Foreword

Introduction

This CCITT Recommendation | ISO/IEC International Standard was prepared by CCITT Study Group VIII and the Joint Photographic Experts Group (JPEG) of ISO/IEC JTC

3.1.6 arithmetic decoder: An embodiment of arithmetic decoding procedure.

3.1.7 arithmetic encoder: An embodiment of arithmetic encoding procedure.

3.1.8 baseline (sequential): A particular sequential DCT-based encoding and decoding process specified in this Specification, and which is required for all DCT-based decoding processes.

3.1.9 binary decision: Choice between two alternatives.

3.1.10 bit stream:

3.1.35 DC coefficient:

Da in DC coding, the DC difference coded for the previous block from the same component;

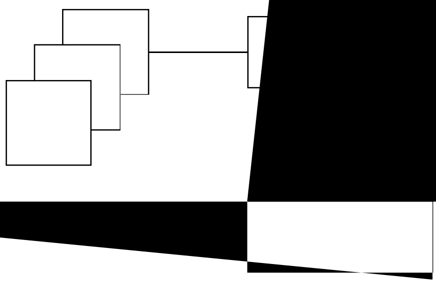
4.1 Elements specified in this Specification

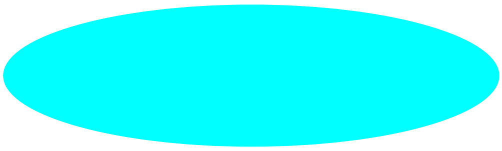
There are three elements specified in this Specification: [redacted]

a) An *encoder* is an embodiment of an [redacted]
digital source image data and *table spe*[redacted]
as output *compressed image data*.

b) A is an embodiment of a *decoding* [redacted]
compressed image data and table specification[redacted]
digital rIconstructed image data.

c) The *interchange format*, shown in Figure 3, [redacted]
table specifications used in the encoding [redacted]
application environments.





4.3 DCT-based coding

The baseline sequential process uses Huffman

4.8.2 Minimum coded unit

Related to the concepts of

5 Interchange format requirements

Annex A

Mathematical definitions

(This annex forms an integral part of this Recommendation | International Standard)

A.1 Source image

Source images to which the encoding processes specified in this Specification can be applied are defined in this annex.

A.1.1 Dimensions and sampling factors

A.2.3 Interleaved order (Ns > 1)

When Ns > 1, each scan component Cs_i is partitioned into small rectangular arrays of H_k horizontal data units by V_k vertical data units. The subscripts k indicate that H_k and V_k are from the position in the k

The uniform quantizer is defined by the following equation. Rounding is to the nearest integer:

$$Sq_{vu} = round\left(\frac{S_{vu}}{Q_{vu}}\right)$$

Sq_{vu} is the quantized DCT coefficient, normalized by the quantizer step size.

NOTE – This equation contains a term which may not be represented with perfect accuracy by any real implementation. The accuracy requirements for the combined FDCT and quantization procedures are specified in Part 2 of this Specification.

At the decoder, this normalization is removed by the following equation, which defines dequantization:

$$R_{vu} = Sq_{vu} \times Q_{vu}$$

NOTE – Depending on the rounding used in quantization, it is possible that the dequantized coefficient may be outside the expected range.

The relationship among samples, DCT coefficients, and quantization is illustrated in Figure A.5.

A.3.5

•

0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42

Table B.1 – Marker code assignments

SOF_3: Lossless (sequential), Huffman coding

SOF_9: Extended sequential DCT, arithmetic coding

SOF_{10}: Progressive DCT, arithmetic coding

SOF_{11}: Lossless (sequential), arithmetic coding

Lf: Frame header length – Specifies the length of the frame header shown in Figure B.3 (see B.1.1.4).

P: Sample precision – Specifies the precision in bits for the samples of the components in the frame.

Y: Number of lines – Specifies the maximum number of lines in the source image. This shall be equal to the number of lines in the component with the maximum number of vertical samples (see A.1.1). Value 0 indicates that 5 0 o1003 Tcı˝0.1 Twı˝[7wı˝ ibey124(]TJı˝9.15382Twı˝[6˝-0.009 Tcı˝0.086 Tw11(with tDNL mark0.1.1282 05.1le2(3Ti5˝dDN

B.2.3 Scan header syntax

Figure B.4 specifies the scan header which shall be present at the start of a scan. This header specifies which component(s) are contained in the scan, specifies the destinations from which the entropy tables to be used with each component are retrieved, and (for the progressive DCT) which part of the DCT quantized coefficient data is contained in the scan. For lossless processes the scan parameters specify the predictor and the point transform.

Td_j: DC entropy coding table destination selector – Specifies one of four possible DC entropy coding table destinations from which the entropy table needed for decoding of the DC coefficients of component Cs_j is retrieved. The DC entropy table shall have been installed in this destination (see B.2.4.2 and B.2.4.3) by the time the decoder is read.1 3Tj installed in this destination (see [(isopy coding table dest4.512-36 0 TD 38 TD -0.003 T

B.2.4 Table-specification and miscellaneous marker segment syntax

Pq:

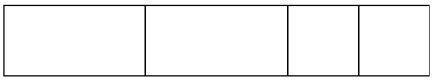
The marker and parameters shown in Figure B.7 are defined below. The size and allowed values of each parameter are given in Table B.5.

DHT: Define Huffman table marker – Marks the beginning of Huffman table definition parameters.

Lh:

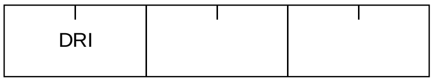
B.2.4.3 Arithmetic conditioning table-specification syntax

Figure B.8 specifies the marker segment which defines one or more arithmetic coding conditioning table specifications. marker for arithmetic coding processes. (See F.1.4.4.1.4 and F.1.4.4.2.1.)

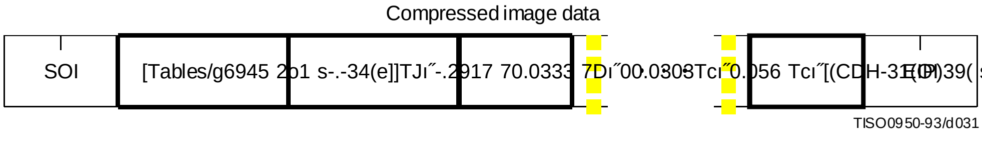


B.2.4.4 Restart interval definition syntax

Figure B.9 specifies the marker segment which defines the restart interval.



The marker and parameters shown in Figure B.10



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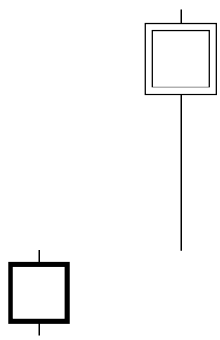


A Huffman code table, HUFFCODE, containing a code

Annex D

Arithmetic coding

(This annex forms an integral part of this Recommendation | International Standard)

An adaptive binary arithmetic coding procedure may be used for entropy coding in any of the coding processes except

The subdivision of the current probability interval would ideally require a multiplication of the interval by the probability estimate for the LPS. Because this subdivision is done

D.1.3 Encoder code register conventions

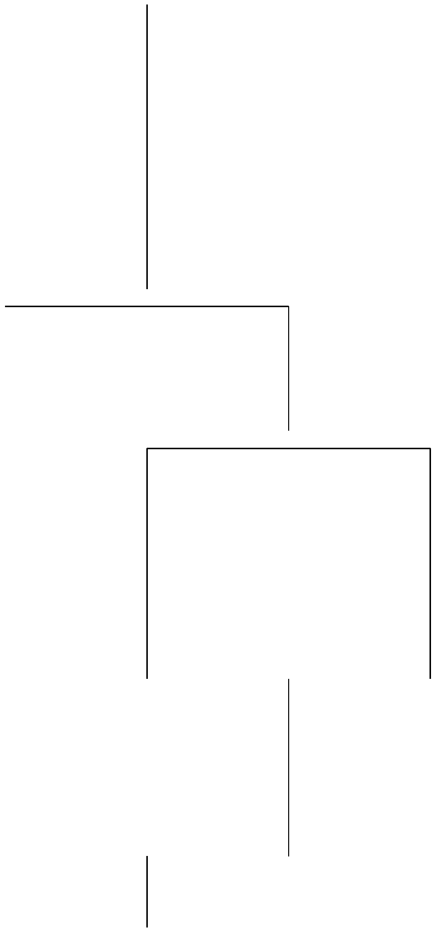


Table D.3 – Qe values and probability estimation state machine

Index	Qe _Value	Next_ Index _LPS	Next_ Index _MPS	Switch _MPS	Index	Qe _Value	Next_ Index _LPS	Next_ Index _MPS	Switch _MPS

D.1.5.2 Renormalization driven estimation

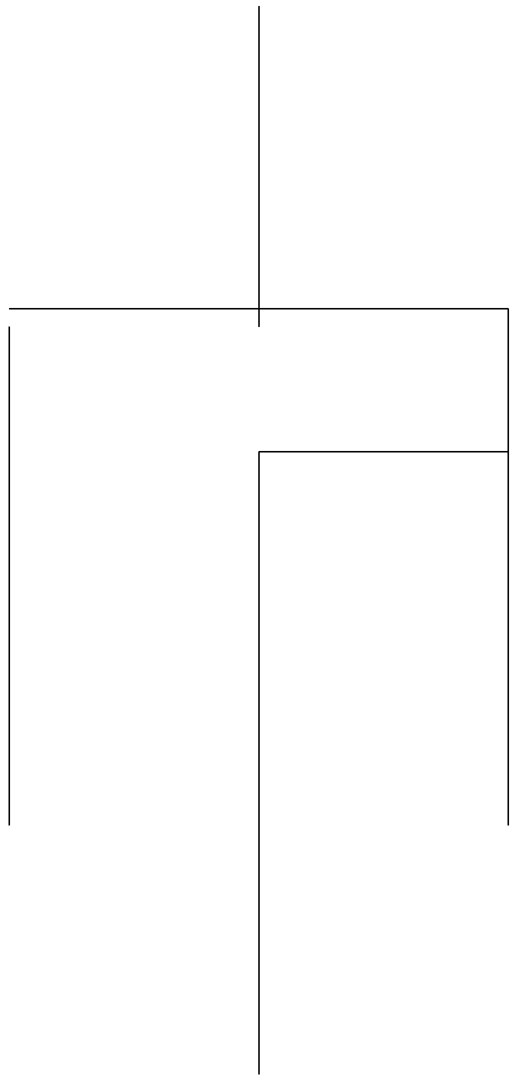
The change in state in Table D.3 occurs only when the arithmetic coder interval register is renormalized. This must always be done after coding an LPS, and whenever the probability interval register is less than X'8000' (0.75 in decimal notation) after coding an MPS.

When the LPS renormalization is required, Next_Index_LPS gives the new index for the LPS probability estimate. When the MPS renormalization is required, Next_Index_MPS gives the new index for the LPS probability estimate. If Switch_MPS is 1 for the old index, the MPS symbol sense must be inverted after an LPS.

D.1.5.3 Estimation following renormalization after MPS

on after LPS

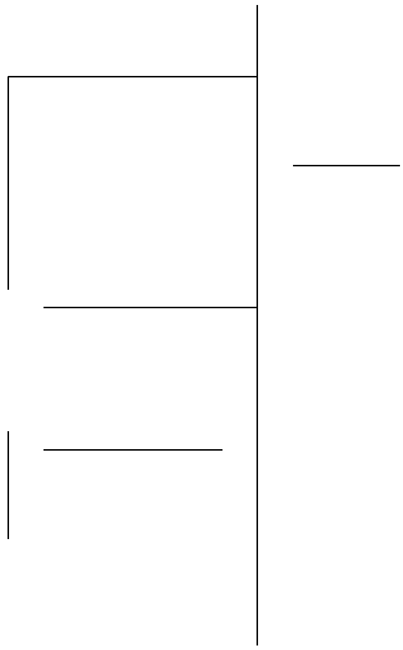
on the LPS renormalization path is shown in Figure D.6. The procedure is
Switch_MPS(I) is 1, the sense of MPS(S) must be inverted.



The probability estimation tables are defined by Table D.3. The statistics areas are initialized to an MPS sense of 0 and a Qe index of zero as defined by Table D.3. The stack count (ST) is cleared, the code register (C) is cleared, and the interval register is set to X’10000’. The counter (CT) is set to 11, reflecting the fact

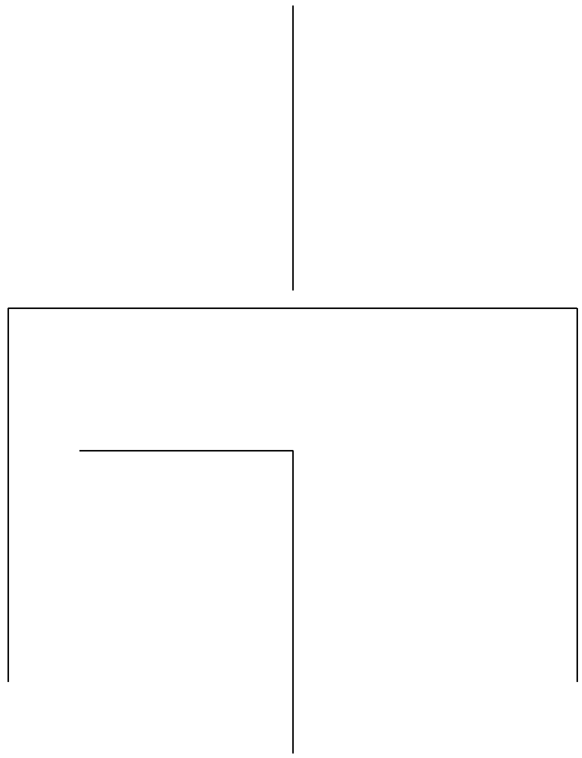
Any trailing zero bytes already written to the entropy-coded segment and not preceded by a X'FF' may, optionally, be discarded. This is done in the Discard_final_zeros procedure. Stuffed zero bytes shall not be discarded.

Entropy coded segments are always followed by a marker. For this reason, the final zero bits needed to



D.2.1

When a renormalization is needed, the MPS/LPS conditional exchange may also be needed. For the LPS path, the conditional exchange procedure is shown in Figure D.17. Note that the probability estimation in the decoder is identical to the probability estimation in the encoder (Figures D.5 and D.6).



D.2.5 Probability estimation in the decoder

The procedures defined for obtaining a new LPS probability estimate in the encoder are also used in the decoder.

D.2.6 Renormalization in the decoder

The Renorm_d procedure for the decoder renormalization is shown in Figure D.19. CT is a counter which keeps track of the number of compressed bits in the C-low section of the C-register. When CT is zero, a new byte is inserted into C-low by the procedure Byte_in and CT is reset to 8.

Both the probability interval register A and the code register C are shifted, one bit at a time, until A is no longer less than X'8000'.

The Byte_in procedure used in Renorm_d is shown in Figure D.20. This procedure fetches one byte of data, compensating for the stuffed zero byte which follows any X'FF' byte. It also detects the marker which must

D.2.7 Initialization of the decoder

The Initdec procedure is used to start the arithmetic decoder. The basic steps are shown in Figure D.22.

Annex E

Encoder and decoder control procedures

(This annex forms an integral part of this Recommendation | International Standard)

This annex describes the encoder and decoder control procedures for the sequential, progressive, and lossless modes of operation.

The encoding and decoding control procedures for the hierarchical processes are specified in Annex J.

NOTES

1 There is **no requirement** in this Specification that any encoder or decoder shall implement the procedures in precisely the manner

E.1.2 Control procedure for encoding a frame

In all cases where markers are appended to the compressed data, optional X'FF' fill bytes may precede the marker.

The control procedure for encoding a frame is oriented around the scans in the

Figure E.3 shows the encoding process scan control procedure. The loop is terminated when the encoding process has coded the number of restart intervals which make up the scan. “m” is the restart interval modulo counter needed for the RST_m marker. The modulo arithmetic for this counter is shown after the “Append RST_m marker” procedure.

E.1.4

E.1.5 Control procedure for encoding a minimum coded unit (MCU)

The minimum coded unit is defined in A.2. Within a given MCU the data units are coded in the order in which they occur in the MCU. The control procedure for encoding a MCU is shown in Figure E.5.

E.2.3 Control procedure for decoding a scan

Figure E.8 shows the decoding of a scan.

The loop is terminated when the expected number of restart intervals has been decoded.

E.2.4 Control procedure for decoding a restart interval

The procedure for decoding a restart interval is shown in Figure E.9. The "Reset_decoder" procedure consists at least of the following:

a) if arithmetic coding is used, initialize the arithmetic decoder using the "Initdec" procedure described in D.2.7;

b) for DCT-based processes, set the DC prediction (PRED) to zero for all components in the scan (see F.2.1.3.1);

c) for lossless process, reset the prediction to a default value for all components in the scan (see H.2.1);

d) do all other implementation-dependent setups that may be necessary.

E.2.5 Control procedure for decoding a minimum coded unit (MCU)

The procedure for decoding a minimum coded unit (MCU) is shown in Figure E.10.

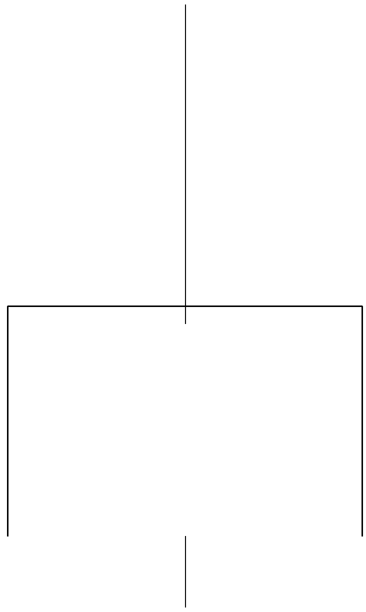
In Figure E.10 Nb is the number of data units in a MCU.

The procedures for decoding a data unit are specified in Annexes F, G, and H.

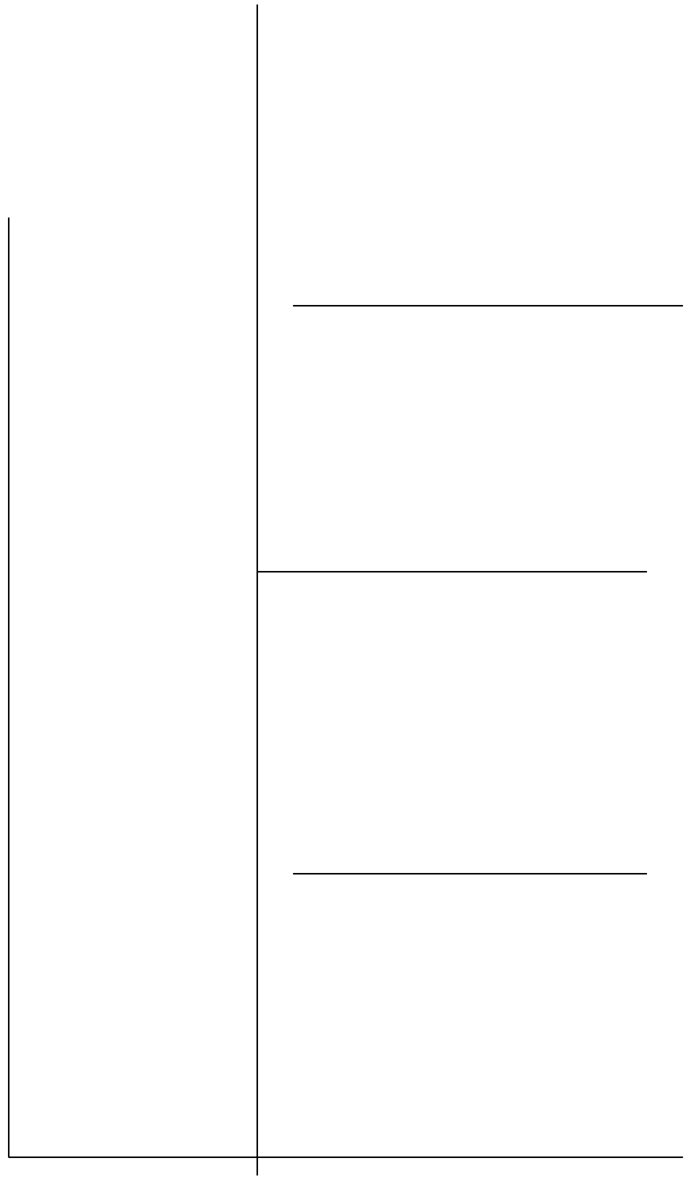
Table F.1 – Difference magnitude categories for DC coding

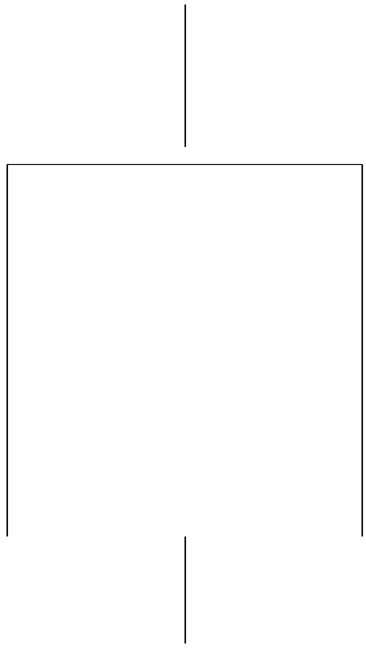
SSSS	DIFF values
0	0
1	–1,1
2	–3,–2,2,3
3	–7..–4,4..7
4	–15..–8,8..15
5	–31..–16,16..31
6	–63..–32,32..63

The format for the additional bits is the same as in the coding of the DC coefficients. The value of SSSS gives the number of additional bits required to specify the sign and precise amplitude of the coefficient. The additional bits are either the low-order SSSS bits of ZZ(K) when



There are two significant differences between this sequence and the similar set of operations described in F.1.2 for Huffman coding. First, the sign is encoded before the magnitude category is identified, and second, the magnitude is decremented by 1 before the magnitude category is identified.

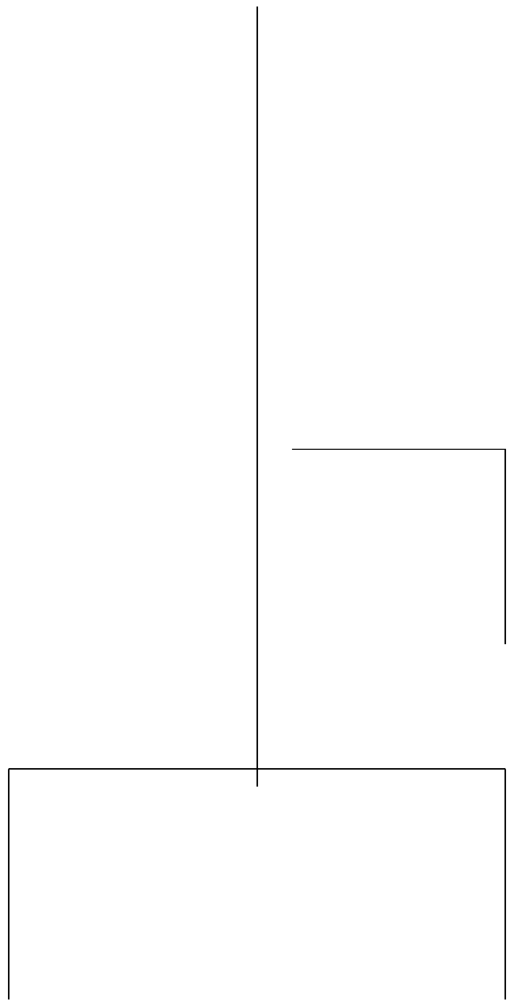




F.1.4.3.1.3 Encoding the exact value of the magnitude

After the magnitude category is encoded, the low order magnitude bits are encoded. These bits are encoded in order of decreasing bit significance. The procedure is shown in Figure F.9. The abbreviation "SRL" indicates the shift-right-logical operation, and M is the exclusive bound established in Figure F.8. Note that M has only one bit set – shifting M right converts it into a bit mask for the logical "AND" operation.

The starting value of the context-index S is determined in Encode_log2_Sz. The increment of S by 14 at the beginning of this procedure sets the context-index to the value required in Tables F.4 and F.5.



F.1.4.4 Statistical models

An adaptive binary arithmetic coder requires a statistical model. The statistical model defines the contexts which are used to select the conditional probability estimates used in the encoding and decoding procedures.

Each decision in the binary decision trees is associated with one or more contexts. These contexts identify the sense of the MPS and the index in Table D.3 of the conditional probability estimate Qe which is used to encode and decode the binary decision.

The arithmetic coder is adaptive, which means that the probability estimates for each context are developed and maintained by the arithmetic coding system on the basean1f the coprih c systemon.F.1.4.4

F.2.1.3.1 Decoding model for DC coefficients

The decoded difference, DIFF, is added to PRED, the DC

F.2.2.4 The RECEIVE procedure

RECEIVE(SSSS) is a procedure which places the next SSSS bits of the entropy-coded segment into the low order bits of DIFF, MSB first. It calls NEXTBIT and it returns the value of DIFF to the calling procedure (see Figure F.17).

The statistical models defined in F.1.4.4 also apply to this decoding process.

The decoder shall be capable of using up to four DC and four AC conditioning tables and associated statistics areas within one scan.

F.2.4.1 Arithmetic decoding of DC coefficients

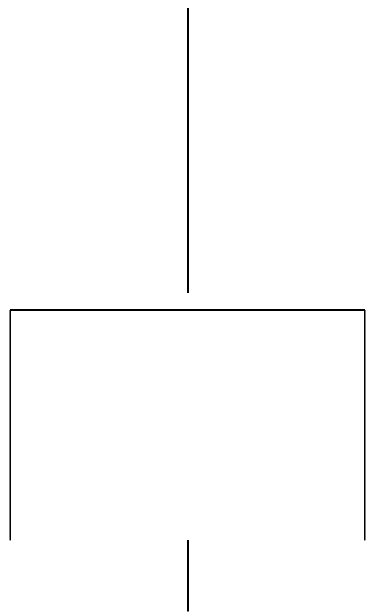
The basic structure of the decision sequence for decoding a DC difference value, DIFF, is shown in Figure

F.2.4.3.1.1 Decoding the sign

The sign is decoded by the procedure shown in Figure F.22.

The context-indices are defined for DC decoding in Table F.4 and AC decoding in Table F.5.

If SIGN = 0, the sign of the coefficient is positive; if SIGN = 1, the sign of the coefficient is negative.



F.2.4.3.1.3 Decoding the exact value of the magnitude

After the magnitude category is

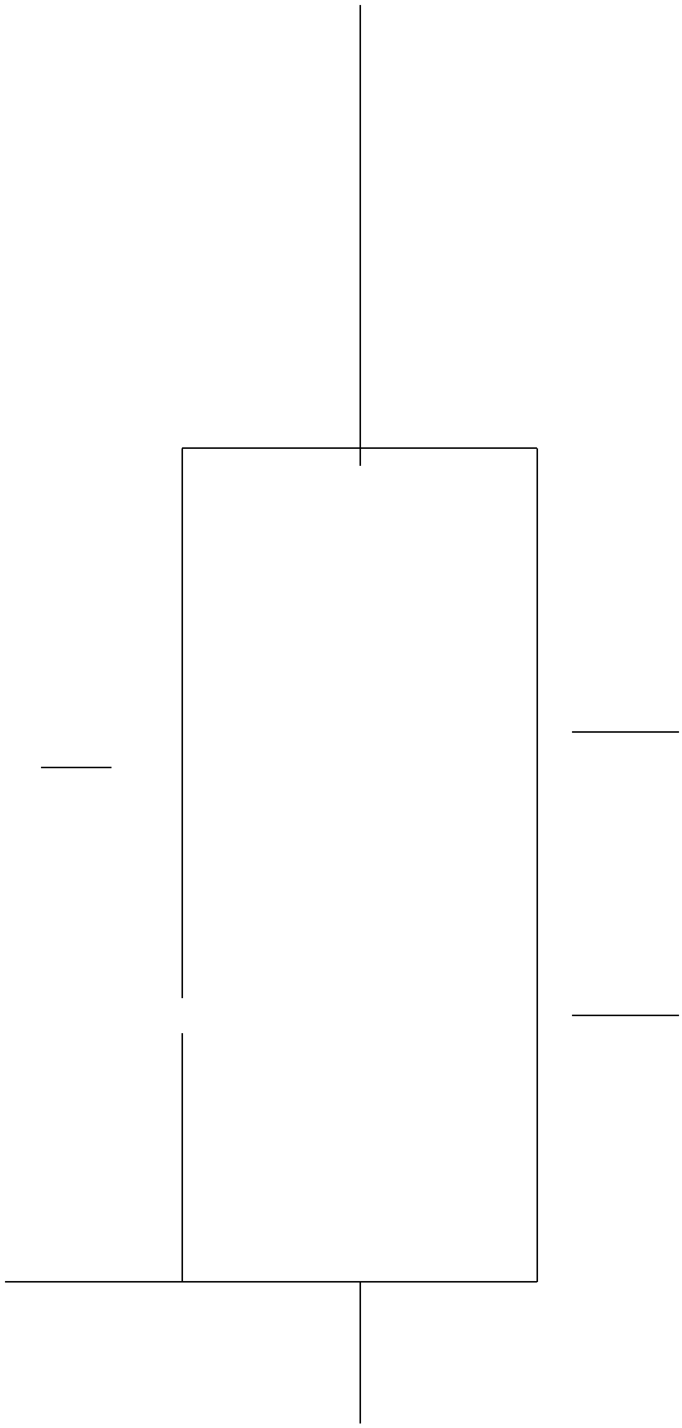
Before error recovery procedures can be invoked, the error condition must first be detected. Errors during decoding can

The procedure for encoding a MCU (see Figure E.5) repetitively invokes the procedure for coding a data unit. For DCT-based encoders the data unit is an 8×8 block of samples.

Only a portion of each 8×8 block is coded in each scan, the portion being determined by the scan header parameters Ss, Se, Ah, and Al (see B.ı˝0nN

Table G.1 – EOBn code run length extensions

EOBn code	Run length
EOB0	1
EOB1	2,3
EOB2	

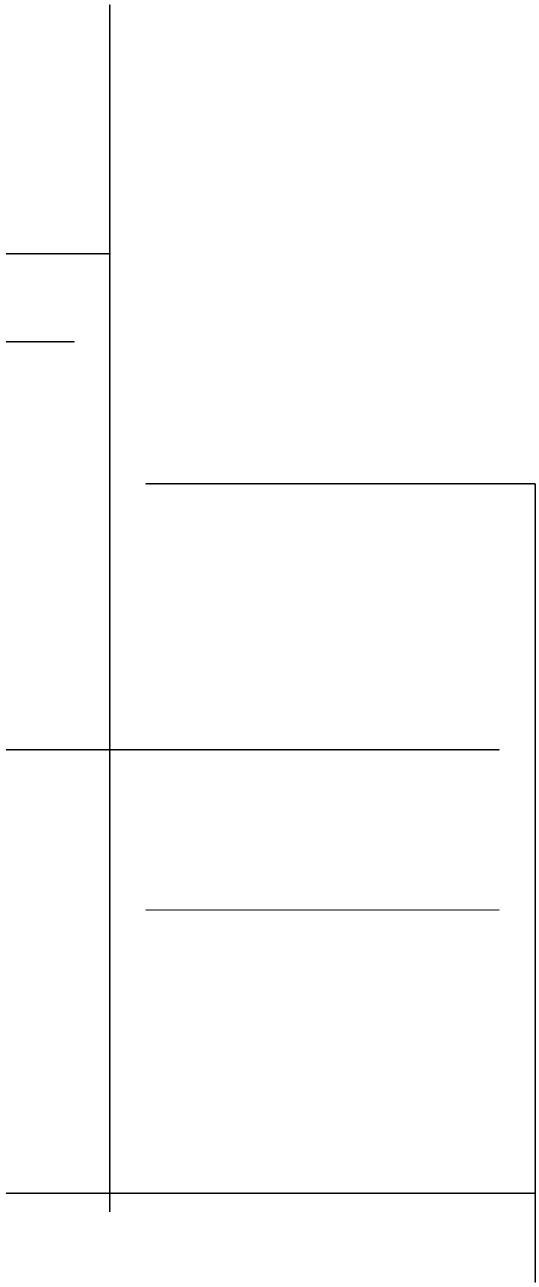


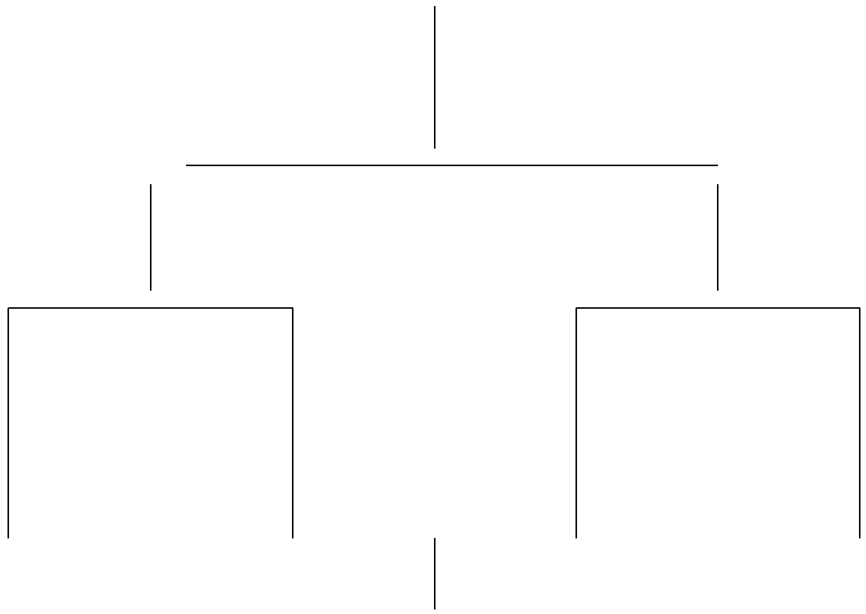
In Figure G.3, Ss is the start of spectral selection, Se is the end of spectral selection, K is the index into the list of coefficients stored in the zig-zag sequence ZZ, R is the run length of

Non-zero coefficients with zero history are coded with a composite code of the form:

HUFFCO(RRRRSSSS) + additional bit (rule a) + correction bits (rule b)

In addition whenever zero





Annex H

Lossless mode of operation

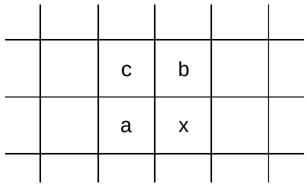
(This annex forms an integral part of this Recommendation | International Standard)

This annex provides a **functional specification** of the following coding processes for the lossless mode of operation:

1) lossless processes with Huffman coding;

2) lossless processes with arithmetic coding.

For each of these, the encoding



TISO1680-93/d106

Figure H.1 – Relationship between sample and prediction samples

= OPı˝(x18r5r(O)-39(16x to(e)7)]T7(thesam)-6pi)1iction /F8 1 0.46154˝(a)TjıTcı˝2 = OPı˝(x)8r5r(and Ra, Rb, and Rc to(e)9)]T9(thesrecon

H.1.2.3.3 Default conditioning bounds

The bounds, L and U, for determining the conditioning category have the default values L = 0 and U = 1. Other bounds

Annex J

Hierarchical mode of operation

(This annex forms an integral part of this Recommendation | International Standard)

This annex provides a **functional specification** of the coding processes for the hierarchical mode of operation.

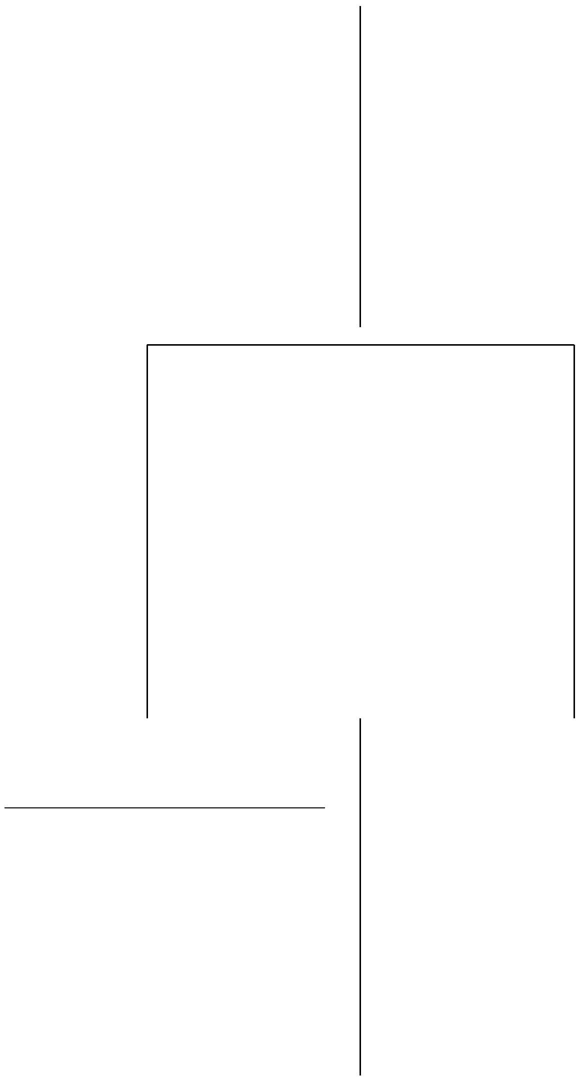
In the hierarchical mode of operation each component is encoded or decoded in a non-differential frame. Such frames may

In the hierarchical mode of operation each component is encoded or decoded in a non-differential frame followed by a sequence of differential frames. A non-differential frame shall use the procedures defined in Annexes F, G, and H. Differential frame procedures are defined in this annex.

J.1 Hierarchical encoding

J.1.1 Hierarchical control procedure for encoding an image

The control structure for encoding of an image using the hierarchical mode is given in Figure J.1.



In the hierarchical mode the define-hierarchical-progression (DHP) marker segment shall be placed in the compressed image data before the first h th2(e˝9.487-38 0 TDı38 TDı˝-0.011 Tcı˝0.131 (the fesselet-11()Tjı. Trstsyntax of)]TJı)Tent

The rule for calculating the interpolated value is:

$$P_x = (Ra + Rb) / 2$$

where Ra and Rb are sample values from adjacent positions a and b of the lower resolution image and Px is the interpolated value. The division indicates truncation, not rounding. The left-most column of the upsampled image matches the left-most column of the lower resolution image. The top line of the upsampled image matches the top line of the lower resolution image. The right column and the bottom line of the lower resolution image are replicated to provide the values required for the right column edge and bottom line interpolations. The upsampling

The Interpret markers procedure shall decode the markers which may precede the SOF marker, continuing this decoding until either a SOF or EOI marker is

K.2 A procedure for generating the lists which specify a Huffman code table

A Huffman table is generated from a collection of statistics in two steps. The first step is the generation of the list of lengths and values which are in accord with the rules for generating the Huffman code tables. The second step is the generation of the Huffman code table from the list of lengths and values.

The first step, the topic of this section, is needed only for custom Huffman table generation and is done only in the encoder. In this step the statistics are used to create a table associating each value to be coded with the size (in bits) of the corresponding Huffman code. This table is sorted by code size.

A procedure for creating a Huffman table for a set of up to 256 symbols is shown in Figure K.1. Three vectors are defined for this procedure:

FREQ(V)	Frequency of occurrence of symbol V
CODESIZE(V)	Code size of symbol V
OTHERS(V)	Index to next symbol in chain of all symbols in current branch of code tree

where V goes from 0 to 256.

Before starting the procedure, the values of FREQ are collected for V = 0 to 255 and the FREQ value for V = 256 is

Figure K.3 gives the procedure for adjusting the BITS list so that no code is longer than 16 bits. Since symbols are paired for the longest Huffman code, the symbols are removed from this length category two at a time. The prefix for the pair (which is one bit shorter) is allocated to one of the pair; then (skipping the BITS entry for that prefix length) a code word from the next shortest non-zero BITS entry is converted into a prefix for two code words one bit longer. After the BITS list is reduced to a maximum code length of 16 bits, the last step removes the reserved code point from the code length count.

Table K.5 – Table for luminance AC coefficients (sheet 1 of 4)

Run/Size	Code length	Code word

Table K.6 – Table for chrominance AC coefficients (sheet 1 of 4)

Run/Size	Code length	Code word

Table K.6 (sheet 2 of 4)

Run/Size	Code length	Code word

Table K.6 (sheet 3 of 4)

Run/Size	Code length	Code word

Table K.6 (sheet 4 of 4)

Run/Size	Code length	Code word
C/6	16	1111111111011111
C/7	16	1111111111100000
C/8	16	1111111111100001
C/9	16	1111111111100010
C/A	16	1111111111100011
D/1	11	11111111001
D/2	16	1111111111100100
D/3	16	1111111111100101
D/4	16	1111111111100110
D/5	16	1111111111100111
D/6	16	1111111111101000
D/7	16	1111111111101001
D/8	16	1111111111101010
D/9	16	1111111111101011
D/A	16	1111111111101100
E/1	14	11111111100000
E/2	16	1111111111101101
E/3	16	1111111111101110
E/4	16	1111111111101111
E/5	16	1111111111110000
E/6	16	1111111111110001
E/7	16	1111111111110010
E/8	16	1111111111110011
E/9	16	1111111111110100
E/A	16	1111111111110101
F/0 (ZRL)	10	1111111010
F/1	15	111111111000011
F/2	16	1111111111110110
F/3	16	1111111111110111
F/4	16	1111111111111000
F/5	16	1111111111111001
F/6	16	1111111111111010
F/7	16	1111111111111011
F/8	16	1111111111111100
F/9	16	1111111111111101
F/A	16	1111111111111110

K.3.3 Huffman table-specification examples

K.3.3.1 Specification of typical tables for DC difference coding

A set of typical tables for DC component coding is given in K.3.1. The specification of these tables is as follows:

For Table K.3 (for luminance DC coefficients), the 16 bytes which specify the list of code lengths for the table are

X’00 01 05 01 01 01 01 01 01 00 00 00 00 00 00 00’

The set of values following this list is

X’00 01 02 03 04 05 06 07 08 09 0A 0B’

For Table K.4 (for chrominance DC coefficients), the 16 bytes which specify the list of code lengths for the table are

X’00 03 01 01 01 01 01 01 01 01 01 00 00 00 00 00’

The set of values following this list is

X’00 01 02 03 04 05 06 07 08 09 0A 0B’

K.3.3.2 Specification of typical tables for AC coefficient coding

A set of typical tables for AC component coding is given in K.3.2. The specification of these tables is as follows:

For Table K.5 (for luminance AC coefficients), the 16 bytes which specify the list of code lengths for the table are

X’00 0For5736ilC1ı˝(For5736ilC3ı˝(For5736ilC3ı˝(For5736ilCDı˝(F255736ilC4ı˝(For5736ilC3ı˝(For5736ilC5ı˝(For5736ilC5

For Table K.6 (for chrominance AC coefficients), the 16 bytes which specify the list of code lengths for the table are

Table K.7 – Encoder test sequence (sheet 1 of 7)

EC	D	MPS	CX	Qe (hexadecimal)	A (hexadecimal)	C (hexadecimal)	CT	ST	Bx	B
1	0	0		5A1D	0000	00000000	11	0		

Table K.7 – Encoder test sequence (sheet 2 of 7)

EC	D	MPS	CX	Qe (hexadecimal)	A (hexadecimal)	C (hexadecimal)	CT	ST	Bx	B
37	0	0		174E	BD9C	000A1400	6	0		
38	0	0		174E	A64E		6	0		

Table K.7 – Encoder test sequence (sheet 4 of 7)

Table K.7 – Encoder test sequence (sheet 5 of 7)

EC	D	MPS	CX	Qe	A	C	CT	ST	Bx	B

Table K.7 – Encoder test sequence (sheet 6 of 7)

EC	D	MPS	CX	Qe	A	C	CT	ST	Bx	B

Table K.7 – Encoder test sequence (sheet 7 of 7)

EC	D	MPS	CX	Qe	A	C	CT	ST	Bx	B

Table K.8 – Decoder test sequence (sheet 2 of 7)

Table K.8 – Decoder test sequence (sheet 4 of 7)

EC	D	MPS	CX	Qe (hexadecimal)	A (hexadecimal)	C (hexadecimal)	CT	B

Table K.8 – Decoder test sequence (sheet 7 of 7)

EC	D	MPS	CX	Qe	A	C	CT	B

K.6 Domain of applicability of DCT and spatial coding techniques

The DCT coder is intended for lossy coding in a range from quite visible loss to distortion well below the threshold for visibility. However in general, DCT-based processes cannot be used for true lossless coding.

The lossless coder is intended for completely lossless coding. The lossless coding process is significantly less effective than the DCT-based processes for distortions near and above the threshold of visibility.

The point transform of the input to the lossless coder permits a very restricted form of lossy coding with the "lossless" coder. (The coder is still lossless after the input point transform.) Since the DCT is intended for lossy coding, there may be some confusion about when this alternative lossy technique should be used.

Lossless coding with a point transformed input is intended for applications which cannot be addressed by DCT coding techniques. Among these are

- true lossless coding to a specified precision;

K.8.2 Quantized AC prediction

Referring to the final scan (Al = 0), the points marked with "t" are the threshold values, while the points marked with "r"

Annex L

Patents

(This annex does not form an integral part of this Recommendation | International Standard)

No other patents required for implementation of any of the other processes specified in Annexes F, G, H, or J had been identified at the time of publication of this Specification.

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