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Question: Q.15/SG16

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Title: Definition of the new coding elements from Telenor

Purpose: Proposal

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1 Scope

This document is a complete description of the Telenor coding model as presented at Osaka. It is based on the TML-1 document. This is for practical reasons only. This is not a TML document.

Some of the differences from H.263 are:

- Only one regular VLC is used for symbol coding
- 1/4 pixel positions are used for motion prediction
- A number of different blocksizes are used for motion prediction
- Residual coding is based on 4x4 blocks and a integer transform is used
- Multiple reference frames may be used for prediction and this is considered to replace any use of B-frames

The first part of the document describes the coding method by mainly defining the decoder actions. Towards the end, 'test model issues' relevant for the encoder to be used as reference for the development of the standard will be covered. This split should make it easy at a later stage to split the document into what is relevant for the standard and a test model. However, at the moment we find it preferable to have one combined document.

2 Organization of source- and compressed data

2.1 Picture formats

At the moment only the QCIF and CIF formats are included in the model.

2.2 Subdivision of a picture into macroblocks

A CIF picture is divided into $18 \times 22 = 396$ macroblocks. Similarly a QCIF picture is divided into 99 macroblocks as indicated in Figure 1. At the moment there are no other layers in the described model.

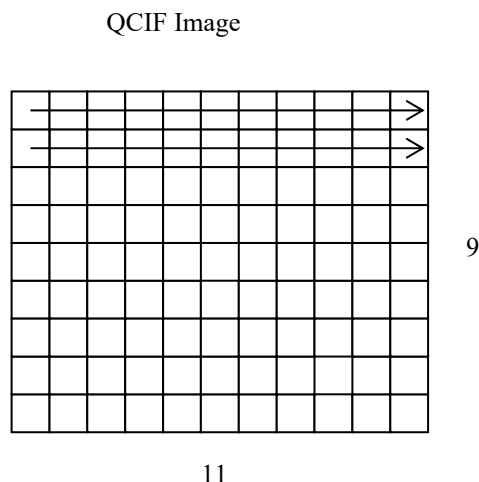


Figure 1 Subdivision of a QCIF picture into 16x16 macroblocks

2.3 Order of the bitstream within a macroblock

Figure 2 and Figure 3 indicates how a macroblock is divided and the order of the different syntax elements resulting from coding a macroblock.

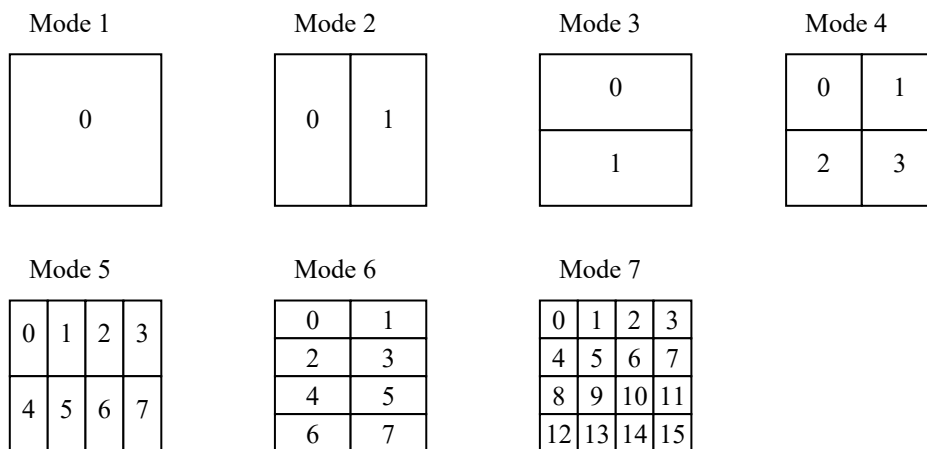
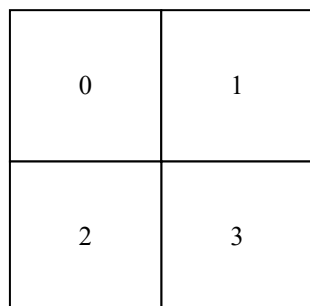
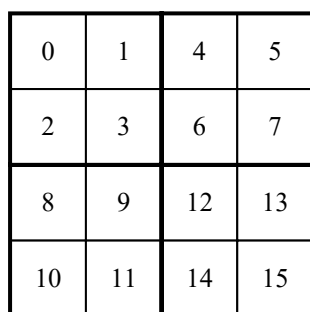


Figure 2 Numbering of the vectors for the different blocks depending on the inter mode. For each block the horizontal component comes first followed by the vertical component

CBPY 8x8 block order



Luma residual coding 4x4 block order



Chroma residual coding 4x4 block order

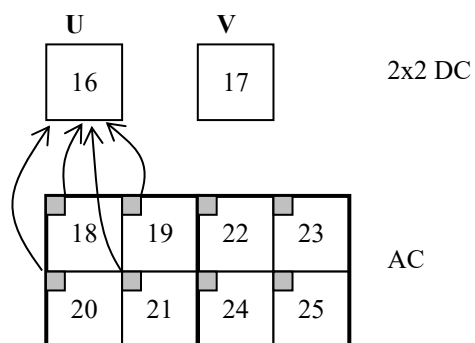


Figure 3 Ordering of blocks for CBBY and residual coding of 4x4 blocks

2.4 Syntax

2.4.1 One VLC to be used for coding

A universal VLC is used to code all syntax elements for the present coding method. The table of codewords may be written in the following compressed form.

```

          1
        0 x0 1
      0 x1 0 x0 1
    0 x2 0 x1 0 x0 1
  0 x3 0 x2 0 x1 0 x0 1
  .....
```

where x_n take values 0 or 1. We will sometimes refer to a codeword with its length in bits (L) and $\text{INFO} = x_n \dots x_1 x_0$. Notice that the number of bits in INFO is $L/2$ (division by truncation). The codewords are numbered from 0 and upwards. The definition of the numbering is:

$\text{Code_number} = 2^{L/2} + \text{INFO} - 1$ ($L/2$ use division with truncation. $\text{INFO} = 0$ when $L = 1$)

Some of the first code numbers and codewords are written explicitly in the table below. As an example, for the code number 5, $L = 5$ and $\text{INFO} = 10$ (binary) = 2 (decimal)

Code number Codewords in explicit form

0	1
1	0 0 1
2	0 1 1
3	0 0 0 0 1
4	0 0 0 1 1
5	0 1 0 0 1
6	0 1 0 1 1
7	0 0 0 0 0 0 1
8	0 0 0 0 0 1 1
9	0 0 0 1 0 0 1
10	0 0 0 1 0 1 1
11	0 1 0 0 0 0 1
.....	

When L and INFO is known, the regular structure of the table makes it easy to create a codeword bit by bit. Similarly, a decoder may easily read bit by bit until the last "1" which gives the end of the codeword. L and INFO is then readily available. For each parameter to be coded, there is a conversion rule from the parameter value to the code number (or L and INFO). Table 1 lists the connection between code number and most of the parameters used in the present coding method.

Table 1 Connection between codeword number and parameter values.

Code number	MB_Type		Intra_pred_mode ¹		MVD	CBP		Tcoeff_chroma_DC ²		Tcoeff_chroma_AC ² Tcoeff_luma ² Simple scan		Tcoeff_luma ² Double scan	
	Intra	Inter	Prob0	Prob1		Intra	Inter	Level	Run	Level	Run	Level	Run
0	Intra4x4	Skip	0	0	0	47	0	EOB	-	EOB	-	EOB	-
1	0,0,0 ³	16x16	1	0	1	31	16	1	0	1	0	1	0
2	1,0,0	8x8	0	1	-1	15	1	-1	0	-1	0	-1	0
3	2,0,0	16x8	0	2	2	0	2	2	0	1	1	1	1
4	3,0,0	8x16	1	1	-2	23	4	-2	0	-1	1	-1	1
5	0,1,0	8x4	2	0	3	27	8	1	1	1	2	2	0
6	1,1,0	4x8	3	0	-3	29	32	-1	1	-1	2	-2	0
7	2,1,0	4x4	2	1	4	30	3	3	0	2	0	1	2
8	3,1,0	Intra4x4	1	2	-4	7	5	-3	0	-2	0	-1	2
9	0,2,0	0,0,0 ³	0	3	5	11	10	2	1	1	3	3	0
10	1,2,0	1,0,0	0	4	-5	13	12	-2	1	-1	3	-3	0
11	2,2,0	2,0,0	1	3	6	14	15	1	2	1	4	4	0
12	3,2,0	3,0,0	2	2	-6	39	47	-1	2	-1	4	-4	0
13	0,0,1	0,1,0	3	1	7	43	7	1	3	1	5	5	0
14	1,0,1	1,1,0	4	0	-7	45	11	-1	3	-1	5	-5	0
15	2,0,1	2,1,0	5	0	8	46	13	4	0	3	0	1	3
16	3,0,1	3,1,0	4	1	-8	16	14	-4	0	-3	0	-1	3
17	0,1,1	0,2,0	3	2	9	3	6	3	1	2	1	1	4
18	1,1,1	1,2,0	2	3	-9	51	9	-3	1	-2	1	-1	4
19	2,1,1	2,2,0	1	4	10	10	31	2	2	2	2	2	1
20	3,1,1	3,2,0	0	5	-10	12	35	-2	2	-2	2	-2	1
21	0,2,1	0,0,1	1	5	11	19	37	2	3	1	6	3	1
22	1,2,1	1,0,1	2	4	-11	21	42	-2	3	-1	6	-3	1
23	2,2,1	2,0,1	3	3	12	26	44	5	0	1	7	6	0
24	3,2,1	3,0,1	4	2	-12	28	33	-5	0	-1	7	-6	0
25		0,1,1	5	1	13	35	34	4	1	1	8	7	0
26		1,1,1	5	2	-13	37	36	-4	1	-1	8	-7	0
27		2,1,1	4	3	14	42	40	3	2	1	9	8	0
28		3,1,1	3	4	-14	44	39	-3	2	-1	9	-8	0
29		0,2,1	2	5	15	1	43	3	3	4	0	9	0
30		1,2,1	3	5	-15	2	45	-3	3	-4	0	-9	0
31		2,2,1	4	4	16	4	46	6	0	5	0	10	0
32		3,2,1	5	3	-16	8	17	-6	0	-5	0	-10	0
33			5	4	17	17	18	5	1	3	1	4	1
34			4	5	-17	18	20	-5	1	-3	1	-4	1
35			5	5	18	20	24	4	2	3	2	2	2
36					-18	24	19	-4	2	-3	2	-2	2
37					19	6	21	4	3	2	3	2	3
38					-19	9	26	-4	3	-2	3	-2	3
39					20	22	28	7	0	2	4	2	4
40					-20	25	23	-7	0	-2	4	-2	4
41					21	32	27	6	1	2	5	2	5
42					-21	33	29	-6	1	-2	5	-2	5
43					22	34	30	5	2	2	6	2	6
44					-22	36	22	-5	2	-2	6	-2	6
45					23	40	25	5	3	2	7	2	7
46					-23	38	38	-5	3	-2	7	-2	7
47					24	41	41	8	0	2	8	11	0
..					..			..	..	..	..	..	..

¹ Prob0 and Prob1 defines the Intra prediction modes of two blocks relative to the prediction of prediction modes (see details in the section for Intra coding).

² For the entries above the horizontal line, the table is needed for relation between code number and Level/Run/EOB. For the remaining Level/Run combination there is a simple rule. The Level/Run combinations are assigned a code number according to the following priority: 1) sign of Level (+ -) 2) Run (ascending) 3) absolute value of Level (ascending).

³ 16x16 based intra mode. The 3 numbers refer to values for (Imode,AC,nc) - see 3.4.9.3.

2.4.2 Syntax diagram

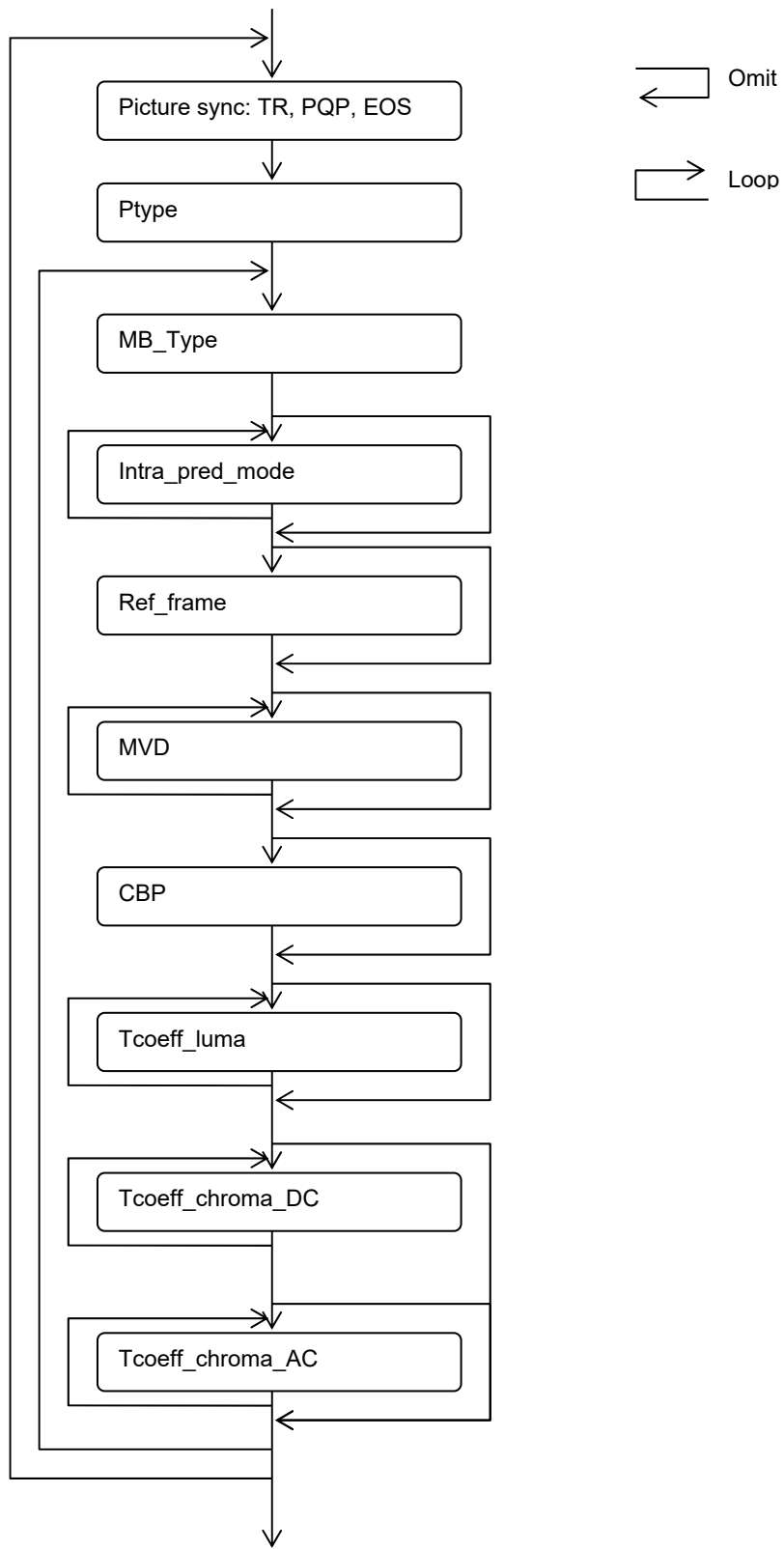


Figure 4 Syntax diagram for all the elements in the video bitstream

3 Description of syntax elements

3.1 Picture sync

The first codeword in a picture is 31 bits long ($L = 31$). It works as a picture sync, but it also contains an INFO part that has 15 bits. These bits are used for:

TR(8 bits)	Temporal reference. The value of TR is formed by incrementing its value in the temporally-previous reference picture header by one plus the number of skipped or non-reference pictures at the picture clock frequency since the previously transmitted one.
PQP(5 bits)	Picture QP: Information about the quantizer QUANT to be used for luma for the picture. (See under Quantization concerning QUANT for chroma). The 5 bit representation is the natural binary representations of the values of QP which range from 0 to 31. QP is a pointer to the actual quantization parameter QUANT to be used. (See below under quantization). The range of quantization value is still about the same as for H.263, 1-31. An approximate relation between the QUANT in H.263 and QP is: $QUANT_{H.263}(QP) \approx QP_0(QP) = 2^{QP/6}$. $QP_0()$ will be used later for scaling purposes when selecting prediction modes.
Formats	0 indicates QCIF, 1 indicates CIF
EOS	0 for picture header. 1 indicates End Of Sequence

The sketch below indicates where the different bits are located within INFO.

8b: TR	5b: PQP	1b: Formats	1b: EOS
--------	---------	-------------	---------

3.2 Picture type (Ptype)

Code_number =0: Inter picture with prediction from the most recent decoded picture only.

Code_number =1: Inter picture with possibility of prediction from more than one previous decoded picture. For this mode information reference picture for prediction must be signalled for each macroblock.

Code_number =2: Intra picture.

3.3 Macro block type (MB_Type)

Refer to Table 1. There are different MB-Type tables for Intra and Inter frames.

3.3.1 Intra

Intra 4x4	Intra coding as defined in sections 3.4.1 to 3.4.8.
Imode, AC, nc	See definition in section 3.4.9.3. These modes refer to 16x16 intra coding.

3.3.2 Inter

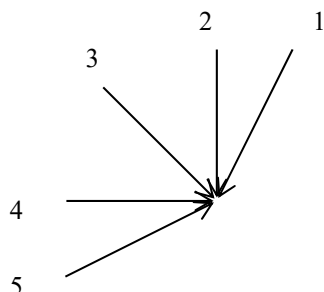
Skip	No further information about the macroblock is transmitted. A copy of the colocated macroblock in the most recent decoded picture is used as reconstruction for the present macroblock.
NxM (eg. 8x4)	The macroblock is predicted from a past picture with block size NxM. For each NxM block motion vector data is provided. Depending on N and M there may be 1 to 16 sets of motion vector data for a macroblock.
Intra 4x4	4x4 intra coding. Code numbers from 9 and upwards represent 16x16 intra coding.

3.4 Intra prediction mode (Intra_pred_mode)

Even in Intra mode, prediction is always used for each sub block in a macroblock. A 4x4 block is to be coded (pixels labelled a to p below). The pixels A to I from neighbouring blocks are already decoded and may be used for prediction.

I	A	B	C	D
E	a	b	c	d
F	e	f	g	h
G	i	j	k	l
H	m	n	o	p

There are 6 intra prediction modes labelled 0 to 5. Mode 0 is 'DC-prediction' (see below). The other modes represent directions of predictions as indicated below.



3.4.1 Mode 0: DC prediction

Generally all pixels are predicted by $(A+B+C+D+E+F+G+H)/8$. If four of the pixels are outside the picture, the average of the remaining four is used for prediction. If all 8 pixels are outside the picture the prediction for all pixels in the block is 128. A block may therefore always be predicted in this mode.

3.4.2 Mode 1:

This mode is used only if all A,B,C,D are inside the picture.

a is predicted by: $(A+B)/2$

e is predicted by B

b,i are predicted by $(B+C)/2$

f,m are predicted by C

c,j are predicted by $(C+D)/2$

d,g,h,k,l,n,o,p are predicted by D

3.4.3 Mode 2: Vertical prediction

If A,B,C,D are inside the picture, a,e,i,m are predicted by A, b,f,j,n by B etc.

3.4.4 Mode 3: Diagonal prediction

This mode is used only if all A,B,C,D,E,F,G,H,I are inside the picture. This is a 'diagonal' prediction.

m is predicted by: $(H+2G+F)/4$

i,n are predicted by $(G+2F+E)/4$

e,j,o are predicted by $(F+2E+I)//4$
a,f,k,p are predicted by $(E+2I+A)//4$
b,g,l are predicted by $(I+2A+B)//4$
c,h are predicted by $(A+2B+C)//4$
d is predicted by $(B+2C+D)//4$

3.4.5 Mode 4:Horizontal prediction

If E,F,G,H are inside the picture, a,b,c,d are predicted by E, e,f,g,h by F etc.

3.4.6 Mode 5:

This mode is used only if all E,F,G,H are inside the picture.

a is predicted by: $(E+F)/2$
b is predicted by F
c,e are predicted by $(F+G)/2$
f,d are predicted by G
i,g are predicted by $(G+H)/2$
h,j,k,l,m,n,o,p are predicted by H

3.4.7 Prediction of chroma blocks

For chroma prediction there is only one mode. No information is therefore needed to be transmitted. The prediction is indicated in the figure below. The 8x8 chroma block consists of 4 4x4 blocks A,B,C,D. S0,1,2,3 are the sums of 4 neighbouring pixels.

If S0, S1, S2, S3 are all inside the frame:

$$A = (S0 + S2 + 4)/8$$

$$B = (S1 + 2)/4$$

$$C = (S3 + 2)/4$$

$$D = (S1 + S3 + 4)/8$$

If only S0 and S1 are inside the frame:

$$A = (S0 + 2)/4$$

$$B = (S1 + 2)/4$$

$$C = (S0 + 2)/4$$

$$D = (S1 + 2)/4$$

If only S2 and S3 are inside the frame:

$$A = (S2 + 2)/4$$

$$B = (S2 + 2)/4$$

$$C = (S3 + 2)/4$$

$$D = (S3 + 2)/4$$

If S0, S1, S2, S3 are all outside the frame: $A = B = C = D = 128$

(Note: This prediction should be considered changed)

	S0	S1
S2	A	B
S3	C	D

3.4.8 Coding of Intra prediction modes

Since each of the 4x4 luma blocks shall be assigned a prediction mode, this will require a considerable number of bits if coded directly. We have therefore tried to find more efficient ways of coding mode information. First of all we observe that the chosen prediction of a block is highly correlated with the prediction modes of adjacent blocks. This is illustrated in Figure 5 a. When the prediction modes of A and

B are known (including the case that A or B or both are outside the picture) an ordering of the most probable, next most probable etc. of C is given. This ordering is listed in Table 2. For each prediction mode of A and B a list of 5 numbers is given. Example: Prediction mode for A and B is 2. The string 2 0 3 1 4 indicates that mode 2 is also the most probable mode for block C. Mode 0 is the next most probable one etc. In the bitstream there will for instance be information that Prob0 = 1 (see Table 1) indicating that the next most probable mode shall be used for block C. In our example this means Intra prediction mode 0. Use of '-' in the table indicates that this instance can not occur. For more efficient coding, information on intra prediction of two 4x4 luma blocks are coded in one codeword (Prob0 and Prob1 in Table 1). The order of the resulting 8 codewords is indicated in Figure 5 b.

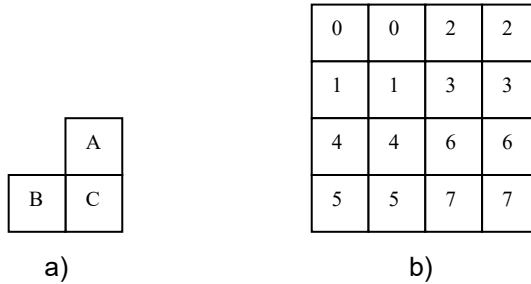


Figure 5 a) Prediction mode of block C shall be established. A and B are adjacent blocks. b) order of intra prediction information in the bitstream

Table 2 Prediction mode as a function of ordering signalled in the bitstream (see text)

B\A	outside	0	1	2	3	4	5
outside	0-----	021---	102---	201---	-----	-----	-----
0	045---	041352	104325	230415	304215	043152	043512
1	-----	014325	102435	203145	032145	041325	014352
2	-----	012345	102345	210345	302145	042135	013245
3	-----	304152	310425	231054	304215	403512	305412
4	405---	403512	401532	240351	430512	403512	405312
5	504---	540312	015432	201453	530412	450312	504132

3.4.9 Intra mode based on 16x16 macroblocks (16x16 intra mode)

This intra mode is particularly suitable for regions with little details, also referred to as 'flat' regions.

3.4.9.1 Prediction modes

Assume that the block to be predicted has pixel locations 0 to 15 horizontally and 0 to 15 vertically. We use the notation $P(i,j)$ where $i,j = 0..15$. $P(i,-1)$, $i=0..15$ are the neighboring pixels above the block and $P(-1,j)$, $j=0..15$ are the neighboring pixels to the left of the block. $Pred(i,j)$, $i,j = 0..15$ is the prediction for the whole luma macroblock. We have 4 different prediction modes:

IMODE = 0 (vertical)

$$Pred(i,j) = P(i,-1), i,j=0..15$$

IMODE = 1 (horizontal)

$$Pred(i,j) = P(-1,j), i,j=0..15$$

IMODE = 2 (DC prediction)

$$Pred(i,j) = \left(\sum_{i=0}^{15} (P(-1,i) + P(i,-1)) \right) / 32 \quad i,j=0..15$$

IMODE = 3 (Plane prediction)

$$Pred(i,j) = (a + bx(i-7) + cx(j-7) + 16) / 32$$

Where:

$$a = 16x(P(-1,15) + P(15,-1))$$

$$b = 5x(H/4)/16$$

$$c = 5x(V/4)/16$$

$$H = \sum_{i=1}^8 ix(P(7+i,-1) + P(7-i,-1))$$

$$V = \sum_{j=1}^8 jx(P(-1,7+j) + P(-1,7-j))$$

3.4.9.2 Residual coding

The residual coding is based on 4x4 transform. But similar to coding of chroma coefficients, another 4x4 transform to the 16 DC coefficients in the macroblock are added. In that way we end up with an overall DC for the whole MB which works well in flat areas.

Since we use the same integer transform to DC coefficients, we have to perform additional normalization to those coefficients, which implies a division by 676. To avoid the division we performed normalization by $49/2^{15}$ on the encoder side and $48/2^{15}$ on the decoder side, which gives sufficient accuracy.

Only single scan is used for 16x16 intra coding.

To produce the bitstream, we first scan through the 16 'DC transform' coefficients. There is no 'CBP' information to indicate no coefficients on this level. If AC = 1 (see below) ac coefficients of the 16 4x4 blocks are scanned. There are 15 coefficients in each block since the DC coefficients are included in the level above.

3.4.9.3 Signalling of mode information for 16x16 intra coding

See Table 1. Three parameters have to be signaled. They are all included in MB-type.

Imode: 0,1,2,3

AC: 0 means there are no ac coefficients in the 16x16 block. 1 means that there is at least one ac coefficient and all 16 blocks are scanned.

nc: CBP for chroma (see 3.7)

3.5 Reference frame (Ref_frame)

If PTYPE indicates possibility of prediction from more than one previous decoded picture, the exact frame to be used must be signalled. This is done according to the following table.

Code number	Reference frame
0	The last decoded frame (1 frame back)
1	2 frames back
2	3 frames back
..	..

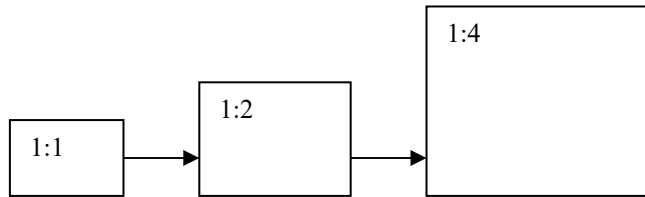
3.6 Motion Vector Data (MVD)

If so indicated by MB_type, vector data for 1-16 blocks are transmitted. For every block a prediction is formed for the horizontal and vertical components of the motion vector. MVD signals the difference between the vector component to be used and this prediction. The order in which vector data is sent is indicated in Figure 2. The reconstructed motion vector shall point to pixels inside the reference frame only.

3.6.1 Fractional pixel accuracy

In the present coding method, 1/4 pixel accuracy is used to define motion vectors. To avoid encoder/decoder mismatch, the interpolation procedure has to be defined in detail.

The figure below indicates that interpolation for luminance may be defined as taking place in two steps.



Interpolation: 6H, 4V bilinear

Step I: Generation of $\frac{1}{2}$ pixel positions

The 'x' - es below represent integer pixel positions. First the '+' - es (horizontal $\frac{1}{2}$ pixel positions) are produced by using a 6 tap filter: $(1, -5, 20, 20, -5, 1)/32$. The result is rounded to the nearest integer and clipped to the range 0 to 255. Then all the '*' - es are produced by using a 4 tap filter: $(-1, 5, 5, -1)/8$. The result is rounded to the nearest integer and clipped to the range 0 to 255. If the filtering process refer to a pixel outside the picture, it is replaced by the nearest picture edge pixel.

```

x + x + x + x + x
* * * * *
x + x + x + x + x
* * * * *
x + x + x + x + x
* * * * *

```

Step II: Generation of $\frac{1}{4}$ pixel positions

The 'x' - es below represent $\frac{1}{2}$ pixel positions (from above). First the '+' - es are produced by linear interpolation (average of the neighbouring $\frac{1}{2}$ pixel positions). The result is truncated to the nearest integer. Then all the '*' - es are produced by vertical linear interpolation with truncation to the nearest integer.

```

x + x + x + x + x
* * * * *
x + x + x + x + x
* * * * *
x + x + x + x + x
* * * * *

```

Interpolation position with more low pass filtering

The figure below indicate a grid with interpolated positions where capital letters represent integer positions, numbers represent $\frac{1}{2}$ pixel positions and lower case letters represent $\frac{1}{4}$ pixel positions.

```

A a 1 b B
c d e f g
2 h 3 i 4
j k l m n
C o 5 p D

```

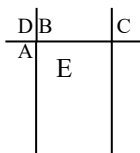
Relative to integer positions, the position m is chosen to represent a position with more low pass filtering. According to the definition above, $m \approx ('3' + '4' + '5' + 'D')/4$. ($\approx$ is used due to possible rounding effects). Instead we define:

$$m = ('A' + 'B' + 'C' + 'D' + 2)/4$$

3.6.2 Prediction of vector components

In the figure below the vector component E of the indicated block shall be predicted. The prediction is normally formed as the median of A, B and C.

- A The component applying to the pixel to the left of the upper left pixel in E
- B The component applying to the pixel just above the upper left pixel in E
- C The component applying to the pixel above and to the right of the upper right pixel in E
- D The component applying to the pixel above and to the left of the upper left pixel in E



A, B, C, D and E may represent motion vectors from different reference pictures. As an example we may be seeking prediction for a motion vector for E from the last decoded picture. Still A, B, C and D may represent vectors from 2, 3, 4 and 5 pictures back but they shall still be used for prediction.

- If A and D are outside the picture, their values are assumed to be zero.
- If D, B, C are outside the picture, the prediction is equal to A.
- If C is outside the picture or still not available due to the order of vector data (see Figure 2), C is replaced by D.

3.6.3 Chroma vectors

Chroma vectors are derived from the luma vectors. Since chroma has half resolution compared to luma, the chroma vectors are obtained by a division of two:

$\text{Croma_vector} = \text{Luma_vector}/2$ - which means that the chroma vectors have a resolution of 1/8 pixel.

Due to the half resolution, a chroma vector applies to 1/4 as many pixels as the luma vector. For example if the luma vector applies to 8x16 luma pixels, the corresponding chroma vector applies to 4x8 chroma pixels and if the luma vector applies to 4x4 luma pixels, the corresponding chroma vector applies to 2x2 chroma pixel.

For fractional pixel interpolation for chroma prediction, bilinear interpolation is used. The result is rounded to the nearest integer.

3.7 Coded Block Pattern (CBP)

The CBP contains information of which 8x8 blocks - luma and chroma - contain transform coefficients. Notice that an 8x8 block contains 4 4x4 blocks meaning that the statement '8x8 block contains coefficients' means that 'one or more of the 4 4x4 blocks contain coefficients'. The 4 least significant bits of CBP contain information on which of 4 8x8 luma blocks in a macroblock contains nonzero coefficients. Let us call these 4 bits CBPY. The ordering of 8x8 blocks is indicated in Figure 3. A 0 in position n of CBP (binary representation) means that the corresponding 8x8 block has no coefficients whereas a 1 means that the 8x8 block has one or more non-zero coefficients.

For chroma we define 3 possibilities:

nc=0: no chroma coefficients at all.

nc=1 There are nonzero 2x2 transform coefficients. All chroma AC coefficients = 0. Therefore we do not send any EOB for chroma AC coefficients.

nc=2 There may be 2x2 nonzero coefficients and there is at least one nonzero chroma AC coefficient present. In this case we need to send 10 EOBs (2 for DC coefficients and 2x4=8 for the 8 4x4 blocks) for chroma in a macroblock.

The total CBP for a macroblock is: **CBP = CBPY + 16xnc**

The CBP is signalled with a different codeword for Inter macroblocks and Intra macroblocks since the statistics of CBP values are different in the two cases.

4 Transform and inverse transform

This section defines all elements related to transform coding and decoding. It is therefore relevant to all the syntax elements 'Tcoeff' in the syntax diagram.

4.1 4x4 block size

Instead of DCT, an integer transform with basically the same coding property as a 4x4 DCT is used. The transformation of the pixels a,b,c,d into 4 transform coefficients A,B,C,D is defined by:

$$A = 13a + 13b + 13c + 13d$$

$$B = 17a + 7b - 7c - 17d$$

$$C = 13a - 13b - 13c + 13d$$

$$D = 7a - 17b + 17c - 7d$$

The inverse transformation of transform coefficients A,B,C,D into 4 pixels a',b',c',d' is defined by:

$$a' = 13A + 17B + 13C + 7D$$

$$b' = 13A + 7B - 13C - 17D$$

$$c' = 13A - 7B - 13C + 17D$$

$$d' = 13A - 17B + 13C - 7D$$

The relation between a and a' is: $a' = 676a$. This is because the expressions defined above contain no normalisation. Normalisation will be performed in the quantization/dequantisation process and a final shift after inverse quantization.

The transform/inverse is performed both vertically and horizontally in the same manner as in H.263. By the above exact definition of inverse transform, the same operations will be performed on coder and decoder side which means that we have no 'inverse transform mismatch'.

4.2 2x2 transform/inverse transform of chroma DC coefficients

With the low resolution of chroma it seems to be preferable to have larger blocksize than 4x4. Specifically the 8x8 DC coefficient seems very useful for better definition of low resolution chroma. The 2 dimensional 2x2 transform procedure is illustrated below. DC0,1,2,3 are the DC coefficients of 2x2 chroma blocks.

$$\begin{array}{cc} \text{DC0} & \text{DC1} \\ \text{DC2} & \text{DC3} \end{array} \quad \text{Two dimensional 2x2 transform} \Rightarrow \quad \begin{array}{cc} \text{DDC}(0,0) & \text{DDC}(1,0) \\ \text{DDC}(0,1) & \text{DDC}(1,1) \end{array}$$

Definition of transform:

$$\text{DCC}(0,0) = (\text{DC0} + \text{DC1} + \text{DC2} + \text{DC3})/2$$

$$\text{DCC}(1,0) = (\text{DC0} - \text{DC1} + \text{DC2} - \text{DC3})/2$$

$$\text{DCC}(0,1) = (\text{DC0} + \text{DC1} - \text{DC2} - \text{DC3})/2$$

$$\text{DCC}(1,1) = (\text{DC0} - \text{DC1} - \text{DC2} + \text{DC3})/2$$

Definition of inverse transform:

$$\text{DC0} = (\text{DCC}(0,0) + \text{DCC}(1,0) + \text{DCC}(0,1) + \text{DCC}(1,1))/2$$

$$\text{DC1} = (\text{DCC}(0,0) - \text{DCC}(1,0) + \text{DCC}(0,1) - \text{DCC}(1,1))/2$$

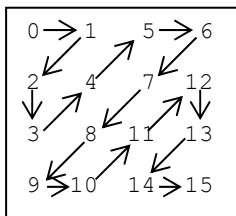
$$\text{DC2} = (\text{DCC}(0,0) + \text{DCC}(1,0) - \text{DCC}(0,1) - \text{DCC}(1,1))/2$$

$$\text{DC3} = (\text{DCC}(0,0) - \text{DCC}(1,0) - \text{DCC}(0,1) + \text{DCC}(1,1))/2$$

4.3 Scanning and quantization

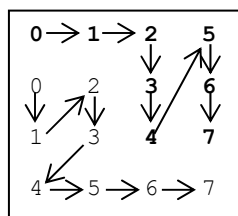
4.3.1 Simple scan

Except for Intra coding of luma with $QP < 24$, simple scan is used. This is basically zig-zag scanning similar to the one used in H.263. The scanning pattern is:



4.3.2 Double scan

When using the VLC defined above, we use a one bit code for EOB. For Inter blocks and Intra with high QP the probability of EOB is typically 50% which is well matched with the VLC. In other words this means that we on average have one non-zero coefficient per 4x4 block in addition to the EOB code (remember that a lot of 4x4 blocks only have EOB). On the other hand, for Intra coding we typically have more than one non-zero coefficient per 4x4 block. This means that the 1 bit EOB becomes inefficient. To improve on this the 4x4 block is subdivided into two parts that are scanned separately and with one EOB each. The two scanning parts are shown below – one of them in bold.



4.3.3 Quantization

The quantization/dequantization process shall perform 'normal' quantization/dequantization as well as take care of the fact that transform operations are kept very simple and therefore do not contain normalization of transform coefficients. 32 different QP values are used. They are arranged so that there is an increase of step size of about 12% from one QP to the next. Increase of QP by 6 means that the step size is about doubled. There is no 'dead zone' in the quantization process and the total range of step size from smallest to largest is about the same as for H.263.

The QP signalled in the bitstream applies for luma quantization/dequantization. This could be called QP_{luma} . For chroma quantization/dequantization a different value - QP_{chroma} - is used. The relation between the two is:

QP_{luma} 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

QP_{chroma} 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 17 18 19 20 20 21 22 22 23 23 24 24 25 25

When QP is used in the following we mean QP_{luma} or QP_{chroma} depending on what is appropriate.

Two arrays of numbers are used for quantization/dequantization.

$A(QP=0,...,31)$

620,553,492,439,391,348,310,276,246,219,195,174,155,138,123,110,98,87,78,69,62,55,49,44,39,35,
31,27,24,22,19,17

B(QP=0,...,31)

3881,4351,4890,5481,6154,6914,7761,8718,9781,10987,12339,13828,15523,17435,19561,21873,24552,27656,30847,34870,38807,43747,49103,54683,61694,68745,77615,89113,100253,109366,126635,141533

The relation between A() and B() is: $A(QP) \times B(QP) \times 676^2 = 2^{40}$.

It is assumed that a coefficient K is quantized in the following way:

$LEVEL = (K \times A(QP) + f \times 2^{20}) / 2^{20}$ |f| is in the range (0-0.5) and f has the same sign as K.

Dequantization:

$K' = LEVEL \times B(QP)$

After inverse transform this results in pixel values that are 2^{20} too high. A shift of 20 bits (with rounding) is therefore needed on the reconstruction side. The definition of transform and quantization is designed so that no overflow will occur with use of 32 bit arithmetic.

4.3.4 Scanning and quantization of 2x2 chroma DC coefficients

DDC() is quantized (and dequantized) separately resulting in LEVEL, RUN and EOB. The scanning order is: DCC(0,0), DCC(1,0), DCC(0,1), DCC(1,1). Inverse 2x2 transform as defined above is then performed after dequantization resulting in dequantized 4x4 DC coefficients: DC0' DC1' DC2' DC3'.

Chroma AC coefficients (4x4 based) are then quantized similarly to before. Notice that there are only 15 AC coefficients. The maximum size of RUN is therefore 14. However, for simplicity we use the same relation between LEVEL, RUN and Code no. As defined for 'Simple scan' in Table 1.

4.4 Use of 2-dimensional model for coefficient coding.

In the 3D model for coefficient coding (see H.263) there is no good use of a short codeword of 1 bit. On the other hand, with the use of 2D VLC plus End Of Block (EOB) (as used in H.261, H.262) and with the small block size, 1 bit for EOB is usually well matched to the VLC.

Furthermore, with the fewer non-zero coefficients per block, the advantage of using 3D VLC is reduced.

As a result we use a 2D model plus End Of Block (EOB) in the present model. This means that an event to be coded (RUN, LEVEL) consists of:

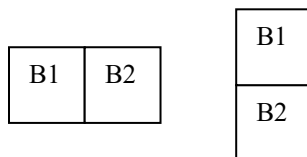
RUN which is the number of zero coefficients since the last nonzero coefficient.

LEVEL the size of the nonzero coefficient

EOB signals that there are no more nonzero coefficients in the block

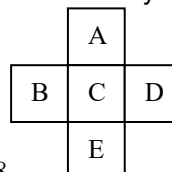
4.5 Deblocking filter

The deblocking filter process takes place both across vertical block edges and horizontal block edges. The filtering is performed first across vertical edges. The filtered pixels are then used when performing filtering across horizontal block edges. As a result block1 and block2 (see below) may be located in one of the positions:



4.5.1 Block strength

The deblocking filter is based on a 4x4 block structure. Each 4x4 block in a reconstructed picture is assigned a **Strength** value ranging from 0 to 3. This value is assigned based on different criteria. The maximum value is chosen. Assume that one criterion results in **value** to be assigned. The new assignment is: **Strength = max(Strength,value)**, so that we always keep the maximum value. In the figure below A, B, C and D are 4x4 blocks.



The procedure for assignment is as follows:

- Initially each 4x4 block of a picture is assigned **Strength = 0**
- If C is intra coded: **Strength_C = 3, Strength_A = max(Strength_A,2), Strength_B = max(Strength_B,2), Strength_D = max(Strength_D,2), Strength_E = max(Strength_E,2)**
- If C has nonzero transform coefficients: **Strength_C = max(Strength_C,2), Strength_A = max(Strength_A,1), Strength_B = max(Strength_B,1), Strength_D = max(Strength_D,1), Strength_E = max(Strength_E,1)**
- If the absolute difference between one of the vector components of block A and block C is at least one integer pixel (four ¼ pixels) then: **Strength_A = max(Strength_A,1), Strength_C = max(Strength_C,1)**. The same procedure is applied to vector differences between blocks (B and C), (C and D) and (C and E)

4.5.2 Filtering of pixels on both sides of a 4x4 block boundary

Assume that the pixels

a b c d e f g h

belong to two neighbouring blocks (1 and 2). There is a block boundary between pixels d and e.

Strength₁ and Strength₂ are available. Filtering takes place only if they are both different from 0. In that case pixels c,d,e,f may be modified in the filtering process.

The following parameters are calculated:

$$S_0 = \text{abs}(4(c-f)+12(e-d)) + \text{abs}(9(c-d-e+f))$$

$$S_{01} = 12\text{abs}(a-2b+c)$$

$$S_{11} = \text{abs}(4(a-d)+12(c-b)) + \text{abs}(9(a-b-c+d))$$

$$S_{02} = 12\text{abs}(e-2f+g)$$

$$S_{12} = \text{abs}(4(e-h)+12(g-f)) + \text{abs}(9(e-f-g+h))$$

abs() is the absolute value function. Lim(qp) is a table defining threshold values for the filtering process depending on qp. As pixels a to h belong to two blocks, qp of the two blocks may differ. In this context qp means the maximum qp for the two blocks. The table is:

QP	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Lim	7	8	9	10	11	12	14	15	17	20	22	25	28	31	35	39	44	49	55	62	69	78	88	98	110	124	139	156	175	197	221	248

4.5.3 Overall activity – Act_{overall}

Act_{overall} = (3-i) where i is the smallest number such that S₀ < Lim(qp)x2ⁱ. Act_{overall} is normally clipped to the range (0,3). If Strength₁ = 3 or Strength₂ = 3 (intra), Act_{overall} is clipped to the range (1,3).

4.5.4 Activity on each side – Act₁, Act₂

- Act₁ is initially set to 1
- If S₀₁ < Lim(qp), Act₁ is incremented by 1
- If S₁₁ < Lim(qp), Act₁ is incremented by 1

The same procedure is made for Act₂.

Finally Act₁₁ = min(Act_{overall}, Act₁), Act₂₂ = min(Act_{overall}, Act₂).

We also need tables depending on qp and Strength for clipping modifications (see below). We call this table Clip(qp,Strength) and the tables are:

QP	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	29	30	31
Clip(qp,1)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3
Clip(qp,2)	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4	5	5
Clip(qp,3)	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	4	4	5	5	5	7	8	9

4.5.5 Modification of edge pixels – d,e

It has proved advantageous to treat these pixels separately and subtract the same amount to one side as is added to the other as is done in the H.263 filter. Another similarity to the H.263 filter is that the modification is limited.

$$Act_{edge} = (Act_{11} + Act_{22})/2$$

$$Clip_{edge} = (Clip(qp, Strength_1) + Clip(qp, Strength_2) + Act_1 + Act_2 - 2)/2$$

Initially set Diff = 0

$$\text{If } Act_{edge} \text{ equals 1 or 2: } Diff = (3(c - f) - 8(d - e))/16$$

$$\text{If } Act_{edge} \text{ equals 3: } Diff = (b + c - 8(d - e) - f - g)/16$$

$$Diff = \max(-Clip_{edge}, \min(Clip_{edge}, Diff))$$

$$d_{modified} = d + Diff \text{ (clipped to stay in the range 0-255)}$$

$$e_{modified} = e - Diff \text{ (clipped to stay in the range 0-255)}$$

4.5.6 Modification of pixels next to the edge – c,f

4.5.6.1 Modification if c in block 1

Initially set Diff = 0

$$\text{If } Act_{11} \text{ equals 2: } Diff = 5(b - 2c + d)/16$$

$$\text{If } Act_{11} \text{ equals 3: } Diff = 3(a + b - 4c + d + e)/16$$

$$Diff = \max(-Clip(qp, Strength_1), \min(Clip(qp, Strength_1), Diff))$$

$$c_{modified} = c + Diff \text{ (clipped to stay in the range 0-255)}$$

4.5.6.2 Modification if f in block 2

Initially set Diff = 0

$$\text{If } Act_{22} \text{ equals 2: } Diff = 5(e - 2f + g)/16$$

$$\text{If } Act_{22} \text{ equals 3: } Diff = 3(d + e - 4f + g + h)/16$$

$$Diff = \max(-Clip(qp, Strength_2), \min(Clip(qp, Strength_2), Diff))$$

$$f_{modified} = f + Diff \text{ (clipped to stay in the range 0-255)}$$

5 Test model issues

5.1 Finding optimum prediction mode

Both for intra prediction and motion compensated prediction, a similar loop as indicated in Figure 6 is run through. The different elements will be described below.

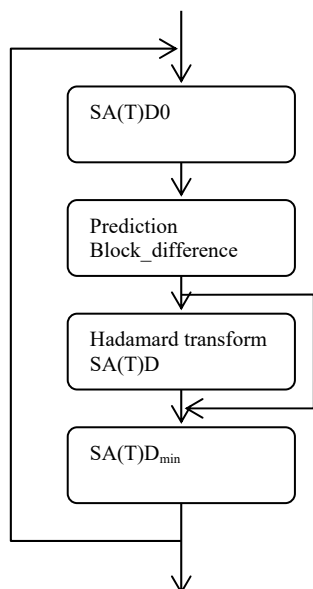


Figure 6 Loop for prediction mode decision

5.1.1 SA(T)D0

The SA(T)D to be minimised is given a 'bias' value initially in order to favour prediction modes that need few bits to be signalled. This bias is basically a parameter representing bit usage times $QP_0(QP)$

Intra mode decision: $SA(T)D0 = QP_0(QP) \times \text{Order_of_prediction_mode}$ (see above)

Motion vector search: $SA(T)D0 = QP_0(QP) \times (\text{Bits_to_code_vector} + 2 \times \text{code_number_of_ref_frame})$

In addition there are two special cases:

- For motion prediction of a 16x16 block with 0 vector components, $16 \times QP_0(QP)$ is subtracted from SA(T)D to favour the skip mode.
- For the whole intra macroblock, $24 \times QP_0(QP)$ is added to the SA(T)D before comparison with the best SA(T)D for inter prediction. This is an empirical value to prevent using too many intra blocks.

5.1.2 Block_difference

For the whole block the difference between the original and prediction is produced

$$\text{Diff}(i,j) = \text{Original}(i,j) - \text{Prediction}(i,j)$$

5.1.3 Hadamard transform

For integer pixel search (see below) we use SAD based on $\text{Diff}(i,j)$ for decision. Hence no Hadamard is done and we use SAD instead of SATD.

$$SAD = \sum_{i,j} |\text{Diff}(i,j)|$$

However, since we will do a transform of $\text{Diff}(i,j)$ before transmission, we will do a better optimisation if a transform is done before producing SAD. Therefore a two dimensional transform is performed in the decision loop for selecting intra modes and for fractional pixel search (see below). To simplify

implementation, the Hadamard transform is chosen in this mode decision loop. The relation between pixels and basis vectors (BV) in a 4 point Hadamard transform is illustrated below (not normalized):

	Pixels →			
B	1	1	1	1
V	1	1	-1	-1
↓	1	-1	-1	1
	1	-1	1	-1

This transformation is performed horizontally and vertically and result in DiffT(i,j). Finally SATD for the block and for the present prediction mode is produced.

$$SATD = (\sum_{i,j} |DiffT(i, j)|) / 2$$

Choose the prediction mode that results in the minimum SA(T)D_{min}.

5.2 Encoding on macroblock level

5.2.1 Intra coding

When starting to code a macroblock, intra mode is checked first. For each 4x4 block, full coding indicated in Figure 6 is performed. At the end of this loop the complete macroblock is intra coded and a SATD_{intra} is calculated.

5.2.2 Table for intra prediction modes to be used at the encoder side

Table 2 gives the table of intra prediction modes according to probability of each mode to be used on the decoder side. On the encoder side we need a sort of inverse table. Prediction modes for A and B are known as in Table 2. For the encoder we have found a Mode that we want to signal with an ordering number in the bitstream (whereas on the decoder we receive the order in the bitstream and want to convert this to a mode). Table 3 is therefore the relevant table for the encoder. Example: Prediction mode for A and B is 2. The string in Table 3 is 1 3 0 2 4. This indicates that prediction mode 0 has order 1 (second most probable). Prediction mode 1 has order 3 and prediction mode 2 has order 0 (most probable) etc.

Table 3 Prediction ordering to be used in the bitstream as a function of prediction mode (see text).

B\A	outside	0	1	2	3	4	5
outside	0-----	021---	102---	120---	-----	-----	-----
0	0---12	025314	104325	240135	143025	035214	045213
1	-----	014325	102435	130245	032145	024315	015324
2	-----	012345	102345	210345	132045	032415	013245
3	-----	135024	214035	320154	143025	145203	145032
4	1---02	145203	125403	250314	245103	145203	145302
5	1---20	245310	015432	120534	245130	245301	135420

5.2.3 Inter mode selection

Next motion vector search is performed for motion compensated prediction. A search is made for all 7 possible block structures for prediction as well as from the 5 past decoded pictures. This result in 35 combinations of block sizes and reference frames.

5.2.4 Integer pixel search

The search positions are organised in a 'spiral' structure around the predicted vector (see vector prediction). The numbering from 0 and upwards for the first positions are listed below:

.15	.	.	.	.
.15	9	11	13	16
.17	3	1	4	18
.19	5	0	6	20
.21	7	2	8	22
.23	10	12	14	24

A parameter MC_range is used as input for each sequence. To speed up the search process, the search range is further reduced:

- Search range is reduced to: $\text{Range} = \text{MC_range}/2$ for all block sizes except 16x16 in prediction from the most recent decoded picture.
- The range is further reduced to: $\text{Range} = \text{Range}/2$ for search relative to all older pictures.

After Range has been found, the centre for the spiral search is adjusted so that:

- No vector position is outside the picture.
- The (0,0) vector position is within the search range. This is done by clipping the horizontal and vertical positions of the search centre to $\pm \text{Range}$.

5.2.5 Fractional pixel search

Fractional pixel search is performed in two steps. This is illustrated below where capital letters represent integer positions, numbers represent $\frac{1}{2}$ pixel positions and lower case letters represent $\frac{1}{4}$ pixel positions.

A		B		C
	1	2	3	
D	4	E	5	F
		a b c		
	6 d 7 e 8			
		f g h		
G		H		I

Assume that the integer search points to position E. Then $\frac{1}{2}$ pixel positions 1,2,3,4,5,6,7,8 are searched. Assume that 7 is the best position. Then the $\frac{1}{4}$ pixel positions a,b,c,d,e,f,g,h are searched. (Notice that by this procedure a position with 'more low pass filtering' – see 3.6.1 - is automatically checked).

After fractional pixel search has been performed for the complete macroblock, the SATD for the whole macroblock is computed: $\text{SATD}_{\text{inter}}$.

5.2.6 Decision between intra and inter

If $\text{SATD}_{\text{intra}} < \text{SATD}_{\text{inter}}$ intra coding is used. Otherwise inter coding is used.

5.3 Quantization

5.3.1 Simple quantization

This may be considered as the main quantization method. It is used for chroma coefficients and as a fallback for luma coefficients (see below). For each transform coefficient K the quantized LEVEL is produced in the following way:

$$\text{LEVEL} = (\text{K} \times \text{A}(\text{QP}) + \text{f} \times 2^{20}) / 2^{20} \quad |\text{f}| \text{ is } 1/3 \text{ for intra and } 1/6 \text{ for inter blocks and f has the same sign as K.}$$

5.3.2 Rate Distortion constrained quantization (RDQ)

It is realised that quantization may be done more efficiently if more than one coefficient are considered together in the quantization process. One way of obtaining this is illustrated in Figure 7 and Figure 8. RDQ is performed on all transform coefficient blocks (luma, chroma, inter, intra, 'DC-transform', 'AC-transform'). There are three main loops in the procedure:

Loop I

Loop through all coefficients in a scan (16 coefficients for simple scan, 8 coefficients for double scan) and make a 'prequantization'.

Assume that the coefficient size is indicated by the arrow $\uparrow$ below. It is considered that there are two possible reconstruction levels: R_0 and R_1 connected to the current QP. The distance between R_0 and R_1 is d . If the coefficient to be quantized is between R_0 and $R_0 + 0.55d$ the reconstruction level is set to R_0 . If the coefficient is between $R_0 + 0.55d$ and R_1 we still keep the possibility open for both R_0 and R_1 .

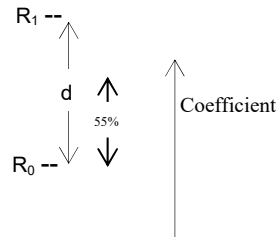


Figure 7 Relation between a coefficient value and reconstruction levels R_0 and R_1

In Figure 8 this is indicated by the calculation of Level0 and Level1. If $\text{Level0} \neq \text{Level1}$, both quantizations will be checked concerning rate distortion gain (see below).

Double_ctr counts the number of coefficients where two quantizations will be considered. In the present method Double_ctr is limited to maximum 3 for complexity reasons.

Level0 and Level1 for all the coefficients in the scan are saved to be used in loops II and III.

Loop II

This loop again scans through all coefficients and accumulates the 'RD_gain' by representing a coefficient by a nonzero reconstruction. The factor 64 is introduced so that integer calculations may be used.

$$\text{RD_gain} = 64 \times (\text{Bits} + \lambda \times ((K' - \text{Level})^2 - K'^2)) = 64 \times \text{Bits} + \lambda \times \text{Level} \times (64 \times \text{Level} - K \times A(\text{QP}) / 2^{13})$$

The middle part of the equation include K' which is a floating non-quantized representation of K . Hence $(K' - \text{Level})^2 - K'^2$ is the distortion if Level is used as reconstruction minus the distortion if the reconstruction is set to 0. We call it 'distortion_gain'. The last part of the equation is used for the actual calculations and integer arithmetic is used.

λ is set to 12 for inter blocks and 14 for intra. Q is the divisor used in the quantization process: $2^{20}/A(\text{QP})$. Bits is the number of bits to code a nonzero coefficient. Notice that for a zero coefficient, $\text{RD_gain} = 0$.

Loop III

This loop scans through $2^{\text{Double_ctr}}$ combinations of quantization to find the one with most gain, that is lowest value. If all combinations of quantization result in positive RD_gain, all coefficients in the scan are set to 0 since this is the optimum solution. Notice that by limiting Double_ctr to 3, there are maximum 8 combinations of quantization to be checked.

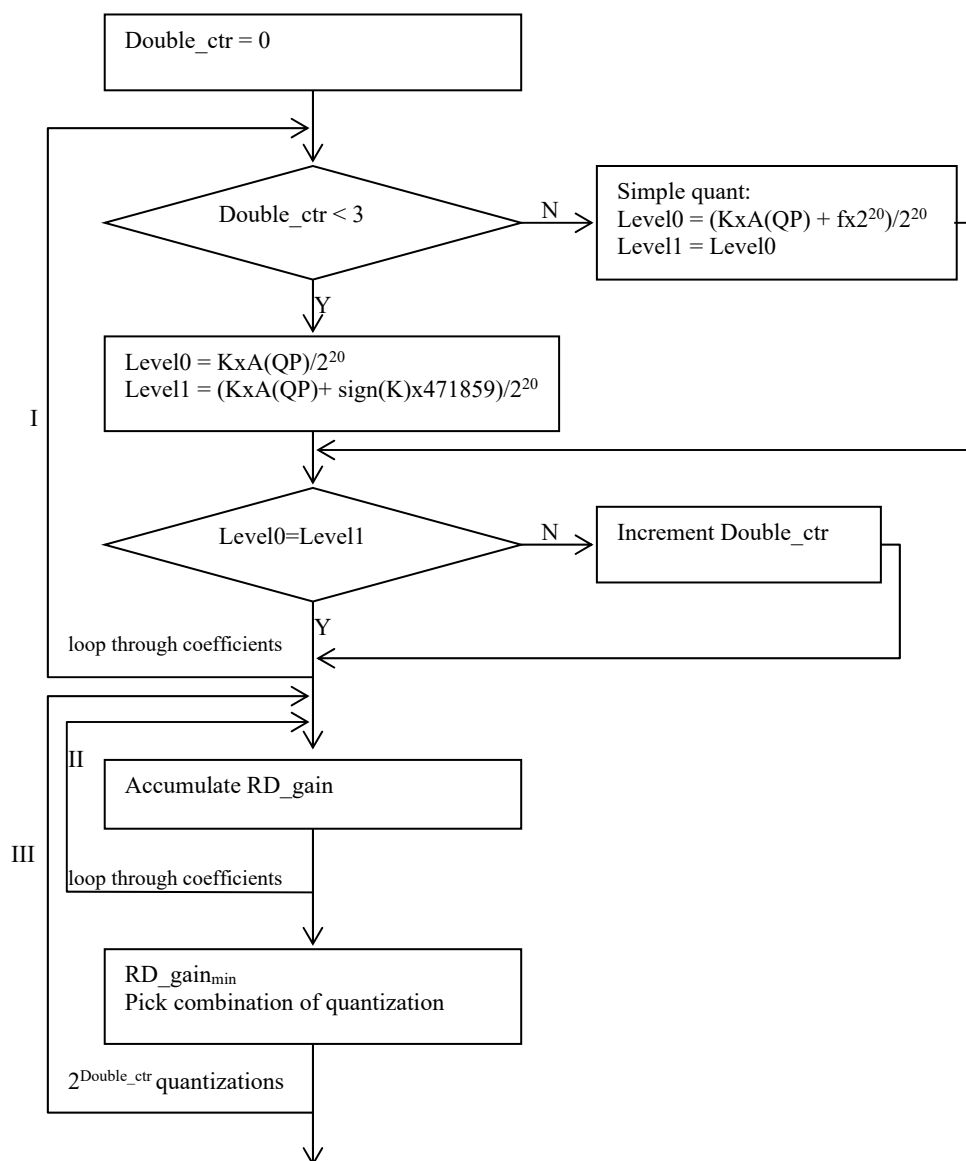


Figure 8 Block diagram of RD-quant

5.4 Elimination of single coefficients in inter macroblocks

With the small 4x4 blocks, it may happen that for instance a macroblock has only one nonzero coefficient with $|\text{Level}| = 1$. This will probably be a very expensive coefficient and it could have been better to set it to zero. For that reason a procedure to check single coefficients have been implemented for inter luma blocks. During the quantization process, a parameter `Single_ctr` is accumulated depending on Run and Level according to the following rule:

If $\text{Level} = 0$ or $(|\text{Level}| = 1 \text{ and } \text{Run} > 5)$ nothing is added to `Single_ctr`.

If $|\text{Level}| > 1$, 9 is added to `Single_ctr`.

If $|\text{Level}| = 1$ and $\text{Run} < 6$, a value $T(\text{Run})$ is added to `Single_ctr`. where $T(0:5) = (3, 2, 2, 1, 1, 1)$

If the accumulated `Single_ctr` for a 8x8 block is less than 4, all coefficients of that luma block are set to zero. Similarly, if the accumulated `Single_ctr` for the whole macroblock is less than 6, all coefficients of that luma macroblock are set to zero.