
**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*

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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*.

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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.

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FOREWORD

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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.

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**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.

3.2.5 break: Explicitly decoded or inferred location within an arc (3.2.4) that indicates a boundary within an image component.

NOTE 1 – Breaks modify the behaviour of breakpoint-dependent transforms on that other image component.

NOTE 2 – An arc has at most one break.

3.2.6 breakpoint: Data structure consisting of break type, location and precision information for an arc (3.2.4).

NOTE – Type-0 breakpoints have no break at all.

3.2.7 breakpoint component: JPEG 2000 codestream image component that represents arc breakpoint (3.2.6) information.

3.2.8 breakpoint tile-component: All the breakpoints of a given tile, within a breakpoint component (3.2.7).

3.2.9 cell: 2×2 configuration of grid-points within a resolution of a breakpoint tile-component (3.2.8).

NOTE – Cells belong to a well-defined partition that is anchored at the global code-block anchor point.

3.2.10 CL band: The sole sub-band associated with each resolution of a breakpoint tile-component (3.2.8) other than the lowest resolution.

3.2.11 code-block anchor point: Origin of the coding partitions, which is one of the locations (0,0), (0,1), (1,0) or (1,1).

[SOURCE: Rec. ITU-T T.801 | ISO/IEC 15444-2]

3.2.12 directly induced break: Break (3.2.5) on an arc that is inferred from a break on a parent arc.

3.2.13 extrapolation qualifier: 2-bit quantity e_b which controls the way gradients are obtained for extrapolation within a TriBPT-dependent transformation.

3.2.14 indefinite break: Induced break (3.2.15) on an arc that is derived from one or more ambivalent breaks (3.2.3), such that there is insufficient precision to determine whether any break at all exists on the arc.

3.2.15 induced break: Break (3.2.5) on an arc that is inferred from breaks on other arcs.

3.2.16 induction block: Condition on an arc (3.2.4) that is explicitly recovered from the decoding of breakpoint code-blocks, indicating that no break (3.2.5) shall be induced on that arc.

3.2.17 non-root arc: Arc (3.2.4) that is not a root arc.

3.2.18 parent arc: Arc (3.2.4) at depth $d + 1$ in the breakpoint decomposition that contains an arc at depth d .

NOTE – At most two arcs at depth d can have the same parent at depth $d + 1$.

3.2.19 pass-complete: Code-block within a breakpoint component for which one or more coding passes are found within the codestream packets and the last such coding pass is identified as completing the code-block's representation via the packet header signalling mechanisms.

3.2.20 QuadBPT: Breakpoint (3.2.6) arrangement involving only horizontal and vertical arcs (3.2.4).

3.2.21 root arc: Arc (3.2.4) that is not contained within any arc projected from the next lower resolution of a breakpoint tile-component (3.2.8), regardless of whether that next lower resolution actually exists within the tile-component's resolution hierarchy.

3.2.22 spatially induced break: Induced break (3.2.15) that is inferred from breaks on non-parent arcs.

3.2.23 tick-point: Possible break (3.2.5) location along an arc.

3.2.24 TriBPT: Breakpoint (3.2.6) arrangement involving horizontal, vertical and diagonal arcs (3.2.4).

3.2.25 TriBPT-LR: TriBPT (3.2.24) breakpoint arrangement involving diagonal arcs that run from the top-left to the bottom-right of a 2-span within any resolution of a breakpoint tile-component (3.2.8).

3.2.26 TriBPT-RL: TriBPT (3.2.24) breakpoint arrangement involving diagonal arcs that run from the top-right to the bottom-left of a 2-span within any resolution of a breakpoint tile-component (3.2.8).

3.2.27 vertex: Explicitly coded break (3.2.5) location.

3.2.28 zero-complete: Code-block within a breakpoint component (3.2.7) that makes no contribution to any codestream packet and is identified as complete by the first packet header of its precinct.

4 Abbreviations

For the purposes of this Recommendation | International Standard, the following abbreviations apply:

BD-IDWT Breakpoint-Dependent Inverse Discrete Wavelet Transformation

BGP	Base Grid Point
BIL	Break Inducing Line
BIP	Base Intersection Point
BLN	Base Line
BSA	Base Arc
CBAP	Code-Block Anchor Point
DIB	Directly Induced Breaks
HDT	Hierarchical Data Type
HGP	Horizontal Grid-Point
MPS	More Probable Symbol
RAC	Round Away from Centre
RTN	Round to Nearest
SBR	Source Breaks
SPB	Spatially induced Break
TPS	Tick-Points
VMR	Vertex Mapping Rule
VRT	Vertex
WDA	Wedge Area

5 Conventions

This Recommendation | International Standard uses the following conventions:

- **CBAP** (z_x, z_y) – code-block anchor point
- **MAX_WDG** – maximum search distance for the gradient extrapolation algorithm used during the TriBPT-dependent prediction step associated with a spatially induced arc.
- **BPT_INTER** – binary flag that is 1 if code-blocks of a breakpoint component use the inter-band coding mode and 0 if the code-blocks of a breakpoint component are coded without reference to any other code-block data.

6 Conformance

6.1 Codestream conformance

A codestream conforming to this Specification shall conform to Annex A.

6.2 Decoder

A decoder conforming to this Specification shall process a codestream that conforms to this Specification in the manner specified in Rec. ITU-T T.800 | ISO/IEC 15444-1 together with any additional signalled capability specified in this Specification, with the exception of breakpoint components and tile-components that identify the use of a breakpoint-dependent spatial wavelet transform, in which case the following shall apply:

- breakpoint components shall have the structure specified in clause 7;
- tile-components that use a breakpoint-dependent spatial wavelet transform shall be processed in accordance with clause 8; and
- breakpoint components shall be reconstructed from breakpoint code-blocks in accordance with clause 10, where breakpoint code-blocks are decoded in accordance with clause 9.

This Recommendation | International Standard is compatible with the coding technologies specified in both Rec. ITU-T T.800 | ISO/IEC 15444-1 and Rec. ITU-T T.801 | ISO/IEC 15444-2. However:

1. Breakpoint components, as specified herein, are not compatible with the multiple component transformations specified in Rec. ITU-T T.800 | ISO/IEC 15444-1 and Rec. ITU-T T.801 | ISO/IEC 15444-2, nor are they compatible with the non-linear transformations specified in Rec. ITU-T T.801 | ISO/IEC 15444-2; and
2. Breakpoint code-blocks, as specified herein, are not compatible with the region of interest coding and extraction techniques specified in Rec. ITU-T T.800 | ISO/IEC 15444-1 and Rec. ITU-T T.801 | ISO/IEC 15444-2.

7 Breakpoint component structure

7.1 Breakpoint components and the reference grid

Breakpoint components have a "hierarchical data type", meaning that they are described at multiple resolutions, in a dyadic hierarchy. Breakpoint components are identified via the HDT marker segment defined in A.4. In particular, component c is a breakpoint component if Ihd^c lies in the range 1 to 3.

Breakpoint component c is defined with respect to the same reference grid as other JPEG 2000 components, in terms of the global image dimensions ($X_{\text{siz}}, Y_{\text{siz}}$), image offset ($XO_{\text{siz}}, YO_{\text{siz}}$) and sampling factors ($XR_{\text{siz}}^c, YR_{\text{siz}}^c$) that are recorded in the SIZ marker segment. The *grid-points* of component c consist of all integer coordinates in the rectangle with upper left hand corner at (x_o, y_o) and lower right hand corner at $(x_l - 1, y_l - 1)$, where

$$x_o = \left\lfloor \frac{XO_{\text{siz}}}{XR_{\text{siz}}^c} \right\rfloor, \quad x_l = \left\lfloor \frac{X_{\text{siz}}}{XR_{\text{siz}}^c} \right\rfloor, \quad y_o = \left\lfloor \frac{YO_{\text{siz}}}{YR_{\text{siz}}^c} \right\rfloor, \quad y_l = \left\lfloor \frac{Y_{\text{siz}}}{YR_{\text{siz}}^c} \right\rfloor. \quad (1)$$

These formulae are identical to the equations for x_o, x_l, y_o and y_l in Rec. ITU-T T.800 | ISO/IEC 15444-1, but note that the term *grid-points* is used here for the locations of a breakpoint component, rather than *samples*.

As with other components, breakpoint components are partitioned into tile-components, following the partitioning of the reference grid into tiles, so that the grid-points of a breakpoint tile-component, having component index c belong to the rectangle with upper left corner at (tcx_o, tcy_o) and lower right hand corner at $(tcx_l - 1, tcy_l - 1)$, where

$$tcx_o = \left\lfloor \frac{tx_o}{XR_{\text{siz}}^c} \right\rfloor, \quad tcx_l = \left\lfloor \frac{tx_l}{XR_{\text{siz}}^c} \right\rfloor, \quad tcy_o = \left\lfloor \frac{ty_o}{YR_{\text{siz}}^c} \right\rfloor, \quad tcy_l = \left\lfloor \frac{ty_l}{YR_{\text{siz}}^c} \right\rfloor, \quad (2)$$

where the tile in question occupies the rectangle with top left corner at (tx_o, ty_o) and lower right corner at $(tx_l - 1, ty_l - 1)$ on the reference grid. These formulae are identical to the equations for tcx_o, tcx_l, tcy_o and tcy_l in Rec. ITU-T T.800 | ISO/IEC 15444-1, except that the breakpoint tile-component's locations are identified as *grid-points* rather than *samples*.

Like other JPEG 2000 components, each breakpoint tile-component has an associated number of *decomposition levels* N_L , that is identified via the applicable COD or COC marker segment, imputing the component with $N_L + 1$ distinct resolution levels, denoted $r = 0, 1, \dots, N_L$; these are the resolutions of the hierarchical breakpoint representation. Level $r = N_L$ is the full resolution of the tile-component, while $r = 0$ is the lowest resolution, also known as the tile-component's LL band. The *grid-points* associated with the resolution r of a breakpoint tile-component correspond to the integer-valued coordinates within the rectangle with upper left corner at (trx_o, try_o) and lower right hand corner at $(trx_l - 1, try_l - 1)$, where

$$trx_o = \left\lfloor \frac{tcx_o}{2^{N_L - r}} \right\rfloor, \quad trx_l = \left\lfloor \frac{tcx_l}{2^{N_L - r}} \right\rfloor, \quad try_o = \left\lfloor \frac{tcy_o}{2^{N_L - r}} \right\rfloor, \quad try_l = \left\lfloor \frac{tcy_l}{2^{N_L - r}} \right\rfloor. \quad (3)$$

Each resolution r has a corresponding depth d within the hierarchical representation. The highest resolution $r = N_L$ corresponds to depth $d = 1$, while the resolution $r = 0$ corresponds to depth $d = N_L$. Unlike other JPEG 2000 components, for which the LL band at resolution $r = 0$ has the same depth $d = N_L$ as resolution 1, the LL band of a breakpoint component has depth $d = N_L + 1$.

7.2 Division of breakpoint resolutions into cells, arcs and the CL band

Breakpoint components, their tile-components and their resolutions, do not have samples, but their grid-points may correspond to the sample locations of other components. Instead of samples, the coded information associated with a breakpoint component belongs to *arcs*.

There are two fundamental arrangements for these arcs, known as QuadBPT and TriBPT, and two mirror-image variants for the TriBPT arrangement, known as TriBPT-LR and TriBPT-RL. All three arrangements are defined in terms of 2×2 cells within each resolution of a breakpoint tile-component. To understand these arrangements, it is helpful to start by introducing the concept of a *2-span*, which consists of 9 grid-points. As shown in Figure 1, each arc runs between grid-points on the boundary of its 2-span. The central grid-point of a 2-span always has odd-valued coordinates in the resolution to which it belongs, while the corners of each 2-span have even-valued coordinates. Within any given resolution arcs have length 2, if we measure the length of diagonal arcs in the vertical direction only. This is equivalent to a length of 2^d at the component's full resolution.

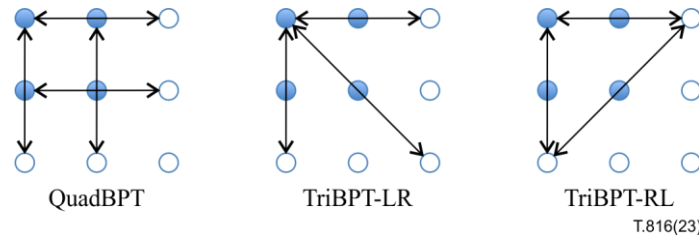


Figure 1 – Arc arrangements within a single 2-span. A 2 × 2 cell is shown here with solid grid-points. See Figure 2 for other geometric relationships between cells and 2-spans

Each 2-span is associated with a cell that contains only 4 unique grid-points. The grid-points of each resolution are partitioned into cells, such that the upper left corner of each cell has coordinates of the form $(2c_x + z_x, 2c_y + z_y)$ and (z_x, z_y) corresponds to the code-block anchor point (CBAP) identified by bits 3 and 4 of the Scod parameter in the extended COD syntax specified in Rec. ITU-T T.801 | ISO/IEC 15444-2. The four possible combinations of CBAP coordinates, $(z_x, z_y) = (0,0), (0,1), (1,0)$ and $(1,1)$, lead to four different cell partitions, that enable geometric manipulation (flipping and rotation) in the compressed domain. Figure 2 illustrates the four different relationships between cells and their 2-spans that result from the different anchor-points.

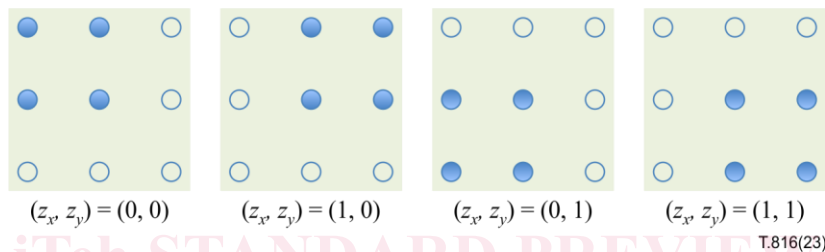


Figure 2 – Cell-span geometry for each of the four possible code-block anchor points

NOTE 1 – The code-block anchor point is also the anchor point for the precinct partitions in JPEG 2000. This means that the cell partition always aligns with the precinct partition for the same resolution of a tile-component.

The cells associated with a resolution of a breakpoint tile-component have coordinates (c_x, c_y) , covering the rectangle with upper left corner at (clx_o, cly_o) and lower right hand corner at $(clx_l - 1, cly_l - 1)$, where

$$clx_o = \left\lfloor \frac{trx_o - z_x}{2} \right\rfloor, \quad clx_l = \left\lfloor \frac{trx_l - z_x}{2} \right\rfloor, \quad cly_o = \left\lfloor \frac{try_o - z_y}{2} \right\rfloor, \quad cly_l = \left\lfloor \frac{try_l - z_y}{2} \right\rfloor. \tag{4}$$

That is, the resolution's cells consist of all 2×2 elements from the partition that intersect with the resolution's region of support, regardless of whether the intersection involves 1, 2 or all 4 grid-points.

Ignoring the LL band (resolution 0) for the moment, each other resolution $r = 1, \dots, N_L$ of a breakpoint tile-component is assigned a single "detail band", similar to the LH, HL and HH sub-bands described in Rec. ITU-T T.800 | ISO/IEC 15444-1. This single detail band is denoted the CL band. Each element of a CL band is a 2×2 cell (or a piece thereof, if the tile-component boundaries dissect the cell). The hierarchical representation of the breakpoint tile-component then consists of one LL band and N_L CL bands. Each CL band is $clx_l - clx_o$ cells wide by $cly_l - cly_o$ cells high, where these quantities are derived from the corresponding resolution's dimensions using Formula (4). The set of cells that constitute a CL band determine the properties of its code-blocks and precincts, as explained next.

The dimensions of the LL band are expressed in grid-points rather than cells, and are identical to the dimensions of resolution 0, as derived from Formula (3) with $r = 0$. The LL band of a breakpoint tile-component is used to record breakpoints that would have been found in a CL band at depth $N_L + 1$, except that they are encoded with extra information to reveal whether or not the breakpoints should be considered to have been induced from even lower (uncoded) levels in the hierarchy. This is explained further in clause 9.

NOTE 2 – Unlike regular image components, the LL bands of breakpoint tile-components are commonly devoid of any significant information – i.e., they need signal no breaks at all – but this might not always be the case.

7.3 Division of breakpoint resolutions into precincts and code-blocks

Like all JPEG 2000 components, each resolution of a breakpoint component is partitioned into precincts, and the associated bands are partitioned into code-blocks, such that each code-block belongs to exactly one precinct. The number of precincts which span a breakpoint tile-component at resolution r is given by