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Lou et al.

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(54) **METHOD OF DETERMINING BINARY CODEWORDS FOR TRANSFORM COEFFICIENTS**

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(51) **Int. Cl.**
H04N 19/645 (2014.01)
H04N 19/18 (2014.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04N 19/00296*** (2013.01); ***H04N 19/645*** (2014.11); ***H04N 19/91*** (2014.11); *H03M 7/4018* (2013.01); *H04N 19/61* (2014.11)

(58) **Field of Classification Search**
CPC H04N 19/00296; H04N 19/645
USPC 375/240.03
See application file for complete search history.

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Assistant Examiner — Rowina Cattungal
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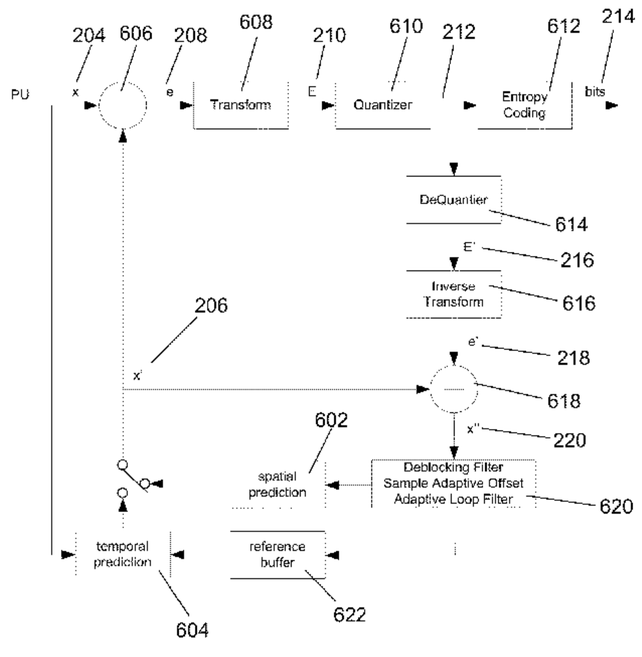
(57) **ABSTRACT**

A system is provided for creating level parameter updating codewords for transform coefficients used for relating transform units (TUs) that divide up coding units (CUs) in a High Efficiency Video Coding (HEVC) system. The system provides binarization of the codewords and removes unnecessary operations to reduce system complexity and increase compression performance. The system generates transform coefficients that relate the TUs and begins by providing a parameter variable (cRiceParam) set to an initial value of zero. The parameter variable is then converted into a binary codeword based on the current value of the parameter variable and the value of a symbol and then updated with a new current value after each symbol has been converted. Updating can be provided with reference to table values or the values can be provided from combination logic.

16 Claims, 15 Drawing Sheets



(51) **Int. Cl.**

H04N 19/91	(2014.01)
H03M 7/40	(2006.01)
H04N 19/61	(2014.01)

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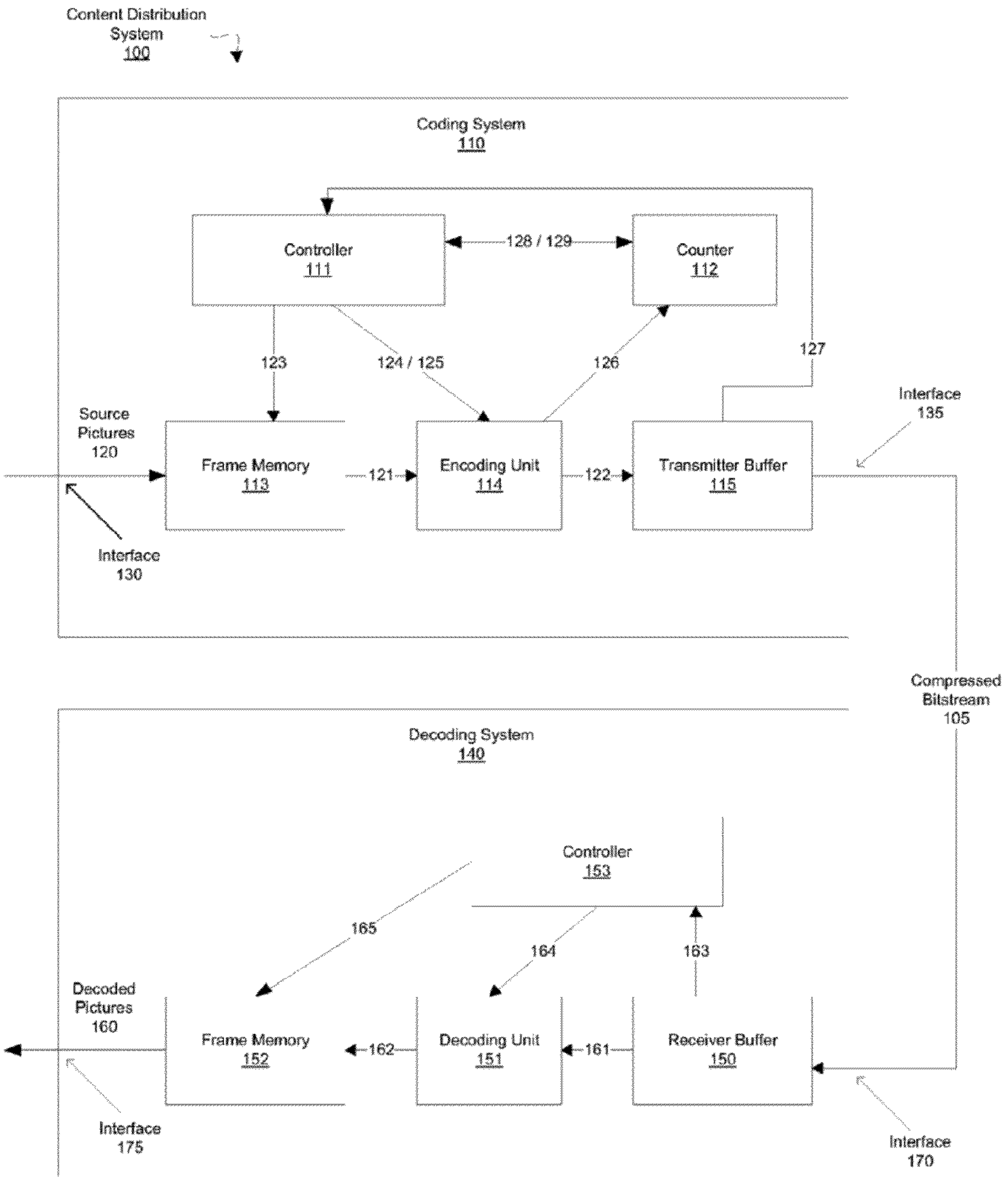

FIG. 1

Prior Art

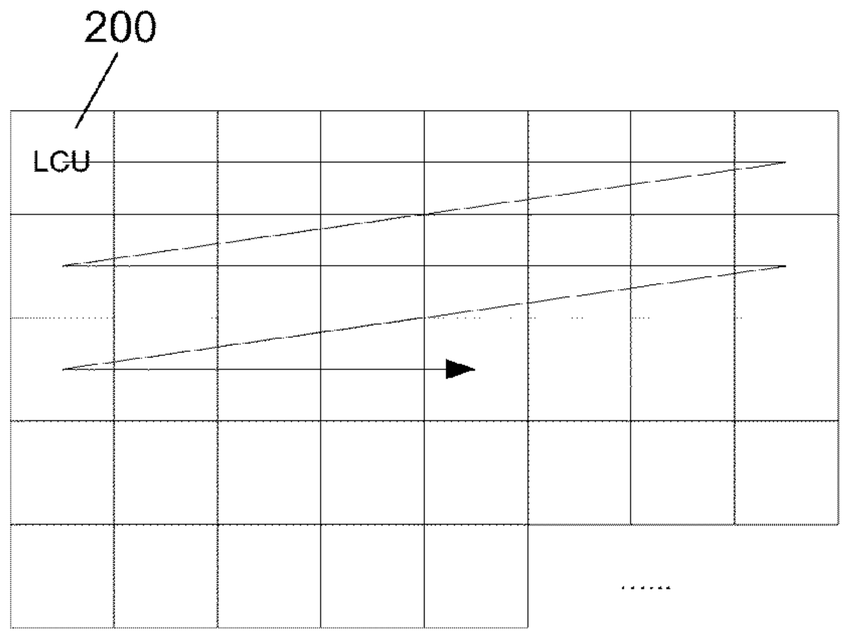

FIG. 2
Prior Art

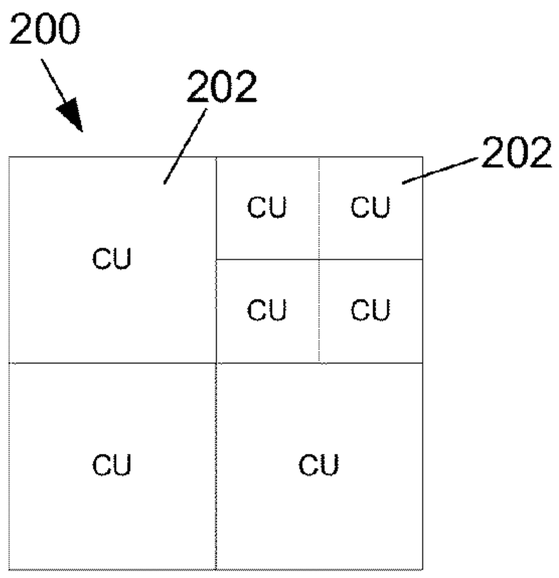

FIG. 3
Prior Art

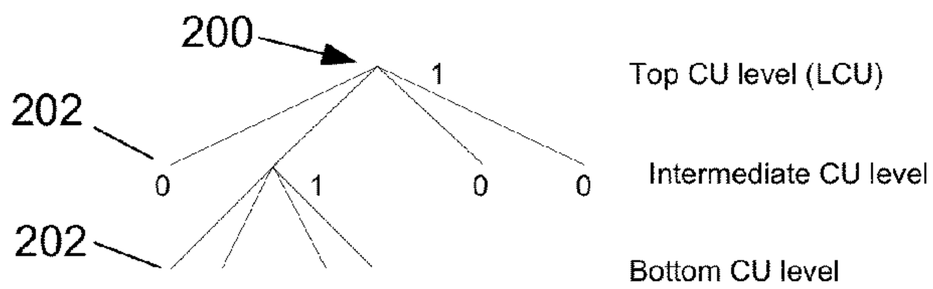

FIG. 4

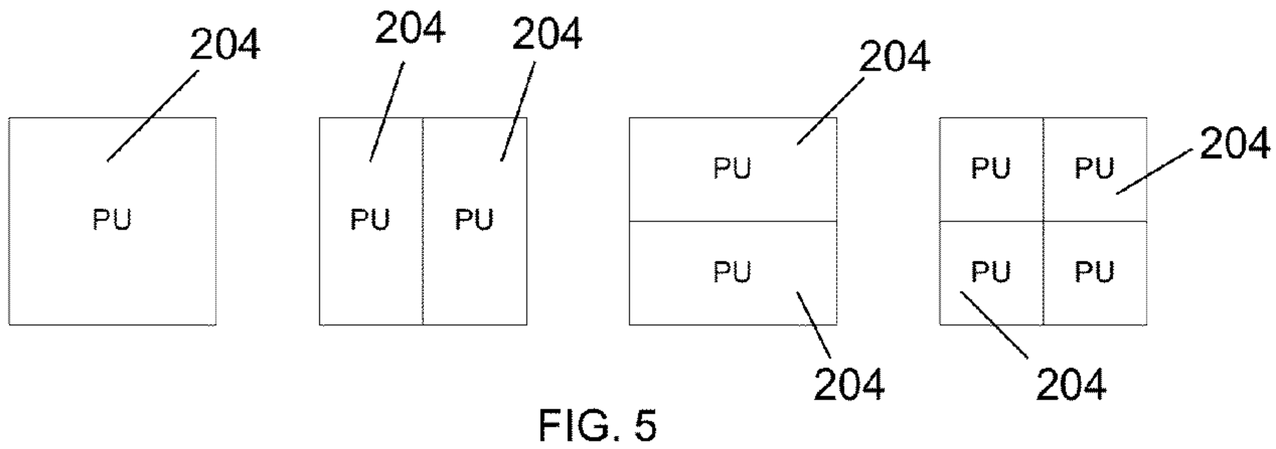

FIG. 5

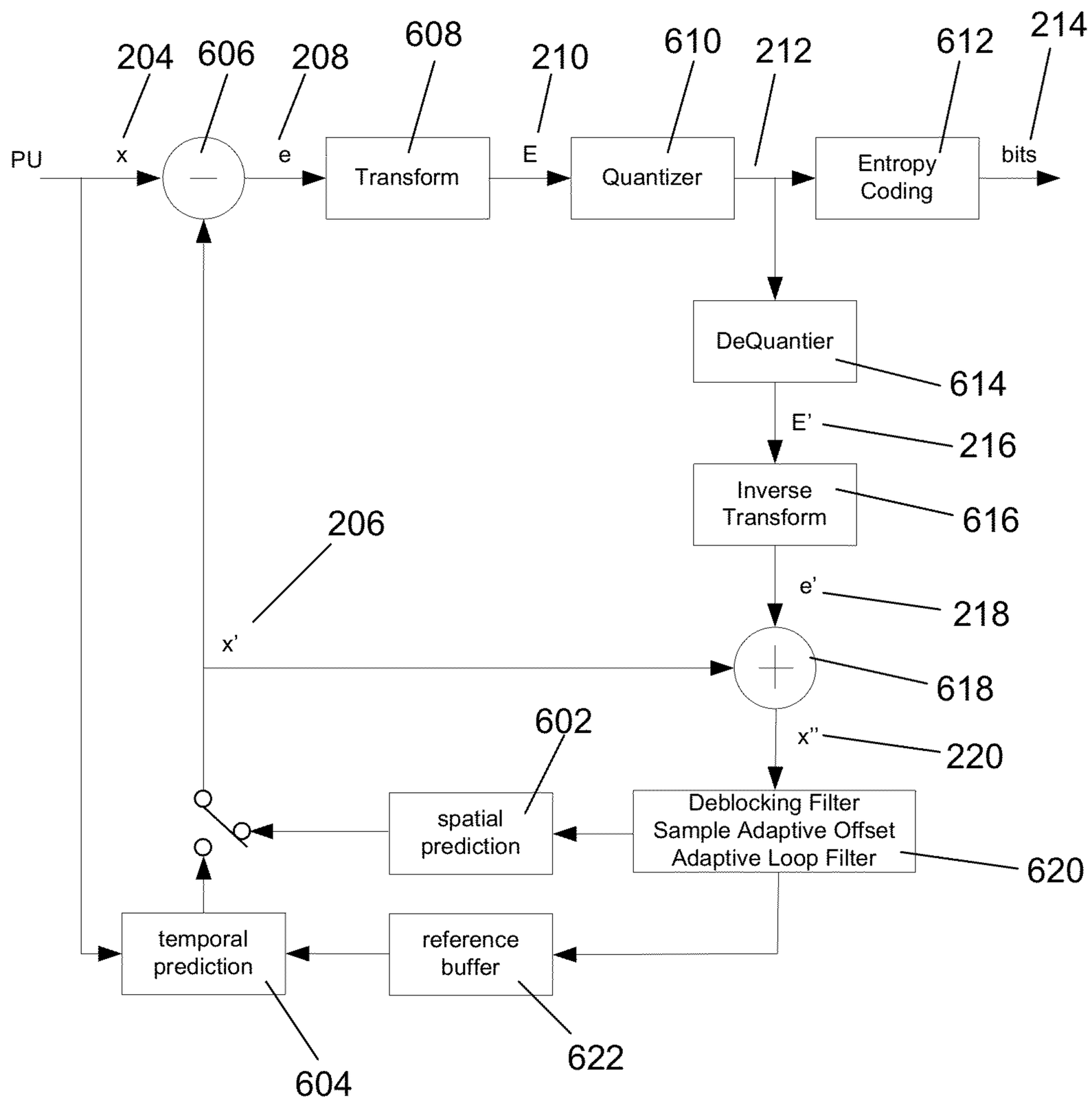
204
606
208
608
210
610
212
612
214
PU
x
e
Transform
E
Quantizer
Entropy Coding
bits
DeQuantier
614
E'
216
Inverse Transform
616
206
e'
218
x'
618
602
x''
220
spatial prediction
Deblocking Filter
Sample Adaptive Offset
Adaptive Loop Filter
620
temporal prediction
reference buffer
604
622

FIG. 6

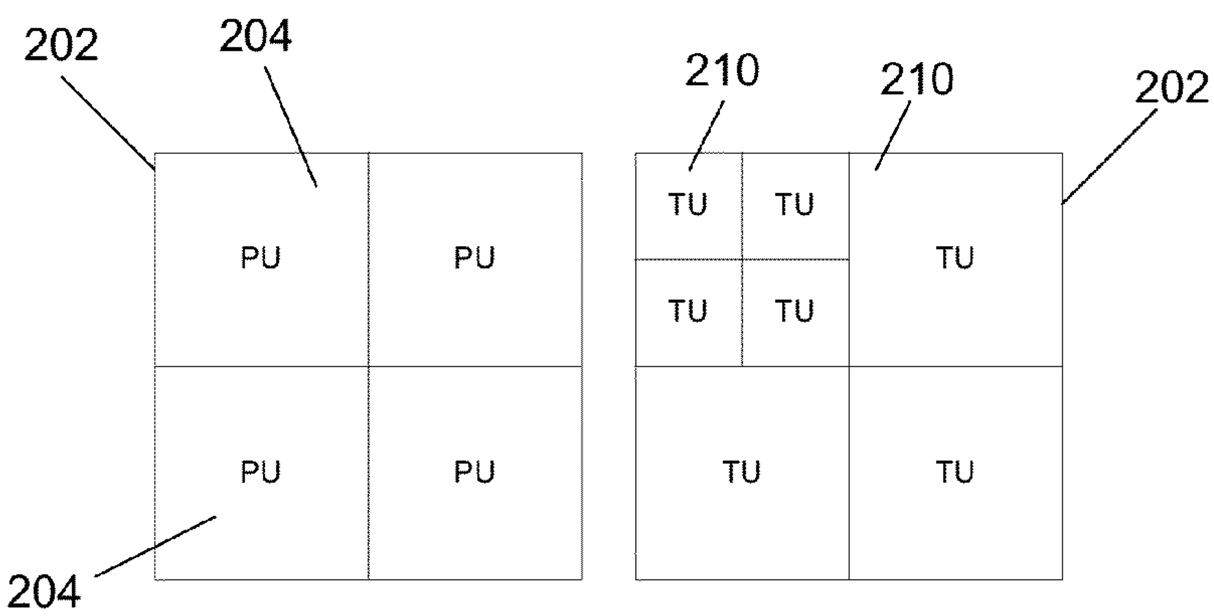

FIG. 7

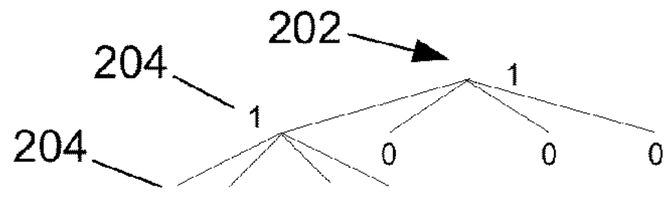

FIG. 8

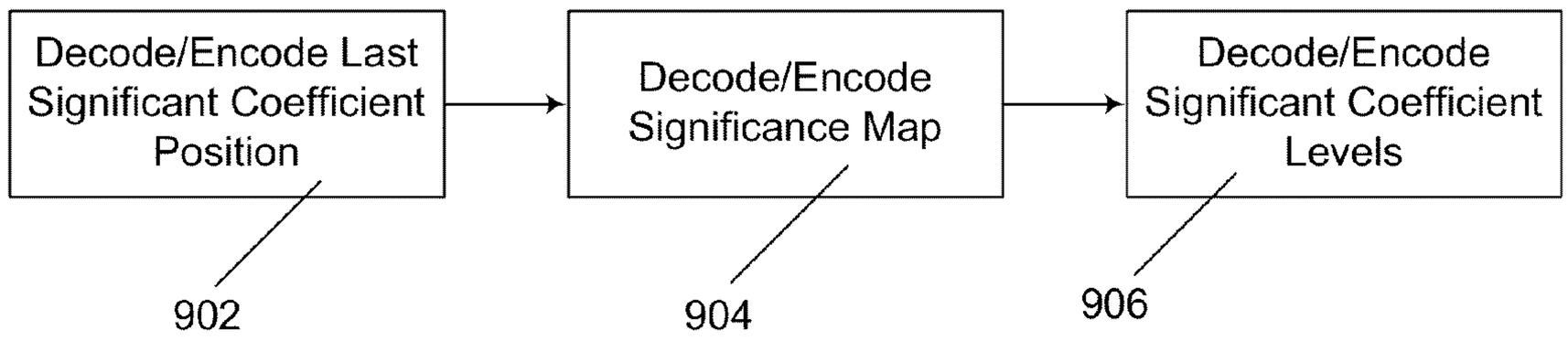

FIG. 9

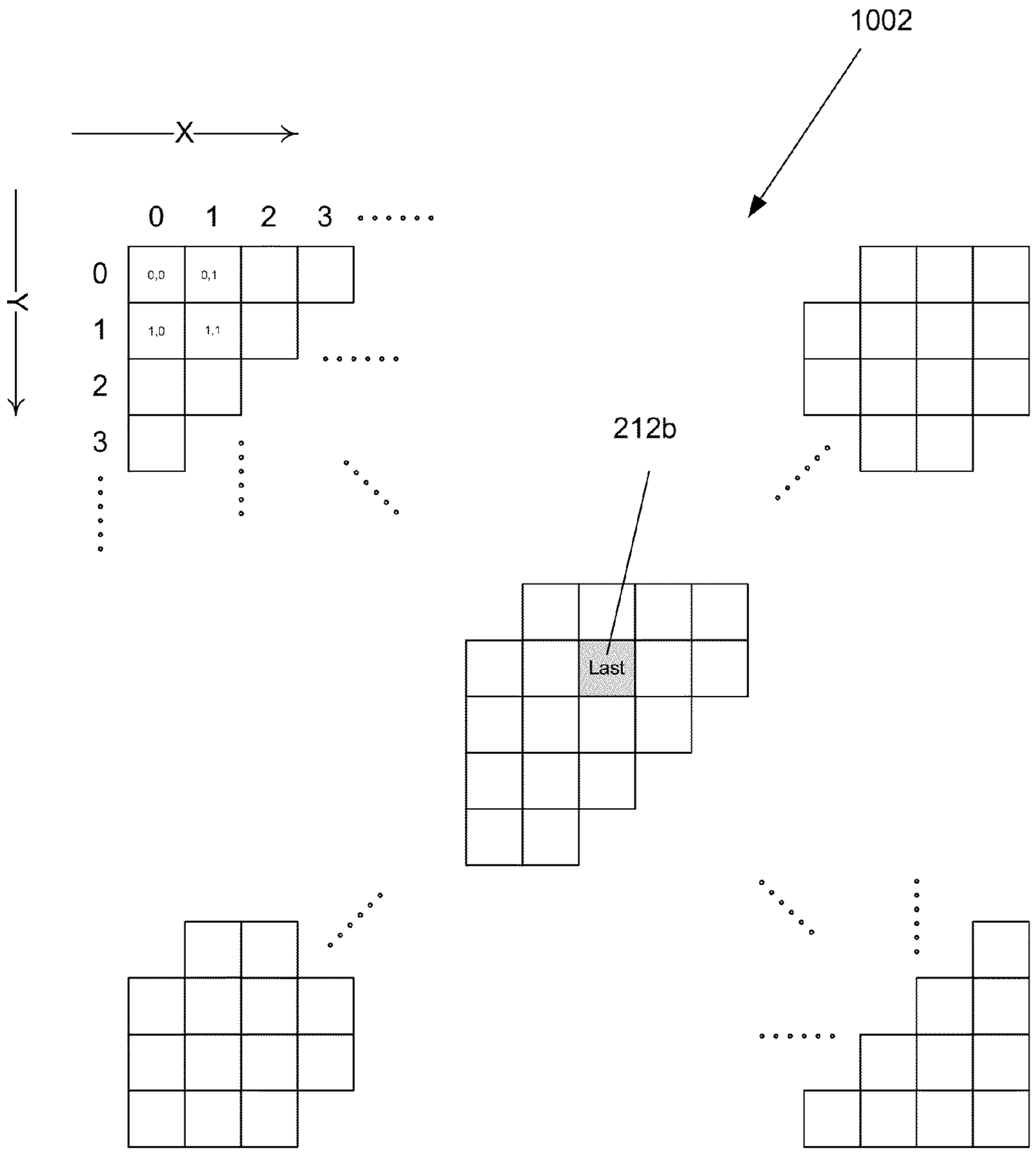

FIG. 10

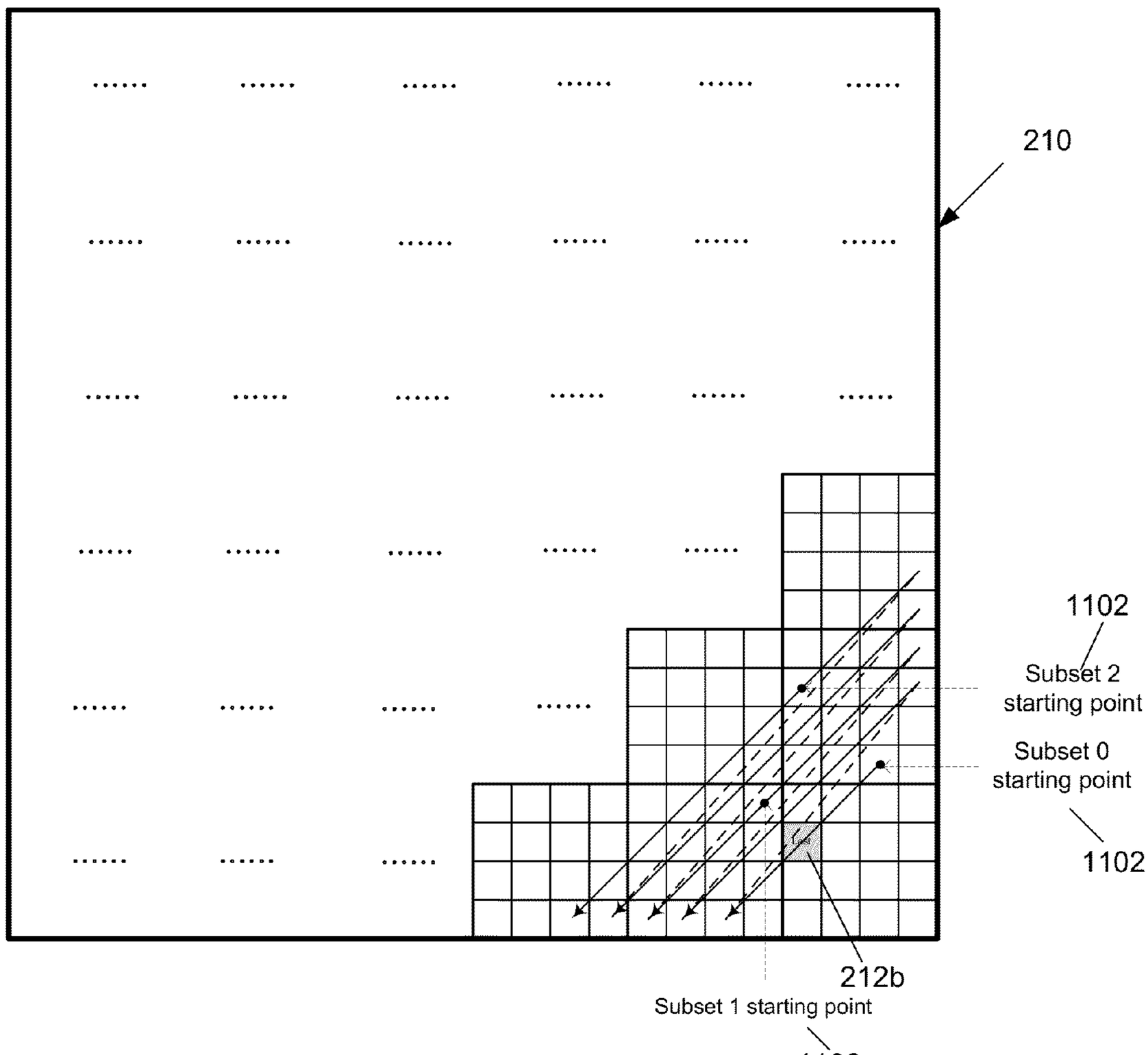
210
1102
Subset 2
starting point
Subset 0
starting point
1102
212b
Subset 1 starting point
1102

FIG. 11

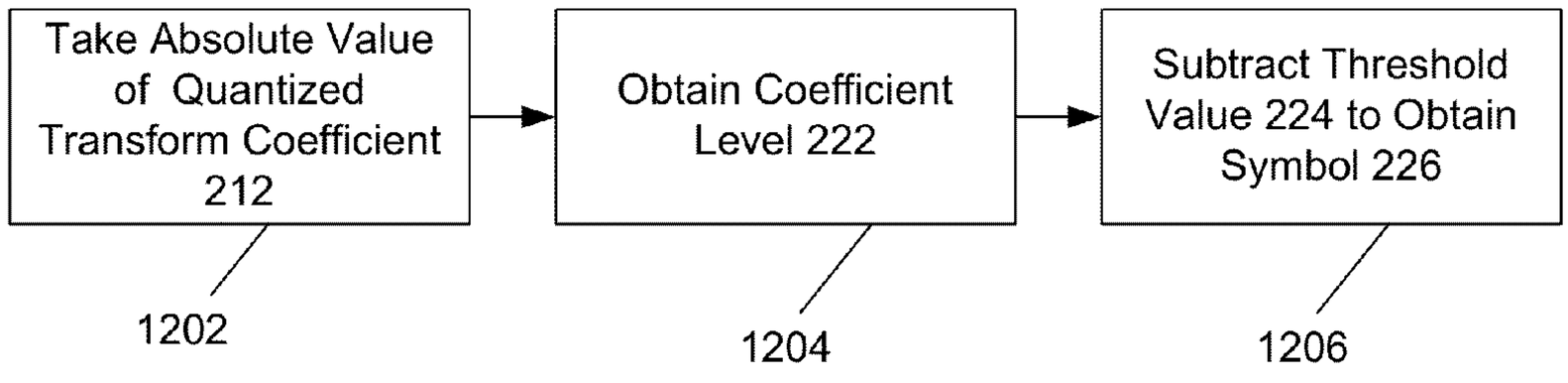
Take Absolute Value of Quantized Transform Coefficient 212
Obtain Coefficient Level 222
Subtract Threshold Value 224 to Obtain Symbol 226
1202
1204
1206

FIG. 12

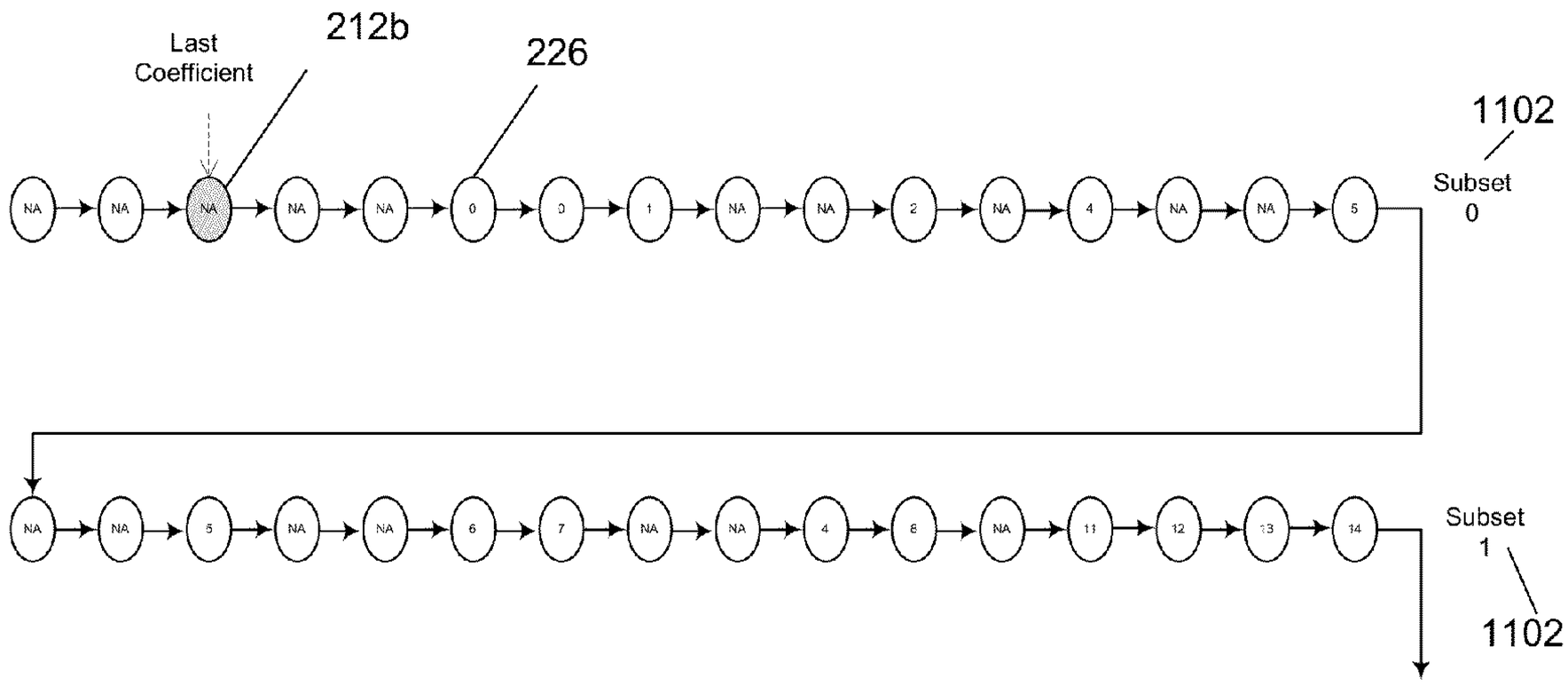

FIG. 13

Table 1

cRiceParam	cTRMax
0	7
1	20
2	42
3	70

FIG. 14

226

228

230

cRiceParam	0		1		2		3	
Symbol	Codeword	Bits	Codeword	Bits	Codeword	Bits	Codeword	Bits
0	0	1	00	2	000	3	0000	4
1	10	2	01	2	001	3	0001	4
2	110	3	100	3	010	3	0010	4
3	1110	4	101	3	011	3	0011	4
4	11110	5	1100	4	1000	4	0100	4
5	111110	6	1101	4	1001	4	0101	4
6	1111110	7	11100	5	1010	4	0110	4
7	11111110	8	11101	5	1011	4	0111	4
8	11111111,EG0	9	111100	6	11000	5	10000	5
9			111101	6	11001	5	10001	5
10			1111100	7	11010	5	10010	5
11			1111101	7	11011	5	10011	5
12			11111100	8	111000	6	10100	5
13			11111101	8	111001	6	10101	5
14			111111100	9	111010	6	10110	5
15			111111101	9	111011	6	10111	5
16			1111111100	10	1111000	7	110000	6
17			1111111101	10	1111001	7	110001	6
18			11111111100	11	1111010	7	110010	6
19			11111111101	11	1111011	7	110011	6
20			11111111110	11	11111000	8	110100	6
21			11111111111,EG0	12	11111001	8	110101	6
22					11111010	8	110110	6
23					11111011	8	110111	6
24					111111000	9	1110000	7
25					111111001	9	1110001	7
26					111111010	9	1110010	7
27					111111011	9	1110011	7
28					1111111000	10	1110100	7
29					1111111001	10	1110101	7
30					1111111010	10	1110110	7
31					1111111011	10	1110111	7
32					11111111000	11	11110000	8
33					11111111001	11	11110001	8
34					11111111010	11	11110010	8
35					11111111011	11	11110011	8
36					111111111000	12	11110100	8
37					111111111001	12	11110101	8
38					111111111010	12	11110110	8
39					111111111011	12	11110111	8
40					111111111100	12	111110000	9
41					111111111101	12	111110001	9
42					111111111110	12	111110010	9
43					111111111111,EG0	13	111110011	9
44							111110100	9
45							111110101	9
46							111110110	9
47							111110111	9
48							1111110000	10
49							1111110001	10
50							1111110010	10
51							1111110011	10
52							1111110100	10
53							1111110101	10
54							1111110110	10
55							1111110111	10
56							11111110000	11
57							11111110001	11
58							11111110010	11
59							11111110011	11
60							11111110100	11
61							11111110101	11
62							11111110110	11
63							11111110111	11
64							11111111000	11
65							11111111001	11
66							11111111010	11
67							11111111011	11
68							11111111100	11
69							11111111101	11
70							11111111110	11
71							11111111111,EG0	12

Table 2

FIG. 15

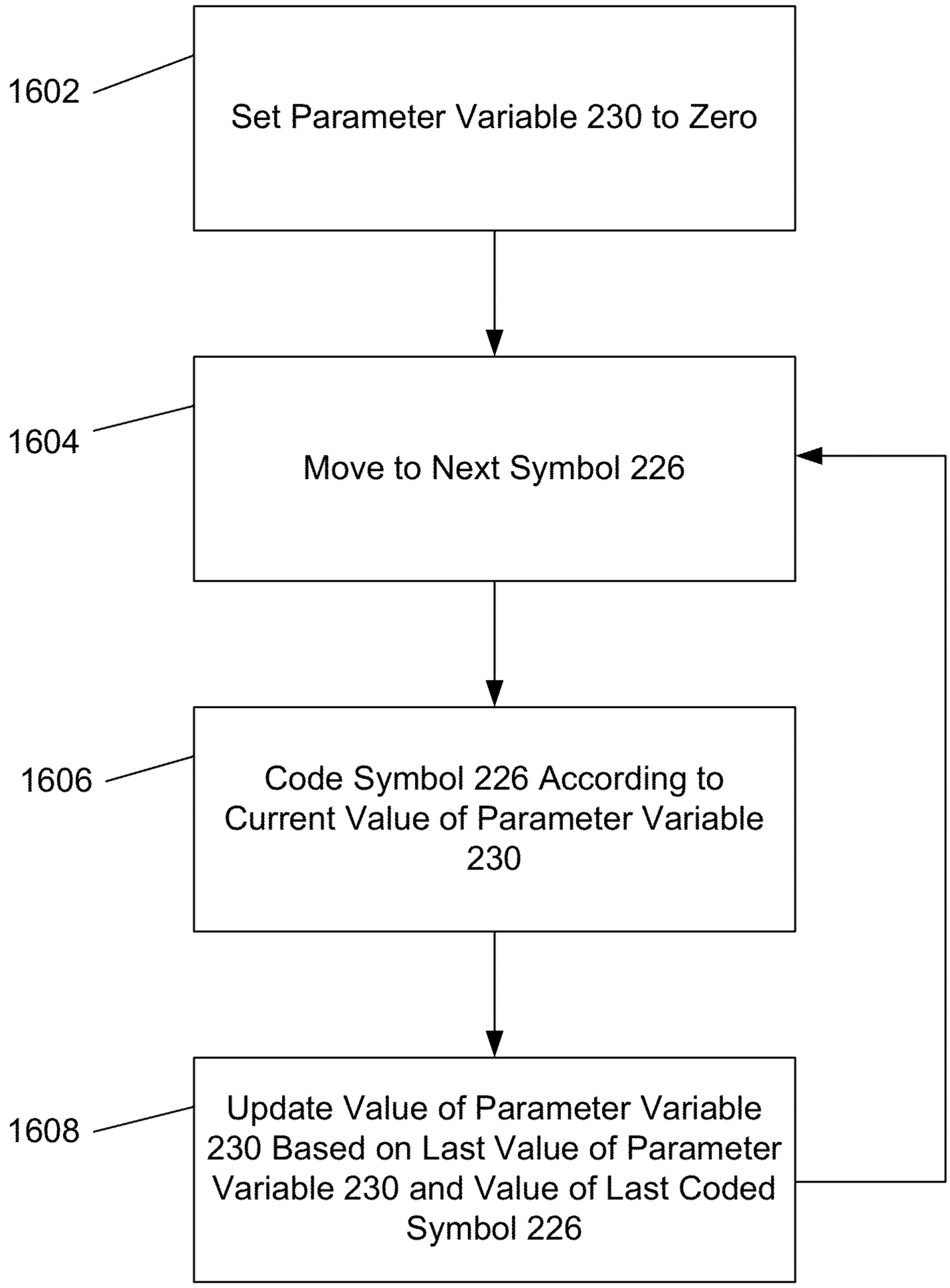
1602
Set Parameter Variable 230 to Zero
1604
Move to Next Symbol 226
1606
Code Symbol 226 According to Current Value of Parameter Variable 230
1608
Update Value of Parameter Variable 230 Based on Last Value of Parameter Variable 230 and Value of Last Coded Symbol 226

FIG. 16

1704

Table 3

226

	coeff_abs_level_minus3[n-1]																
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	1	1	2	2	2	2	2	2	2	2	2	3	3	3
	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 17

1704

Table 4

226

	coeff_abs_level_minus3[n-1]																
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	0	1	1	1	2	2	2	2	2	2	3	3	3	3
	1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 18

1704

Table 5

226

	coeff_abs_level_minus3[n-1]																
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	1	1	1	2	2	2	2	2	2	3	3	3	3	3
	1	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 19

```
cRiceParam = cRiceParam
        + (coeff_abs_level_minus3[n-1] >= 2   &&  cRiceParam == 0)
        + (coeff_abs_level_minus3[n-1] >= 4   &&  cRiceParam <= 1)
        + (coeff_abs_level_minus3[n-1] >= 13  &&  cRiceParam == 0)
        + (coeff_abs_level_minus3[n-1] >= 11  &&  cRiceParam == 1)
        + (coeff_abs_level_minus3[n-1] >= 10  &&  cRiceParam == 2));
```

1702 1702 1702 1702 1702

1706

FIG. 20

```
cRiceParam = cRiceParam
        + (coeff_abs_level_minus3[n-1] >= 3  &&  cRiceParam == 0)
        + (coeff_abs_level_minus3[n-1] >= 6  &&  cRiceParam <= 1)
        + (coeff_abs_level_minus3[n-1] >= 12  &&  cRiceParam <= 2);
```

1702 1702 1702

1706

FIG. 21

```
cRiceParam = cRiceParam
        + (coeff_abs_level_minus3[n-1] >= 2   &&  cRiceParam == 0)
        + (coeff_abs_level_minus3[n-1] >= 5   &&  cRiceParam <= 1)
        + (coeff_abs_level_minus3[n-1] >= 11  &&  cRiceParam <= 2);
```

1702 1702 1702

1706

FIG. 22

1704

Table 6

226

	coeff_abs_level_minus3[n-1]															
		0	…	…	…	A	…	…	…	B	…	…	…	≥C	…	…
Previous cRiceParam	0	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3
	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 23

```
cRiceParam = cRiceParam                                                    1702
           + (coeff_abs_level_minus3[n-1] >= A  &&  cRiceParam == 0)      1702
           + (coeff_abs_level_minus3[n-1] >= B  &&  cRiceParam <= 1)      1702
           + (coeff_abs_level_minus3[n-1] >= C  &&  cRiceParam <= 2);
```

FIG. 24

1704

Table 7

226

	coeff_abs_level_minus3[n-1]																
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	1	1	2	2	2	2	2	2	2	2	2	3	3	3
	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 25

```
cRiceParam = cRiceParam                                                    1702
        + (coeff_abs_level_minus3[n-1] >= 2   &&  cRiceParam == 0)
        + (coeff_abs_level_minus3[n-1] >= 4   &&  cRiceParam <= 1)         1702
        + (coeff_abs_level_minus3[n-1] >= 12  &&  cRiceParam <= 2);        1702
```

1706

FIG. 26

1704

Table 8

226

	coeff_abs_level_minus3[n-1]																
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	1	1	2	2	2	2	2	2	2	2	3	3	3	3
	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 27

```
cRiceParam = cRiceParam                                                    1702
        + (coeff_abs_level_minus3[n-1] >= 2  &&  cRiceParam == 0)
        + (coeff_abs_level_minus3[n-1] >= 4  &&  cRiceParam <= 1)          1702
        + (coeff_abs_level_minus3[n-1] >= 13 &&  cRiceParam <= 2);         1702
```

1706

FIG. 28

1704

Table 9

226

		coeff_abs_level_minus3[n-1]															
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	1	1	2	2	2	2	2	2	2	2	2	3	3	3
	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 29

```
cRiceParam = cRiceParam
                + (coeff_abs_level_minus3[n-1] >= 2   &&  cRiceParam == 0)
                + (coeff_abs_level_minus3[n-1] >= 4   &&  cRiceParam <= 1)
                + (coeff_abs_level_minus3[n-1] >= 11  &&  cRiceParam <= 2);
```

1702 1702 1702

1706

FIG. 30

1704

Table 10

226

		coeff_abs_level_minus3[n-1]															
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	≥15
Previous cRiceParam	0	0	0	1	1	2	2	2	2	2	2	3	3	3	3	3	3
	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3
	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3
	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

230 230

FIG. 31

```
cRiceParam = cRiceParam
                + (coeff_abs_level_minus3[n-1] >= 2  &&  cRiceParam == 0)
                + (coeff_abs_level_minus3[n-1] >= 4  &&  cRiceParam <= 1)
                + (coeff_abs_level_minus3[n-1] >= 10 &&  cRiceParam <= 2);
```

1702 1702 1702

1706

FIG. 32

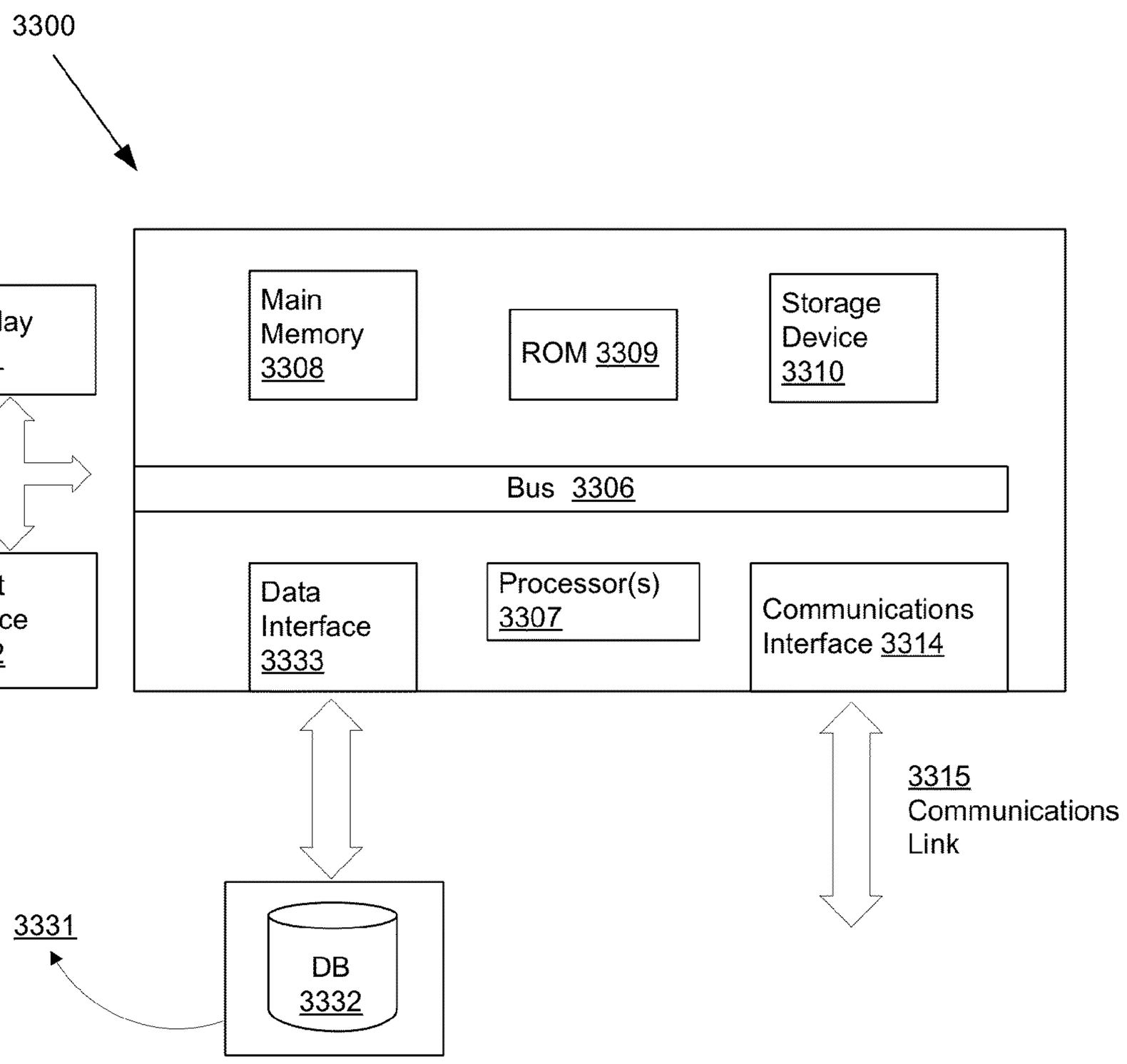
3300
Display 3311
Main Memory 3308
ROM 3309
Storage Device 3310
Bus 3306
Input Device 3312
Data Interface 3333
Processor(s) 3307
Communications Interface 3314
3315 Communications Link
3331
DB 3332

FIG. 33

METHOD OF DETERMINING BINARY CODEWORDS FOR TRANSFORM COEFFICIENTS

CROSS REFERENCE TO RELATED APPLICATIONS

This Application claims priority under 35 U.S.C. §119(e) from: earlier filed U.S. Provisional Application Ser. No. 61/556,826, filed Nov. 8, 2011; earlier filed U.S. Provisional Application Ser. No. 61/563,774, filed Nov. 26, 2011; and earlier filed U.S. Provisional Application Ser. No. 61/564,248, filed Nov. 28, 2011, the entirety of which are incorporated herein by reference.

BACKGROUND

1. Technical Field

The present disclosure relates to the field of video compression, particularly video compression using High Efficiency Video Coding (HEVC) that employ block processing.

2. Related Art

FIG. **1** depicts a content distribution system **100** comprising a coding system **110** and a decoding system **140** that can be used to transmit and receive HEVC data. In some embodiments, the coding system **110** can comprise an input interface **130**, a controller **111**, a counter **112**, a frame memory **113**, an encoding unit **114**, a transmitter buffer **115** and an output interface **135**. The decoding system **140** can comprise a receiver buffer **150**, a decoding unit **151**, a frame memory **152** and a controller **153**. The coding system **110** and the decoding system **140** can be coupled with each other via a transmission path which can carry a compressed bitstream **105**. The controller **111** of the coding system **110** can control the amount of data to be transmitted on the basis of the capacity of the receiver buffer **150** and can include other parameters such as the amount of data per a unit of time. The controller **111** can control the encoding unit **114** to prevent the occurrence of a failure of a received signal decoding operation of the decoding system **140**. The controller **111** can be a processor or include, by way of a non-limiting example, a microcomputer having a processor, a random access memory and a read only memory.

Source pictures **120** supplied from, by way of a non-limiting example, a content provider can include a video sequence of frames including source pictures in a video sequence. The source pictures **120** can be uncompressed or compressed. If the source pictures **120** are uncompressed, the coding system **110** can have an encoding function. If the source pictures **120** are compressed, the coding system **110** can have a transcoding function. Coding units can be derived from the source pictures utilizing the controller **111**. The frame memory **113** can have a first area that can be used for storing the incoming frames from the source pictures **120** and a second area that can be used for reading out the frames and outputting them to the encoding unit **114**. The controller **111** can output an area switching control signal **123** to the frame memory **113**. The area switching control signal **123** can indicate whether the first area or the second area is to be utilized.

The controller **111** can output an encoding control signal **124** to the encoding unit **114**. The encoding control signal **124** can cause the encoding unit **114** to start an encoding operation, such as preparing the Coding Units based on a source picture. In response to the encoding control signal **124** from the controller **111**, the encoding unit **114** can begin to read out the prepared Coding Units to a high-efficiency encoding process, such as a prediction coding process or a transform coding process which process the prepared Coding Units generating video compression data based on the source pictures associated with the Coding Units.

The encoding unit **114** can package the generated video compression data in a packetized elementary stream (PES) including video packets. The encoding unit **114** can map the video packets into an encoded video signal **122** using control information and a program time stamp (PTS) and the encoded video signal **122** can be transmitted to the transmitter buffer **115**.

The encoded video signal **122**, including the generated video compression data, can be stored in the transmitter buffer **115**. The information amount counter **112** can be incremented to indicate the total amount of data in the transmitter buffer **115**. As data is retrieved and removed from the buffer, the counter **112** can be decremented to reflect the amount of data in the transmitter buffer **115**. The occupied area information signal **126** can be transmitted to the counter **112** to indicate whether data from the encoding unit **114** has been added or removed from the transmitted buffer **115** so the counter **112** can be incremented or decremented. The controller **111** can control the production of video packets produced by the encoding unit **114** on the basis of the occupied area information **126** which can be communicated in order to anticipate, avoid, prevent, and/or detect an overflow or underflow from taking place in the transmitter buffer **115**.

The information amount counter **112** can be reset in response to a preset signal **128** generated and output by the controller **111**. After the information counter **112** is reset, it can count data output by the encoding unit **114** and obtain the amount of video compression data and/or video packets which have been generated. The information amount counter **112** can supply the controller **111** with an information amount signal **129** representative of the obtained amount of information. The controller **111** can control the encoding unit **114** so that there is no overflow at the transmitter buffer **115**.

In some embodiments, the decoding system **140** can comprise an input interface **170**, a receiver buffer **150**, a controller **153**, a frame memory **152**, a decoding unit **151** and an output interface **175**. The receiver buffer **150** of the decoding system **140** can temporarily store the compressed bitstream **105**, including the received video compression data and video packets based on the source pictures from the source pictures **120**. The decoding system **140** can read the control information and presentation time stamp information associated with video packets in the received data and output a frame number signal **163** which can be applied to the controller **153**. The controller **153** can supervise the counted number of frames at a predetermined interval. By way of a non-limiting example, the controller **153** can supervise the counted number of frames each time the decoding unit **151** completes a decoding operation.

In some embodiments, when the frame number signal **163** indicates the receiver buffer **150** is at a predetermined capacity, the controller **153** can output a decoding start signal **164** to the decoding unit **151**. When the frame number signal **163** indicates the receiver buffer **150** is at less than a predetermined capacity, the controller **153** can wait for the occurrence of a situation in which the counted number of frames becomes equal to the predetermined amount. The controller **153** can output the decoding start signal **164** when the situation occurs. By way of a non-limiting example, the controller **153** can output the decoding start signal **164** when the frame number signal **163** indicates the receiver buffer **150** is at the predetermined capacity. The encoded video packets and video compression data can be decoded in a monotonic order

(i.e., increasing or decreasing) based on presentation time stamps associated with the encoded video packets.

In response to the decoding start signal **164**, the decoding unit **151** can decode data amounting to one picture associated with a frame and compressed video data associated with the picture associated with video packets from the receiver buffer **150**. The decoding unit **151** can write a decoded video signal **162** into the frame memory **152**. The frame memory **152** can have a first area into which the decoded video signal is written, and a second area used for reading out decoded pictures **160** to the output interface **175**.

In various embodiments, the coding system **110** can be incorporated or otherwise associated with a transcoder or an encoding apparatus at a headend and the decoding system **140** can be incorporated or otherwise associated with a downstream device, such as a mobile device, a set top box or a transcoder.

The coding system **110** and decoding system **140** can be utilized separately or together to encode and decode video data according to various coding formats, including High Efficiency Video Coding (HEVC). HEVC is a block based hybrid spatial and temporal predictive coding scheme. In HEVC, input images, such as video frames, can be divided into square blocks called Largest Coding Units (LCUs) **200**, as shown in FIG. **2**. LCUs **200** can each be as large as 128×128 pixels, unlike other coding schemes that break input images into macroblocks of 16×16 pixels. As shown in FIG. **3**, each LCU **200** can be partitioned by splitting the LCU **200** into four Coding Units (CUs) **202**. CUs **202** can be square blocks each a quarter size of the LCU **200**. Each CU **202** can be further split into four smaller CUs **202** each a quarter size of the larger CU **202**. By way of a non-limiting example, the CU **202** in the upper right corner of the LCU **200** depicted in FIG. **3** can be divided into four smaller CUs **202**. In some embodiments, these smaller CUs **202** can be further split into even smaller sized quarters, and this process of splitting CUs **202** into smaller CUs **202** can be completed multiple times.

With higher and higher video data density, what is needed are further improved ways to code the CUs so that large input images and/or macroblocks can be rapidly, efficiently and accurately encoded and decoded.

SUMMARY

The present invention provides an improved system for HEVC. In embodiments for the system, a method of determining binary codewords for transform coefficients in an efficient manner is provided. Codewords for the transform coefficients within transform units (TUs) that are subdivisions of the CUs **202** are used in encoding input images and/or macroblocks.

In one embodiment, a method is provided that comprises providing a transform unit including one or more subsets of transform coefficients, each transform coefficient having a quantized value, determining a symbol for each transform coefficient having a quantized value equal to or greater than a threshold value by subtracting the threshold value from the quantized value of the transform coefficient, providing a parameter variable set to an initial value of zero, converting each symbol into a binary codeword based on the current value of the parameter variable and the value of the symbol, and updating the value of the parameter variable with a new current value after each symbol has been converted, the new current value being based at least in part on the last value of the parameter variable and the value of the last converted symbol in the current or previous subset.

In another embodiment, the invention includes a method of determining binary codewords for transform coefficients that uses a look up table to determine the transform coefficients. The method comprises providing a transform unit comprising one or more subsets of transform coefficients, each transform coefficient having a quantized value, determining a symbol for each transform coefficient having a quantized value equal to or greater than a threshold value, by subtracting the threshold value from the quantized value of the transform coefficient, providing a parameter variable set to an initial value of zero, converting each symbol into a binary codeword based on the current value of the parameter variable and the value of the symbol, looking up a new current value from a table based on the last value of the parameter variable and the value of the last converted symbol, and replacing the value of the parameter variable with the new current value.

In another embodiment, the invention includes a method of determining binary codewords for transform coefficients that uses one or more mathematical conditions that can be performed using logic rather than requiring a look up table. The method comprises providing a transform unit comprising one or more subsets of transform coefficients, each transform coefficient having a quantized value, determining a symbol for each transform coefficient having a quantized value equal to or greater than a threshold value, by subtracting the threshold value from the quantized value of the transform coefficient, providing a parameter variable set to an initial value of zero, converting each symbol into a binary codeword based on the current value of the parameter variable and the value of the symbol, determining whether the last value of the parameter variable and the value of the last converted symbol together satisfy one or more conditions, and mathematically adding an integer of one to the last value of the parameter variable for each of the one or more conditions that is satisfied.

BRIEF DESCRIPTION OF THE DRAWINGS

Further details of the present invention are explained with the help of the attached drawings in which:

FIG. **1** depicts an embodiment of a content distribution system.

FIG. **2** depicts an embodiment of an input image divided into Large Coding Units.

FIG. **3** depicts an embodiment of a Large Coding Unit divided into Coding Units.

FIG. **4** depicts a quadtree representation of a Large Coding Unit divided into Coding Units.

FIG. **5** depicts possible exemplary arrangements of Prediction Units within a Coding Unit.

FIG. **6** depicts a block diagram of an embodiment of a method for encoding and/or decoding a Prediction Unit.

FIG. **7** depicts an exemplary embodiment of a Coding Unit divided into Prediction Units and Transform Units.

FIG. **8** depicts an exemplary embodiment of a quadtree representation of a Coding Unit divided into Transform Units.

FIG. **9** depicts an embodiment of a method of performing context-based adaptive binary arithmetic coding.

FIG. **10** depicts an exemplary embodiment of a significance map.

FIG. **11** depicts an embodiment of a reverse zig-zag scan of transform coefficients within a Transform Unit and subsets of transform coefficients.

FIG. **12** depicts an embodiment of a method of obtaining coefficient levels and symbols for transform coefficients.

FIG. **13** depicts an embodiment of the scanning order of transform coefficients within subsets.

FIG. **14** depicts exemplary embodiments of maximum symbol values for associated parameter variables.

FIG. **15** depicts an exemplary embodiment of a table for converting symbols into binary codewords based on parameter variables.

FIG. **16** depicts an embodiment of a method for coding symbols and updating parameter variables.

FIG. **17** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 2, 4, 13, 11, and 10.

FIG. **18** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 3, 6, and 12.

FIG. **19** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 2, 5, and 11.

FIG. **20** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of 2, 4, 13, 11, and 10.

FIG. **21** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of 3, 6, and 12.

FIG. **22** depicts exemplary code that can be used to update the parameter variable based on conditional symbol thresholds of 2, 5, and 11.

FIG. **23** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of A, B, and C.

FIG. **24** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of A, B, and C.

FIG. **25** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 2, 4, and 12.

FIG. **26** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of 2, 4, and 12.

FIG. **27** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 2, 4, and 13.

FIG. **28** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of 2, 4, and 13.

FIG. **29** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 2, 4, and 11.

FIG. **30** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of 2, 4, and 11.

FIG. **31** depicts an exemplary embodiment of a low complexity updating table with conditional symbol thresholds of 2, 4, and 10.

FIG. **32** depicts an exemplary embodiment of a combination logic representation of conditions for conditional symbol thresholds of 2, 4, and 10.

FIG. **33** depicts an exemplary embodiment of computer hardware.

DETAILED DESCRIPTION

In HEVC, an input image, such as a video frame, is broken up into CUs that are then identified in code. The CUs are then further broken into sub-units that are coded as will be described subsequently.

Initially for the coding a quadtree data representation can be used to describe the partition of a LCU **200**. The quadtree representation can have nodes corresponding to the LCU **200** and CUs **202**. At each node of the quadtree representation, a flag "1" can be assigned if the LCU **200** or CU **202** is split into four CUs **202**. If the node is not split into CUs **202**, a flag "0" can be assigned. By way of a non-limiting example, the quadtree representation shown in FIG. **4** can describe the LCU partition shown in FIG. **3**, in which the LCU **200** is split into four CUs **202**, and the second CU **202** is split into four smaller CUs **202**. The binary data representation of the quadtree can be a CU split flag that can be coded and transmitted as overhead, along with other data such as a skip mode flag, merge mode flag, and the PU coding mode described subsequently. By way of a non-limiting example, the CU split flag quadtree representation shown in FIG. **4** can be coded as the binary data representation "10100."

At each leaf of the quadtree, the final CUs **202** can be broken up into one or more blocks called prediction units (PUs) **204**. PUs **204** can be square or rectangular. A CU **202** with dimensions of 2N×2N can have one of the four exemplary arrangements of PUs **204** shown in FIG. **5**, with PUs **204** having dimensions of 2N×2N, 2N×N, N×2N, or N×N.

A PU can be obtained through spatial or temporal prediction. Temporal prediction is related to inter mode pictures. Spatial prediction relates to intra mode pictures. The PUs **204** of each CU **202** can, thus, be coded in either intra mode or inter mode. Features of coding relating to intra mode and inter mode pictures is described in the paragraphs to follow.

Intra mode coding can use data from the current input image, without referring to other images, to code an I picture. In intra mode the PUs **204** can be spatially predictive coded. Each PU **204** of a CU **202** can have its own spatial prediction direction. Spatial prediction directions can be horizontal, vertical, 45-degree diagonal, 135 degree diagonal, DC, planar, or any other direction. The spatial prediction direction for the PU **204** can be coded as a syntax element. In some embodiments, brightness information (Luma) and color information (Chroma) for the PU **204** can be predicted separately. In some embodiments, the number of Luma intra prediction modes for 4×4, 8×8, 16×16, 32×32, and 64×64 blocks can be 18, 35, 35, 35, and 4 respectively. In alternate embodiments, the number of Luma intra prediction modes for blocks of any size can be 35. An additional mode can used for the Chroma intra prediction mode. In some embodiments, the Chroma prediction mode can be called "IntraFromLuma."

Inter mode coding can use data from the current input image and one or more reference images to code "P" pictures and/or "B" pictures. In some situations and/or embodiments, inter mode coding can result in higher compression than intra mode coding. In inter mode PUs **204** can be temporally predictive coded, such that each PU **204** of the CU **202** can have one or more motion vectors and one or more associated reference images. Temporal prediction can be performed through a motion estimation operation that searches for a best match prediction for the PU **204** over the associated reference images. The best match prediction can be described by the motion vectors and associated reference images. P pictures use data from the current input image and one or more previous reference images. B pictures use data from the current input image and both previous and subsequent reference images, and can have up to two motion vectors. The motion vectors and reference pictures can be coded in the HEVC bitstream. In some embodiments, the motion vectors can be coded as syntax elements "MV," and the reference pictures can be coded as syntax elements "refIdx." In some embodiments, inter mode coding can allow both spatial and temporal predictive coding.

FIG. **6** depicts a block diagram of how a PU **204**, x, can be encoded and/or decoded. At **606** a predicted PU **206**, x', that

is predicted by intra mode at **602** or inter mode at **604**, as described above, can be subtracted from the current PU **204**, x, to obtain a residual PU **208**, e. At **608** the residual PU **208**, e, can be transformed with a block transform into one or more transform units (TUs) **210**, E. Each TU **210** can comprise one or more transform coefficients **212**. In some embodiments, the block transform can be square. In alternate embodiments, the block transform can be non-square.

As shown in FIG. **7**, in HEVC, a set of block transforms of different sizes can be performed on a CU **202**, such that some PUs **204** can be divided into smaller TUs **210** and other PUs **204** can have TUs **210** the same size as the PU **204**. Division of CUs **202** and PUs **204** into TUs **210** can be shown by a quadtree representation. By way of a non-limiting example, the quadtree representation shown in FIG. **8** depicts the arrangement of TUs **210** within the CU **202** shown in FIG. **7**.

Referring back to FIG. **6**, at **610** the transform coefficients **212** of the TU **210**, E, can be quantized into one of a finite number of possible values. In some embodiments, this is a lossy operation in which data lost by quantization may not be recoverable. After the transform coefficients **212** have been quantized, at **612** the quantized transform coefficients **212** can be entropy coded, as discussed below, to obtain the final compression bits **214**.

At **614** the quantized transform coefficients **212** can be dequantized into dequantized transform coefficients **216** E'. At **616** the dequantized transform coefficients **216** E' can then be inverse transformed to reconstruct the residual PU **218**, e'. At **618** the reconstructed residual PU **218**, e', can then be added to a corresponding prediction PU **206**, x', obtained through either spatial prediction at **602** or temporal prediction at **604**, to obtain a reconstructed PU **220**, x". At **620** a deblocking filter can be used on reconstructed PUs **220**, x", to reduce blocking artifacts. At **620** a sample adaptive offset process is also provided that can be conditionally performed to compensate the pixel value offset between reconstructed pixels and original pixels. Further, at **620**, an adaptive loop filter can be conditionally used on the reconstructed PUs **220**, x", to reduce or minimize coding distortion between input and output images.

If the reconstructed image is a reference image that will be used for future temporal prediction in inter mode coding, the reconstructed images can be stored in a reference buffer **622**. Intra mode coded images can be a possible point where decoding can begin without needing additional reconstructed images.

HEVC can use entropy coding schemes during step **612** such as context-based adaptive binary arithmetic coding (CABAC). The coding process for CABAC is shown in FIG. **9**. At **902**, the position of the last significant transform coefficient of the transform units **210** can be coded. Referring back to FIG. **6**, the quantized transform coefficients are created by quantizing the TUs **210**. Transform coefficients **212** can be significant or insignificant. FIG. **10** shows a significance map **1002** of the transform coefficients **212**. Insignificant transform coefficients **212** can have a quantized value of zero, while significant transform coefficients **212** can have a quantized value of one or more. In some embodiments, significant transform coefficients **212** can also be known as non-zero quantized transform coefficients **212**. If a TU **210** comprises one or more significant transform coefficients **212**, the coordinates of the last significant transform coefficient **212** along a forward zig-zag coding scan from the top left corner of the TU **210** to the lower right corner of the TU **210**, as shown in FIG. **10**, can be coded. In alternate embodiments, the significant transform coefficients **212** can be scanned along an inverse wavefront scan, inverse horizontal scan, inverse vertical scan, or any other scan order. In some embodiments, these coordinates can be coded as the syntax elements "last_significant_coeff_y" and "last_significant_coeff_x." By way of a non-limiting example, FIG. **10** depicts the position of the last significant transform **212***b* within a TU **210** which is being coded in block **902** of FIG. **9**.

At block **904** in FIG. **9**, the significance map **1002** can be coded to indicate the positions of each of the significant transform coefficients **212** in the TU **210**. A significance map **1002** can comprise a binary element for each position in the TU **210**. The binary element can be coded as "0" to indicate that the transform coefficient **212** at that position is not significant. The binary element can be coded as "1" to indicate that the transform coefficient **212** at that position is significant.

FIG. **11** illustrates how the quantized transform coefficients **212** of the TUs **210** can be divided into groups. In some embodiments, the groups can be sub-blocks. Sub-blocks can be square blocks of 16 quantized transform coefficients **212**. In other embodiments, the groups can be subsets **1102**. Subsets **1102** can comprise 16 quantized transform coefficients **212** that are consecutive along the scan order of a backwards zig-zag scan, as shown in FIG. **11**. The first subset can be the subset **1102** that includes the last significant transform coefficient **212***b*, regardless of where the last significant transform coefficient **212***b* is within the subset. By way of a non-limiting example, the last significant transform coefficient **212***b* can be the 14th transform coefficient **212** in the subset, followed by two insignificant transform coefficients.

In some situations and/or embodiments, there can be one or more groups of 16 quantized transform coefficients **212** that do not contain a significant transform coefficient along the reverse scan order prior to the group containing the last significant transform coefficient **212***b*. In these situations and/or embodiments, the first subset can be the subset **1102** containing the last significant transform coefficient **212***b*, and any groups before the first subset **1102** are not considered part of a subset **1102**. By way of a non-limiting example, in FIG. **11**, the first subset **1102** "Subset 0" is the second grouping of 16 transform coefficients **212** along the reverse zig-zap scan order, while the group of 16 transform coefficients **212** at the lower right corner of the TU **210** are not part of a subset **1102** because none of those transform coefficients **212** are significant. In some embodiments, the first subset **1102** can be denoted as "subset 0," and additional subsets **1102** can be denoted as "subset 1," "subset 2," up to "subset N." The last subset **1102** can be the subset **1102** with the DC transform coefficient **212** at position 0, 0 at the upper left corner of the TU **210**.

Referring back to FIG. **9** in the last block **906**, each quantized transform coefficient **212** can be coded into binary values to obtain final compression bits **214** shown in FIG. **6**, including coding for significant coefficient levels. During coding the absolute value of each quantized transform coefficient **212** can be coded separately from the sign of the quantized transform coefficient **212**. FIG. **12** illustrates coding steps that deal with taking an absolute value of the quantized transform coefficients. As shown in FIG. **12**, at **1202** the absolute value of each quantized transform coefficient **212** can be taken to enable obtaining the coefficient level **222** for that quantized transform coefficient **212** at block **1204**.

The coefficient levels **222** obtained at block **1204** that are expected to occur with a higher frequency can be coded before coefficient levels **222** that are expected to occur with lower frequencies. By way of a non-limiting example, in some embodiments coefficient levels **222** of 0, 1, or 2 can be expected to occur most frequently. Coding the coefficient

levels **222** in three parts can identify the most frequently occurring coefficient levels **222**, leaving more complex calculations for the coefficient levels **222** that can be expected to occur less frequently. In some embodiments, this can be done by coding the coefficient levels **222** in three parts. First, the coefficient level **222** of a quantized transform coefficient **212** can be checked to determine whether it is greater than one. If the coefficient level **222** is greater than one, the coefficient level **222** can be checked to determine whether it is greater than two.

At **1206** in FIG. **12**, if the coefficient level **222** is greater than two, the coefficient level **222** can be subtracted by a threshold value **224** of three to obtain a symbol. By way of a non-limiting example, in some embodiments, the coefficient level **222** can be coded as three variables: "coeff_abs_level_greater1_flag," "coeff_abs_level_greater2_flag," and "coeff_abs_level_minus3." For quantized transform coefficients **212** with a coefficient level **222** of two or more, "coeff_abs_level_greater1_flag" can be set to "1." If "coeff_abs_level_greater1_flag" is set to "1" and the quantized transform coefficient **212** also has a coefficient level **222** of three or more, "coeff_abs_level_greater2_flag" can be set to "1." If "coeff_abs_level_greater2_flag" is set to "1," the threshold value **224** of three can be subtracted from the coefficient level **222** to get the quantized transform coefficient's symbol **226**, coded as "coeff_abs_level_minus3." In alternate embodiments, the coefficient level **222** can be coded in a different number of parts, and/or the threshold value **224** can be an integer other than three.

For the quantized transform coefficients **212** that occur less frequently and have coefficient levels **222** of three or more as determined in the blocks of FIG. **12**, as determined in the blocks of FIG. **12**, the quantized transform coefficient's symbol **226** can be converted to a binary codeword **228** that can be part of the final compression bits **214** generated as shown in FIG. **6**.

FIG. **13** illustrates how each symbol **226** can be coded by scanning through each subset **1102** and converting each symbol **226** of the subset **1102** in order according to the value of the parameter variable **230**, and then moving to the symbols **226** of the next subset **1102**. The conversion to a binary codeword **228** can be performed with Truncated Rice code alone, or with a combination of Truncated Rice code and 0th order exponential-Golomb (Exp-Golomb) code. The Truncated Rice code can obtain a binary codeword **228** based a parameter variable **230** and the symbol **226**. A diagram showing this coding progression is shown in FIG. **13** for the subsets 0 and 1 along the zig-zag lines of FIG. **11**. In some embodiments, the current scanning position can be denoted by "n."

Referring to FIG. **15**, the parameter variable **230** can be a global variable that can be updated as each symbol **226** is coded. The parameter variable **230** can control the flatness of the codeword distribution. In some embodiments, the parameter variable **230** can be any integer between 0 and N. By way of a non-limiting example, in some embodiments N can be 3, such that the parameter variable **230** can be 0, 1, 2, or 3. In some embodiments, the parameter variable **230** can be denoted as "cRiceParam" as illustrated in FIG. **15** as well as FIG. **14**.

Referring still to FIG. **14**, each parameter variable **230** can have an associated maximum symbol value **232** that denotes the truncation point for the Truncated Rice code. In some embodiments, the maximum symbol value **232** for a particular parameter variable **230** can be denoted as "cTRMax" **232** as illustrated in FIG. **14** which depicts an exemplary table of maximum symbol values **232** "cTRMax" for parameter variables **230** "cRiceParam." The table of FIG. **14** is labeled as Table 1, as it provides a first listing cRiceParam values **230** relative to maximum value symbols cTRMax **232**. If the symbol **226** of FIG. **15** is less than or equal to the maximum symbol value **232** for the parameter variable **230**, the symbol **226** can be converted into a binary codeword **228** using only Truncated Rice code. If the symbol **226** is greater than the maximum symbol value **232** for the parameter variable **230**, the binary codeword **228** can be generated using a combination of the Truncated Rice code and Exp-Golomb code, with the Truncated Rice codeword for the maximum symbol value **232** being concatenated with the 0th order Exp-Golomb code for the symbol **226** minus the maximum symbol value **232** minus one. By way of a non-limiting example, FIG. **15** depicts an exemplary table of binary codewords **228** generated based on symbols **226** and parameter variables **230**. Since FIG. **15** provides a second table listing cRiceParam parameter variables **230** relative to other values, it is labeled as Table 2.

In some situations and/or embodiments, converting the symbol **226** according to Truncated Rice code with a lower parameter variable **230** can result in a binary codeword **228** having fewer bits than converting the same symbol **226** according to Truncated Rice code with a higher parameter variable **230**. By way of a non-limiting example, as shown by the table depicted in FIG. **15**, using a parameter variable **230** of 0 to convert a symbol **226** of 0 can result in the binary codeword **228** of "0" having 1 bit, while using the parameter variable **230** of 1 to convert the symbol **226** of 0 can result in the binary codeword **228** of "00" having 2 bits.

In other situations and/or embodiments, converting the symbol **226** according to Truncated Rice code with a higher parameter variable **230** can result in a binary codeword **228** having fewer bits than converting the same symbol **226** according to Truncated Rice code with a lower parameter variable **230**. By way of a non-limiting example, as shown in the table depicted in FIG. **14**, using a parameter variable **230** of 0 to convert a symbol **226** of 6 can result in the binary codeword **228** of "1111110" having 7 bits, while using the parameter variable **230** of 2 to convert the symbol **226** of 6 can result in the binary codeword **228** of "1010" having 4 bits.

FIG. **16** is a flow chart depicting a method for entropy coding the symbols **226**. At **1602**, for each TU **210**, the parameter variable **230** can be initially set to a value of zero. At **1604** the coding system **110** can move to the next symbol **226**. In some situations and/or embodiments, the next symbol **226** can be the first symbol **226** in the first subset **1102** as illustrated in FIG. **11**. At **1606**, the symbol **226** can be coded with Truncated Rice and/or Exp-Golomb code using the current value of the parameter variable **230**. At **1608**, the parameter variable **230** can be updated based on the last value of the parameter variable **230** and the value of the last symbol **226** that was coded. In some situations and/or embodiments, the updated value of the parameter variable **230** can be the same as the last value of the parameter variable **230**. In other situations and/or embodiments, the updated value of the parameter variable **230** can be greater than the last value of the parameter variable **230**. The parameter variable **230** can be updated based upon calculations or upon values derived from a table as described herein subsequently.

After the parameter variable **230** has been updated at **1608**, the coding system **110** can return to **1604** and move to the next symbol **226**. The next symbol **226** can be in the current subset **1102** or in the next subset **1102**. The next symbol **226** can then be coded at **1606** using the updated value of the parameter variable **230** and the process can repeat for all remaining symbols **226** in the TU **210**. In some embodiments, when

symbols **226** in a subsequent subset **1102** are coded, the parameter variable **230** can be updated based on the last value of the parameter variable **230** from the previous subset **1102**, such that the parameter variable **230** is not reset to zero at the first symbol **226** of each subset **1102**. In alternate embodiments, the parameter variable **230** can be set to zero at the first symbol **226** of each subset **1102**.

Generally referring to FIG. **15**, Truncated Rice code with a smaller cRiceParam parameter value **230** can be preferred to code the symbols with smaller codewords, as they need fewer bits to represent. For example, if a symbol **226** has a value of 0, using Truncated Rice code with a cRiceParam parameter value **230** equal to 0, only 1 bit is needed, but 2, 3, or 4 bits are needed when the cRiceParam value is 2, 3, or 4, respectively. If a symbol has a value of 6, using Truncated Rice code with a cRiceParam value equal to 0, 7 bits are needed. But 5, 4, or 4 bits are needed when the cRiceParam value is 2, 3, or 4, respectively.

In one embodiment illustrated with the table of FIG. **17**, the cRiceParam **230** labeled with a variable coeff_level_minus3[n] is derived and updated based on a table as follows. For a TU subset, the cRiceParam **230** is initially set to 0, and is then updated based on the previous cRiceParam and the coeff_abs_level_minus3[n−1] according to the table of FIG. **17**. Because FIG. **17** shows a third table listing symbol values **226** relative to cRiceParam parameter values **230**, the table is labeled as Table 3. Subsequent tables showing a similar comparison will, likewise, be labeled consecutively.

Note that in conventional implementations, cRiceParam **230** is reset once per subset with initial "0" values. For a TU with more than one subset of 16 consecutive symbol coefficients **226**, the cRiceParam calculation for coeff_abs_level_minus3 can be reset to 0 for each subset, which favors smaller symbol value coding. Generally, inside each TU, starting from the last non-zero quantized transform coefficient, the absolute values of the non-zero quantized transform coefficients tend to get larger and larger. Therefore, resetting cRiceParam to 0 for each subset might not give optimal compression performance.

In FIG. **13**, each circle stands for a quantized transform coefficient and the number inside each circle is the value of coeff_abs_level_minus3. If it is "NA", it means there is no syntax of coeff_abs_level_minus3 for that coefficient. Following the reverse scanning pattern, the values of coeff_abs_level_minus3 tend to get larger within each subset and also from subset to subset, as shown in the example of FIG. **13**. In the example, cRiceParam is set to 2 for "5" in subset 0, and with cRiceParam set to 2, the value of "5" is binarized into a codeword of "1001", or 4 bits, as shown in Table 2 of FIG. **15**. In conventional implementations, cRiceParam is then reset to 0 in subset 1. Now, with the reset cRiceParam of 0, the same value of "5" in subset 1 is now binarized into a codeword of 111110, or 6 bits, as shown in Table 2. Clearly, this resetting process not only introduces additional checking operations, but also can possibly result in inferior coding performance.

Tables 4 and 5 as illustrated in respective FIGS. **18** and **19** depict alternate embodiments on an update table. For these and other embodiments, the cRiceParam parameters **230** are derived as follows. First, for a TU, cRiceParam is initially set to 0, and is then updated based on the previous cRiceParam and coeff_abs_level_minus3[n−1] according to a cRiceParam update table, such as Tables 4 and 5. In these embodiments, cRiceParam is only reset once per TU, and not per subset of a TU as indicated with respect to the embodiment using Table 3.

By not resetting the cRiceParam to 0 at each subset, the operations of resetting for each subset are saved and once the cRiceParam reaches 3, the symbols will always be binarized with the same set truncated rice codes (cRiceParam equals 3), which can reduce hardware complexity.

Note that Table 5 of FIG. **19** is generated from Table 2 of FIG. **15** by analyzing the number of bits needed for each symbol **226** with a different cRiceParam value **230** while assuming the next level value is statistically no smaller than the current level along a reverse scan. For example, if the current symbol **226** is 2 and the cRiceParam is 0, the chance that the next symbol is larger than 2 is high and applying Truncated Rice code with cRiceParam equal to 1 might reduce the number of bits. If the current symbol is 5 and cRiceParam is 1, the chance that the next symbol is larger than 5 is high and applying Truncated Rice code with cRiceParam equal to 2 might reduce the number of bits. If the current symbol is 11 and the cRiceParam is 2, the chance that the next symbol is larger than 11 is high and applying Truncated Rice code with cRiceParam equal to 3 might reduce the number of bits.

In some embodiments, updating the parameter variable **230** at **1608**, referring back to FIG. **16**, can be determined from a comparison equation rather than a table. In the comparison, it is determined whether both the last value of the parameter variable **230** and the value of the last coded symbol **226** meet one or more conditions **1702**, as illustrated in FIG. **20**. In some embodiments, the value of the last coded symbol **226** can be denoted as "coeff_abs_level_minus3[n−1]" as it was in Tables 3-5. The parameter variable **230** can be updated depending on which conditions **1702** are met, and the value of the current symbol **226** can then be coded based on the updated parameter variable **230** using Truncated Rice code and/or Exp-Golomb Code.

In some embodiments, each condition **1702** can comprise two parts, a conditional symbol threshold and a conditional parameter threshold. In these embodiments, the condition **1702** can be met if the value of the symbol **226** is equal to greater than the conditional symbol threshold and the parameter variable **230** is equal to or greater than the conditional parameter threshold. In alternate embodiments, each condition **1702** can have any number of parts or have any type of condition for either or both the symbol **226** and parameter variable **230**.

Since updating tables can need extra memory to store and fetch the data and the memory can require a lot of processor cycles, it can be preferable to use combination logics to perform the comparison in place of an updating table as the logic can use very few processor cycles. An example of the combination logic that determines the cRiceParam for updating in the place of Table 3 is shown in FIG. **20**. An example of combination logic for representing Table 4 is shown in FIG. **21**. An example of combination logic for representing Table 5 is shown in FIG. **22**.

In some embodiments, the possible outcomes of the conditions **1702** based on possible values of the parameter variable **230** and the last coded symbols **226** can be stored in memory as a low complexity update table **1704** as illustrated in the table of FIG. **17** as well as other subsequent figures. In these embodiments, the parameter variable **230** can be updated by performing a table lookup from the low complexity update table **1704** based on the last value of the parameter variable **230** and the value of the last coded symbol **226**.

In further embodiments, a low complexity level parameter updating table in CABAC can be provided that in some embodiments can operate more efficiently than previous tables and not require the logic illustrated in FIGS. **20-22**. For these low complexity level parameter updating tables, the following applies: (1) Inputs: Previous cRiceParam and coef-

f_abs_level_minus3[n−1]. (2) Outputs: cRiceParam. (3) Previous cRiceParam and cRiceParam could have a value of 0, 1, 2 or 3.

Further in this low complexity level parameter updating tables, the following further applies: (1) The parameter variable **230** can: remain the same when the value of the last coded symbol **226** is between 0 and A−1; (2) The parameter variable **230** can be set to one or remain at the last value of the parameter variable **230**, whichever is greater, when the symbol **226** is between A and B−1; (3) The parameter variable **230** can be set to two or remain at the last value of the parameter variable **230**, whichever is greater, when the symbol **226** is between B and C−1; or (4) The parameter variable **230** can be set to three when the symbol **226** is greater than C−1. The low complexity update table **1704**, labeled Table 6, for these conditions **1702** is depicted in FIG. **23**. The combination logic representation for Table 6 is depicted in FIG. **24**. The values of A, B, and C can be set to any desired values. In this exemplary embodiment, A, B, or C can be the conditional symbol threshold respectively, and the value of 0, 1, or 2 can be the parameter symbol threshold respectively.

A selection of non-limiting examples of update tables **1704** and their associated combination logic representations **1706** with particular values of A, B, and C, are depicted in FIGS. **19-31**. FIGS. **19** and **20** respectively depict an update table **1704** and combination logic representation for conditional symbol thresholds of 3, 6, and 13. FIGS. **29** and **30** respectively depict an update table **9** and combination logic representation for conditional symbol thresholds of 2, 4, and 11. FIGS. **31** and **32** respectively depict an update table **10** and combination logic representation for conditional symbol thresholds of 2, 4, and 10.

The execution of the sequences of instructions required to practice the embodiments may be performed by a computer system **3300** as shown in FIG. **20**. In an embodiment, execution of the sequences of instructions is performed by a single computer system **3300**. According to other embodiments, two or more computer systems **3300** coupled by a communication link **3315** may perform the sequence of instructions in coordination with one another. Although a description of only one computer system **3300** may be presented herein, it should be understood that any number of computer systems **3300** may be employed.

A computer system **3300** according to an embodiment will now be described with reference to FIG. **20**, which is a block diagram of the functional components of a computer system **3300**. As used herein, the term computer system **3300** is broadly used to describe any computing device that can store and independently run one or more programs.

The computer system **3300** may include a communication interface **3314** coupled to the bus **3306**. The communication interface **3314** provides two-way communication between computer systems **3300**. The communication interface **3314** of a respective computer system **3300** transmits and receives electrical, electromagnetic or optical signals that include data streams representing various types of signal information, e.g., instructions, messages and data. A communication link **3315** links one computer system **3300** with another computer system **3300**. For example, the communication link **3315** may be a LAN, an integrated services digital network (ISDN) card, a modem, or the Internet.

A computer system **3300** may transmit and receive messages, data, and instructions, including programs, i.e., application, code, through its respective communication link **3315** and communication interface **3314**. Received program code may be executed by the respective processor(s) **3307** as it is received, and/or stored in the storage device **3310**, or other associated non-volatile media, for later execution.

In an embodiment, the computer system **3300** operates in conjunction with a data storage system **3331**, e.g., a data storage system **3331** that contains a database **3332** that is readily accessible by the computer system **3300**. The computer system **3300** communicates with the data storage system **3331** through a data interface **3333**.

Computer system **3300** can include a bus **3306** or other communication mechanism for communicating the instructions, messages and data, collectively, information, and one or more processors **3307** coupled with the bus **3306** for processing information. Computer system **3300** also includes a main memory **3308**, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus **3306** for storing dynamic data and instructions to be executed by the processor(s) **3307**. The computer system **3300** may further include a read only memory (ROM) **3309** or other static storage device coupled to the bus **3306** for storing static data and instructions for the processor(s) **3307**. A storage device **3310**, such as a magnetic disk or optical disk, may also be provided and coupled to the bus **3306** for storing data and instructions for the processor(s) **3307**.

A computer system **3300** may be coupled via the bus **3306** to a display device **3311**, such as an LCD screen. An input device **3312**, e.g., alphanumeric and other keys, is coupled to the bus **3306** for communicating information and command selections to the processor(s) **3307**.

According to one embodiment, an individual computer system **3300** performs specific operations by their respective processor(s) **3307** executing one or more sequences of one or more instructions contained in the main memory **3308**. Such instructions may be read into the main memory **3308** from another computer-usable medium, such as the ROM **3309** or the storage device **3310**. Execution of the sequences of instructions contained in the main memory **3308** causes the processor(s) **3307** to perform the processes described herein. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions. Thus, embodiments are not limited to any specific combination of hardware circuitry and/or software.

Although the present invention has been described above with particularity, this was merely to teach one of ordinary skill in the art how to make and use the invention. Many additional modifications will fall within the scope of the invention, as that scope is defined by the following claims.

What is claimed:

1. A method of determining binary codewords for transform coefficients, comprising:

providing a transform unit comprising one or more subsets of the transform coefficients, each of the transform coefficients having a quantized value;

determining a symbol for each of the transform coefficients that have a quantized value equal to or greater than a threshold value, by subtracting said threshold value from the quantized value of said transform coefficient;

providing a parameter variable set to an initial value of zero;

converting the symbols into a binary codeword based on a current value of said parameter variable and a value of said symbol; and

updating the value of said parameter variable with a new current value for each of the symbols after each symbols has been converted by mathematically incrementing the last value of said parameter variable when the last value of said parameter variable and the value of the last converted symbol together satisfy one or more conditions

including a conditional symbol threshold and a conditional parameter threshold and wherein one of said one or more conditions is satisfied when the value of the last converted symbol is greater than or equal to said conditional symbol threshold for that condition and the last value of said parameter variable is less than or equal to said conditional parameter threshold for that condition.

2. The method of claim **1**, wherein said converting comprises looking up said binary codeword from a table based on the value of the said symbol and said updated value of said parameter variable.

3. The method of claim **1**, wherein said threshold value is three.

4. The method of claim **1**, wherein updating said parameter variable comprises:

looking up said new value from a table based on: (1) the last value of said parameter variable, and (2) the value of the last converted symbol.

5. The method of claim **1**, wherein said conditional symbol threshold is different for each of said one or more conditions.

6. The method of claim **1**, wherein the value of said parameter variable is configured to be zero, one, two, or three.

7. The method of claim **1**, wherein the value of said parameter variable is configured to be zero, one, two, or any integer between two and a designated upper limit value.

8. The method of claim **1**, wherein the transform coefficients are provided within a transform unit (TU) that provides a subdivision of a coding unit (CU) in a High Efficiency Video Coding (HEVC) signal.

9. The method of claim **1**, wherein the transform coefficients are provided within a subset of a transform unit (TU) that provides a subdivision of a coding unit (CU) in a High Efficiency Video Coding (HEVC) signal.

10. The method of claim **1**, wherein mathematically incrementing the last value comprises mathematically adding an integer of one to the last value of said parameter variable for each of said one or more conditions that are satisfied.

11. A method of determining binary codewords for transform coefficients, comprising:

providing a transform unit comprising one or more subsets of the transform coefficients, of the each transform coefficients having a quantized value;

determining a symbol for each of the transform coefficients that have a quantized value equal to or greater than a threshold value, by subtracting said threshold value from the quantized value of said transform coefficient;

providing a parameter variable set to an initial value of zero;

converting the symbols into a binary codeword based on a current value of said parameter variable and a value of said symbol;

looking up a new current value from a table based on the last value of said parameter variable and the value of the last converted symbol; and

replacing the value of said parameter variable with said new current value, said new current value being a value resulting from incrementing the last value of said parameter variable when the last value of said parameter variable and the value of the last converted symbol together satisfy one or more conditions including a conditional symbol threshold and a conditional parameter threshold and wherein one of said one or more conditions is satisfied when the value of the last converted symbol is greater than or equal to said conditional symbol threshold for that condition and the last value of said parameter variable is less than or equal to said conditional parameter threshold for that condition.

12. The method of claim **11**, wherein incrementing the last value comprises adding an integer of one to the last value of said parameter variable for each of said one or more conditions that are satisfied.

13. A method of determining binary codewords for transform coefficients, comprising:

providing a transform unit comprising one or more subsets of transform coefficients, each transform coefficient having a quantized value;

determining a symbol for each transform coefficient having a quantized value equal to or greater than a threshold value, by subtracting said threshold value from the quantized value of said transform coefficient;

providing a parameter variable set to an initial value of zero;

converting each symbol into a binary codeword based on the current value of said parameter variable and the value of said symbol; and

determining whether the last value of said parameter variable and the value of the last converted symbol together satisfy one or more conditions, wherein each of said one or more conditions comprises a conditional symbol threshold and a conditional parameter threshold; and

mathematically adding an integer of one to the last value of said parameter variable for each of said one or more conditions that are satisfied;

wherein one of said one or more conditions is satisfied when the value of the last converted symbol is greater than or equal to a conditional symbol threshold for that condition and the last value of said parameter variable is less than or equal to a conditional parameter threshold for that condition.

14. The method of claim **13**, wherein said conditional symbol threshold is different for each of said one or more conditions.

15. The method of claim **13**, wherein the value of said parameter variable is configured to be zero, one, two, or three.

16. The method of claim **13**, wherein the value of said parameter variable is configured to be zero, one, two, or any integer between two and a designated upper limit value.

* * * * *