitstream generated by the encoder to produce the Run_before information and the Coefficient_level information. For the example discussed above, this first step in the decoding process results in the following two sequences:

Run_before: 6, 5, −4, 3, −1, 1

Coefficient_level: 0, 1, 1, 3, 1, 3

The second step in the decoding process is to use the zigzag scan order described above to recover the 4×4 block of quantized transform coefficients based on the above two sequences.

As described above, the decoding process starts by entropy decoding the information provided by the encoder **18**. Entropy decoding represents a significant component of the decoding process, especially when a significant number of transform coefficients are to be decoded. FIG. **5** and FIG. **6** illustrate the steps involved in the decoding process **200** of the CAVLC coded transform coefficients. The process **200** takes as input a context-adaptive variable-length-encoded bitstream and outputs a sequence of Run_before and Coefficient_levels of a single transform block. The Run_before and Coefficient_level sequences are decoded in the backward zigzag order, from coefficients **50** corresponding to high frequency to coefficients **50** corresponding to low frequency.

In the first step **202**, the total number of non-zero coefficients and the number of trailing ones are decoded using 2-dimensional VLC tables. It is noted that the number of trailing ones (T1s) is always less than or equal to three. The rest of the coeficients, regardless of whether their absolute value is one or not, are decoded in step **206**. Limiting of the number of trailing ones (T1s) to three is given by example only. In step **204**, the sign bits of the trailing ones are decoded using 1 bit each, where the value "0" is given for positive and the value "1" is given for negative signs. In step **206**, the rest of the coefficient_levels are decoded using different tables Lev-VLCN (further defined below) and an adaptive table selection scheme **300** shown in FIG. **6**. In step **208**, the total sum of Run_before and all the Run_before are decoded. In particular in step **206**, the 7 VLC tables are named Lev-VLC**0**, Lev-VLC**1**, Lev-VLC**2**, Lev-VLC**3**, Lev-VL**4**, Lev-VL**5**, and Lev-VL**6**, referred to collectively as Lev-VLCN. It should be noted that Lev-VLC**0** has its own structure, while the other tables Lev-VLC**1**, Lev-VLC**2**, Lev-VLC**3**, Lev-VL**4**, Lev-VL**5**, and Lev-VL**6** share a common structure defined as follows:

```
Let "level_code" be the level information to be decoded from the
tables Lev-VLCN,
If(|level_code|−1)<(15<<(N−1)),
Code 0 . . . 01x . . . xs,
      where   number of 0's =   (|level_code|−1) >> (N−1),
              number of x's =   N−1,
              value of x's =    (|level_code|−1) % 2^(N−1),
              s =               sign bit(0-positive, 1-negative)
elseif(|level_code|−1 >= 15<<(N−1)),
28-bit escape code:     0000 0000 0000 0001 xxxx xxxx xxxs,
      where   value of x's =    (|level_code|−1) − (15>>(N−1)),
              s =               sign bit(0-positive, 1-negative).
```

In the above, N is a value used for table Lev-VLCN selection (i.e. N=1 specifies table Lev-VLC**1**). Since the structure of the tables is well defined by N, it is recognised that new tables Lev-VLCN can easily be created above Lev-VLC**6**, if desired. The tables Lev-VLCN for N=0 to 6 are as follows:

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Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
	Lev-VLC0	
0	1	1
1	01	−1
. . .	. . .	. . .
13	00000000000001	−7
14–29	000000000000001xxxs	±8 to ±15
30 −>	000000000000000001xxxxxxxxxxxs	±16 −>
	Lev-VLC1	
0–1	1s	±1
2–3	01s	±2
. . .	. . .	. . .
28–29	0000000000000001s	±15
30 −>	00000000000000001xxxxxxxxxxxs	±16 −>
	Lev-VLC2	
0–3	1xs	±1 to ±2
4–7	01sx	±3 to ±4
. . .	. . .	. . .
56–59	0000000000000001xs	±29 to ±30
60 −>	00000000000000001xxxxxxxxxxxs	±30 −>
	Lev-VLC3	
0–7	1xxs	±1 to ±4
8–16	01xxs	±5 to ±8
. . .	. . .	. . .
112–119	0000000000000001xxs	±57 to ±60
120 −>	00000000000000001xxxxxxxxxxxs	±61 −>
	Lev-VLC4	
0–15	1xxxs	±1 to ±8
16–31	01xxxs	±9 to ±16
. . .	. . .	. . .
224–239	0000000000000001xxxs	±113 to ±120
240 −>	00000000000000001xxxxxxxxxxxs	±121 −>
	Lev-VLC5	
0–31	1xxxxs	±1 to ±16
32–63	01xxxxs	±17 to ±32
. . .	. . .	. . .
448–479	0000000000000001xxxxs	±225 to ±240
480 −>	00000000000000001xxxxxxxxxxxs	±241 −>
	Lev-VLC6	
0–63	1xxxxxs	±1 to ±32
64–127	01xxxxxs	±33 to ±64
. . .	. . .	. . .
896–959	0000000000000001xxxxxs	±449 to ±480
960 −>	00000000000000001xxxxxxxxxxxs	±481 −>

Regarding the above tables Lev-VLCN, all coefficient **50** levels "Coefficient_level" are equal to the decoded LevelCode value given in tables Lev-VLCN. In other words, the data elements of the coefficient **50** matrix are represented by the LevelCode column of the tables Lev-VLCN. Further, when the number of trailing ones is less than three, the level of the first coefficient (after the T**1**s) is equal to the decoded LevelCode plus 1, such that

If this is the first coefficient after trailing ones and number of trailing ones is <3
coefficient_level=(|LevelCode |+1)*sign(LevelCode)
else
Coefficient_level=LevelCode.

Further, it is noted that the last two entries in table Lev-VLC**0** are escape codes. The first escape code with 19 bits, three "x" s and a "s" (level code and sign bit), is used to decode the 8 levels above the last regularly coded level. The next escape code with 28 bits, 11 "x" s and a "s" (level code and sign bit), is used to decode all remaining higher levels. It should be noted that for Lev-VLC**1**, Lev-VLC**2**, Lev-VLC**3**, Lev-VLC**4**, Lev-VLC**5**, and Lev-VLC**6**, only the 28 bit escape code is used.

Referring to FIG. **7**, the Coefficient_levels **400** are decoded from the encoded bits **402** through the use of the tables, represented graphically by the lines **404**. The 28 bit escape codes represent the discontinuities **406**, while the 19 bit escape codes represent the discontinuity **408**. It is further recognized that Lev-VLC**0** is only used in first coefficient. Thus, a decoder module may process the subsequent coefficients in a loop that involves only 28-bit escape code.

Referring to FIG. **6**, the scheme **300** (details of step **206** of FIG. **5**) decodes the sequence of Coefficient_levels from the input bitstream. First, in step **302**, the initial Lev-VLCN table is selected based on the number of non-zero coefficients of the current block **24** and the number of T**1**s, as:

if (total number of coefficients>10 and number of trailing ones is <3) then
N=1//Use Lev-VLC**1** for the first coefficient after trailing ones
else
N=0 //Use Lev-VLC**0** for the first coefficient after trailing ones

For the remaining **304** non-zero coefficients, the table Lev-VLC**1** or Lev-VLC**0** selected is then used to decode **306** or **308** the first coefficient level corresponding to the selected table. A decision **307** is performed to toggle between the two initial table selections Lev-VLC**1** or Lev-VLC**0**.

After decoding the initial coefficient level of the sequence of Coefficient_levels, a table selection update step **310** is performed to select an appropriate table Lev-VLCN for decoding the next Coefficient_level in the sequence. The most recently decoded level and current Lev-VLCN table is used to select the next table Lev-VLCN to be used. The update step **310** is as follows.

Let "N" denote current table number N in Lev-VLCN, and |level| denote the absolute value of most recently decoded Coefficient_level.

1. Lookup vlc_inc from VLC_INC Table using N

VLC_INC Table

N	vlc_inc
0	0
1	3
2	6
3	12
4	24
5	48
6	Infinite

(or vlc_inc table[N] = {0, 3, 6, 12, 24, 48, infinite})

2. if (|level|>vlc_inc[N])
N=N+1
else
N=N
3. if (this is first coefficient after trailing ones and |level|>3)
N=2

In other words, the current Lev-VLCN table is used for decoding the next coefficient **50** except when the absolute value of the most recent decoded level (|level|) is greater than a threshold based on vlc_inc table, and in such cases the next bigger Lev-VLCN+1 table is selected for decoding the next coefficient **50**. An exception applies when the most recent decoded coefficient **50** is the first coefficient **50** after

trailing ones. In such cases, when |level| is greater than three, Lev-VLC**2** is used for next coefficient level. Accordingly, the process **300** for decoding the Coefficient_levels and then updating Lev-VLCN tables repeats for each non-zero Coefficient_level of the sequence of Coefficient_levels for the current block **24** until all non-zero Coefficient_levels are decoded. It should be noted that the first coefficient **50** of the sequence of Coefficient_levels is decoded with table Lev-VLC**1** or Lev-VLC**0**, while the rest of the coefficients **50** are decoded with Lev-VLC**1** to Lev-VLC**6**.

It should be noted that in the known prior art coding schemes, every table has two escape codes (both 19-bit escape and 28-bit escape codes (similar to table Lev-VLC**0** as given above)). This can lead to two discontinuities in every table, which can significantly decrease possible levels of parallel processing during the decoding process and can increase decoding process complexity. It has been experimentally determined that given the table selection scheme **300**, removal of the 19-bit discontinuity in tables Lev-VLC**1** to Lev-VLC**4** did not lead to any significant reduction in compression efficiency, and significantly decreased complexity as compared to the known tables.

Further, in the known coding schemes as described above, Lev-VLC**1** is used only when the block is intra-coded with low quantization parameter (high bit rate) i.e. QP<21. It has also been experimentally determined for the new scheme **300** that using table Lev-VLC**1** for the first coefficient can be also beneficial for some inter-coded blocks that have many coefficients. In fact, the number of coefficients and number of trailing ones was experimentally determined to predict VLC statistics better than the intra/inter-coding mode and QP. Furthermore, removing the coding mode and QP as input parameters for the scheme **300** can help reduce data structure loads. This modification can help to improve both compression efficiency and reduce the complexity of the implementation of the CAVLC decoding method.

Further, in the known prior art as described above, VLC table selections were updated differently for intra blocks with QP<21 and other block types. It has been experimentally determined that one method can be designed to provide good compression for all block types and QP by employing the following rules which are used by the scheme **300**:

1. Increase Lev-VLCN only when Coefficient_level exceeds the optimal compression range of current table: (upper_optimal_limit(Lev-VLCN))=$3\times2^{N-1}$, and
2. Extend the number of tables to seven (Lev-VLC**5**, Lev-VLC**6**) using the same structure as the Lev-VLC**1** to Lev-VLC**4** tables to adjust to large coefficient levels without increasing complexity

These rules lead to the design of the new table selection update threshold while helping to reduce complexity (reduced number of logic paths) and enhancing compression efficiency and robustness.

In summary, the range of Lev-VLC tables of the scheme is extended according to one general formula, as described above. Further, only 1 escape code (28-bit escape code) is used for tables Lev-VLC**1** to Lev-VLC**6**. The table Lev-VLCN selection initialization step of the scheme **300** depends only on the total number of non-zero coefficients and the number of trailing ones, which are local variables in the transform coefficient entropy decoding module. The table selection update step **310** uses one table of thresholds to select the Lev-VLCN table for the next coefficient, regardless of the particular block modes and quantization parameters under consideration.

The following are Table Initialization examples using the scheme **300**. Table initialization process **302** is used to select appropriate VLC table for coding the first coefficient **50** in the sequence of Coefficient_levels. It is noted that both the # of coefficients (number of coefficients) and the # of trailing ones (number of trailing ones) are locally available parameters of the scheme (note bolded levels are coded already from steps selected from steps **26 306**, **307**, and **202**, **204**).

```
InitialTable = Initiatization(# of coefficients (local), # of trailing
                ones (local))
                if(#coeff >10 and #trailing ones < 3)
                  use VLC1
                else
            use VLC0
                    [trailing ones already decoded in step 202]
Example 1:
Coeficient levels in bitstream: 1, 3, 3, 4, 6, 8, 8, 10, 11, 15
          level to be decoded now: 3
# of coefficients = 11
# of trailing ones = 1
Initial Table = VLC1
Note: Lev-VLC1 is used to decode 3 which is more efficient than Lev-
VLC0
                    [trailing ones already decoded in step 202]
Example 2:
Coefficient levels in bitstream: 1, 1, 1, 1, 2
level to be decoded now: 1
# of coefficients = 5
# of trailing ones = 3        (only up to 3 T1's are decoded in step 202)
Initial Table = VLC0
Note: Lev-VLC0 is well suited for small levels such as a value of 1
```

The following are Table Update examples using the scheme **300**. The step **310** is used to select tables for decoding subsequent coefficient levels.

```
NextTable = Update(VLC table (recursive), previous level)
        if (|previous level| > vlc_inc)
            next N = N + 1
        else
            next N = N
    Example 1: (note bolded levels are decoded already from steps
    306, 307, and 202, 204)
    Coefficient level in bitstream: 1, 3, 4, 6, 8, 8, 10, 11, 15
          level to be decoded now: 4
    Previous Level:    3
    Previous Table:  VLC1
    vlc_inc(VLC1):    3 (selected from N=1 in table)
    Table =          VLC1
    Since 3 is not greater than 3, we use VLC1 to decode level = 4
    Example 2:
    Coefficient level in bitstream: 1, 3, 4, 5, 5, 6, 8, 8, 10, 11, 15
          level to be decoded now: 5
    Previous Level     4
    Previous Table   VLC1
    vlc_inc(VLC1):    3 (selected from N=1 in table)
    Table =          VLC2
    Since 4 is greater than 3, we use VLC2 to decode level = 5.
```

VLC_INC Table

N	vlc_inc
0	0
1	**3**
2	6
3	12
4	24
5	48
6	Infinite

Although the invention has been described with reference to certain specific embodiments, various modifications

thereof will be apparent to those skill in the art without departing from the spirit and scope of the invention as outlined in the claim appended hereto.

The embodiments of the invention in which an exclusive property on privilege is claimed are defined as follows:

1. A Context-Adaptive Variable Length Coding (CAVLC) system for decoding quantised transform coefficient levels, the system comprising:

a) an input for a bitstream including context-adaptive variable-length-encoded Run_before and Coefficient_level data corresponding to quantized transform coefficients;

b) an entropy decoding section for decoding the Run_before and Coefficient_level data; and

c) a plurality of decoding tables used by the entropy coding section for decoding coefficient_levels, at least two of the decoding tables have a single escape sequence and are generated by a common function;

wherein selection from the plurality of decoding tables for the first Coefficient_level is determined solely by local variables representing a total number of non-zero coefficients and a number of trailing ones in the sequence of Coefficient_levels and selection from the plurality of decoding tables for subsequent Coefficient_levels is determined solely by a previous decoded coefficient_level and an experimentally pre-determined table.

2. The system according to claim **1**, wherein the decoding process further comprises a first sub-process and a second sub-process for decoding the quantized transform coefficients.

3. The system according to claim **1**, wherein the first sub-process performs an initial table selection from a primary table or a secondary table chosen from the plurality of tables.

4. The system according to claim **3**, wherein the primary table is LEV-VLC**0** and the secondary table is Lev-VLC**1**.

5. The system according to claim **4**, wherein the first sub-process selects the table Lev-VLC**0** if a number of non-zero coefficients of the quantized coefficients is greater than ten and a number of trailing coefficients with a level equal to one is less than three, otherwise the first sub-process selects the table Lev-VLC**1**.

6. The system according to claim **5**, wherein the first sub-process is:

```
if (total_coeff(coeff_token)>10 && trailing ones(coeff_token) <3)
    N=1 //Use Lev-VLC1 for the first coefficient
else
    N=0 //Use Lev-VLC0 for the first coefficient.
```

7. The system according to claim **1** further comprising selection from the plurality of decoding tables for the first Coefficient_level after trailing ones is determined solely by local variables representing a total number of non-zero coefficients and a number of trailing ones in the sequence of Coefficient_*levels*.

8. The system according to claim **7**, wherein the selection criteria for the plurality of tables further comprises a local table listing and a previous decoded coefficient_level.

9. The system according to claim **8**, wherein the local table listing is:

VLC_INC Table

N	vlc_inc
0	0
1	3
2	6
3	12
4	24
5	48
6	Infinite.

10. The system according to claim **2**, wherein the second sub-process selects a secondary table from the plurality of tables.

11. The system according to claim **10**, wherein the second sub-process is:

```
1.    Lookup vlc_inc from VLC_INC Table using Lev-VLCN from
vlc_inc table[N] = {0, 3, 6, 12, 24, 48, Infinite};
2.    if(|level| > vlc_inc[N])
          N = N + 1
      else
          N = N;
3.    if(this is first coefficient and |level| > 3)
N = 2.
```

12. The system according to claim **1** further comprising a single function for generating at least two of the plurality of tables.

13. The system according to claim **12**, wherein the single function is:

```
if(level_code|−1)<(15<<(N−1)),
Code: 0 . . . 01x . . . xs,
    where    number of 0's =    (|level_code|−1) >> (N−1),
             number of x's =    N−1,
             value of x's =     (|level_code|−1) % 2^(N−1)
             s =                sign bit(0-positive, 1-negative)
    elseif(|level_code|−1 >= 15<<(N−1),
    28-bit escape code:         0000 0000 0000 0001 xxxx xxxx xxxs,
    where    value of x's =     (|level_code|−1) − (15<<(N−1)),
             s =                sign bit(0-positive, 1-negative),
```

where "level_code" is the level information to be decoded from the plurality of tables.

14. The system according to claim **1**, wherein one of the plurality of tables is Lev-VLC**1** as:

Lev-VLC1

Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
0–1	1s	±1
2–3	01s	±2
. . .	. . .	. . .
28–29	0000000000000001s	±15
30—>	0000000000000001xxxxxxxxxxxxs	±16—>.

15. The system according to claim **1**, wherein one of the plurality of tables is Lev-VLC**2** as:

Lev-VLC2

Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
0–3	1xs	±1 to ±2
4–7	01xs	±3 to ±4
. . .	. . .	. . .
56–59	000000000000001xs	±29 to ±30
60—>	000000000000000001xxxxxxxxxxxs	±31—>.

16. The system according to claim **1**, wherein one the of the plurality of tables is Lev-VLC**3** as:

Lev-VLC3

Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
0–7	1xxs	±1 to ±4
8–16	01xxs	±5 to ±8
. . .	. . .	. . .
112–119	0000000000000001xxs	±57 to ±60
120—>	0000000000000001xxxxxxxxxxxs	±61—>.

17. The system according to claim **1**, wherein one the of the plurality of tables is Lev-VLC**4** as:

Lev-VLC4

Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
0–15	1xxxs	±1 to ±8
16–31	01xxxs	±9 to ±16
. . .	. . .	. . .
224–239	0000000000000001xxxs	±113 to ±120
240—>	0000000000000001xxxxxxxxxxs	±121—>.

18. The system according to claim **1**, wherein one the of the plurality of tables is Lev-VLC**5** as:

Lev-VLC5

Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
0–31	1xxxxs	±1 to ±16
32–63	01xxxxs	±17 to 32
. . .	. . .	. . .
448–479	0000000000000001xxxxs	±225 to ±240
480—>	0000000000000001xxxxxxxxxxs	±241—>.

19. The system according to claim **1**, wherein one the of the plurality of tables is Lev-VLC**6** as:

Lev-VLC6

Code no	Code (bitstream bits)	Coefficient Level (LevelCode)
0–63	1xxxxs	±1 to ±32
64–127	01xxxxs	±33 to ±64
. . .	. . .	. . .
896–959	0000000000000001xxxxxs	±449 to ±480
960 –>	00000000000000001xxxxxxxxxxs	±481 –>.

20. The system according to claim **1**, wherein an initial table separate from the plurality of tables is Lev-VLC**0** as

Lev-VLC0

Code (bitstream bits)	Coefficient Level (LevelCode)
1	1
01	−1
. . .	. . .
00000000000001	−7
0000000000000001xxxs	±8 to ±15
0000000000000001xxxxxxxxxxs	±16 –>.

21. The system according to claim **1**, wherein the single escape sequence is 28 bit long.

22. The system according to claim **1**, wherein the tables having the single escape sequence are tables Lev-VLC**1**, Lev-VLC**2**, Lev-VLC**3**, Lev-VLC**4**, Lev-VLC**5**, Lev-VLC**6**.

23. A Context-Adaptive Variable Length Coding (CAVLC) method for decoding transform coefficient levels, the method comprising the step of:

a) receiving a bitstream including context-adaptive variable-length-encoded Run_before and Coefficient_level data corresponding to quantized transform coefficients;

b) accessing a plurality of decoding tables for decoding the data, wherein at least two of the decoding tables have a single escape sequence and are generated by a common function; and

c) selecting one of the plurality of tables for decoding the Coefficient_level data.

* * * * *

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