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**Rec. T.809**

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**ISO/IEC**

**15444-  
10:200X**

COMMON TEXT PUBLICATION

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**Information technology — JPEG 2000 image  
coding system — Part 10: Extensions for three-  
dimensional data**

ITU-T Recommendation T.809 | ISO/IEC 15444-10:200X

(version 1)

## CONTENTS

1	Scope .....	1
2	Normative references .....	1
3	Terms and definitions.....	1
3.1	3D Bit-block .....	1
3.2	3D Code-block.....	1
3.3	3D Code-block scan .....	1
3.4	Component (Update of ITU-T Rec. T.801   ISO/IEC 15444-2).....	2
3.5	Conforming reader (Update of ITU-T Rec. T.800   ISO/IEC 15444-1).....	2
3.6	Decomposition level (Update of ITU-T Rec. T.801   ISO/IEC 15444-2).....	2
3.7	[H L X][H L X][H L X] subband .....	2
3.8	Image (Update of ITU-T Rec. T.800   ISO/IEC 15444-1).....	2
3.9	Image area offset (Update of ITU-T Rec. T.800   ISO/IEC 15444-1) .....	2
3.10	Intermediate component (Update of ITU-T Rec. T.801   ISO/IEC 15444-2).....	2
3.11	Raster order (Update of ITU-T Rec. T.800   ISO/IEC 15444-1).....	2
3.12	Resolution (Update of ITU-T Rec. T.801   ISO/IEC 15444-2) .....	2
3.13	Resolution level (Update of ITU-T Rec. T.800   ISO/IEC 15444-1).....	2
3.14	Sample (Update of ITU-T Rec. T.800   ISO/IEC 15444-1).....	3
3.15	Slice.....	3
3.16	Spatial coordinates .....	3
3.17	Subband (Update of ITU-T Rec. T.800   ISO/IEC 15444-1) .....	3
3.18	Subband order .....	3
3.19	Tile (Update of ITU-T Rec. T.800   ISO/IEC 15444-1).....	3
4	Abbreviations.....	3
5	Symbols (and abbreviated terms).....	3
6	General description .....	3
Annex A	Code stream syntax, extension.....	5
A.1	Extended capabilities.....	5
A.2	Extensions to ITU-T Rec. T.800   ISO/IEC 15444-1 and ITU-T Rec. T.801   ISO/IEC 15444-2 marker segment parameters.....	7
Annex B	Image and compressed image data ordering, extension .....	20
B.1	Introduction .....	20
B.2	Introduction to image data structure concepts .....	20
B.3	Component mapping to the reference grid.....	20
B.4	Image area division into tiles and tile-components.....	21
B.5	Transformed tile-component division into resolution levels and subbands.....	22
B.6	Division of resolution levels into precincts .....	23
B.7	Division of subbands into code-blocks .....	24
B.8	Packets.....	24
B.9	Packet header information coding .....	24
B.10	Progression order .....	25
Annex C	Coefficient bit modeling .....	28
C.1	Introduction .....	28
C.2	Code-block scan pattern within code-blocks, extended.....	28
C.3	Context model updates.....	28
Annex D	Discrete wavelet transformation of tile-components.....	30
D.1	Introduction .....	30
D.2	Tile-component parameters.....	30
D.3	Discrete wavelet transformations.....	30
D.4	Inverse discrete wavelet transformation.....	30
D.5	Forward transformation (informative).....	37
Annex E	Coding of images with regions of interest, extension .....	46

E.1	Introduction .....	46
E.2	Decoding of ROI .....	46
E.3	Encoding with ROI (informative) .....	47
E.4	Region of interest mask generation.....	49
E.5	Remarks on region of interest coding .....	52
Annex F	Examples and guidelines, extensions .....	53
F.1	Rate-Distortion Modeling .....	53

## FIGURES

Figure A-1 — Additional dimension image and tile size syntax (extended) .....	7
Figure A-2 — Coding style default syntax .....	8
Figure A-3 — Coding style parameter diagram of the <i>SGcod</i> and <i>SPcod</i> parameters .....	9
Figure A-4 — Coding style component syntax .....	12
Figure A-5 — Coding style parameter diagram of the <i>SPcoc</i> parameter .....	13
Figure A-6 — Region of interest syntax .....	14
Figure A-7 — Quantization default style .....	15
Figure A-8 — Quantization component syntax .....	17
Figure A-9 — Component registration syntax .....	18
Figure D-1 — Inputs and output of the IDWT procedure .....	31
Figure D-2 — The IDWT procedure .....	31
Figure D-3 — Inputs and outputs of the 3D_SR procedure .....	32
Figure D-4 — The 3D_SR procedure .....	32
Figure D-5 — Inputs and outputs of the TO_ARRAY procedure .....	33
Figure D-6 — All possible subband configurations for 3D DWT .....	33
Figure D-7 — Parameters of the 1D_INTERLEAVE procedure .....	34
Figure D-8 — The 1D_INTERLEAVE procedure .....	34
Figure D-9 — Inputs and outputs of the HOR_SR procedure .....	35
Figure D-10 — The HOR_SR procedure .....	35
Figure D-11 — Inputs and outputs of the VER_SR procedure .....	36
Figure D-12 — The VER_SR procedure .....	36
Figure D-13 — Inputs and outputs of the AXIAL_SR procedure .....	37
Figure D-14 — The AXIAL_SR procedure .....	38
Figure D-15 — Inputs and outputs of the FDWT procedure .....	38
Figure D-16 — The FDWT procedure .....	39
Figure D-17 — Inputs and outputs of the 3D_SD procedure .....	39
Figure D-18 — The 3D_SD procedure .....	40
Figure D-19 — Inputs and outputs of the AXIAL_SD procedure .....	40
Figure D-20 — The AXIAL_SD procedure .....	41
Figure D-21 — Inputs and outputs of the VER_SD procedure .....	42
Figure D-22 — The VER_SD procedure .....	43
Figure D-23 — Inputs and outputs of the HOR_SD procedure .....	43
Figure D-24 — The HOR_SD procedure .....	44
Figure D-25 — Parameters of the 1D_DEINTERLEAVE procedure .....	45
Figure D-26 — The 1D_DEINTERLEAVE procedure .....	45
Figure E-1 — Cuboid mask on the reference grid .....	50
Figure E-2 — Ellipsoidal mask on the reference grid .....	51

## TABLES

Table A-1 — List of JP3D markers and marker segments .....	5
Table A-2 – Additional dimension image and tile size parameter values (extended).....	7
Table A-3 – Coding style default parameters values, extended .....	9
Table A-4 – Coding style parameter values for the Scod parameter.....	9
Table A-5 – Coding style parameter values for the SGcod parameter.....	10
Table A-6 – Coding style parameter values of the SPcod and SPcoc paramaters, extended .....	10
Table A-7 – Width, height or depth exponent of the 3D code-blocks for the SPcod and SPcoc parameters.....	11
Table A-8 – 3D code-block style for the SPcod and SPcoc paramaters, extended .....	11
Table A-9 – Precinct width, height and depth for the SPcod and SPcoc parameters, extended.....	12
Table A-10 – Coding style component parameter values, extended.....	13
Table A-11 – Coding style parameter values for the Scoc parameter, extended.....	13
Table A-12 – Region of interest parameter values, extended .....	14
Table A-13 – Region of interest values from <i>SPrgn</i> parameter ( <i>Srgn</i> = 1 or <i>Srgn</i> = 2), extended .....	15
Table A-14 – Quantization default parameter values, extended .....	16
Table A-15 – Quantization component paramater values .....	17
Table A-16 – Component registration parameter values .....	18
Table A-17 – Ccap <sup>1</sup> , extended.....	19
Table B-1 — Quantities $(xO_b, yO_b, zO_b)$ for subband <i>b</i> .....	23
Table C-1 – Contexts for the significance propagation and cleanup coding passes.....	28

## Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of Recommendation | International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

Recommendation | International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare Recommendation | International Standards. Draft Recommendation | International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as a Recommendation | International Standard requires approval by at least 75 % of the national bodies casting a vote.

ITU-T Rec. T.809 | ISO/IEC 15444-10 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information Technology*, Subcommittee SC 29, *Coding of Audio, Picture, Multimedia and Hypermedia Information*.

ISO/IEC 15444 consists of the following parts, under the general title *Information technology — JPEG 2000 image coding system*:

- *Part 1: Core coding system*
- *Part 2: Extensions*
- *Part 3: Motion JPEG 2000*
- *Part 4: Conformance testing*
- *Part 5: Reference software*
- *Part 6: Compound image file format*
- *Part 8: Secure JPEG 2000*
- *Part 9: Interactivity tools, APIs and protocols*
- *Part 10: Extensions for three-dimensional data*
- *Part 11: Wireless*
- *Part 12: ISO base media file format*
- *Part 13: Entry Level JPEG 2000 Encoder*

**INTERNATIONAL STANDARD**  
**ISO/IEC FCD 15444-10:200X (E)**  
**ITU-T Rec. T.809 (200X E)**  
**ITU-T RECOMMENDATION**

**Information Technology –**  
**JPEG 2000 image coding system: Extensions for three-dimensional data**

## **1 Scope**

ISO/IEC 15444-10 is a work item subdivision of ISO/IEC 15444 that provides extensions of ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2 for logically cuboidal data sets. In particular, it respects all existing capabilities and syntax of ITU-T Rec. T.800 | ISO/IEC 15444-1 and part of the existing capabilities of ITU-T Rec. T.801 | ISO/IEC 15444-2 for multicomponent images, while providing alternatives and extensions to some of those capabilities. Within these constraints, it provides an isotropic specification for three-dimensional data sets; i.e. the project provides identical processing capabilities in all three dimensions even though ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2 codestream syntax differentiates between the two spatial axes and the cross-component axis.

## **2 Normative references**

The following Recommendations | International Standards contain provisions which, through reference in this text, constitute provisions of this Recommendation | International Standard. At the time of publication, the editions indicated were valid. All Recommendations and Standards are subject to revision, and parties to agreements based on this Recommendation | International Standard are encouraged to investigate the possibility of applying the most recent edition of the Recommendations and Standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards. The Telecommunication Standardization Bureau of the ITU maintains a list of currently valid ITU-T Recommendations.

- ITU-T Rec. T.800 | ISO/IEC 15444-1:2004, *Information technology — JPEG 2000 image coding system: Core coding system*
- ITU-T Rec. T.801 | ISO/IEC 15444-2:2004, *Information technology — JPEG 2000 image coding system: Extensions*

## **3 Terms and definitions**

### **3.1 3D Bit-block**

A three-dimensional array of bits. In this Recommendation | International Standard a 3D bit-block refers to all the bits of the same magnitude in all coefficients or samples. This could refer to a 3D bit-block in a component, tile-component, 3D code-block, region of interest, or other.

### **3.2 3D Code-block**

A rectangular three-dimensional grouping of coefficients from the same subband of a tile-component.

### **3.3 3D Code-block scan**

The order in which the coefficients within a 3D code-block are visited during a coding pass. The 3D code-block is processed in stripes, each consisting of four rows (or all remaining rows if less than four) and spanning the width of the

## **ISO/IEC FCD 15444-10:200X (E)**

3D code-block. Each stripe is processed column by column from top to bottom and from left to right. The complete 3D code-block is consequently scanned slice by slice. Within a slice ITU-T Rec. T.800 | ISO/IEC 15444-1 is followed.

### **3.4 Component (Update of ITU-T Rec. T.801 | ISO/IEC 15444-2)**

Compressed data from the codestream representing a single set of two- or three-dimensional data.

### **3.5 Conforming reader (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

An application that reads and interprets a JP3D file correctly.

### **3.6 Decomposition level (Update of ITU-T Rec. T.801 | ISO/IEC 15444-2)**

A collection of subbands where each coefficient has the same spatial impact or span with respect to the original samples. These include the [H|L|X][H|L|X][H|L|X] subband (e.g. LLL, LXL, XXH, ..., exclusive XXX) split out of the three-dimensional decomposition sublevels.

### **3.7 [H|L|X][H|L|X][H|L|X] subband**

H refers to high-pass filtering and L to low-pass filtering, while X refers to no filtering. The filter specified first refers to the horizontal filtering, the second to the vertical filtering and the third to the axial filtering (i.e. respectively along X-, Y- and Z-axes). The filter ordering for this subband should always be respected. The reconstruction will follow the inverse filtering order.

NOTE The XXX subband does not exist (as defined in 3.6).

### **3.8 Image (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

The set of all components, which can have either two- or three spatial dimensions.

### **3.9 Image area offset (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

The number of reference grid points down, to the right (and to an increased axial position) of the reference grid origin.

### **3.10 Intermediate component (Update of ITU-T Rec. T.801 | ISO/IEC 15444-2)**

A single two- or three-dimensional array of data involved in a stage of a multiple component transformation.

### **3.11 Raster order (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

A particular sequential order of data of any type within an array. The raster order starts with the top left data point of the first slice and moves to the data point immediately to the right, and so on to the end of the row. After the end of the row is reached the next data point in the sequence is the left-most data point immediately below the current row. This order is continued to the end of the slice. Thereafter the next slice is processed in case of a three dimensional array. This order is continued to the end of the array.

### **3.12 Resolution (Update of ITU-T Rec. T.801 | ISO/IEC 15444-2)**

The spatial relation of samples to a physical space. In this Recommendation | International standard the decomposition levels of the wavelet transform create resolutions that differ by powers of two in the horizontal, the vertical, or – in the three-dimensional case – the axial direction, or any possible combination of directions. The last (highest) decomposition level includes an [L|X][L|X][L|X] subband (note that XXX is non-existing), which is considered to be a lower resolution. Therefore, there is one more resolution level than decomposition levels.

### **3.13 Resolution level (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

Equivalent to decomposition level with the exception that the [L|X][L|X][L|X] subband is also a separate resolution level.

**3.14 Sample (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

One element in the two-dimensional or three-dimensional array that comprises a component.

**3.15 Slice**

A slice is a two-dimensional pixel subset of a volumetric entity, a volumetric code-block or a volumetric image. A slice is positioned perpendicular to the axial or z-axis.

**3.16 Spatial coordinates**

Spatial coordinates are indicated by  $x$ ,  $y$  and  $z$ . Generally, the term axial will be used to address the  $Z$  dimension.

**3.17 Subband (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

A group of transform coefficients resulting from the same sequence of low-pass and high-pass filtering operations.

**3.18 Subband order**

Within one resolution level subbands are processed and signaled as defined in ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2 for two-dimensional filtering, following a Morton scanning order [1]. The specification is extended to the three-dimensional case by deploying consequently a three-dimensional Morton scanning order.

**3.19 Tile (Update of ITU-T Rec. T.800 | ISO/IEC 15444-1)**

A cuboidal array of points on the reference grid, registered with an offset from the reference grid origin and defined by a width ( $x$  dimension), a height ( $y$  dimension) and a depth ( $z$  dimension). The tiles that overlap are used to define tile-components.

**4 Abbreviations**

For the purposes of this Recommendation | International Standard, the Abbreviations defined in ITU-T Rec. T.800 | ISO/IEC 15444-1 section 3 and ITU-T Rec. T.801 | ISO/IEC 15444-2 section 4 also apply to this Recommendation | International Standard.

**5 Symbols (and abbreviated terms)**

For the purposes of this Recommendation | International Standard, the symbols defined in ITU-T Rec. T.800 | ISO/IEC 15444-1 section 4 and ITU-T Rec. T.801 | ISO/IEC 15444-2 section 5 also apply to this Recommendation | International Standard.

NSI: Additional dimension image and tile size

**6 General description**

This Recommendation | International Standard defines a set of lossless (bit-preserving) and lossy compression methods for coding continuous-tone, bi-level, grey-scale, colour digital volumetric images, or multi-component volumetric images. This set of methods (see Annex A) extends the elements in the core coding system described in ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2. Extensions which pertain to encoding and decoding are defined as procedures which may be used in combination with the encoding and decoding processes described in ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2. Each encoding or decoding extension shall be used only in combination with particular coding processes and only in accordance with the requirements set forth herein. This Recommendation | International Standard also defines extensions to the compressed data format, i.e. interchange format and the abbreviated formats.

## **ISO/IEC FCD 15444-10:200X (E)**

In particular, for ITU-T Rec. T.801 | ISO/IEC 15444-2 the following extensions are supported by this Recommendation | International Standard:

- [1] Variable DC offset
- [2] Arbitrary Wavelet Transform Kernels
- [3] Multi component transformations
- [4] Non-linear transformations
- [5] Region-of-interest

## Annex A

### Code stream syntax, extension

(This annex forms a normative and integral part of this Recommendation | International Standard.)

#### A.1 Extended capabilities

The syntax in this Annex supports the extensions in this Recommendation | International Standard. These marker segments conform to the same rules as the syntax in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex A. The addition of parameter values to some marker segments in ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2 and the addition of new marker segments signals the information specific to the extensions in this Recommendation | International Standard.

In every marker segment the first two bytes after the marker shall be an unsigned value that denotes the length in bytes of the marker segment parameters (including the two bytes of this length parameter but not the two bytes of the marker itself).

When a marker segment that is not specified in this Recommendation | International Standard or in ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2 is encountered in a codestream, the decoder shall use the length parameter to discard the marker segment. Table A-1 shows the marker segments adopted/extended for this Recommendation | International Standard.

**Table A-1 — List of JP3D markers and marker segments**

	Symbol	Code	Main Header	Tile-part header	ITU-T Rec. T.80x   ISO/IEC 15444-x Heritage / Extended
<b>Delimiting markers and marker segments</b>					
Start of codestream	SOC	0xFF4F	required <sup>a</sup>	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1
Start of tile-part	SOT	0xFF90	not allowed	required	ITU-T Rec. T.801   ISO/IEC 15444-2
Start of data	SOD	0xFF93	not allowed	last marker	ITU-T Rec. T.800   ISO/IEC 15444-1
End of codestream	EOC	0xFFD9	not allowed	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1
<b>Fixed information marker segments</b>					
Image and tile size	SIZ	0xFF51	required	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1
Additional dimension image and tile size	NSI	0xFF54	required	not allowed	
<b>Functional marker segments</b>					
Coding style default	COD	0xFF52	required	optional	ITU-T Rec. T.800   ISO/IEC 15444-1, Extended

**ISO/IEC FCD 15444-10:200X (E)**

Coding style component	COC	0xFF53	optional	optional	ITU-T Rec. T.800   ISO/IEC 15444-1, Extended
Region-of-interest	RGN	0xFF5E	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2, Extended
Quantization default	QCD	0xFF5C	required	optional	ITU-T Rec. T.800   ISO/IEC 15444-1, Extended
Quantization component	QCC	0xFF5D	optional	optional	ITU-T Rec. T.800   ISO/IEC 15444-1, Extended
Arbitrary transformation kernels	ATK	0xFF79	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
Component bit depth definition	CBD	0xFF78	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
Multiple component transformation definition	MCT	0xFF74	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
Multiple component transform collection	MCC	0xFF75	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
Multiple component transform ordering	MCO	0xFF77	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
Non-linearity point transformation	NLT	0xFF76	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
Variable DC offset	DCO	0xFF70	optional	optional	ITU-T Rec. T.801   ISO/IEC 15444-2
<b>Pointer marker segments</b>					
Tile-part lengths	TLM	0xFF55	optional	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1
Packet length, main header	PLM	0xFF57	optional	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1
Packet length, tile-part header	PLT	0xFF58	not allowed	optional	ITU-T Rec. T.800   ISO/IEC 15444-1
Packed packet headers, main header	PPM	0xFF60	optional	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1
Packed packet headers, tile-part header	PPT	0xFF61	not allowed	optional	ITU-T Rec. T.800   ISO/IEC 15444-1
<b>In bit stream markers and marker segments</b>					
Start of packet	SOP	0xFF91	not allowed	not allowed in tile-part header, optional in bit stream	ITU-T Rec. T.800   ISO/IEC 15444-1
End of packet header	EPH	0xFF92	optional inside PPM marker segment	optional inside PPT marker segment or in bit stream	ITU-T Rec. T.800   ISO/IEC 15444-1

<b>Informational marker segments</b>					
Component registration	CRG	0xFF63	optional	not allowed	ITU-T Rec. T.800   ISO/IEC 15444-1, Extended
Comment	COM	0xFF64	optional	optional	ITU-T Rec. T.800   ISO/IEC 15444-1

<sup>a</sup> Required means the marker or marker segment shall be in this header, optional means it may be used.

## A.2 Extensions to ITU-T Rec. T.800 | ISO/IEC 15444-1 and ITU-T Rec. T.801 | ISO/IEC 15444-2 marker segment parameters

### A.2.1 Additional dimension image and tile size (NSI)

**Function:** Provides information about the uncompressed image such as the depth of the reference grid, the depth of the tiles, and the separation of component samples with respect to the reference grid.

**Usage:** Main header. There shall be one and only one in the main header after the CAP marker segment and before the first JP3D-extended marker segment. There shall be only one NSI per codestream.

**Length:** Variable depending on the number of components.



Figure A-1 — Additional dimension image and tile size syntax (extended)

**NSI:** Marker code. Table A-2 shows the size and parameter values of the symbol and parameters for additional dimension image and tile size marker segment.

**Lnsi:** Length of marker segment in bytes (not including the marker). The value of this parameter is determined by the following equation:

$$Lnsi = 19 + Csiz \tag{A.1}$$

**Ndim:** Defines the dimensionality of the dataset (disregarding the component dimension). This value is set to 3 by default.

**Zsiz:** Depth of the reference grid.

**ZOsiz:** Depth offset from the origin of the reference grid to the front left upper corner of the image volume.

**ZTsiz:** Depth of one reference tile with respect to the reference grid.

**ZTOsiz:** Vertical offset from the origin of the reference grid to the front left upper corner of the first tile.

**ZRsiz<sup>i</sup>:** Depth separation of a sample of the *i*th component with respect to the reference grid. There is one occurrence of this parameter for each component, in order.

Table A-2 – Additional dimension image and tile size parameter values (extended)

Parameter	Size (bits)	Values
NSI	16	0xFF54

Lnsi	16	20-16403
Ndim	8	3
Zsiz	32	$1 - (2^{32} - 1)$
ZOsiz	32	$0 - (2^{32} - 1)$
ZTsiz	32	$1 - (2^{32} - 1)$
ZTOsiz	32	$1 - (2^{32} - 2)$
ZRsiz <sup>i</sup>	8	1 - 255

**A.2.2 Coding Style default (COD), ITU-T Rec. T.800 | ISO/IEC 15444-1 extended**

**Function:** Describes the coding style, number of decomposition levels, and layering that is the default used for compressing all components of an image (if in the main header) or a tile (if in the tile-part header). The parameter values can be overridden for an individual component by a COC marker segment in either the main or tile-part header.

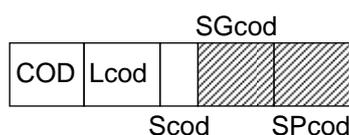
**Usage:** Main and first tile-part header of a given tile. Shall be one and only one in the main header. Additionally, there may be at most one for each tile. If there are multiple tile-parts in a tile, and this marker segment is present, it shall be found only in the first tile-part (*TPsot = 0*).

When used in the main header, the COD marker segment parameter values are used for all tile-components that do not have a corresponding COC marker segment in either the main or tile-part header. When used in the tile-part header it overrides the main header COD and COCs and is used for all components in that tile without a corresponding COC marker segment in the tile-part. Thus, the order of precedence is the following:

Tile-part COC > Tile-part COD > Main COC > Main COD

where the "greater than" sign, >, means that the greater overrides the lessor marker segment.

**Length:** Variable depending on the value of Scod (see Lcod parameter).



**Figure A-2 — Coding style default syntax**

**COD:** Marker code. Table A-3 shows the size and values of the symbol and parameters for coding style default marker segment.

**Lcod:** Length of marker segment in bytes (not including the marker). The value of this parameter is determined by the following equation:

$$Lcod = \begin{cases} 17 & \text{maximum\_precincts} \\ 17 + 2 \cdot \text{number\_of\_resolution\_levels} & \text{user-defined\_precincts} \end{cases} \quad \text{A.2}$$

where *maximum\_precincts* and *user-defined\_precincts* are indicated in the *Scod* parameter and *number\_of\_resolution\_levels* is calculated by use of the number of decomposition level parameters for each of the three dimensions, X, Y and Z, as indicated in the *SPcod* parameter. The actual equation for calculating the number of resolution levels is given in Annex B.5.

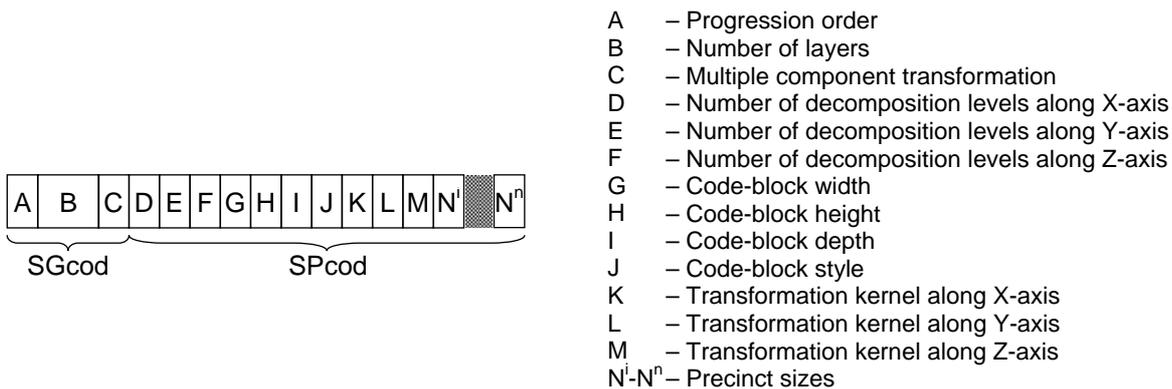
**Scod:** Coding style for all components. Table A-4 shows the value for the *Scod* parameter.

**SGcod:** Parameters for coding style designated in *Scod*. The parameters are independent of components and are designated, in order from top to bottom, in Table A-5. The coding style parameters within the *SGcod* field appear in the sequence shown in Figure A-3.

**SPcod:** Parameters for coding style designated in *Scod*. The parameters relate to all components and are designated, in order from top to bottom, in Table A-6. The coding style parameters within the *SPcod* field appear in the sequence shown in Figure A-3.

**Table A-3 – Coding style default parameters values, extended**

Parameter	Size (bits)	Values
COD	16	0xFF52
Lcod	16	17–83
Scod	8	Table A-4
SGcod	32	Table A-5
SPcod	variable	Table A-6



**Figure A-3 — Coding style parameter diagram of the *SGcod* and *SPcod* parameters**

**Table A-4 – Coding style parameter values for the *Scod* parameter**

Values (bits) MSB LSB	Coding style
xxxx xxx0	Entropy coder, precincts with $PP_x = 15$ , $PP_y = 15$ and $PP_z = 15$
xxxx xxx1	Entropy coder with custom precincts defined below
xxxx xx0x	No SOP marker segments used
xxxx xx1x	SOP marker segments may be used
xxxx x0xx	No EPH marker used
xxxx x1xx	EPH marker shall be used
	All other values reserved

Table A-5 – Coding style parameter values for the SGcod parameter

Parameters (in order)	Size (bits)	Values	Meaning of SGcod values
Progression order	8	ITU-T Rec. T.800   ISO/IEC 15444-1 Table A-16	Progression order
Number of layers	16	1-65535	Number of layers
Multiple component transform	8	ITU-T Rec. T.800   ISO/IEC 15444-2 Table A-8	Multiple component transform usage

Table A-6 – Coding style parameter values of the SPcod and SPcoc parameters, extended

Parameters (in order)	Size (bits)	Values	Meaning of SPcod values
Number of decomposition levels along X-axis	8	0-32	Number of decomposition levels along X-axis, $N_{LX}$ , zero implies no transformation
Number of decomposition levels along Y-axis	8	0-32	Number of decomposition levels along Y-axis, $N_{LY}$ , zero implies no transformation
Number of decomposition levels along Z-axis	8	0-32	Number of decomposition levels along Z-axis, $N_{LZ}$ , zero implies no transformation
3D code-block width	8	Table A-7	Code-block width exponent offset value, $xcb$
3D code-block height	8	Table A-7	Code-block height exponent offset value, $ycb$
3D code-block depth	8	Table A-7	Code-block depth exponent offset value, $zcb$
3D code-block style	8	Table A-8	Style of the 3D code-block coding passes
Transformation kernel along X-axis	8	ITU-T Rec. T.800   ISO/IEC 15444-2 Table A-10	Wavelet transformation used along X-axis
Transformation kernel along Y-axis	8	ITU-T Rec. T.800   ISO/IEC 15444-2 Table A-10	Wavelet transformation used along Y-axis
Transformation kernel along Z-axis	8	ITU-T Rec. T.800   ISO/IEC 15444-2 Table A-10	Wavelet transformation used along Z-axis
Precinct size	variable	Table A-9	If $Scod$ or $Scoc = xxxx\ xxx0$ , this parameter is not present, otherwise this indicates precinct width, height and depth. The first parameter (16 bits) corresponds to the $N_{L,LLL}$ subband. Each successive parameter corresponds to each successive resolution level in order.

Table A-7 – Width, height or depth exponent of the 3D code-blocks for the SPcod and SPcoc parameters

Values (bits) MSB LSB	3D code-block width, height and depth
xxxx 0000 – xxxx 1011	3D code-block width, height and depth exponent values $xcb = value$ , $ycb = value$ or $zcb = value$ (Note: THIS REDEFINES ITU-T Rec. T.800   ISO/IEC 15444-1 SIGNIFICANTLY!) The 3D code-block width, height and depth are limited to powers of two with the minimum size being $2^0$ and the maximum being $2^{10}$ .  Further, the 3D code-block size is restricted so that $4 \leq xcb+ycb+zcb \leq 18$ .
	All other values reserved

Table A-8 – 3D code-block style for the SPcod and SPcoc parameters, extended

Values (bits) MSB LSB	3D code-block style
xxxx xxx0	No selective arithmetic coding bypass
xxxx xxx1	Selective arithmetic coding bypass
xxxx xx0x	No reset of context probabilities on coding pass boundaries
xxxx xx1x	Reset context probabilities on coding pass boundaries
xxxx x0xx	No termination on each coding pass
xxxx x1xx	Termination on each coding pass
xxxx 0xxx	No causal contexts
xxxx 1xxx	Causal contexts
xxx0 xxxx	No predictable termination
xxx1 xxxx	Predictable termination
xx0x xxxx	No segmentation symbols are used
xx1x xxxx	Segmentation symbols are used
	All other values reserved

**Table A-9 – Precinct width, height and depth for the SPcod and SPcoc parameters, extended**

Values (bits) MSB LSB	Precinct size
xxxx xxxx xxxx 0000 – xxxx xxxx xxxx 1111	4 LSBs are the precinct width exponent $PPx = value$ . This value may only equal zero at the resolution level corresponding to the $N_{lLLL}$ band.
xxxx xxxx 0000 xxxx – xxxx xxxx 1111 xxxx	Next 4 bits are the precinct height exponent $PPy = value$ . This value may only equal zero at the resolution level corresponding to the $N_{lLLL}$ band.
xxxx 0000 xxxx xxxx – xxxx 1111 xxxx xxxx	Next 4 bits are the precinct depth exponent $PPz = value$ . This value may only equal zero at the resolution level corresponding to the $N_{lLLL}$ band.
	All other values reserved

**A.2.3 Coding style component (COC), ITU-T Rec. T.800 | ISO/IEC 15444-1 extended**

**Function:** Describes the coding style and number of decomposition levels used for compressing a particular component.

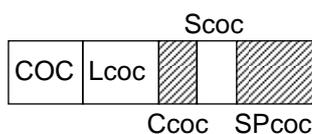
**Usage:** Main and first tile-part header of a given tile. Optional in both the main and tile-part headers. No more than one per any given component may be present in either the main or tile-part headers. If there are multiple tile-parts in a tile, and this marker segment is present, it shall be found only in the first tile-part ( $TP_{sot} = 0$ ).

When used in the main header it overrides the main COD marker segment for the specific component. When used in the tile-part header it overrides the main header COD, main COC and tile COD for the specific component. Thus, the order of precedence is the following:

$$\text{Tile-part COC} > \text{Tile-part COD} > \text{Main COC} > \text{Main COD}$$

where the "greater than" sign,  $>$ , means that the greater overrides the lessor marker segment.

**Length:** Variable depending on the value of Scoc (see Lcoc parameter).



**Figure A-4 – Coding style component syntax**

**COC:** Marker code. Table A-10 shows the size and values of the symbol and parameters for the coding style component marker segment.

**Lcoc:** Length of marker segment in bytes (not including the marker). The value of this parameter is determined by the following equation:

$$Lcoc = \begin{cases} 14 & \text{maximum\_precincts AND } Csiz < 257 \\ 15 & \text{maximum\_precincts AND } Csiz \geq 257 \\ 14 + 2 \cdot \text{number\_of\_resolution\_levels} & \text{user-defined\_precincts AND } Csiz < 257 \\ 15 + 2 \cdot \text{number\_of\_resolution\_levels} & \text{user-defined\_precincts AND } Csiz \geq 257 \end{cases} \quad \text{A.3}$$

**Ccoc:** The index of the component to which this marker segment relates. The components are indexed 0, 1, 2, etc.

**Scoc:** Coding style for this component. Table A-11 shows the values for each *Scoc* parameter.

**SPcoc:** Parameters for coding style designated in *Scoc*. The coding style parameters within the *SPcoc* field appear in the order sequence shown in Figure A-5.

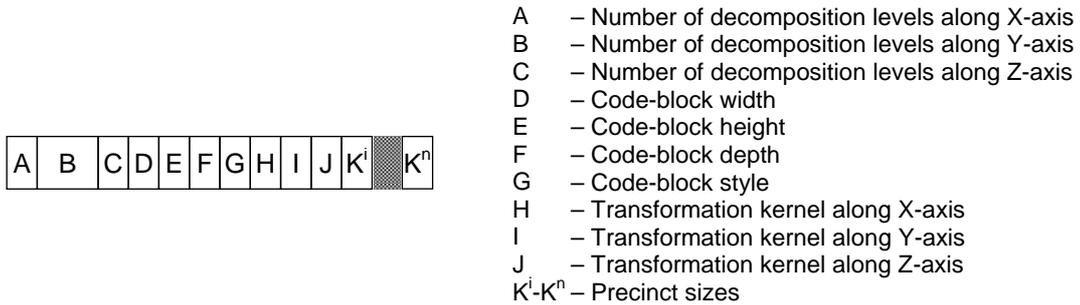


Figure A-5 – Coding style parameter diagram of the *SPcoc* parameter

Table A-10 – Coding style component parameter values, extended

Parameter	Size (bits)	Values
COC	16	0xFF53
Lcoc	16	4–102
Ccoc	8 16	0–255; if <i>Csiz</i> < 257 0–16383; if <i>Csiz</i> ≥ 257
Scoc	8	Table A-11
SPcoc <sup>i</sup>	variable	Table A-6

Table A-11 – Coding style parameter values for the *Scoc* parameter, extended

Values (bits) MSB LSB	Coding style
xxxx xxx0	Entropy coder with maximum precinct values $PP_x = PP_y = PP_z = 15$
xxxx xxx1	Entropy coder with precinct values defined in <i>SPcoc</i> .
	All other values reserved

#### A.2.4 Region of Interest (RGN), ITU-T Rec. T.801 | ISO/IEC 15444-2 extended

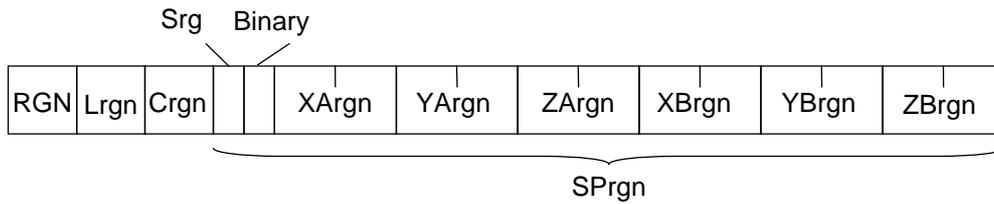
**Function:** Signals the presence of a Region of interest (ROI) in the codestream.

**Usage:** Main and first tile-part header of a given tile. If used in the main header it refers to the ROI scaling value for one component in the whole image, valid for all tiles except those with an RGN marker segment.

When used in the tile-part header the scaling value is valid only for one component in that tile. There may be at most one RGN marker segment for each component in either the main or tile-part headers. The RGN marker segment for a particular component which appears in a tile-part header overrides any marker for

that component in the main header, for the tile in which it appears. If there are multiple tile-parts in a tile, then this marker segment shall be found only in the first tile-part header.

**Length:** Variable.



**Figure A-6 – Region of interest syntax**

**RGN:** Marker code. Table A-12 shows the size and values of the symbol and parameters for the region of interest marker segment.

**Lrgn:** Length of the marker segment in bytes (not including the marker).

**Crgn:** The index of the component to which this marker segment relates. The components are indexed 0, 1, 2, etc.

**Srgn:** ROI style for the current ROI. ITU-T Rec. T.801 | ISO/IEC 15444-2 Table A-16 shows the value for the Srgn parameter.

**SPrgn:** Parameter for ROI style designated in *Srgn*. *SPrgn* is only signaled for *Srgn* = 1 or *Srgn* = 2.

**Table A-12 – Region of interest parameter values, extended**

Parameter	Size (bits)	Values
RGN	16	0xFF5E
Lrgn	16	5—30
Crgn	16	ITU-T Rec. T.801   ISO/IEC 15444-2 Table A-17
Srgn	8	ITU-T Rec. T.801   ISO/IEC 15444-2 Table A-16
SPrgn	variable	Table A-13

**Table A-13 – Region of interest values from *SPrgn* parameter (*Srgn* = 1 or *Srgn* = 2), extended**

Parameters (in order)	Size (bits)	Values	Meaning of <i>SPrgn</i> values
Binary shift	8	0—255	Binary shifting of coefficients in the region of interest above the background.
XArgn (left)	32	0—(2 <sup>32</sup> -1)	Horizontal reference grid point from the origin of the first point. (In the case of the ellipse, <i>Srgn</i> = 2, this value shall not exceed the width of the image.)
YArgn (top)	32	0—(2 <sup>32</sup> -1)	Vertical reference grid point from the origin of the first point. (In the case of the ellipse, <i>Srgn</i> = 2, this value shall not exceed the height of the image.)
ZArgn (front)	32	0—(2 <sup>32</sup> -1)	Axial reference grid point from the origin of the first point. (In the case of the ellipse, <i>Srgn</i> = 2, this value shall not exceed the depth of the image.)
XBrng (right)	32	0—(2 <sup>32</sup> -1)	Horizontal reference grid point from the origin of the second point.
YBrng (bottom)	32	0—(2 <sup>32</sup> -1)	Vertical reference grid point from the origin of the second point.
ZBrng (back)	32	0—(2 <sup>32</sup> -1)	Axial reference grid point from the origin of the second point.

**A.2.5 Quantization component default (QCD), ITU-T Rec. T.800 | ISO/IEC 15444-1 extended**

**Function:** Describes the quantization default used for compressing all components not defined by a QCC marker segment. The parameter values can be overridden for an individual component by a QCC marker segment in either the main or tile-part header.

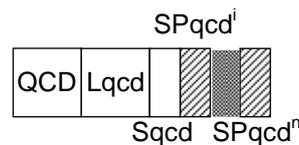
**Usage:** Main and first tile-part header of a given tile. Shall be one and only one in the main header. May be at most one for all tile-part headers of a tile. If there are multiple tile-parts for a tile, and this marker segment is present, it shall be found only in the first tile-part (*TPsot* = 0).

When used in the tile-part header it overrides the main QCD and the main QCC for the specific component. Thus, the order of precedence is the following:

$$\text{Tile-part QCC} > \text{Tile-part QCD} > \text{Main QCC} > \text{Main QCD}$$

where the “greater than” sign, >, means that the greater overrides the lessor marker segment.

**Length:** Variable depending on the number of quantized elements.



**Figure A-7 – Quantization default style**

**QCD:** Marker code. Table A-14 shows the size and values of the symbol and parameters for the quantization default marker segment.

**Lqcd:** Length of the marker segment in bytes (not including the marker). The value of this parameter is determined by the following equation:

$$Lqcd = \begin{cases} 4 + \text{number\_of\_subbands} & \text{no\_quantization} \\ 5 & \text{scalar\_quantization\_derived} \\ 5 + 2 \cdot \text{number\_of\_subbands} & \text{scalar\_quantization\_expounded} \end{cases} \quad \text{A.4}$$

where *number\_of\_subbands* (depending on number of decomposition levels along X, Y and Z axis) is defined in the COD and COC marker segments, and *no\_quantization*, *scalar\_quantization\_derived*, or *scalar\_quantization\_expounded* is signaled in the *Sqcd* parameter.

NOTE The *Lqcd* can be used to determine how many quantization step sizes are present in the marker segment. However, there is not necessarily a correspondence with the number of subbands present because the subbands can be truncated with no requirement to correct this marker segment.

**Sqcd:** Quantization style for all components.

**SPqcd<sup>i</sup>:** Quantization step size value for the *i*th subband in the defined order (see Annex B). The number of parameters is the same as the number of subbands in the tile-component with the greatest number of decomposition levels, *N<sub>L</sub>*.

**Table A-14 – Quantization default parameter values, extended**

Parameter	Size (bits)	Values
QCD	16	0xFF5C
Lqcd	16	4—441
Sqcd	8	ITU-T Rec. T.800   ISO/IEC 15444-1 Table A-28
SPqcd <sup>i</sup>	variable	ITU-T Rec. T.800   ISO/IEC 15444-1 Table A-28

### A.2.6 Quantisation component (QCC), ITU-T Rec. T.800 | ISO/IEC 15444-1 extended

**Function:** Describes the quantization used for compressing a particular component.

**Usage:** Main and first tile-part header of a given tile. Optional in both the main and tile-part headers. No more than one per any given component may be present in either the main or tile-part headers. If there are multiple tile-parts in a tile, and this marker segment is present, it shall be found only in the first tile-part (*TP<sub>sot</sub> = 0*).

Optional in both the main and tile-part headers. When used in the main header it overrides the main QCD marker segment for the specific component. When used in the tile-part header it overrides the main QCD, main QCC, and tile QCD for the specific component. Thus, the order of precedence is the following:

Tile-part QCC > Tile-part QCD > Main QCC > Main QCD

where the “greater than” sign, >, means that the greater overrides the lessor marker segment.

**Length:** Variable depending on the number of quantized elements.

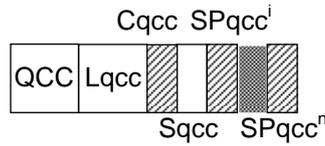


Figure A-8 – Quantization component syntax

**QCC:** Marker code. Table A-15 shows the size and values of the symbol and parameters for the quantization component marker segment.

**Lqcc:** Length of the marker segment in bytes (not including the marker). The value of this parameter is determined by the following equation:

$$Lqcc = \begin{cases} 5 + \text{number\_of\_subbands} & \text{no\_quantization AND } Csiz < 257 \\ 6 & \text{scalar\_quantization\_derived AND } Csiz < 257 \\ 6 + 2 \cdot \text{number\_of\_subbands} & \text{scalar\_quantization\_expounded AND } Csiz < 257 \\ 6 + \text{number\_of\_subbands} & \text{no\_quantization AND } Csiz \geq 257 \\ 7 & \text{scalar\_quantization\_derived AND } Csiz \geq 257 \\ 7 + 2 \cdot \text{number\_of\_subbands} & \text{scalar\_quantization\_expounded AND } Csiz \geq 257 \end{cases} \quad A.5$$

**NOTE** The *Lqcc* can be used to determine how many step sizes are present in the marker segment. However, there is not necessarily a correspondence with the number of subbands present because the subbands can be truncated with no requirement to correct this marker segment.

**Cqcc:** The index of the component to which this marker segment relates. The components are indexed 0, 1, 2, etc. (Either 8 or 16 bits depending on *Csiz* value.)

**Sqcc:** Quantization style for this component.

**SPqcc<sup>i</sup>:** Quantization value for each subband in the defined order (see Annex D). The number of parameters is the same as the number of subbands in the tile-component with the greatest number of decomposition levels.

Table A-15 – Quantization component parameter values

Parameter	Size (bits)	Values
QCC	16	0xFF5D
Lqcc	16	5–443
Cqcc	8 16	0–255; if <i>Csiz</i> < 257 0–16383; if <i>Csiz</i> ≥ 257
Sqcc	8	ITU-T Rec. T.800   ISO/IEC 15444-1 Table A-28
SPqcc <sup>i</sup>	variable	ITU-T Rec. T.800   ISO/IEC 15444-1 Table A-28

### A.2.7 Component Registration (CRG), ITU-T Rec. T.800 | ISO/IEC 15444-1 extended

**Function:** Allows specific registration of components with respect to each other. For coding purposes the samples of components are considered to be located at reference grid points that are integer multiples of *XR<sub>siz</sub>*, *YR<sub>siz</sub>* and *ZR<sub>siz</sub>* (see Annex B). However, this may be inappropriate for rendering the image. The CRG marker segment describes the “center of mass” of each component’s samples with respect to the separation. This marker segment has no effect on decoding the codestream.

**ISO/IEC FCD 15444-10:200X (E)**

**NOTE** This component registration offset is with respect to the image offset ( $XO_{siz}$ ,  $YO_{siz}$  and  $ZO_{siz}$ ) and the component separation ( $XR_{siz}^i$ ,  $YR_{siz}^i$  and  $ZR_{siz}^i$ ). For example, the horizontal reference grid point for the left most samples of component  $c$  is  $XR_{siz}^c \cdot \lceil XO_{siz} / XR_{siz}^c \rceil$ . (Likewise for the vertical and axial direction.) The horizontal offset denoted in this marker segment is in addition to this offset.

**Usage:** Main header only. Only one CRG may be used in the main header and it is applicable for all tiles.

**Length:** Variable depending on the number of components.



**Figure A-9 – Component registration syntax**

**CRG:** Marker code. Table A-16 shows the size and values of the symbol and parameters for the component registration marker segment.

**Lcrg:** Length of the marker segment in bytes (not including the marker).

**Xcrg<sup>i</sup>:** Value of the horizontal offset, in units of  $1 / 65\,536$  of the horizontal separation  $XR_{siz}^i$ , for the  $i$ th component. Thus, values range from  $0 / 65\,536$  (sample occupies its reference grid point) to  $XR_{siz}^i (65\,535 / 65\,536)$  (just before the next sample’s reference grid point). This value is repeated for every component.

**Ycrg<sup>i</sup>:** Value of the vertical offset, in units of  $1 / 65\,536$  of the vertical separation  $YR_{siz}^i$ , for the  $i$ th component. Thus, values range from  $0 / 65\,536$  (sample occupies its reference grid point) to  $YR_{siz}^i (65\,535 / 65\,536)$  (just before the next sample’s reference grid point). This value is repeated for every component.

**Zcrg<sup>i</sup>:** Value of the axial offset, in units of  $1 / 65\,536$  of the axial separation  $ZR_{siz}^i$ , for the  $i$ th component. Thus, values range from  $0 / 65\,536$  (sample occupies its reference grid point) to  $ZR_{siz}^i (65\,535 / 65\,536)$  (just before the next sample’s reference grid point). This value is repeated for every component.

**Table A-16 – Component registration parameter values**

Parameter	Size (bits)	Values
CRG	16	0xFF63
Lcrg	16	6–65534
Xcrg <sup>i</sup>	16	0–65535
Ycrg <sup>i</sup>	16	0–65535
Zcrg <sup>i</sup>	16	0–65535

**A.2.8 The Extended Capabilities (CAP) Marker Segment**

This section describes the Ccapi marker segment field for ITU-T Rec. T.809 | ISO/IEC 15444-10 (see ITU-T Rec. T.801 | ISO/IEC 15444-2 AMD2 for more information on CAP marker segment).

Table A-17 – Ccap<sup>i</sup>, extended

Values (bits) MSB LSB	Coding style
0000 0000 0000 0000 0000	No extended capabilities
	All other values reserved

## Annex B

### Image and compressed image data ordering, extension

(This annex forms a normative and integral part of this Recommendation | International Standard.)

#### B.1 Introduction

In this Annex and all of its subclauses, the flow charts and tables are normative only in the sense that they are defining an output that alternative implementations shall duplicate. This Annex describes the various structural entities, and their organization in the codestream: components, tiles, subbands, and their divisions.

This Annex is the extension of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B with volumetric coding functionality, i.e. from two to three spatial dimensions. The following sections will describe only the changed items to ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B that are needed to add the extra axial dimension. Unless explicitly noted, all descriptions and specifications of ISO/IEC 15444-1 remain valid.

#### B.2 Introduction to image data structure concepts

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.1.

Components no longer consist of two-dimensional-arrays of samples, but instead they consist of three-dimensional-arrays of samples. Each component,  $c$ , now has parameters  $XR_{siz}^c$ ,  $YR_{siz}^c$  and  $ZR_{siz}^c$  which define the mapping between component samples and the reference grid points.

Each resolution level consists of either the [L|H|X][L|H|X][L|H|X] subbands (excluding the LLL subband) or the  $N_L$ LLL subband, thus changing the number of subbands per decomposition level,  $m$ , with  $m < N_L$ , from three to the range [2;7] (see Figure D-6).

Each subband has its own origin. The subband boundary conditions are unique for each of the [L|H|X][L|H|X][L|H|X] subbands.

#### B.3 Component mapping to the reference grid

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.2.

The reference grid becomes a three dimensional space of points with the indices from  $(0,0,0)$  to  $(X_{siz}-1, Y_{siz}-1, Z_{siz}-1)$ . An "image area" is then defined on the reference grid by the dimensional parameters,  $(X_{siz}, Y_{siz}, Z_{siz})$  and  $(XO_{siz}, YO_{siz}, ZO_{siz})$ . Specifically, the image area on the reference grid is defined by its reference grid points at location  $(XO_{siz}, YO_{siz}, ZO_{siz})$  and  $(X_{siz}-1, Y_{siz}-1, Z_{siz}-1)$ .

The samples of component  $c$  are now at integer multiples of  $(XR_{siz}^c, YR_{siz}^c, ZR_{siz}^c)$  on the reference grid. Each component domain is a sub-sampled version of the reference grid with the  $(0,0,0)$  coordinate as common point for each component.

Thus, the samples of component  $c$  are mapped to a cuboid with corner coordinates  $(x_0, y_0, z_0)$  and  $(x_1-1, y_1-1, z_1-1)$ , where  $x_0, y_0, x_1$  and  $y_1$  are given by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.1 and  $z_0$  and  $z_1$  as

$$z_0 = \left\lceil \frac{ZO_{siz}}{ZR_{siz}^c} \right\rceil \quad z_1 = \left\lceil \frac{Z_{siz}}{ZR_{siz}^c} \right\rceil \quad \text{B.1}$$

Thus, the three dimensions of component  $c$  are given by

$$(\text{width, height, depth}) = (x_1 - x_0, y_1 - y_0, z_1 - z_0) \quad \text{B.2}$$

The parameters  $Zsiz$ ,  $ZOsiz$  and  $ZRsiz^c$  are all defined in the NSI marker segment (see Annex A.2.1).

## B.4 Image area division into tiles and tile-components

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.3.

The reference grid is partitioned into a regular sized three dimensional array of tiles. The tile size and tiling offset are defined, on the reference grid, by dimensional pairs  $(XTsiz, YTsiz, ZTsiz)$  and  $(XTOsiz, YTOsiz, ZTOsiz)$ , respectively.  $ZTsiz$  and  $ZTOsiz$  are parameters from the NSI marker segment.

Every tile is  $XTsiz$  reference grid points wide,  $YTsiz$  reference grid points high and  $ZTsiz$  reference grid points deep. The upper left front corner of the first tile (tile 0) is offset from the upper left front corner of the reference grid by  $(ZTOsiz, YTOsiz, ZTOsiz)$ . The tiles are numbered in raster order (i.e. from left to right, top to bottom, front to back). This number is the tile index.

The tile grid offsets  $(XTOsiz, YTOsiz, ZTOsiz)$  are constrained to be not larger than the image area offsets. This is expressed by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.3 and additionally by the following range:

$$0 \leq ZTOsiz \leq ZOsiz \quad \text{B.3}$$

Also, the tile size plus the tile offset shall be greater than the image area offset. This ensures that the first tile (tile 0) will contain at least one reference grid point from the image area. This is expressed by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.4 and additionally by the following range:

$$ZTsiz + ZTOsiz > ZOsiz \quad \text{B.4}$$

The number of tiles in the X direction ( $numXtiles$ ), the Y direction ( $numYtiles$ ) are given by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.5. The number of tiles for the Z direction ( $numZtiles$ ) is the following:

$$numZtiles = \left\lceil \frac{Zsiz - ZTOsiz}{ZTsiz} \right\rceil \quad \text{B.5}$$

For the purpose of this description, it is useful to have tiles indexed in terms of horizontal, vertical and axial position. Let  $p_x$  be the horizontal index of a tile and  $p_y$  be the vertical index of a tile, then  $p_z$  represents the axial index of a tile, ranging from 0 to  $(numZtiles - 1)$ . The following expression redefines  $p_x$  and  $p_y$  (ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.6) and defines  $p_z$ :

$$\begin{aligned} p_x &= \text{mod}(\text{mod}(t, numXtiles \cdot numYtiles), numXtiles) \\ p_y &= \left\lfloor \frac{\text{mod}(t, numXtiles \cdot numYtiles)}{numXtiles} \right\rfloor \\ p_z &= \left\lfloor \frac{t}{numXtiles \cdot numYtiles} \right\rfloor \end{aligned} \quad \text{B.6}$$

As for the coordinates of a particular tile on the reference grid, these are described by the following equations:

$$\begin{aligned} tx_0(p_x, p_y, p_z) &= \max(XTOsiz + p_x \cdot XTsiz, XOsiz) \\ ty_0(p_x, p_y, p_z) &= \max(YTOsiz + p_y \cdot YTsiz, YOsiz) \\ tz_0(p_x, p_y, p_z) &= \max(ZTOsiz + p_z \cdot ZTsiz, ZOsiz) \\ tx_1(p_x, p_y, p_z) &= \min(XTOsiz + (p_x + 1) \cdot XTsiz, Xsiz) \\ ty_1(p_x, p_y, p_z) &= \min(YTOsiz + (p_y + 1) \cdot YTsiz, Ysiz) \\ tz_1(p_x, p_y, p_z) &= \min(ZTOsiz + (p_z + 1) \cdot ZTsiz, Zsiz) \end{aligned} \quad \text{B.7}$$

Where  $tx_0(p_x, p_y, p_z)$ ,  $ty_0(p_x, p_y, p_z)$  and  $tz_0(p_x, p_y, p_z)$  are the coordinates of the upper left front corner of the tile and  $tx_1(p_x, p_y, p_z) - 1$ ,  $ty_1(p_x, p_y, p_z) - 1$  and  $tz_1(p_x, p_y, p_z) - 1$  are the coordinates of the lower right back corner of the tile. We will often drop the tile's coordinates in referring to a specific tile and refer instead to coordinates  $(tx_0, ty_0, tz_0)$  and  $(tx_1, ty_1, tz_1)$ .

Thus, the dimensions of a tile in the reference grid are:

$$(tx_1 - tx_0, ty_1 - ty_0, tz_1 - tz_0) \quad \text{B.8}$$

Within the domain of image component  $i$ , the coordinates of the upper left front hand samples are given by  $(tcx_0, tcy_0, tcz_0)$  and the coordinates of the lower right back hand sample are given by  $(tcx_1, tcy_1, tcz_1)$ , where  $tx_0, ty_0, tx_1$  and  $ty_1$  are described in ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.12 and  $tcz_0$  and  $tcz_1$  are given by the following equation:

$$tcz_0 = \left\lceil \frac{tz_0}{ZRsiz^i} \right\rceil \quad tcz_1 = \left\lceil \frac{tz_1}{ZRsiz^i} \right\rceil \quad \text{B.9}$$

So, the dimensions of the tile-component in the reference grid are:

$$(tcx_1 - tcx_0, tcy_1 - tcy_0, tcz_1 - tcz_0) \quad \text{B.10}$$

## B.5 Transformed tile-component division into resolution levels and subbands

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.5.

NOTE Although ITU-T Rec. T.809 | ISO/IEC 15444-10 (JP3D) allows a different number of decomposition levels for each of the three dimensions (X, Y and Z), it is fundamentally different from ITU-T Rec. T.801 | ISO/IEC 15444-2 Annex F "Arbitrary Decomposition of Tile-components". The decomposition of a tile-component described in this specification is NOT arbitrary.

Each tile-component is wavelet transformed with  $N_{LX}$  decomposition levels in the horizontal direction,  $N_{LY}$  decomposition levels in the vertical direction and  $N_{LZ}$  decomposition levels in the axial direction as described in Annex D. The direction with the highest number of decomposition levels also determines the number of resolution levels. Thus, with  $N_L = \max(N_{LX}, N_{LY}, N_{LZ})$  as defined in Annex D.3.2, there are  $(N_L + 1)$  distinct resolution levels, denoted  $r = 0, 1, \dots, N_L$ . Each resolution level,  $r$ , is represented by the  $n[L|X][L|X][L|X]$  band, with  $n = N_L - r$ , where the actual subband type is determined by the number of decompositions in each of the directions (see Annex D.4.1). For example, when  $N_{LX}$  is 3,  $N_{LY}$  is 3 and  $N_{LZ}$  is 2, then at  $r = 0$ , the lowest resolution level is represented by the 3LLX band, while at  $r = 1$ , the resolution level is represented by the 2LLL band. This section describes the dimensions of this reduced resolution.

The given tile-component's coordinates with respect to the reference grid at a particular resolution level,  $r$ , yield upper left front hand sample coordinates,  $(trx_0, try_0, trz_0)$  and lower right back hand sample coordinates,  $(trx_1-1, try_1-1, trz_1-1)$ , where

$$\begin{aligned} trx_0 &= \left\lceil \frac{tcx_0}{2^{\min(N_{Lmax}-r, N_{LX})}} \right\rceil & trx_1 &= \left\lceil \frac{tcx_1}{2^{\min(N_{Lmax}-r, N_{LX})}} \right\rceil \\ try_0 &= \left\lceil \frac{tcy_0}{2^{\min(N_{Lmax}-r, N_{LY})}} \right\rceil & try_1 &= \left\lceil \frac{tcy_1}{2^{\min(N_{Lmax}-r, N_{LY})}} \right\rceil \\ trz_0 &= \left\lceil \frac{tcz_0}{2^{\min(N_{Lmax}-r, N_{LZ})}} \right\rceil & trz_1 &= \left\lceil \frac{tcz_1}{2^{\min(N_{Lmax}-r, N_{LZ})}} \right\rceil \end{aligned} \quad \text{B.11}$$

In a similar manner, the tile coordinates may be mapped into any particular subband,  $b$ , yielding upper left front hand sample coordinates  $(tbx_0, tby_0, tbz_0)$  and lower right back hand sample coordinates  $(tbx_1-1, tby_1-1, tbz_1-1)$  where

$$\begin{aligned} tbx_0 &= \left\lceil \frac{tcx_0 - (2^{n_b-1} \cdot xo_b)}{2^{n_b}} \right\rceil & tbx_1 &= \left\lceil \frac{tcx_1 - (2^{n_b-1} \cdot xo_b)}{2^{n_b}} \right\rceil \\ tby_0 &= \left\lceil \frac{tcy_0 - (2^{n_b-1} \cdot yo_b)}{2^{n_b}} \right\rceil & tby_1 &= \left\lceil \frac{tcy_1 - (2^{n_b-1} \cdot yo_b)}{2^{n_b}} \right\rceil \\ tbz_0 &= \left\lceil \frac{tcz_0 - (2^{n_b-1} \cdot zo_b)}{2^{n_b}} \right\rceil & tbz_1 &= \left\lceil \frac{tcz_1 - (2^{n_b-1} \cdot zo_b)}{2^{n_b}} \right\rceil \end{aligned} \quad \text{B.12}$$

where  $n_b$  is the decomposition level associated with subband  $b$ , (see ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F) and the quantities  $(x_{o_b}, y_{o_b}, z_{o_b})$  are given by Table B-1.

**Table B-1 — Quantities  $(x_{o_b}, y_{o_b}, z_{o_b})$  for subband  $b$**

Subband	$x_{o_b}$	$y_{o_b}$	$z_{o_b}$
$n_b[L X][L X][L X]$	0	0	0
$n_bH[L X][L X]$	1	0	0
$n_b[L X]H[L X]$	0	1	0
$n_bHH[L X]$	1	1	0
$n_b[L X][L X]H$	0	0	1
$n_bH[L X]H$	1	0	1
$n_b[L X]HH$	0	1	1
$n_bHHH$	1	1	1

For each subband, these coordinates define the tile boundaries in distinct subband domains. Furthermore the dimensions of each subband is given by:

$$(tbx_1 - tbx_0, tby_1 - tby_0, tbz_1 - tbz_0) \quad \text{B.13}$$

## B.6 Division of resolution levels into precincts

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.6.

Consider a particular tile-component and resolution level whose bounding sample coordinates in the reduced resolution image domain are  $(trx_0, try_0, trz_0)$  and  $(trx_1-1, try_1-1, trz_1-1)$ , as already described. Analogue to the method described in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.6, the three-dimensional tile-component resolution level is partitioned into precincts, using  $trx_0$ ,  $trx_1$ ,  $try_0$  and  $try_1$ , and additionally also  $trz_0$  and  $trz_1$ . The precinct is anchored at  $(0,0,0)$ , so that the upper left front hand corner of any given precinct in the partition is located at integer multiples of  $(2^{PPx}, 2^{PPy}, 2^{PPz})$  where  $PPx$ ,  $PPy$  and  $PPz$  are signaled in the COD or COC marker segments. As for  $PPx$  and  $PPy$ ,  $PPz$  may be different for each tile-component and resolution level.  $PPz$  must be at least 1 for all resolution levels,  $r$ , except when  $r = 0$  where it is allowed to be zero.

The number of precincts which span the tile-component at resolution level,  $r$ , is given by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.16 and by the following equation:

$$\text{numprecinctsdeep} = \begin{cases} \left\lceil \frac{trz_1}{2^{PPz}} \right\rceil - \left\lceil \frac{trz_0}{2^{PPz}} \right\rceil & trz_1 > trz_0 \\ 0 & trz_1 = trz_0 \end{cases} \quad \text{B.14}$$

Even if ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.16 or Equation E.14 of this specification indicate that both  $\text{numprecinctswide}$ ,  $\text{numprecinctshigh}$ , and  $\text{numprecinctsdeep}$  are nonzero, some, or all, precincts may still be empty as explained in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.6. The precinct index runs from 0 to  $\text{numprecincts}-1$  where  $\text{numprecincts} = \text{numprecinctswide} \cdot \text{numprecinctshigh} \cdot \text{numprecinctsdeep}$  in raster order (i.e. from left to right, top to bottom, front to back). The index is used in determining the order of appearance, in the codestream, of packets corresponding to each precinct, as explained in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.12.

## B.7 Division of subbands into code-blocks

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.7.

The subbands are partitioned into rectangular 3D code-blocks for the purpose of coefficient modeling and coding. The size of each code-block is determined from three parameters,  $xcb$ ,  $ycb$  and  $zcb$ , which are signaled in the COD or COC marker segments. The code-block size for each subband at a particular resolution level is determined as  $2^{xcb'}$  by  $2^{ycb'}$  by  $2^{zcb'}$  where  $xcb'$  and  $ycb'$  are described by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equations B.17 and B.18 and  $zcb'$  is given by:

$$zcb' = \begin{cases} \min(zcb, PPz - 1) & r > 0 \\ \min(zcb, PPz) & r = 0 \end{cases} \quad \text{B.15}$$

These equations reflect the fact that the code-block size is constrained both by the precinct size and the code-block size, whose parameters,  $xcb$ ,  $ycb$  and  $zcb$ , are identical for all subbands in the tile-component. Like the precinct, the code-block partition is anchored at  $(0,0,0)$ . Thus, all boundaries of code-blocks in the code-block partition are located at  $x = g_x 2^{xcb'}$ ,  $y = g_y 2^{ycb'}$  and  $z = g_z 2^{zcb'}$  where  $g_x$ ,  $g_y$  and  $g_z$  are integers.

## B.8 Packets

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.9.

All compressed image data representing a specific tile, layer, component, resolution level and precinct appears in the codestream in a contiguous segment called a packet. Packet data is aligned at 8-bit (one byte) boundaries.

As defined in Annex D, resolution level  $r = 0$  contains the subband coefficients from the  $N_L$ LLL band, where  $N_L$  is the number of decomposition levels as defined in Annex D.3.2. Each subsequent resolution level,  $r > 0$ , contains the subband coefficients from the  $n$ [L|H|X][L|H|X][L|H|X] subbands,  $n$ LLL excluded, as defined in Annex D, where  $n = N_L - r + 1$ . There are  $(N_L + 1)$  resolution levels for a tilecomponent with  $N_L$  decomposition levels.

The compressed image data in a packet is ordered such that the contribution from the LLL, XLL, LXL, LLX, LXX, XLX, XXL, HLL, HXL, HLX, HXX, LHL, XHL, LHX, XHX, HHL, HHX, LLH, XLH, LXH, XXH, HLH, HXH, LHH, XHH and HHH subbands appear in that order (i.e. Morton scanning order). Within each subband, the codeblock contributions appear in raster order, confined to the bounds established by the relevant precinct. Resolution level  $r = 0$  contains only the  $N_L$ LLL band and resolution levels  $r > 0$  can only contain some of the  $N_L$ [L|H|X][L|H|X][L|H|X] bands, excluded  $N_L$ LLL. Only those codeblocks that contain samples from the relevant subband, confined to the precinct, have any representation in the packet.

Packet data is introduced by a packet header whose syntax is described in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.10 and is followed by a packet body containing the actual code-bytes contributed by each of the relevant code-blocks. The order defined above is followed in constructing both the packet header and the packet body.

## B.9 Packet header information coding

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.10.

### B.9.1 Tag trees

ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.10.2 describes two dimensional tag trees. For the purpose of a three dimensional extension, three dimensional tag trees are required.

A 3D tag tree is a way of representing a three-dimensional array of non-negative integers in a hierarchical way. It successively creates reduced resolution levels of this three-dimensional array, forming a tree. At every node of this tree the minimum integer of the top (up to eight) nodes below is recorded. The notation,  $q_i(m_x, m_y, m_z)$ , is the value at the node that is  $m_x$ th from the left,  $m_y$ th from the top and  $m_z$ th from the front, at the  $i$ th level. Level 0 is the lowest level of the tag tree; it contains the top node.

See ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.10.2 for further information on how to actually encode and decode values with the tag tree. The description given there is independent of the number of actual dimensions.

## B.9.2 Order of information within a packet

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.10.8.

The following is the packet header information order for one packet of a specific layer, tile-component, resolution level and precinct.

```

bit for zero or non-zero length packet
for each subband ([L|H|X][L|H|X][L|H|X])
for all code-blocks in this subband confined to the relevant precinct, in raster order
code-block inclusion bits (if not previously included then tag tree, else one bit)
if code-block included
if first instance of code-block
zero bit-planes information
number of coding passes included
increase of code-block length indicator (Lblock)
for each codeword segment
length of codeword segment

```

## B.10 Progression order

Update of ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.12.

For a given tile-part, the packets contain all compressed image data from a specific layer, a specific component, a specific resolution level, and a specific precinct. The order in which these packets are found in the codestream is called the progression order. The ordering of the packets can progress along four axes: layer, component, resolution level and precinct.

It is possible that components have a different number of resolution levels. In this case, the resolution level that corresponds to the  $N_{L,LLL}$  subband is the first resolution level ( $r = 0$ ) for all components. The indices are synchronized from that point on.

### B.10.1 Progression order determination

This section describes the algorithms that define the five possible progression orders. They are basically identical to those described in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.12.1, but extended to three dimensions. The lines printed in bold indicate the additions necessary for the third dimension.

The COD marker segments signal which of the five progression orders are used (see ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex A.6.1). The progression order can also be overridden with the POC marker segment (see ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex A.6.6) in any tile-part header. For each of the possible progression orders the mechanism to determine the order in which packets are included is described below.

#### B.10.1.1 Layer-resolution level-component-position progression

See ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.12.1.1.

#### B.10.1.2 Resolution level-layer-component-position progression

See ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex B.12.1.2.

#### B.10.1.3 Resolution level-position-component-layer progression

Resolution level-position-component-layer progression for three dimensions is defined as the interleaving of the packets in the following order:

for each  $r = 0, \dots, N_{max}$   
 for each  $z = tz_0, \dots, tz_1 - 1$ ,  
 for each  $y = ty_0, \dots, ty_1 - 1$ ,  
 for each  $x = tx_0, \dots, tx_1 - 1$ ,  
 for each  $i = 0, \dots, Csiz - 1$   
 if (( $z$  divisible by  $ZRsiz(i) \cdot 2^{PPz(r, i) + N_L(i) - r}$ ) OR (( $z = tz_0$ ) AND ( $trz_0 \cdot 2^{N_L(i) - r}$  NOT divisible by  $2^{PPz(r, i) + N_L(i) - r}$ ))  
 if (( $y$  divisible by  $YRsiz(i) \cdot 2^{PPy(r, i) + N_L(i) - r}$ ) OR (( $y = ty_0$ ) AND ( $try_0 \cdot 2^{N_L(i) - r}$  NOT divisible by  $2^{PPy(r, i) + N_L(i) - r}$ ))  
 if (( $x$  divisible by  $XRsiz(i) \cdot 2^{PPx(r, i) + N_L(i) - r}$ ) OR (( $x = tx_0$ ) AND ( $trx_0 \cdot 2^{N_L(i) - r}$  NOT divisible by  $2^{PPx(r, i) + N_L(i) - r}$ ))  
 for the next precinct,  $k$ , if one exists,  
 for each  $l = 0, \dots, L - 1$   
 packet for component  $i$ , resolution level  $r$ , layer  $l$ , and precinct  $k$

In the above,  $k$  can be obtained from:

$$k = \left\lfloor \frac{\left\lceil \frac{x}{XRsiz(i) \cdot 2^{N_L - r}} \right\rceil}{2^{PPx(r, i)}} \right\rfloor - \left\lfloor \frac{trx_0}{2^{PPx(r, i)}} \right\rfloor + numprecinctswide(r, i) \cdot \left( \left\lfloor \frac{\left\lceil \frac{y}{YRsiz(i) \cdot 2^{N_L - r}} \right\rceil}{2^{PPy(r, i)}} \right\rfloor - \left\lfloor \frac{try_0}{2^{PPy(r, i)}} \right\rfloor \right) + numprecinctswide \cdot numprecinctshigh \cdot \left( \left\lfloor \frac{\left\lceil \frac{z}{ZRsiz(i) \cdot 2^{N_L - r}} \right\rceil}{2^{PPz(r, i)}} \right\rfloor - \left\lfloor \frac{trz_0}{2^{PPz(r, i)}} \right\rfloor \right) \quad \text{B.16}$$

To use this progression,  $XRsiz$ ,  $YRsiz$  and  $ZRsiz$  values must be powers of two for each component.

#### B.10.1.4 Position-component-resolution level-layer progression

Position-component-resolution level-layer progression is defined as the interleaving of the packets in the following order:

for each  $z = tz_0, \dots, tz_1 - 1$ ,  
 for each  $y = ty_0, \dots, ty_1 - 1$ ,  
 for each  $x = tx_0, \dots, tx_1 - 1$ ,  
 for each  $i = 0, \dots, Csiz - 1$   
 for each  $r = 0, \dots, N_{max}$  where  $N_L$  is the number of decomposition levels for component  $i$ ,  
 if (( $z$  divisible by  $ZRsiz(i) \cdot 2^{PPz(r, i) + N_L(i) - r}$ ) OR (( $z = tz_0$ ) AND ( $trz_0 \cdot 2^{N_L(i) - r}$  NOT divisible by  $2^{PPz(r, i) + N_L(i) - r}$ ))  
 if (( $y$  divisible by  $YRsiz(i) \cdot 2^{PPy(r, i) + N_L(i) - r}$ ) OR (( $y = ty_0$ ) AND ( $try_0 \cdot 2^{N_L(i) - r}$  NOT divisible by  $2^{PPy(r, i) + N_L(i) - r}$ ))  
 if (( $x$  divisible by  $XRsiz(i) \cdot 2^{PPx(r, i) + N_L(i) - r}$ ) OR (( $x = tx_0$ ) AND ( $trx_0 \cdot 2^{N_L(i) - r}$  NOT divisible by  $2^{PPx(r, i) + N_L(i) - r}$ ))  
 for the next precinct,  $k$ , if one exists,  
 for each  $l = 0, \dots, L - 1$   
 packet for component  $i$ , resolution level  $r$ , layer  $l$ , and precinct  $k$

In the above,  $k$  can be obtained from Equation B.16. To use this progression,  $XRsiz$ ,  $YRsiz$  and  $ZRsiz$  values must be powers of two for each component.

#### B.10.1.5 Component-position-resolution level-layer progression

Component-position-resolution level-layer progression is defined as the interleaving of the packets in the following order:

for each  $i = 0, \dots, \text{Csiz} - 1$   
 for each  $z = tz_0, \dots, tz_1 - 1$ ,  
 for each  $y = ty_0, \dots, ty_1 - 1$ ,  
 for each  $x = tx_0, \dots, tx_1 - 1$ ,  
 for each  $r = 0, \dots, N_{max}$  where  $N_L$  is the number of decomposition levels for component  $i$ ,  
 if (( $z$  divisible by  $ZRsiz(i) \cdot 2^{PPz(r, i) + N_L(i) - r}$ ) OR (( $z = tz_0$ ) AND ( $trz_0 \cdot 2^{N_L(i) - r}$   
 NOT divisible by  $2^{PPz(r, i) + N_L(i) - r}$ ))  
 if (( $y$  divisible by  $YRsiz(i) \cdot 2^{PPy(r, i) + N_L(i) - r}$ ) OR (( $y = ty_0$ ) AND ( $try_0 \cdot 2^{N_L(i) - r}$   
 NOT divisible by  $2^{PPy(r, i) + N_L(i) - r}$ ))  
 if (( $x$  divisible by  $XRsiz(i) \cdot 2^{PPx(r, i) + N_L(i) - r}$ ) OR (( $x = tx_0$ ) AND ( $trx_0 \cdot 2^{N_L(i) - r}$   
 NOT divisible by  $2^{PPx(r, i) + N_L(i) - r}$ ))  
 for the next precinct,  $k$ , if one exists,  
 for each  $l = 0, \dots, L - 1$   
 packet for component  $i$ , resolution level  $r$ , layer  $l$ , and precinct  $k$

In the above,  $k$  can be obtained from Equation B.16.

## Annex C

### Coefficient bit modeling

(This annex forms a normative and integral part of this Recommendation | International Standard.)

#### C.1 Introduction

In this Annex and all of its subclauses, the flow charts and tables are normative only in the sense that they are defining an output that alternative implementations shall duplicate. This Annex formally extends ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex D with volumetric coding functionality.

This Annex defines the modeling and scanning of transform coefficient bits.

Code-blocks (see Annex B) are decoded a bit-plane at a time starting from the most significant bit-plane with a non-zero element to the least significant bit-plane. For each bit-plane in a code-block, a special code-block scan pattern is used for each of three coding passes. Each coefficient bit in the bit-plane appears in only one of the three coding passes called significance propagation, magnitude refinement, and cleanup. For each pass contexts are created which are provided to the arithmetic coder, CX, along with the bit stream, CD, (see ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex C.3).

#### C.2 Code-block scan pattern within code-blocks, extended

Each bit-plane of a code-block is scanned in a particular order. The 3D code-block is processed in stripes, each consisting of four rows (or all remaining rows if less than four) and spanning the width of the 3D code-block. Each stripe is processed column by column from top to bottom and from left to right. The complete 3D code-block is consequently scanned slice by slice. Within a slice ITU-T Rec. T.800 | ISO/IEC 15444-1 is followed.

#### C.3 Context model updates

For the context modeling, the model described in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex D is slightly modified with respect to the significance propagation and cleanup coding passes.

The context vector for a given current coefficient is the binary vector consisting of the significance states of its 8 nearest-neighbour coefficients in the XY plane, as shown in ITU-T Rec. T.800 | ISO/IEC 15444-1 Figure D-2. Any nearest neighbour lying outside the current coefficient's code-block is regarded as insignificant (i.e., it is treated as having a zero significance state) for the purpose creating a context vector for decoding the current coefficient.

ITU-T Rec. T.800 | ISO/IEC 15444-1 Table D-1 is to be replaced with Table C-1.

**Table C-1 – Contexts for the significance propagation and cleanup coding passes**

Subbands with primary orientation of L[L H X][L H X], X[L H][L H X] or XX[L H]			Subbands with primary orientation of H[L X][L H X]			Subbands with primary orientation of HH[L H X]		Context label <sup>a</sup>
$\Sigma H_i$	$\Sigma V_i$	$\Sigma D_i$	$\Sigma H_i$	$\Sigma V_i$	$\Sigma D_i$	$\Sigma(H_i+V_i)$	$\Sigma D_i$	
2	$x^b$	x	x	2	x	x	$\geq 3$	8
1	$\geq 1$	x	$\geq 1$	1	x	$\geq 1$	2	7
1	0	$\geq 1$	0	1	$\geq 1$	0	2	6
1	0	0	0	1	0	$\geq 2$	1	5

0	2	x	2	0	x	1	1	4
0	1	x	1	0	x	0	1	3
0	0	$\geq 2$	0	0	$\geq 2$	$\geq 2$	0	2
0	0	1	0	0	1	1	0	1
0	0	0	0	0	0	0	0	0

<sup>a</sup> Note that the context labels are indexed only for identification convenience in this specification. The actual identifiers used is a matter of implementation.

<sup>b</sup> x = do not care.

## Annex D

### Discrete wavelet transformation of tile-components

(This annex forms a normative and integral part of this Recommendation | International Standard.)

#### D.1 Introduction

In this Annex and all of its subclauses, the flow charts and tables are normative only in the sense that they are defining an output that alternative implementations shall duplicate.

This Annex describes the three-dimensional forward discrete wavelet transformation applied to one tile-component and specifies the inverse three-dimensional discrete wavelet transformation used to reconstruct the tile-component. This Annex formally extends ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F with volumetric coding functionality.

#### D.2 Tile-component parameters

Consider the tile-component define by the coordinates  $tcx_0$ ,  $tcx_1$ ,  $tcy_0$ ,  $tcy_1$ ,  $tcz_0$  and  $tcz_1$  given in ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation B.12 and in Equation B.9 of this specification. Then the coordinates  $(x,y,z)$  of the tile-component (with sample values  $I(x,y,z)$ ) lie in the range defined by:

$$tcx_0 \leq x < tcx_1, tcy_0 \leq y < tcy_1 \text{ and } tcz_0 \leq z < tcz_1 \quad \text{D.1}$$

#### D.3 Discrete wavelet transformations

##### D.3.1 Low-pass and high-pass filtering (informative)

See ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.2.1.

##### D.3.2 Decomposition levels

Each tile-component is transformed into a set of three-dimensional subband signals (called subbands), each representing the activity of the signal in various frequency bands, at various spatial resolutions.  $N_{LX}$  denotes the number of decomposition levels in the horizontal direction,  $N_{LY}$  denotes the number of decomposition levels in the vertical direction and  $N_{LZ}$  denotes the number of decomposition levels in the axial direction. For the purpose of this specification we define  $N_L = \max(N_{LX}, N_{LY}, N_{LZ})$ .

##### D.3.3 Discrete wavelet filters (informative)

See ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.2.3.

#### D.4 Inverse discrete wavelet transformation

##### D.4.1 The IDWT procedure

The inverse discrete wavelet transformation (IDWT) transforms a set of subbands,  $a_b(u_b, v_b, w_b)$  into a DC-level shifted tile-component,  $I(x,y,z)$  (IDWT procedure). The IDWT procedure (see Figure D-1) also takes as input the set of parameters  $N_{LX}$ ,  $N_{LY}$  and  $N_{LZ}$ , which represent the number of decomposition levels in each of the three dimensions and are signaled in the COD or COC markers (see Annex A.2.2 and Annex A.2.3).

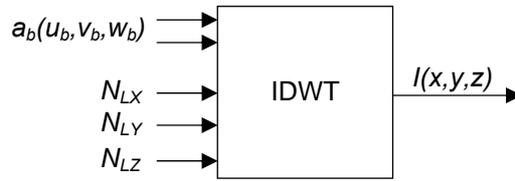


Figure D-1 — Inputs and output of the IDWT procedure

The subbands are labelled in the following way: an index  $lev$  corresponding to the decomposition level, followed by three letters of which each letter is either L, H or X. Thus a subband label is given as  $lev[L|H|X][L|H|X][L|H|X]$ .

The subband  $b = lev[L|X][L|X][L|X]$  corresponds to a downsampled version of the subband  $(lev - 1)[L|X][L|X][L|X]$  which has been low-pass filtered for those directions (horizontal, vertical and/or axial) that are denoted by the L letter. If at decomposition level,  $(lev - 1)$ , a specific direction is not low-pass filtered (i.e. the letter X was used), it may no longer be low-pass filtered in any of the subsequent higher decomposition levels,  $n > (lev - 1)$ . Thus, when the number of decompositions in direction  $d$  (with  $d$  being either X, Y or Z),  $N_{Ld}$ , is less than  $lev$ , the decomposition type of that respective dimension is X, otherwise it is L. The subband  $b = 0LLL$  corresponds to the original tile-component.

Similarly to ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.3.1, the subbands are signaled in the codestream, in the order given below:

$N_L LLL, N_L XLL, N_L LXL, N_L LLX, N_L LXX, N_L XLX, N_L XXL, N_L HLL, N_L HXL, N_L HLX, N_L HXX, N_L LHL, N_L XHL,$   
 $N_L LHX, N_L XHX, N_L HHL, N_L HHX, N_L LLH, N_L XLH, N_L LXH, N_L XXH, N_L HLH, N_L HXH, N_L LHH, N_L XHH, N_L HHH,$   
 $(N_L - 1)HLL, (N_L - 1)HXL, (N_L - 1)HLX, (N_L - 1)HXX, (N_L - 1)LHL, (N_L - 1)XHL, (N_L - 1)LHX, \dots, 1XHX, 1HHL, 1HHX,$   
 $1LLH, 1XLH, 1LXH, 1XXH, 1HLH, 1HXH, 1LHH, 1XHH, 1HHH.$

Note that, from the list of subbands given above, only those subbands that exist, given the parameters  $N_{LX}$ ,  $N_{LY}$  and  $N_{LZ}$ , will be present in the codestream. These are the exact subbands necessary to fully reconstruct the original tile-component.

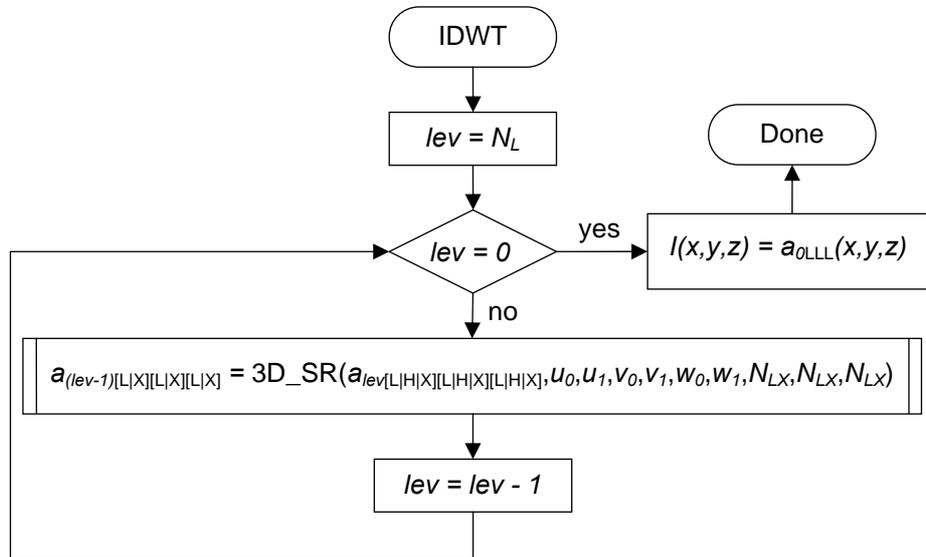


Figure D-2 — The IDWT procedure

As in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.3.1, the IDWT procedure starts with the initialization of the variable  $lev$  (the current decomposition level) to  $N_L$ . The 3D\_SR procedure (see Annex D.4.2) is performed at every level  $lev$ , where the level  $lev$  decreases at each iteration, until  $N_L$  iterations are performed. The 3D\_SR procedure is iterated over the  $lev[L|X][L|X][L|X]$  subband produced at each iteration.

Finally, the subband  $a_{0LLL}(u_{0LLL}, u_{1LLL}, v_{0LLL}, v_{1LLL}, w_{0LLL}, w_{1LLL})$  is the output array  $I(x, y, z)$ .

As defined in Equation B.12, the indices of subband coefficients for a given subband  $b$  lie in the range defined by:

$$tbx_0 \leq u_b < tbx_1, tby_0 \leq v_b < tby_1 \text{ and } tbz_0 \leq w_b < tbz_1 \tag{D.2}$$

### D.4.2 The 3D\_SR procedure

The 3D\_SR procedure performs a reconstruction of subband  $a_{(lev-1)[L][X][L][X][L][X]}(u,v,w)$  from the given subbands  $a_{lev[L][H][X][L][H][X][L][H][X]}(u,v,w)$ . The total number of coefficients of the reconstructed  $(lev-1)[L][X][L][X][L][X]$  subband is equal to the sum of the total number of coefficients of the subbands used as input to the 3D\_SR procedure.

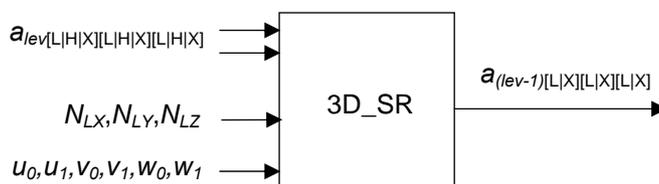


Figure D-3 — Inputs and outputs of the 3D\_SR procedure

The subbands  $a_{lev[L][H][X][L][H][X][L][H][X]}(u,v,w)$  are merged into the array  $a(u,v,w)$ , using the TO\_ARRAY procedure. This temporary array is used to store the intermediate results and is constantly updated as the 3D\_SR procedure is executed. Subsequently, the 3D\_SR procedure reconstructs each direction,  $d$ , for which  $lev < N_{Ld} \leq \bar{N}_L$ , with  $d$  being  $X, Y$  or  $Z$ , using the HOR\_SR, VER\_SR and AXIAL\_SR procedures respectively. The end result is the subband  $a_{(lev-1)[L][X][L][X][L][X]}(u,v,w)$ . Figure D-4 describes the 3D\_SR procedure in detail.

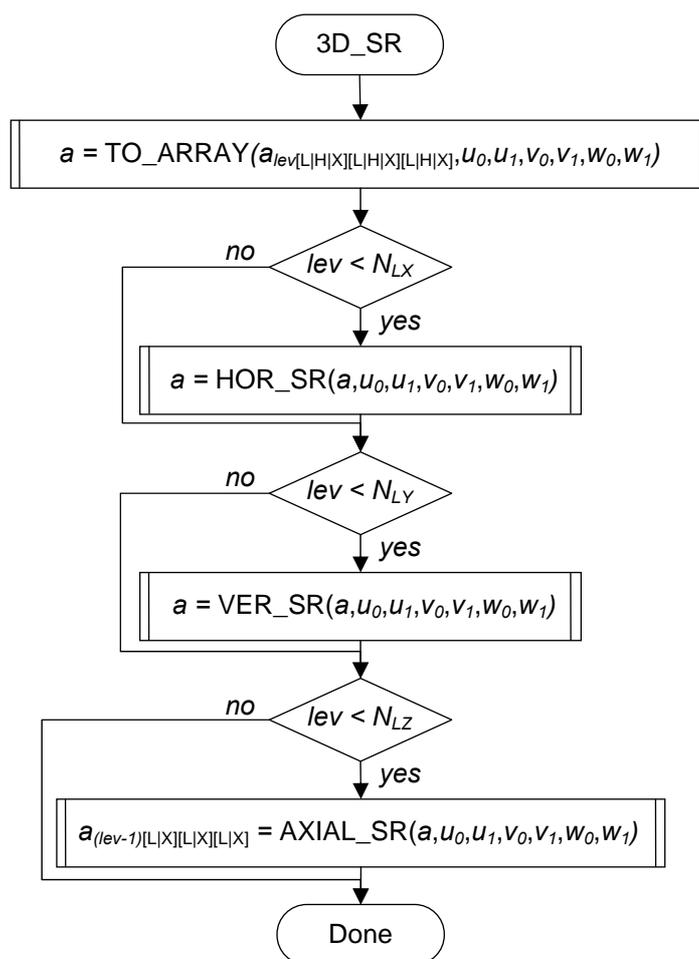
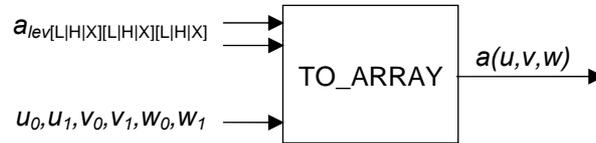


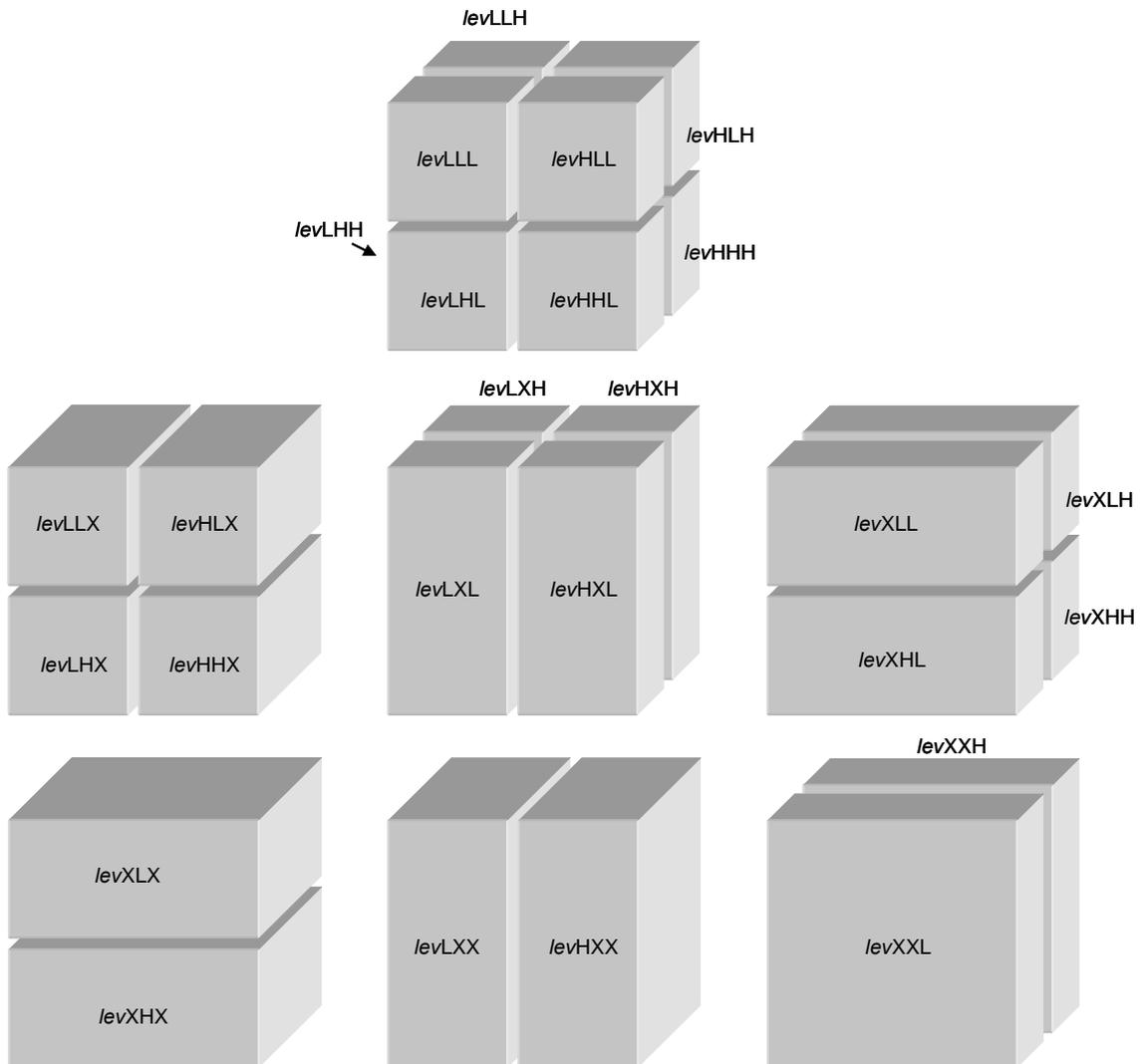
Figure D-4 — The 3D\_SR procedure

**D.4.3 The TO\_ARRAY procedure**

The TO\_ARRAY procedure takes all subbands of decomposition level  $lev$  and merges them into a three-dimensional array  $a(u,v,w)$  as shown in Figure D-6. It takes as input the subbands  $a_{lev[L|H|X][L|H|X][L|H|X]}(u,v,w)$  and the horizontal, vertical and axial extent of the coefficients of subband  $a_{(lev-1)[L|X][L|X][L|X]}$ , given as  $u_0, u_1, v_0, v_1, w_0$  and  $w_1$ . The output array takes the horizontal, vertical and axial extent of the coefficients as indicated by  $u_0 \leq u < u_1, v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$ .



**Figure D-5 — Inputs and outputs of the TO\_ARRAY procedure**



**Figure D-6 — All possible subband configurations for 3D DWT**

**D.4.4 The 1D\_INTERLEAVE procedure**

As illustrated in Figure D-7, the 1D\_INTERLEAVE procedure interleaves the low-pass and high-pass coefficients of a wavelet transform. It takes as input a one-dimensional signal,  $Y(n)$ , and rearranges the coefficient values within the signal by interleaving them. The values of  $i_0$  and  $i_1$  used by the 1D\_INTERLEAVE procedure represent the start and the end of the signal respectively. The way the signal is interleaved to form the output is described by the 1D\_INTERLEAVE procedure, given in Figure D-8.

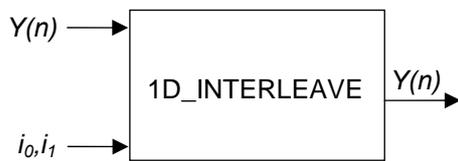


Figure D-7 — Parameters of the 1D\_INTERLEAVE procedure

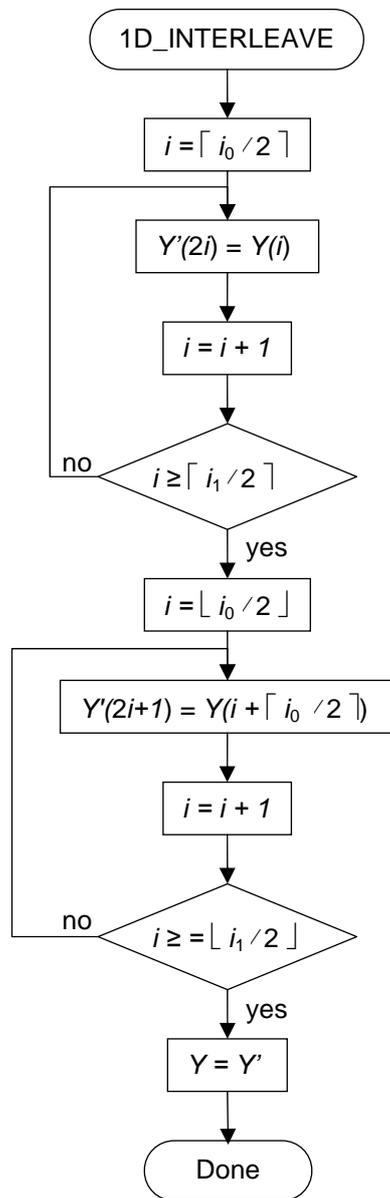


Figure D-8 — The 1D\_INTERLEAVE procedure

**D.4.5 The HOR\_SR procedure**

The HOR\_SR procedure performs an interleave operation and a horizontal subband reconstruction of a three-dimensional array of coefficients. It takes as input a three-dimensional array  $a(u,v,w)$ , the horizontal, vertical and axial extent of its coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$  (see Figure D-9) and produces as output a horizontally filtered version of the input array, row by row and slice by slice.

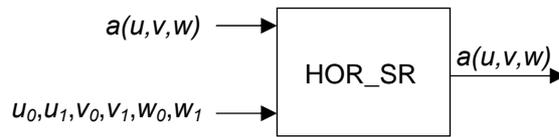


Figure D-9 — Inputs and outputs of the HOR\_SR procedure

As illustrated in Figure D-10, the HOR\_SR procedure applies the one-dimensional subband reconstruction (1D\_SR procedure) to each row of the input array  $a(u,v,w)$ , and stores the result back in each row.

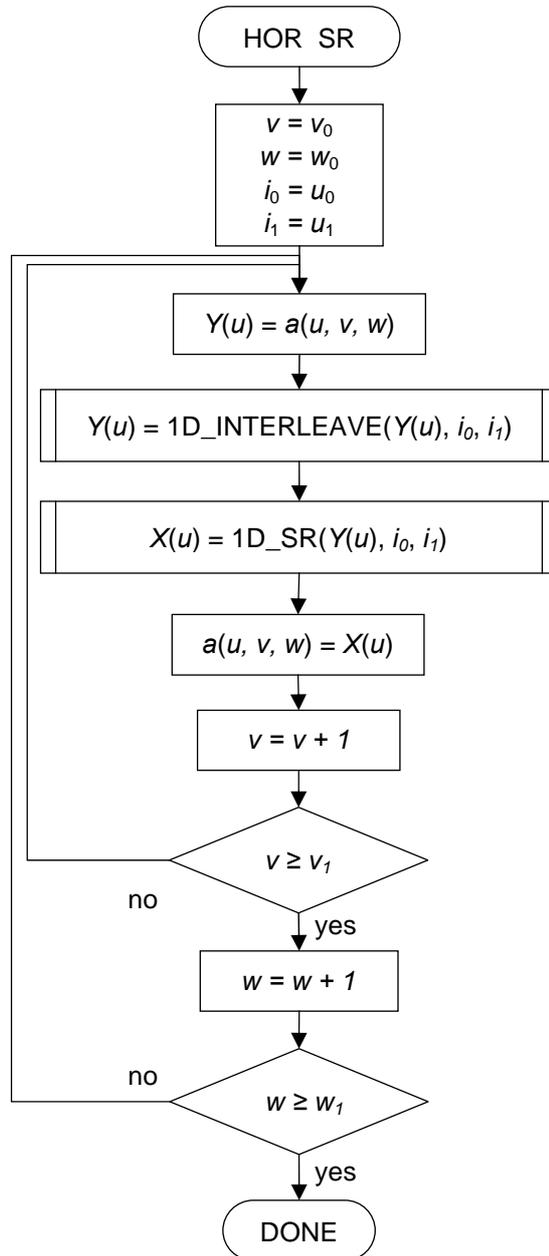


Figure D-10 — The HOR\_SR procedure

#### D.4.6 The VER\_SR procedure

The VER\_SR procedure performs an interleave operation and a vertical subband reconstruction of a three-dimensional array of coefficients. It takes as input a three-dimensional array  $a(u,v,w)$ , the horizontal, vertical and axial extent of its coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$  (see Figure D-11) and produces as output a vertically filtered version of the input array, column by column and slice by slice.

As illustrated in Figure D-12, the VER\_SR procedure applies the one-dimensional subband reconstruction (1D\_SR procedure) to each column of the input array  $a(u,v,w)$ , and stores the result back in each column.

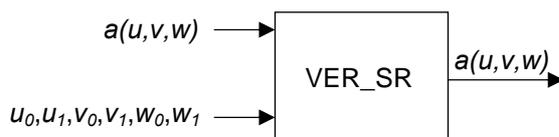


Figure D-11 — Inputs and outputs of the VER\_SR procedure

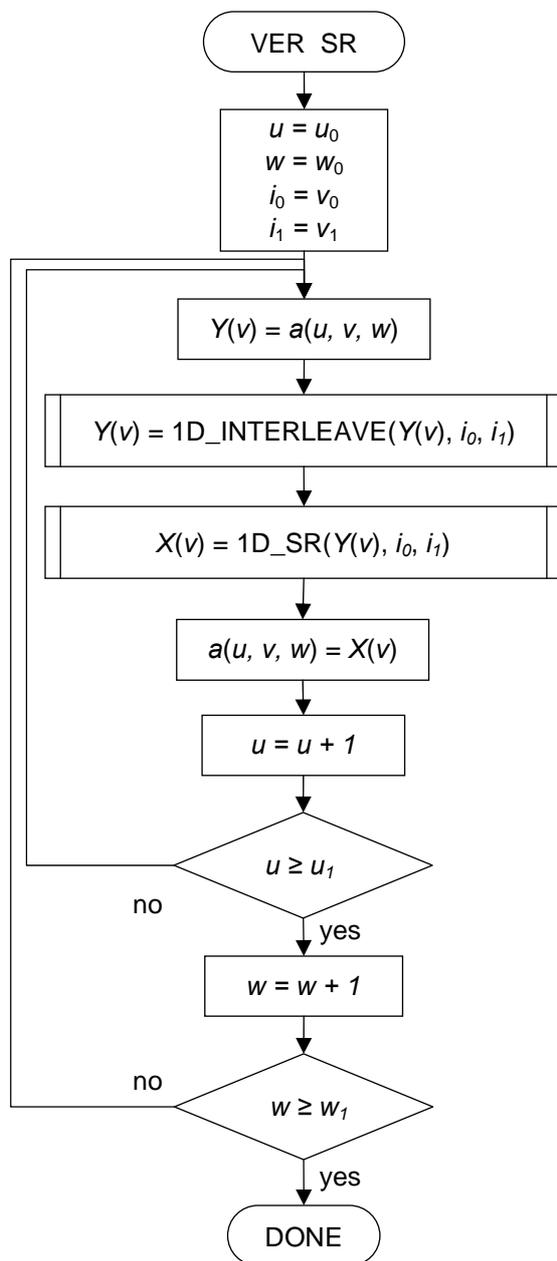


Figure D-12 — The VER\_SR procedure

#### D.4.7 The AXIAL\_SR procedure

The AXIAL\_SR procedure performs an interleave operation and a axial subband reconstruction of a three-dimensional array of coefficients. It takes as input a three-dimensional array  $a(u,v,w)$ , the horizontal, vertical and axial extent of its coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$  (see Figure D-13) and produces as output an axially filtered version of the input array, row by row and column by column.

As illustrated in Figure D-14, the AXIAL\_SR procedure applies the one-dimensional subband reconstruction (1D\_SR procedure) to each depth of the input array  $a(u,v,w)$ , and stores the result back in each depth.

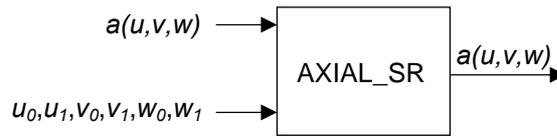


Figure D-13 — Inputs and outputs of the AXIAL\_SR procedure

#### D.4.8 The 1D\_SR procedure

The 1D\_SR procedure used to perform the subband reconstruction is given in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.3.6. Also, all subsequent procedures and specifications, needed directly or indirectly by the 1D\_SR procedure are given in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.

### D.5 Forward transformation (informative)

#### D.5.1 The FDWT procedure (informative)

The forward discrete wavelet transformation (FDWT) transforms DC-level shifted tile-component samples  $I(x,y,z)$  into a set of subbands with coefficients  $a_b(u_b, v_b, w_b)$  (FDWT procedure). The FDWT procedure (see Figure D-15) also takes as input the number of decomposition levels in each of the three dimensions and are signaled in the COD or COC markers (see Annex A.2.2 and Annex A.2.3).

As in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.4.1, the FDWT procedure starts with the initialization of the variable  $lev$  (the current decomposition level) to 1 and assigning the three-dimensional array  $I(x,y,z)$  to subband  $a_{0LLL}(u_{0LLL}, v_{0LLL}, w_{0LLL})$ . The 3D\_SD procedure (see Annex D.5.2) is performed at every level  $lev$ , where the level  $lev$  increases at each iteration, until  $N_L$  iterations are performed. The 3D\_SD procedure is iterated over the  $(lev-1)[L|X][L|X][L|X]$  subband produced at each iteration.

The complete FDWT procedure is described in detail in Figure D-16.

Similarly to what is described in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F, the generated subbands are signaled in the codestream in the order given below:

$$N_L LLL, N_L XLL, N_L LXL, N_L LLX, N_L LXX, N_L XLX, N_L XXL, N_L HLL, N_L HXL, N_L HLX, N_L HXX, N_L LHL, N_L XHL, \\ N_L LHX, N_L XHX, N_L HHL, N_L HHX, N_L LLH, N_L XLH, N_L LXH, N_L XXH, N_L HLH, N_L HXH, N_L LHH, N_L XHH, N_L HHH, \\ (N_L-1)HLL, (N_L-1)HXL, (N_L-1)HLX, (N_L-1)HXX, (N_L-1)LHL, (N_L-1)XHL, (N_L-1)LHX, \dots, 1XHX, 1HHL, 1HHX, \\ 1LLH, 1XLH, 1LXH, 1XXH, 1HLH, 1HXH, 1LHH, 1XHH, 1HHH.$$

Note that, from the list of subbands given above, only those subbands that exist, given the parameters  $N_{LX}$ ,  $N_{LY}$  and  $N_{LZ}$ , will be present in the codestream. These are the exact subbands necessary to fully reconstruct the original tile-component. Also note that  $N_L[L|X][L|X][L|X]$  is the only  $[L|X][L|X][L|X]$  type subband that is signaled in the codestream.

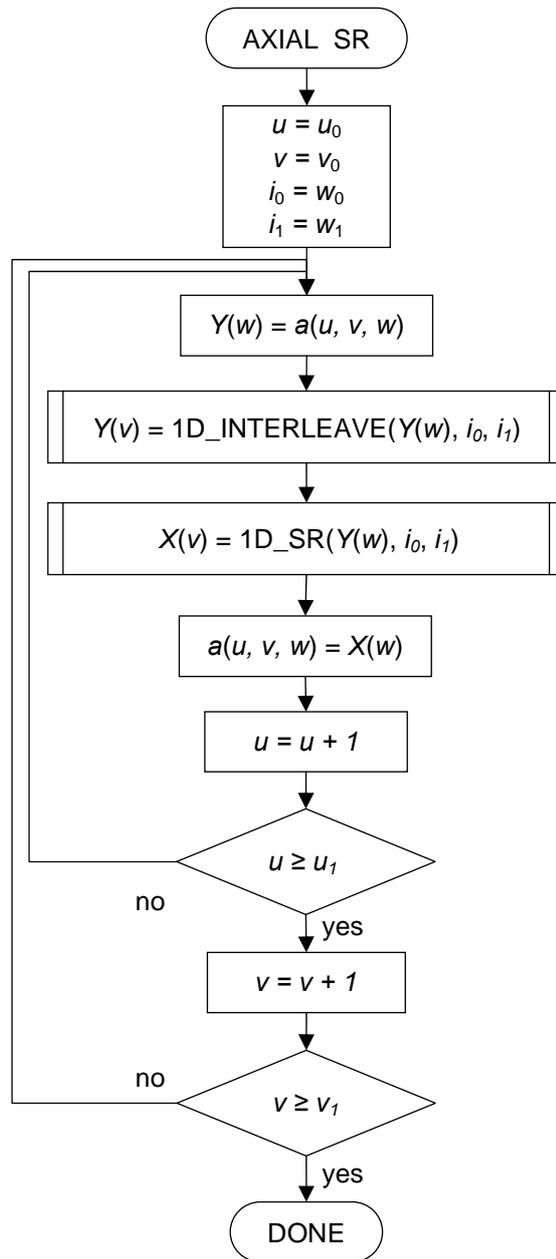


Figure D-14 — The AXIAL\_SR procedure

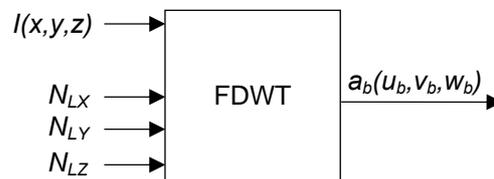


Figure D-15 — Inputs and outputs of the FDWT procedure

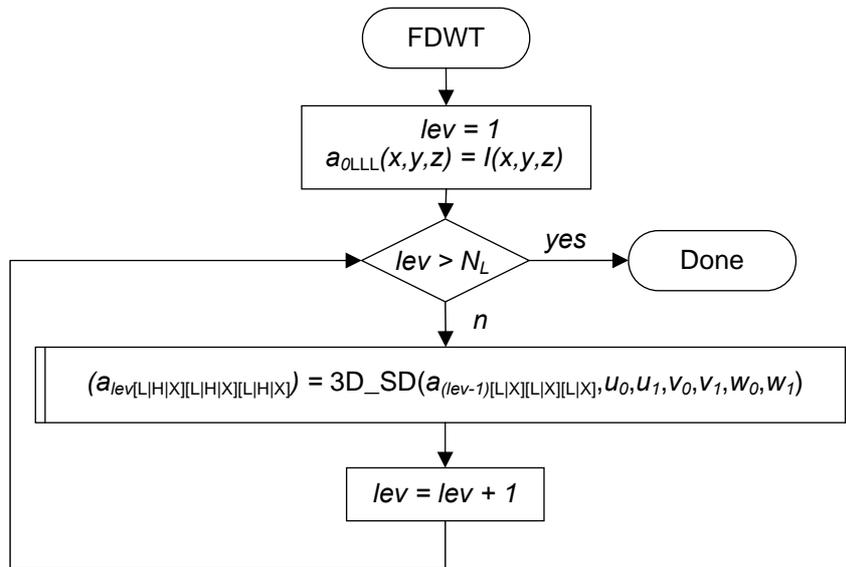


Figure D-16 — The FDWT procedure

**D.5.2 The 3D\_SD procedure (informative)**

The 3D\_SD procedure performs a decomposition of a three-dimensional array of coefficients or samples  $a_{(lev-1)[L|X][L|X][L|X]}(u,v,w)$  into a number of groups of subband coefficients  $a_{lev[L|H|X][L|H|X][L|H|X]}(u,v,w)$ , depending on the number of decompositions  $N_{LX}$ ,  $N_{LY}$  and  $N_{LZ}$ .

The total number of coefficients of the subband  $(lev-1)[L|X][L|X][L|X]$  is equal to the sum of the total number of coefficients of the subbands  $lev[L|H|X][L|H|X][L|H|X]$  resulting from the 3D\_SD procedure.

Figure D-17 describes the input and output parameters of the 3D\_SD procedure.

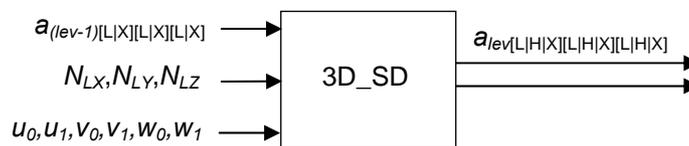


Figure D-17 — Inputs and outputs of the 3D\_SD procedure

The 3D\_SR procedure decomposes each direction,  $d$ , for which  $lev < N_{Ld} \leq N_L$ , with  $d$  being  $X$ ,  $Y$  or  $Z$ , using the HOR\_SD, VER\_SD and AXIAL\_SD procedures respectively. Subsequently, the three-dimensional array  $a(u,v,w)$  is split into the different constructed subbands  $a_{lev[L|H|X][L|H|X][L|H|X]}(u,v,w)$ . Of these subbands the  $lev[L|X][L|X][L|X]$  subband is used in the next iteration of the FDWT procedure for further decomposition (as long as less than  $N_L$  iterations occurred). The other subbands are further processed for signalling in the codestream.

**D.5.3 The TO\_SUBBANDS procedure (informative)**

The TO\_SUBBANDS procedure takes a three-dimensional array  $a(u,v,w)$  as input and returns the subbands as indicated in Figure D-6 as output. The array  $a(u,v,w)$  has the horizontal, vertical and axial extent of the coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$ .

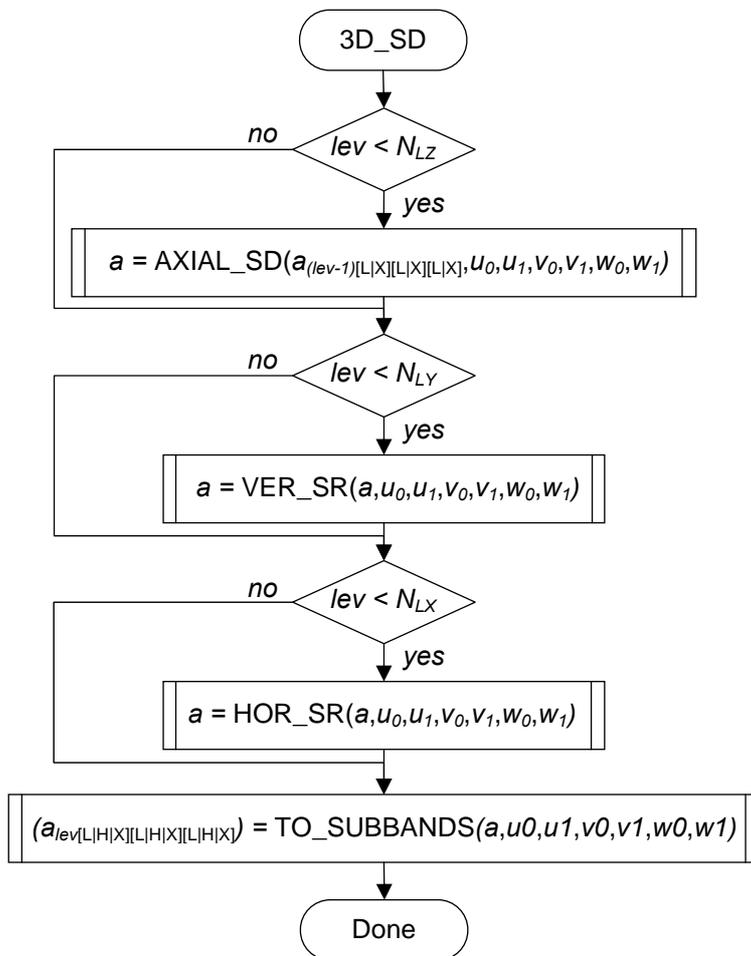


Figure D-18 — The 3D\_SD procedure

**D.5.4 The AXIAL\_SD procedure (informative)**

The AXIAL\_SD procedure performs an axial subband decomposition of a three-dimensional array of coefficients. It takes as input a three-dimensional array  $a(u, v, w)$ , the horizontal, vertical and axial extent of its coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$  (see Figure D-19) and produces as output an axially filtered version of the input array, row by row and column by column. After the decomposition, a deinterleave operation is performed.

As illustrated in Figure D-20, the AXIAL\_SD procedure applies the one-dimensional subband decomposition (1D\_SD procedure) to each depth of the input array  $a(u, v, w)$ , and stores the result back in each depth.

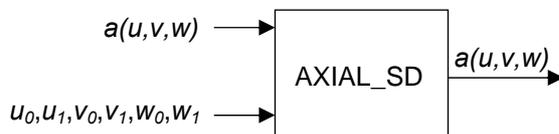


Figure D-19 — Inputs and outputs of the AXIAL\_SD procedure

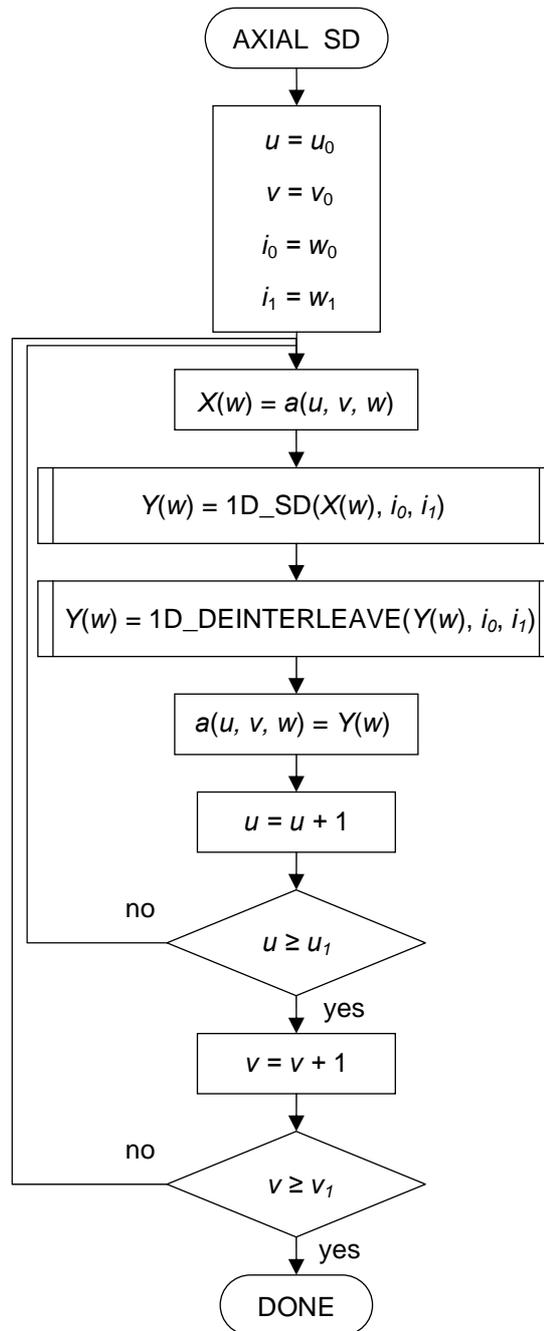


Figure D-20 — The AXIAL\_SD procedure

### D.5.5 The VER\_SD procedure (informative)

The VER\_SD procedure performs a vertical subband decomposition of a three-dimensional array of coefficients. It takes as input a three-dimensional array  $a(u, v, w)$ , the horizontal, vertical and axial extent of its coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$  (see Figure D-21) and produces as output a vertically filtered version of the input array, column by column and slice by slice. After the decomposition, a deinterleave operation is performed.

As illustrated in Figure D-22, the VER\_SD procedure applies the one-dimensional subband decomposition (1D\_SD procedure) to each column of the input array  $a(u, v, w)$ , and stores the result back in each column.

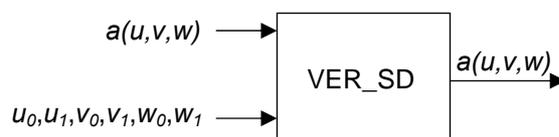


Figure D-21 — Inputs and outputs of the VER\_SD procedure

#### D.5.6 The HOR\_SD procedure (informative)

The HOR\_SD procedure performs a horizontal subband decomposition of a three-dimensional array of coefficients. It takes as input a three-dimensional array  $a(u,v,w)$ , the horizontal, vertical and axial extent of its coefficients as indicated by  $u_0 \leq u < u_1$ ,  $v_0 \leq v < v_1$  and  $w_0 \leq w < w_1$  (see Figure D-23) and produces as output a horizontally filtered version of the input array, row by row and slice by slice. After the decomposition, a deinterleave operation is performed.

As illustrated in Figure D-24, the HOR\_SD procedure applies the one-dimensional subband decomposition (1D\_SD procedure) to each row of the input array  $a(u,v,w)$ , and stores the result back in each row.

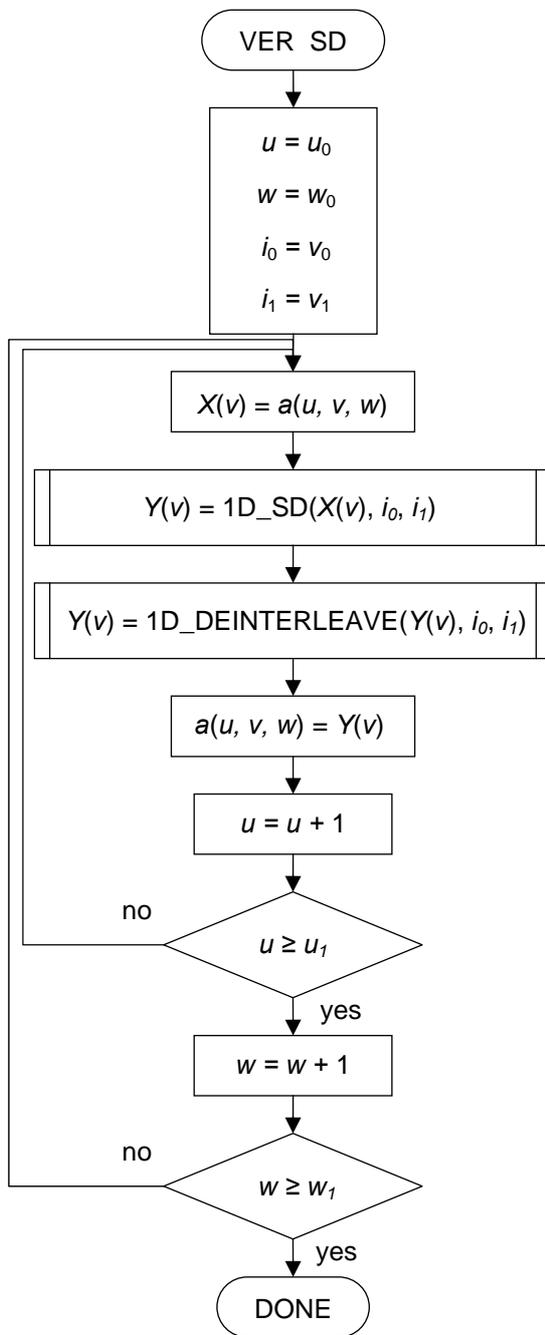


Figure D-22 — The VER\_SD procedure

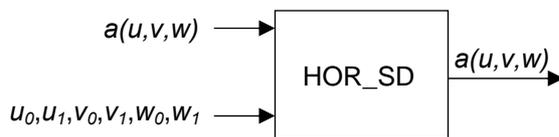


Figure D-23 — Inputs and outputs of the HOR\_SD procedure

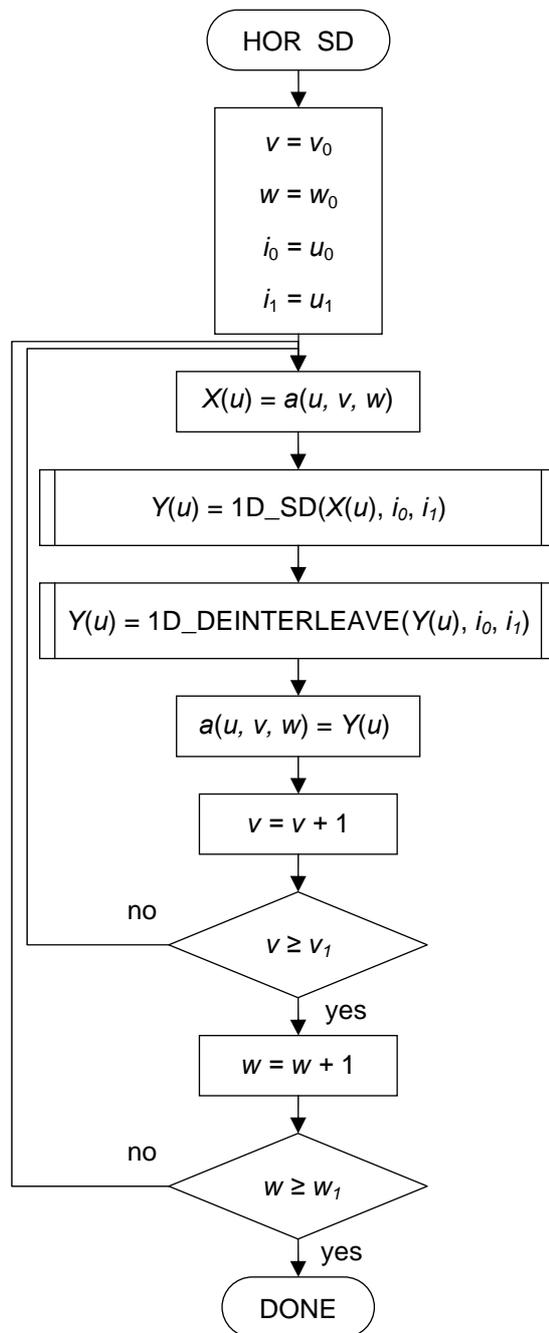


Figure D-24 — The HOR\_SD procedure

**D.5.7 The 1D\_DEINTERLEAVE procedure (informative)**

As illustrated in Figure D-25, the 1D\_DEINTERLEAVE procedure deinterleaves the low-pass and high-pass coefficients of a wavelet transform. It takes as input a one-dimensional signal,  $X(n)$ , and rearranges the coefficient values within the signal by deinterleaving them. The values of  $i_0$  and  $i_1$  used by the 1D\_DEINTERLEAVE procedure represent the start and the end of the signal respectively. The way the signal is deinterleaved to form the output is described by the 1D\_DEINTERLEAVE procedure, given in Figure D-26.

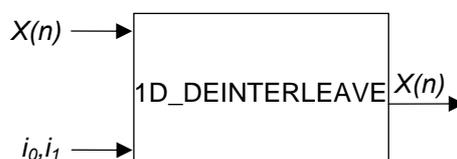


Figure D-25 — Parameters of the 1D\_DEINTERLEAVE procedure

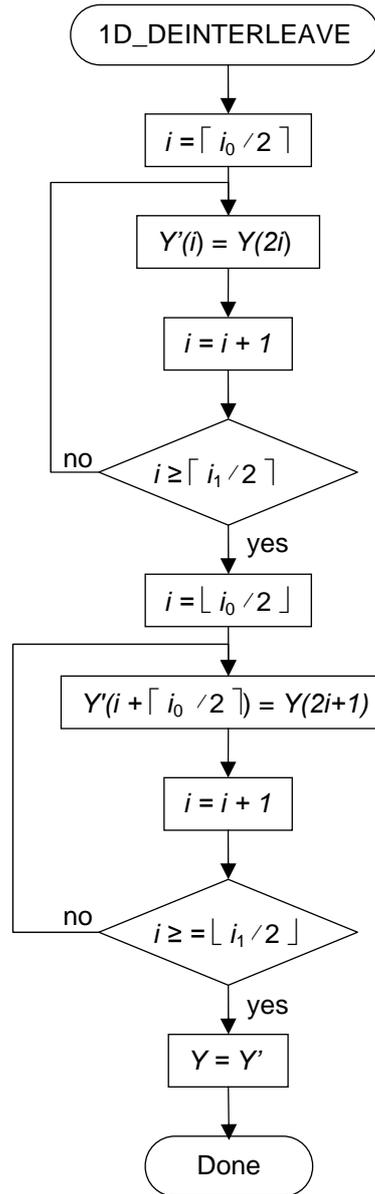


Figure D-26 — The 1D\_DEINTERLEAVE procedure

**D.5.8 The 1D\_SD procedure (informative)**

The 1D\_SD procedure used to perform the subband decomposition is given in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.4.6. Also, all subsequent procedures and specifications, needed directly or indirectly by the 1D\_SD procedure are given in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex F.

## Annex E

### Coding of images with regions of interest, extension

(This annex forms a normative and integral part of this Recommendation | International Standard.)

#### E.1 Introduction

In this Annex and all of its subclauses, the specifications are normative only in the sense that they are defining an output that alternative implementations shall duplicate. This Annex describes the volumetric extension of region of interest coding to both ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex H and ITU-T Rec. T.801 | ISO/IEC 15444-2 Annex L.

This Annex describes three-dimensional region of interest (ROI) technology. An ROI is a part of an image that is encoded with higher fidelity than the rest of the image (the background). The encoding is also done in such a way that the information associated with the ROI precedes the information associated with the background.

#### E.2 Decoding of ROI

The procedures specified in this section are applied only in the case of the presence of a RGN marker segment, (see Annex A.2.4) indicating the presence of a ROI coded with the Maxshift or the Scaling based method.

##### E.2.1 Decoding of ROI with the Maxshift method

The procedure realigns the significant bits of ROI coefficients and background coefficients. It is defined using the following steps:

- 1) Get the scaling value,  $s$ , from the SPrgn parameter of the RGN marker segment in the codestream (see Annex A.2.4). The following steps (2, 3 and 4) are applied to each coefficient of subband  $b$ .
- 2) If  $N_b(u,v,w) < M_b$  (see definitions of  $N_b$  in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex D.2.1 and of  $M_b$  in ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation E.2), then no modification takes place.
- 3) If  $N_b(u,v,w) \geq M_b$  and if at least one of the first  $M_b$  MSBs ( $i=1, \dots, M_b$ ) is non-zero, then the value of  $N_b(u,v,w)$  is updated as  $N_b(u,v,w) = M_b$ .
- 4) If  $N_b(u,v,w) \geq M_b$  and if all first  $M_b$  MSBs are equal to zero, then the following modifications are made:
  - i) discard the first  $s$  MSBs and shift the remaining MSBs  $s$  places, as described in Equation E.1, for  $i = 1, \dots, M_b$

$$MSB_i(b,u,v,w) = \begin{cases} MSB_{i+s}(b,u,v,w) & i + s \leq N_b(u,v,w) \\ 0 & i + s > N_b(u,v,w) \end{cases} \quad \text{E.1}$$

- ii) update the value of  $N_b(u,v,w)$  as given in the following equation:

$$N_b(u,v,w) = \max(0, N_b(u,v,w) - s) \quad \text{E.2}$$

##### E.2.2 Decoding of ROI with the Scaling method

The procedure realigns the significant bits of ROI coefficients and background coefficients. It is defined using the following steps:

- 1) Get the corresponding shape information and the scaling value,  $s$ , from the RGN marker segment for each ROI. Then, steps 2 to 6 are applied to each coefficient  $(u,v,w)$  of subband  $b$ .

- 2) Generate the ROI mask  $\{M_i(u, v, w)\}$  for all ROI, see Annex E.4.2 for details on how to generate the ROI mask.
- 3) For each coding block find the largest scaling value,  $s_{max}$ , for any coefficient  $(u, v, w)$ .
- 4) For each coefficient in each coding block find the highest scaling value and set  $s(u, v, w)$  to

$$s(u, v, w) = s_{Max} - \max(s_i \cdot M_i(u, v, w)) \quad E.3$$

where  $i=0 \dots (\text{Number of ROI} - 1)$ .

- 5) For each coefficient  $(u, v, w)$  discard the first  $s(u, v, w)$  MSBs and shift up the remaining MSBs  $s(u, v, w)$  places, as described in Equation E.4, for  $i = 1, \dots, M_b$

$$MSB_i(b, u, v, w) = \begin{cases} MSB_{i+s}(u, v, w) & i + s(u, v, w) \leq N_b(u, v, w) \\ 0 & i + s(u, v, w) > N_b(u, v, w) \end{cases} \quad E.4$$

- 6) Update the value of  $N_b(u, v, w)$  as given in Equation E.5,

$$N_b(u, v, w) = \max(0, N_b(u, v, w) - s(u, v, w)) \quad E.5$$

### E.3 Encoding with ROI (informative)

This section describes how to encode an image with one or more ROI, using either the Maxshift or the Scaling based method. The encoding is given here as an informative section. At the encoder side an ROI mask is created describing which quantized transformation coefficients must be encoded with better quality (up to lossless). The ROI mask is a bit map describing these coefficients.

#### E.3.1 Description of the Maxshift method (informative)

The quantized transform coefficients outside of the ROI mask, called background coefficients, are scaled down so that the bits associated with the ROI are placed in higher bit-planes than the background. This means that when the entropy coder encodes the quantized transform coefficients, the bit-planes associated with the ROI are coded before the information associated with the background. For the ROI mask generation with the Maxshift method, see Annex E.4.1.

The Maxshift method can be described using the following steps:

- 1) Generate the ROI mask,  $M(x, y, z)$ , see Annex E.4.1.
- 2) Find the scaling value  $s$  (see Annex E.3.2).
- 3) Add  $s$  LSBs to each coefficient  $|q_b(u, v, w)|$ . The number  $M'_b$  of magnitude bit-planes will then be

$$M'_b = M_b + s \quad E.6$$

where  $M_b$  is given by ITU Rec. T.800 | ISO/IEC 15444-1 Equation E.2 and the new value of each coefficient is given by

$$|q_b(u, v, w)| = |q_b(u, v, w)| \cdot 2^s \quad E.7$$

- 4) Scale down all background coefficients given by  $M(x, y, z)$  using the scaling value  $s$  (see Annex E.3.2). Thus, if  $|q_b(u, v, w)|$  is a background coefficient given by  $M(x, y, z)$ , then

$$|q_b(u, v, w)| = \frac{|q_b(u, v, w)|}{2^s} \quad E.8$$

- 5) Write the scaling value  $s$  into the codestream using the SPRgn parameter of the RGN marker segment.

After these steps the quantized transform coefficients are entropy coded as usual.

### E.3.2 Selection of scaling value, $s$ , for Maxshift method at encoder side (informative)

The scaling value,  $s$ , may be chosen so that Equation E.9 holds, where  $\max(M_b)$  is the largest number of magnitude bitplanes (see ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation E.1), for any background coefficient,  $q_{BG}(x,y,z)$ , in any code-block in the current component.

$$s \geq \max(M_b) \quad \text{E.9}$$

This guarantees that the scaling value used will be sufficiently large to ensure all the significant bits associated with the ROI will be in higher bit-planes than all the significant bits associated with the background.

### E.3.3 Description of the Scaling based method (informative)

As stated in the introduction part of this section (Annex E.3), the description of encoding with ROI is informative. However, when using the Scaling based ROI method, failure to generate the correct ROI mask at the encoder side will greatly reduce the quality of the decoded image and will not allow lossless decoding. For the ROI mask generation with the Scaling based method, see Annex E.4.2.

The quantized transformation coefficients are scaled in such a manner that the relative significance of each transformation coefficient is equal to the specified scaling value,  $s$ , of the ROI to which it applies. If a transformation coefficient belongs to several ROI the largest  $s$  value is chosen. If a transformation coefficient belongs to the background, the scaling value  $s$  equals 0. Before scaling the quantized transformation coefficients of one code-block, the highest,  $s_{Max}$ , and lowest,  $s_{Min}$ , scaling value for the coding block are found.

Consider a quantized transformation coefficient,  $q_b(u,v,w)$ , in the current coding block with corresponding scaling value,  $s$  (where  $s_{Min} \leq s \leq s_{Max}$ ). After scaling, the individual bits of  $q_b(u,v,w)$  end up  $abs(s_{Max} - s)$  bit planes lower than the corresponding bits of a coefficient with  $s = s_{Max}$ . The number of magnitude bits for this coding block will hence increase by  $(s_{Max} - s_{Min})$ .

Since the coding blocks are treated independently, quantized transformation coefficients belonging to the same ROI might end up having different levels of significance in different coding blocks. This difference between coding blocks must be taken care of by the rate allocator. An example of this would be if an entire coding block belongs to the image background and another coding block has both ROI and background coefficients. In this case, the background coefficients in the second coding block would be downshifted by  $s-0$  steps whereas in the first coding block no shifting would be done. In this case it is up to the rate allocation algorithm to make sure that the bit planes from the two coding blocks are put in the bit stream in the correct order.

When the entropy coder encodes the quantized transformation coefficients, the bit planes associated with the ROI are coded before or at the same time as the information associated with the background. The scaling value,  $s_i$ , for each ROI is specified by the user or application.

The method can be described using the following steps for a set of  $n$  ROIs:

- For each coding block in each component:
  - 1) Generate ROI mask for all ROI  $i$ ,  $\{M_i(u,v,w)\}$ , see Annex E.4.2.
  - 2) Find  $s_{Min}$  and  $s_{Max}$ , where  $s_{Min}$  and  $s_{Max}$  are the smallest and largest scaling value in the current coding block, respectively.
  - 3) Add  $s_{Block} = s_{Max} - s_{Min}$  LSBs to each coefficient  $|q_b(u,v,w)|$ . The number  $M'_b$  of magnitude bit-planes for subband,  $b$ , will then be

$$M'_b = M_b + s_{Block} \quad \text{E.10}$$

where  $M_b$  is given by ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation E.2 and the new value of each coefficient is given by

$$|q_b(u,v,w)| = |q_b(u,v,w)| \cdot 2^{s_{Block}} \quad \text{E.11}$$

- 4) For each coefficient in each coding block find the highest scaling value and set  $s(u,v,w)$  to

$$s(u, v, w) = s_{max} - \max(s_i - M_i(u, v, w)) \quad \text{E.12}$$

where  $i = 0 \dots (\text{Number of ROI} - 1)$ .

5) Scale down all coefficients so that

$$|q_b(u, v, w)| = \frac{|q_b(u, v, w)|}{2^{s(u, v, w)}} \quad \text{E.13}$$

6) For each ROI write the scaling value,  $s$ , shape, and reference points into the codestream using the RGN marker segment as described in Annex A.2.4.

## E.4 Region of interest mask generation

To achieve an ROI with better quality than the rest of the image while maintaining a fair amount of compression, bits need to be saved by sending less information for the background. To do this an ROI mask is calculated. The mask is a bit-plane indicating a set of quantized transformation coefficients whose coding is sufficient in order for the receiver to reconstruct the desired region with better quality than the background (up to lossless).

To illustrate the concept of ROI mask generation, let us restrict ourselves to a single ROI and a single volume component, and identify the samples that belong to the ROI in the volume domain by a binary mask,  $M(x, y, z)$ , where

$$M(u, v, w) = \begin{cases} 1 & \text{wavelet coefficient } (u, v, w) \text{ is needed} \\ 0 & \text{accuracy on } (u, v, w) \text{ can be sacrificed without affecting ROI} \end{cases} \quad \text{E.14}$$

The mask is a map of the ROI in the wavelet domain so that it has a non-zero value inside the ROI and 0 outside. In each step each sub-band of the mask is then updated in a raster scan order. The mask will then indicate which coefficients are needed at this step so that the inverse transformation will reproduce the coefficients of the previous mask.

For example, the last step of the inverse transformation is a composition of two sub-bands into one. Then to trace this step backwards, the coefficients of both sub-bands that are needed, are found. The step before that is a composition of four sub-bands into two. To trace this step backwards, the coefficients in the four sub-bands that are needed to give a perfect reconstruction of the coefficients included in the mask for two sub-bands are found. Again, the step before that is a composition of eight sub-bands into four. Once again, to trace this step backwards, the coefficients in the eight sub-bands that are needed for all four sub-bands are found.

All steps are then traced backwards to give the mask. If the coefficients corresponding to the mask are transmitted and received, and the inverse transformation calculated on them, the desired ROI will be reconstructed with better quality than the rest of the volume (up to lossless if the ROI coefficients were coded losslessly).

### E.4.1 Region of interest mask generation for Maxshift method (informative)

Given below is a description of how the expansion of the mask is acquired from the various filters. Similar methods can be used for other filters.

#### E.4.1.1 Region of interest mask generation using the 5-3 reversible filter (informative)

In order to get the optimal set of quantized coefficients to be scaled, the following equations described in this section should be used.

To see what coefficients need to be in the mask, the inverse wavelet transformation is studied. ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation F.5 and ITU-T Rec. T.800 | ISO/IEC 15444-1 Equation F.6 give the coefficients needed to reconstruct  $X(2n)$  and  $X(2n+1)$  losslessly. It can immediately be seen that these are  $L(n)$ ,  $L(n+1)$ ,  $H(n-1)$ ,  $H(n)$ ,  $H(n+1)$  (see ITU-T Rec. T.800 | ISO/IEC 15444-1 Figure H-1). Hence if  $X(2n)$  and  $X(2n+1)$  are in the ROI, the listed low and high subband coefficients are in the mask. Notice that  $X(2n)$  and  $X(2n+1)$  are even and odd indexed points respectively, relative to the origin of the reference grid.

**E.4.1.2 Region of interest mask generation using the 9-7 irreversible filter (informative)**

Successful decoding does not depend upon the selection of samples to be scaled. In order to get the optimal set of quantized coefficients to be scaled the following equations described in this section should be used.

To see what coefficients need to be in the mask, the inverse wavelet transformation is studied as in ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex H.3.1.1. Figure H-2 shows this.  $X(2n)$  and  $X(2n+1)$  are even and odd indexed points respectively, related to the origin of the reference grid.

The coefficients needed to reconstruct  $X(2n)$  and  $X(2n+1)$  losslessly can immediately be seen to be  $L(n-1)$  to  $L(n+2)$  and  $H(n-2)$  to  $H(n+2)$ . Hence if  $X(2n)$  and  $X(2n+1)$  are in the ROI, those Low and High subband coefficients are in the mask.

**E.4.2 Region of interest mask generation for Scaling based method**

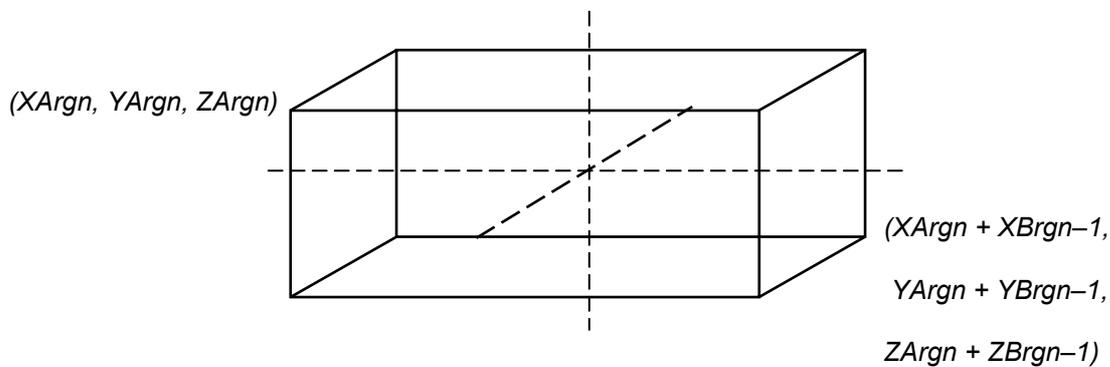
Given below are descriptions of how the expansion of the mask is acquired in the cuboidal and ellipsoidal case and also how this is done for the various filters. Similar methods can be used for other filters.

**E.4.2.1 Cuboidal mask generation on the reference grid**

The cuboidal mask described in this section is generated on the reference grid. When generated on the reference grid, the method described in Annex E.4.2.3 is used for mask generation in the wavelet domain. A cuboid is described by six parameters, see Figure E-1, all signaled in the RGN marker (see Annex A.2.4). The parameters are  $(XArgn, YArgn, ZArgn, XBrgn, YBrgn, ZBrgn)$ , where  $XArgn, YArgn$  and  $ZArgn$  are the  $x, y$  and  $z$  offset of the upper left front corner of the cuboid from the reference grid origin, whereas  $XBrgn, YBrgn$  and  $ZBrgn$  are the *width*, the *height* and the *depth* of the cuboid respectively.

The correct mask for the reference grid is given by Equation E.15.

$$\begin{aligned}
 XArgn \leq x &\leq XArgn + XBrgn \\
 YArgn \leq y &\leq YArgn + YBrgn \\
 ZArgn \leq z &\leq ZArgn + ZBrgn
 \end{aligned}
 \tag{E.15}$$



**Figure E-1 — Cuboid mask on the reference grid**

**E.4.2.2 Ellipsoidal mask generation on the reference grid**

The ellipsoidal mask described in this section is generated on the reference grid. When generated on the reference grid the method described in Annex E.4.2.3 is used for mask generation in the wavelet domain. An ellipsoid is described by six parameters, see Figure E-2, all signaled in the RGN marker (see Annex A.2.4). The parameters are  $(XArgn, YArgn, ZArgn, XBrgn, YBrgn, ZBrgn)$ , where  $XArgn, YArgn$  and  $ZArgn$  are the  $x, y$  and  $z$  offset of the center of the ellipsoid from the reference grid origin, whereas  $XBrgn, YBrgn$  and  $ZBrgn$  are the *width*, the *height* and the *depth* of the ellipsoid respectively.

The correct mask for the reference grid is given by Equation E.16.

$$\frac{(x - XArgn)^2}{XBrgn^2} + \frac{(y - YArgn)^2}{YBrgn^2} + \frac{(z - ZArgn)^2}{ZBrgn^2} \leq 1 \quad \text{E.16}$$

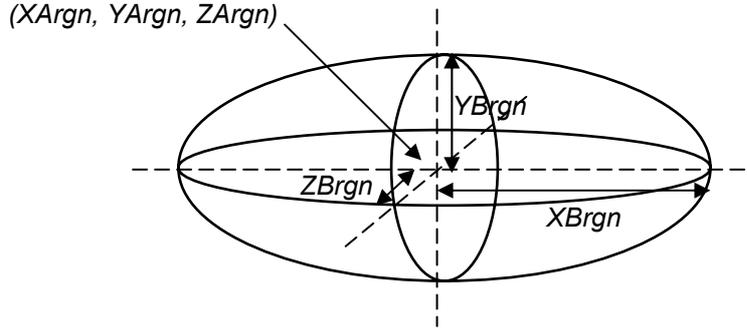


Figure E-2 — Ellipsoidal mask on the reference grid

#### E.4.2.3 Fast generation of a cuboidal mask (informative)

In the case of a cuboidal ROI, the mask can be derived more quickly than for arbitrary shapes. In this case, instead of tracing how each coefficient and voxel value is reconstructed in the inverse transform, only two positions need to be studied, namely the upper left front and the lower right back corners of the mask. The front-top-left corner  $(x_1, y_1, z_1)$  on the reference grid will be given in the RGN marker segment as  $(XArgn, YArgn, ZArgn)$ , whereas the rear-bottom-right corner  $(x_2, y_2, z_2)$  on the reference grid will be given by the parameters in the RGN marker segment as  $(XArgn + XBrgn-1, YArgn + YBrgn-1, ZArgn + ZBrgn-1)$ .

The mask generation must take into account what type of filter that has been used by the transform.

In each level of decomposition, the steps described in the previous section are followed to see how the mask expands. Let the 1D mask, to be decomposed, be  $R_{ext}$  and let  $x_1$  and  $x_2$  be the lowest and highest indices of non-zero samples in  $R_{ext}$ .

- 1) For each lifting step  $s$  where  $s$  ranges from  $0$  to  $N_{LS} - 1$ ,
  - i) Find the lowest sample index  $(2n + m_s \geq x_1)$  that is in the mask

$$x'_1 = 2n + 1 - m_s + 2off_s \quad \text{E.17}$$

$$\text{if } (x'_1 > x_1) \text{ then } x'_1 = x_1; \quad \text{E.18}$$

- ii) Find the highest sample index  $(2n + m_s \leq x_2)$

$$x'_2 = 2n + 1 - m_s + 2(L_s - 1 + off_s) \quad \text{E.19}$$

$$\text{if } (x'_2 > x_2) \text{ then } x'_2 = x_2; \quad \text{E.20}$$

- iii) Set  $x_1 = x'_1, x_2 = x'_2$  where  $m_s = 1 - m_{s-1}$  indicates whether the  $s$ th lifting step applies to even-indexed coefficients ( $m_s = 0$ ) or odd-indexed coefficients ( $m_s = 1$ ), and where  $L_s$  is the number of lifting coefficients for lifting step  $s$ .

Let all samples between  $x_1$  and  $x_2$ , inclusive, be non-zero and then separate the ROI mask samples into subbands the same way as the wavelet coefficients are separated in using the deinterleave procedure described in Annex F.4.5 of ITU-T Rec. T.800 | ISO/IEC 15444-1.

## **E.5 Remarks on region of interest coding**

### **E.5.1 Usage of Scaling and Maxshift methods**

The Maxshift method must not be used together with the Scaling based method and vice versa.

### **E.5.2 Multi-component remark (informative)**

For the case of color images, the method applies separately in each color component. If some of the color components are down-sampled, the mask for the down-sampled components is created in the same way as the mask of the non-down-sampled components.

### **E.5.3 Implementation precision remark (informative)**

This ROI coding method might in some cases create situations where the dynamic range is exceeded. This is however easily solved by simply discarding the least significant bit planes that exceed the limit due to the down scaling operation. The effect will be that the ROI will have better quality compared to the background, even though the entire bit stream is decoded. It might however create problems when the image is coded with ROI's in a lossless mode. Discarding least significant bit-planes for the background might have the result that the background is not coded losslessly; and in the worst case the background may not be reconstructed at all. This depends on the dynamic range available.

## **Annex F**

### **Examples and guidelines, extensions**

(This annex is an informative part of this Recommendation | International Standard.)

#### **F.1 Rate-Distortion Modeling**

See ITU-T Rec. T.800 | ISO/IEC 15444-1 Annex J.14.

## Bibliography

- [1] G. M. Morton, "A Computer Oriented Geodetic Data Base and a New Technique in File Sequencing," IBM Ltd, Ottawa, Canada 1966.