INTERNATIONAL STANDARD

**ISO/IEC 15444-17**

First edition
2023-06

# Information technology — JPEG 2000 image coding system —

## Part 17: Extensions for coding of discontinuous media

*Technologies de l'information — Système de codage d'images JPEG 2000 —*

*Partie 17: Extensions pour le codage des supports discontinus*

Reference number
ISO/IEC 15444-17:2023(E)

© ISO/IEC 2023



**COPYRIGHT PROTECTED DOCUMENT**

© ISO/IEC 2023

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland



© ISO/IEC 2023 – All rights reserved

# 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 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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of document should be noted.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents) or the IEC list of patent declarations received (see https://patents.iec.ch).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html. In the IEC, see www.iec.ch/understanding-standards.

This document was prepared by ITU-T (as ITU-T - T.816) and drafted in accordance with its editorial rules, in collaboration with Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 29, *Coding of audio, picture, multimedia and hypermedia information*.

A list of all parts in the ISO/IEC 15444 series can be found on the ISO and IEC websites.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees.

© ISO/IEC 2023 – All rights reserved

**INTERNATIONAL STANDARD ISO/IEC 15444-17**
**RECOMMENDATION ITU-T T.816 (V1)**

# Information technology – JPEG 2000 image coding system: Extensions for coding of discontinuous media

**Summary**

Rec. ITU-T T.816 | ISO/IEC 15444-17 provides extensions of the scalable image coding tools described in Rec. ITU-T T.800 | ISO/IEC 15444-1 and Rec. ITU-T T.801 | ISO/IEC 15444-2, of two types. First, new wavelet-like image transforms known as "breakpoint-dependent" transforms are defined, whose underlying basis functions can be discontinuous at defined locations within the image component to which they are applied. Second, new scalable coding tools are described for a new type of image component known as a "breakpoint component", which provides a successively refinable and hierarchical description of the breakpoint locations used by the breakpoint-dependent transforms. Any non-initial component or components within a codestream conforming to this Recommendation | International Standard can be breakpoint components and any of the components in the codestream other than breakpoint components can use a breakpoint-dependent transform that depends upon one of the breakpoint components in the same codestream. These new tools together allow for the scalable coding of imagery that naturally exhibits strong discontinuities in the spatial domain. An important example of such imagery is depth maps.

This Recommendation was developed jointly with ISO/IEC JTC 1/SC 29/WG 1 (JPEG) and is common text with ISO/IEC 15444-17.

**History**

| Edition | Recommendation | Approval | Study Group | Unique ID* |
|---|---|---|---|---|
| 1.0 | ITU-T T.816 (V1) | 2023-02-13 | 16 | 11.1002/1000/15206 |

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.


© ISO/IEC 2023 – All rights reserved

## FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

## NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

## INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

© ITU 2023

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without the prior written permission of ITU.

**CONTENTS**

**Page**


1 Scope ... 1
2 Normative references ... 1
3 Terms and definitions ... 1
4 Abbreviations ... 2
5 5 Conventions ... 3
6 Conformance ... 3
6.1 Codestream conformance ... 3
6.2 Decoder ... 3
7 Breakpoint component structure ... 4
7.1 Breakpoint components and the reference grid ... 4
7.2 Division of breakpoint resolutions into cells, arcs and the CL band ... 4
7.3 Division of breakpoint resolutions into precincts and code-blocks ... 5
7.4 Root and non-root arc breakpoint associations ... 7
7.5 Breakpoint values and vertices ... 8
8 Breakpoint-dependent spatial wavelet transformation ... 10
8.1 Overview ... 10
8.2 TriBPT-dependent irreversible transforms ... 11
8.2.1 Introduction ... 11
8.2.2 Arcs with $tb = 0$ ... 12
8.2.3 Arcs with $tb = 3$ ... 13
8.2.4 Arcs with $tb = 2$ ... 13
8.2.5 Arcs with $tb = 1$ ... 17
8.3 TriBPT-dependent reversible transforms ... 21
8.3.1 Arcs with $tb = 0$ ... 22
8.3.2 Arcs with $tb = 3$ ... 22
8.3.3 Arcs with $tb = 2$ ... 22
8.3.4 Arcs with $tb = 1$ ... 22
8.4 QuadBPT-dependent transforms ... 23
8.4.1 Introduction ... 23
8.4.2 BD_2D_SR phase 1 ... 24
8.4.3 BD_2D_SR phase 2 ... 26
9 Decoding of breakpoint code-blocks ... 28
9.1 Embedded bit-plane decoding of breakpoints ... 28
9.2 Inter-band coding mode (BPT_INTER) ... 29
9.3 Cell-based scanning patterns and CBAP-based block flipping ... 30
9.4 QuadBPT decoding procedures ... 32
9.4.1 MQ Coder contexts and initial states for QuadBPT decoding ... 32
9.4.2 Derivation of context labels for QuadBPT CL band significance coding passes ... 33
9.4.3 Non-root significance decoding for QuadBPT CL code-blocks ... 35
9.4.4 Root significance decoding for QuadBPT CL code-blocks ... 36
9.4.5 Root significance decoding for QuadBPT LL code-blocks ... 37
9.4.6 Position refinement decoding for QuadBPT code-blocks ... 37
9.5 TriBPT decoding procedures ... 38
9.5.1 MQ Coder contexts and initial states for TriBPT decoding ... 38
9.5.2 Derivation of context labels for TriBPT CL band significance coding passes ... 39
9.5.3 Non-root significance decoding for TriBPT CL code-blocks ... 42
9.5.4 Root significance decoding for TriBPT CL code-blocks ... 43
9.5.5 Root significance decoding for TriBPT LL code-blocks ... 44
9.5.6 Position refinement decoding for TriBPT code-blocks ... 45
9.6 Quality layers and packets for breakpoint components ... 45
10 Reconstruction of breakpoint components ... 47
10.1 Overview ... 47
10.2 Direct induction step ... 47
10.2.1 Introduction ... 47
10.2.2 Extrapolation Qualifier for TriBPT direct induction ... 48



© ISO/IEC 2023 – All rights reserved

Page

10.3 QuadBPT spatial induction ..... 49
10.3.1 Introduction ..... 49
10.4 TriBPT spatial induction ..... 51
10.4.1 TriBPT induction modes and corner notation ..... 51
10.4.2 4-arc mode ..... 51
10.4.3 3-arc mode ..... 52
10.4.4 Extrapolation qualifier for TriBPT spatial induction ..... 53
10.4.5 Rounding policies for TriBPT spatial induction ..... 56
10.4.6 Image boundary handling for TriBPT ..... 56

Annex A (This annex forms an integral part of this Recommendation | International Standard.) – Codestream syntax ..... 58
A.1 General ..... 58
A.2 SIZ marker segment ..... 58
A.3 CAP marker segment ..... 58
A.4 Hierarchical data type (HDT) marker segment ..... 59
A.5 COD and COC marker segments ..... 59

Annex B (This annex does not form an integral part of this Recommendation | International Standard) – Hierarchical breakpoint encapsulation and raw file format ..... 62
B.1 General ..... 62
B.2 Raster organization of breakpoints ..... 62
B.3 16- and 32-bit packed breakpoint values ..... 63
B.4 A raw file format for breakpoints ..... 64

Bibliography ..... 67

## List of Tables

Page

Table 1 – Constraints on PPx and PPy precinct size parameters breakpoint components ..... 6

Table 2 – MQ coder contexts for QuadBPT CL code-block decoding passes. State index values correspond to the Qe values and probability estimation transitions tabulated in Rec. ITU-T T.800 | ISO/IEC 15444-1 ..... 33

Table 3 – Context labels from Table 2 that are used for QuadBPT LL code-block decoding passes ..... 33

Table 4 – MQ coder contexts for TriBPT CL code-block decoding passes. State index values correspond to the Qe values and probability estimation transitions tabulated in Rec. ITU-T T.800 | ISO/IEC 15444-1 ..... 38

Table 5 – Context labels from Table 4 that are used for TriBPT LL code-block decoding passes ..... 38

Table A.1 – Extensions and constraints to marker segments specified in Rec. ITU-T T.800 | ISO/IEC 15444-1 and new marker segments specified in this Recommendation | International Standard ..... 58

Table A.2 – Ccap[17] Syntax and Semantics ..... 58

Table A.3 – Hierarchical data type parameter values ..... 59

Table A.4 – Allowed values for Ihdt[i] ..... 59

Table A.5 – Scod and Scoc semantics for bit 5 ..... 60

Table A.6 – SXcod bit fields specified by this Recommendation | International Standard ..... 60

Table A.7 – Allowed values for the SEcod field ..... 61

Table A.8 – Transformation for the SPcod and SPcoc parameters when $Dc \neq 0$ ..... 61

© ISO/IEC 2023 – All rights reserved

## List of Figures

**Page**

Figure 1 – Arc arrangements within a single 2-span. A $\mathbf{2 \times 2}$ cell is shown here with solid grid-points. See Figure 2 for other geometric relationships between cells and 2-spans ..... 5

Figure 2 – Cell-span geometry for each of the four possible code-block anchor points ..... 5

Figure 3 – Root arc (dotted lines) and non-root arcs (solid lines) ..... 8

Figure 4 – Possible break locations (tick-points) at the finest resolution, with $\boldsymbol{FB = 2}$, shown for the QuadBPT case. Also shows the mapping of vertices with precision $\boldsymbol{Pb}$ to tick-points ..... 9

Figure 5 – Stages of the breakpoint dependent inverse discrete wavelet transform ..... 10

Figure 6 – Interleaving of sub-band coefficients to a triangular grid for a given resolution *r* ..... 12

Figure 7 – Update step examples for TriBPT-LR arrangement ..... 12

Figure 8 – Predict step examples for a horizontal arc ..... 12

Figure 9 – Example of direct induction of a breakpoint ..... 14

Figure 10 – Example illustrating spatially induced breaks ..... 14

Figure 11 – Example of a spatially induced breakpoint on a non-root arc for the TriBPT-LR arrangement ..... 15

Figure 12 – Examples showing base-arc $\boldsymbol{bsa}$ and gradients $\boldsymbol{Gbsa}$ and $\boldsymbol{Gwdg}$ along with corresponding binary flags ORN and $\boldsymbol{DRCTNX_FLAG\ induced}$ for root arcs ..... 16

Figure 13 – Example showing base-arc $\boldsymbol{bsa}$ and gradients $\boldsymbol{Gbsa}$ and $\boldsymbol{Gwdg}$ along with corresponding binary flags ORN and $\boldsymbol{DRCTNX_FLAG\ induced}$ for diagonal non-root arc containing a spatially induced break ..... 16

Figure 14 – Examples of arcs $\boldsymbol{prl}$ parallel in orientation to root arcs centred at $\boldsymbol{p}$ and containing a spatially induced break. Gradient calculated across arc $\boldsymbol{prl}$ is denoted as $\boldsymbol{Gprl}$ ..... 19

Figure 15 – Example of arc $\boldsymbol{prl}$ parallel to the non-root arc centred and at $\boldsymbol{p}$ and containing a spatially induced break. Corresponding gradient across arc $\boldsymbol{prl}$ is shown as $\boldsymbol{Gprl}$ ..... 19

Figure 16 – Algorithm for determining the gradient $\boldsymbol{Gb}$ based on validity flags VALID_WDG and VALID_PRL and corresponding attributes ..... 20

Figure 17 – Parent 4-span arrangement at resolution $\boldsymbol{rrt = r - 1}$ for arc $\boldsymbol{a}$ at resolution $\boldsymbol{r}$ and centred at $\boldsymbol{p}$ ..... 21

Figure 18 – Algorithm for determining the gradient $\boldsymbol{Gb}$ for the reversible transform, based on validity flags VALID_WDG and VALID_PRL and corresponding attributes ..... 23

Figure 19 – Interleaving of sub-band coefficients to a quadrilateral grid for a given resolution *r* ..... 23

Figure 20 – Phase 1 update step for (even, even) location $\boldsymbol{2n, 2m}$ ..... 24

Figure 21 – Phase 1 update step for (even, odd) location $\boldsymbol{2n, 2m + 1}$ and (odd, even) location $\boldsymbol{2n + 1, 2m}$ ..... 25

Figure 22 – Phase 1 predict step for (odd, odd) location $\boldsymbol{2n + 1, 2m + 1}$ with source locations of $\boldsymbol{Ic, r}$ ∗shown ..... 26

Figure 23 – Phase 2 update step for (even, even) location $\boldsymbol{2n, 2m}$ ..... 27

Figure 24 – Phase 2 predict step examples ..... 28

Figure 25 – Canonical scanning pattern used for the significance coding passes of CL band code-blocks in a QuadBPT component. In this case, missing cells within a $\mathbf{2 \times 2}$ group are not included in the scan ..... 30

Figure 26 – Canonical scanning pattern used for the significance coding passes of CL band code-blocks in TriLR components. Arcs belonging to cells that lie beyond the code-block boundaries are included in the significance coding passes ..... 31

Figure 27 – Canonical scanning pattern used for the significance coding passes of CL band code-blocks in TriRL components. Arcs belonging to cells that lie beyond the code-block boundaries are included in the significance coding passes ..... 31

Figure 28 – Neighbouring cells and arcs involved in forming coding contexts for QuadBPT significance decoding in CL band code-blocks ..... 34

Figure 29 – Neighbouring cells and arcs involved in forming coding contexts for TriLR significance decoding in CL band code-blocks ..... 39


© ISO/IEC 2023 – All rights reserved

**Page**

Figure 30 – Neighbouring cells and arcs involved in forming coding contexts for TriRL significance decoding in CL band code-blocks ..... 40

Figure 31 – Breakpoint synthesis stages ..... 47

Figure 32 – Relationship between non-root and parent arcs during direct induction in synthesis stage $r$, shown for the case of horizontal arcs ..... 48

Figure 33 – Rounding policies used in QuadBPT spatial induction, showing different induction examples in three of the four 2-spans within a 4-span ..... 50

Figure 34 – Arc and corner labels for the TriBPT-LR arrangement ..... 51

Figure 35 – 4-arc mode spatial induction examples for the TriBPT-LR arrangement ..... 52

Figure 36 – 3-arc mode spatial induction examples for the TriBPT-LR arrangement ..... 53

Figure 37 – Example of intersection points, arcs and grid-lines required for determining the extrapolation qualifier for a spatially induced break ..... 55

Figure 38 – Examples of rounding policy for 3-arc mode spatial induction when the inducing line intersects the root arc X at its centre. The direction of rounding is highlighted by the black arrows ..... 56

Figure A.1 – Hierarchical data type syntax ..... 59

Figure A.2 – Coding style default syntax ..... 60

Figure A.3 – Coding style component syntax ..... 60

Figure B.1 – Bit fields within 16- and 32-bit packed breakpoint representations. The most significant bit of the 16- or 32-bit integer, as appropriate, is shown at the top of the figure, while the least significant bit appears at the bottom ..... 64

© ISO/IEC 2023 – All rights reserved

## Introduction

The JPEG 2000 core coding system specified in Rec. ITU-T T.800 | ISO/IEC 15444-1 and its extensions specified in Rec. ITU-T T.801 | ISO/IEC 15444-2 provide a suite of scalable coding technologies that are particularly suitable for photographic media, but less effective at coding media with hard discontinuities. An important example of such media is depth imagery, where each image sample is related to the length of the 3D line segment between the corresponding scene point and the camera. Depth imagery includes stereo disparity maps, where sample values are reciprocally related to depth. Another example of media with strong discontinuities is optical flow data, where each sample location is a two-dimensional vector. In these examples, discontinuities arise naturally at the boundaries of scene objects. Moreover, where this happens, intermediate values that might be obtained by bandlimited image resampling or interpolation operations have no physical meaning – i.e., they do not correspond to the depth or flow vector of any object in the original scene. The discrete wavelet transform (DWT) employed in JPEG 2000 is not well suited to the coding of such media, both from the perspective of coding efficiency and considering the nature of distortions that result when the wavelet sub-band samples are quantized.

To address these challenges, this Recommendation | International Standard introduces alternate "breakpoint-dependent" spatial wavelet transforms that are dependent on an auxiliary image component, known as a "breakpoint component." This Recommendation | International Standard also introduces scalable coding technologies for breakpoint components. Any non-initial component or components within the codestream can be designated as breakpoint components, allowing them to be used as the source of breakpoints for other components, or tiles thereof, which specify the use of breakpoint-dependent wavelet transforms.

This Recommendation | International Standard specifies two different types of breakpoint components, designated as "QuadBPT" and "TriBPT" components, with associated decoding and synthesis tools. Associated with the type of breakpoint component is a corresponding breakpoint-dependent wavelet transform, with its synthesis tools. The reconstruction procedures described in this Recommendation | International Standard produce individual sample values. In the TriBPT case, it is possible instead to directly reconstruct a deformable triangular mesh, whose complexity is related to the number of non-zero wavelet coefficients and the number of decoded breaks, which are identified here as "vertices." In each case, breakpoints introduce tears in the mesh. This feature can be valuable in computer graphics applications, where the mesh elements provide a more convenient description of the data than individual samples.

The normative material of this Recommendation | International Standard is contained within the main body together with Annex A. Additionally, Annex B describes ways of encapsulating breakpoint data within a linear file structure, that can be used as a source for encoding and a target for decoding procedures.


© ISO/IEC 2023 – All rights reserved

**INTERNATIONAL STANDARD**
**ITU-T RECOMMENDATION**

# Information technology – JPEG 2000 image coding system: Extensions for coding of discontinuous media

## 1 Scope

This Recommendation | International Standard defines QuadBPT and TriBPT image components, collectively known as "breakpoint components", and specifies decoding and reconstruction procedures for recovering breakpoint component sample values from the codestream. This Recommendation | International Standard also specifies "breakpoint-dependent" spatial wavelet transforms that can be used in place of the transforms specified in Recommendation ITU-T T.800 | ISO/IEC 15444-1 for selected image components or tile-components. Extensions to the codestream syntax of Rec. ITU-T T.800 | ISO/IEC 15444-1 are specified to enable the identification of breakpoint components, of components that can use a breakpoint-dependent spatial wavelet transform, and the association of breakpoint components with such breakpoint-dependent wavelet transforms.

## 2 Normative references

The following Recommendations and 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.

### 2.1 Identical Recommendations | International Standards

- Recommendation ITU-T T.800 (2019) | ISO/IEC 15444-1:2019, *Information technology – JPEG 2000 image coding system: Core coding system*.
- Recommendation ITU-T T.801 (2021) | ISO/IEC 15444-2:2021, *Information technology – JPEG 2000 image coding system: Extensions*.

## 3 Definitions

### 3.1 Terms defined elsewhere

For the purposes of this Recommendation | International Standard, the terms and definitions given in Rec. ITU-T T.800 | ISO/IEC 15444-1 apply.

ITU, ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ITU Terms and definitions database: available at https://www.itu.int/go/terms
- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

### 3.2 Terms defined in this Recommendation | International Standard

This Recommendation | International Standard defines the following terms:

**3.2.1 2-span**: Square configuration of width 2 and height 2, with 9 grid-points, such that the four corner grid-points all have coordinates that are divisible by 2.

**3.2.2 4-span**: 2 × 2 configuration of 2-spans (3.2.1), involving 25 grid-points, such that the four corner grid-points all have coordinates that are divisible by 4.

**3.2.3 ambivalent break**: Induced break (3.2.5) that has insufficient precision to determine whether the break occurs in the first or second half of the arc.

**3.2.4 arc**: Line segment connecting grid-points with even valued coordinates at any resolution of a breakpoint tile-component.

© ISO/IEC 2023 – All rights reserved