AV1 Bitstream & Decoding Process Specification

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Authors
Peter de Rivaz, Argon Design Ltd
Jack Haughton, Argon Design Ltd

Codec Working Group Chair
Adrian Grange, Google LLC

Document Design
Lou Quillio, Google LLC

Version 1.0.0 with Errata 1

This version 1.0.0 with Errata 1 of the AV1 Bitstream Specification supercedes all previous versions of the AV1 Bitstream Specification, most notably version 1.0.0, which is now obsolete.

This version 1.0.0 with Errata 1 of the AV1 Bitstream Specification corresponds to the Git tag **v1.0.0-errata1** in the **AOMediaCodec/av1-spec** project. Its content has been validated as consistent with the reference decoder provided by **libaom v1.0.0-errata1**.

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Abstract

This document defines the bitstream formats and decoding process for the Alliance for Open Media AV1 video codec.

Contents

1. Scope

This document specifies the Alliance for Open Media AV1 bitstream formats and decoding process.

2. Terms and definitions

For the purposes of this document, the following terms and definitions apply:

AC coefficient
Any transform coefficient whose frequency indices are non-zero in at least one dimension.

Altref
(Alternative reference frame) A frame that can be used in inter coding.

Base layer
The layer with spatial_id and temporal_id values equal to 0.

Bitstream
The sequence of bits generated by encoding a sequence of frames.

Bit string
An ordered string with limited number of bits. The left most bit is the most significant bit (MSB), the right most bit is the least significant bit (LSB).

Block
A square or rectangular region of samples.

Block scan
A specified serial ordering of quantized coefficients.

Byte
An 8-bit bit string.

Byte alignment
One bit is byte aligned if the position of the bit is an integer multiple of eight from the position of the first bit in the bitstream.

CDEF
Constrained Directional Enhancement Filter designed to adaptively filter blocks based on identifying the direction.

CDF
Cumulative distribution function representing the probability times 32768 that a symbol has value less than or equal to a given level.

Chroma
A sample value matrix or a single sample value of one of the two color difference signals.

> **Note:** Symbols of chroma are U and V.

Coded frame
The representation of one frame before the decoding process.

Component
One of the three sample value matrices (one luma matrix and two chroma matrices) or its single sample value.

Compound prediction
A type of inter prediction where sample values are computed by blending together predictions from two reference frames (the frames blended can be the same or different).

DC coefficient
A transform coefficient whose frequency indices are zero in both dimensions.

Decoded frame
The frame reconstructed out of the bitstream by the decoder.

Decoder
One embodiment of the decoding process.

Decoding process
The process that derives decoded frames from syntax elements, including any processing steps used prior to and for the film grain synthesis process.

Dequantization
The process in which transform coefficients are obtained by scaling the quantized coefficients.

Encoder
One embodiment of the encoding process.

Encoding process
A process not specified in this Specification that generates the bitstream that conforms to the description provided in this document.

Enhancement layer
A layer with either spatial_id greater than 0 or temporal_id greater than 0.

Flag
A binary variable - some variables and syntax elements (e.g. obu_extension_flag) are described using the word flag to highlight that the syntax element can only be equal to 0 or equal to 1.

Frame
The representation of video signals in the spatial domain, composed of one luma sample matrix (Y) and two chroma sample matrices (U and V).

Frame context
A set of probabilities used in the decoding process.

Golden frame
A frame that can be used in inter coding. Typically the golden frame is encoded with higher quality and is used as a reference for multiple inter frames.

Inter coding
Coding one block or frame using inter prediction.

Inter frame
A frame compressed by referencing previously decoded frames and which may use intra prediction or inter prediction.

Inter prediction
The process of deriving the prediction value for the current frame using previously decoded frames.

Intra coding
Coding one block or frame using intra prediction.

Intra frame
A frame compressed using only intra prediction which can be independently decoded.

Intra prediction
The process of deriving the prediction value for the current sample using previously decoded sample values in the same decoded frame.

Inverse transform
The process in which a transform coefficient matrix is transformed into a spatial sample value matrix.

Key frame
An Intra frame which resets the decoding process when it is shown.

Layer
A set of tile group OBUs with identical spatial_id and identical temporal_id values.

Level
A defined set of constraints on the values for the syntax elements and variables.

Loop filter
A filtering process applied to the reconstruction intended to reduce the visibility of block edges.

Luma
A sample value matrix or a single sample value representing the monochrome signal related to the primary colors.

> **Note:** The symbol representing luma is Y.

Mode info
Syntax elements sent for a block containing an indication of how a block is to be predicted during the decoding process.

Mode info block
A luma sample value block of size 4x4 or larger and its two corresponding chroma sample value blocks (if present).

Motion vector
A two-dimensional vector used for inter prediction which refers the current frame to the reference frame, the value of which provides the coordinate offsets from a location in the current frame to a location in the reference frame.

OBU
All structures are packetized in “Open Bitstream Units” or OBUs. Each OBU has a header, which provides identifying information for the contained data (payload).

Parse
The procedure of getting the syntax element from the bitstream.

Prediction
The implementation of the prediction process consisting of either inter or intra prediction.

Prediction process
The process of estimating the decoded sample value or data element using a predictor.

Prediction value
The value, which is the combination of the previously decoded sample values or data elements, used in the decoding process of the next sample value or data element.

Profile
A subset of syntax, semantics and algorithms defined in a part.

Quantization parameter
A variable used for scaling the quantized coefficients in the decoding process.

Quantized coefficient
A transform coefficient before dequantization.

Raster scan
Maps a two dimensional rectangular raster into a one dimensional raster, in which the entry of the one dimensional raster starts from the first row of the two dimensional raster, and the scanning then goes through the second row and the third row, and so on. Each raster row is scanned in left to right order.

Reconstruction
Obtaining the addition of the decoded residual and the corresponding prediction values.

Reference
One of a set of tags, each of which is mapped to a reference frame.

Reference frame
A storage area for a previously decoded frame and associated information.

Reserved
A special syntax element value which may be used to extend this part in the future.

Residual
The differences between the reconstructed samples and the corresponding prediction values.

Sample
The basic elements that compose the frame.

Sample value
The value of a sample. This is an integer from 0 to 255 (inclusive) for 8-bit frames, from 0 to 1023 (inclusive) for 10-bit frames, and from 0 to 4095 (inclusive) for 12-bit frames.

Segmentation map
A 3-bit number containing the segment affiliation for each 4x4 block in the image. A segmentation map is stored for each reference frame to allow new frames to use a previously coded map.

Sequence
The highest level syntax structure of coding bitstream, including one or several consecutive coded frames.

Superblock
The top level of the block quadtree within a tile. All superblocks within a frame are the same size and are square. The superblocks may be 128x128 luma samples or 64x64 luma samples. A superblock may contain 1 or 2 or 4 mode info blocks, or may be bisected in each direction to create 4 sub-blocks, which may themselves be further subpartitioned, forming the block quadtree.

Switch Frame
An inter frame that can be used as a point to switch between sequences. Switch frames overwrite all the reference frames without forcing the use of intra coding. The intention is to allow a streaming use case where videos can be encoded in small chunks (say of 1 second duration), each starting with a switch frame. If the available bandwidth drops, the server can start sending chunks from a lower bitrate encoding instead. When this happens the inter prediction uses the existing higher quality reference frames to decode the switch frame. This approach allows a bitrate switch without the cost of a full key frame.

Syntax element
An element of data represented in the bitstream.

Temporal delimiter OBU
An indication that the following OBUs will have a different presentation/decoding time stamp from the one of the last frame prior to the temporal delimiter.

Temporal unit
A Temporal unit consists of all the OBUs that are associated with a specific, distinct time instant. It consists of a temporal delimiter OBU, and all the OBUs that follow, up to but not including the next temporal delimiter.

Temporal group
A set of frames whose temporal prediction structure is used periodically in a video sequence.

Tile
A rectangular region of the frame that can be decoded and encoded independently, although loop-filtering across tile edges is still applied.

Transform block
A rectangular transform coefficient matrix, used as input to the inverse transform process.

Transform coefficient
A scalar value, considered to be in a frequency domain, contained in a transform block.

Uncompressed header
High level description of the frame to be decoded that is encoded without the use of arithmetic encoding.

3. Symbols and abbreviated terms

DCT
Discrete Cosine Transform

ADST
Asymmetric Discrete Sine Transform

LSB
Least Significant Bit

MSB
Most Significant Bit

WHT
Walsh Hadamard Transform

The specification makes use of a number of constant integers. Constants that relate to the semantics of a particular syntax element are defined in section 6.

Additional constants are defined below:

Symbol name	Value	Description
`REFS_PER_FRAME`	7	Number of reference frames that can be used for inter prediction
`TOTAL_REFS_PER_FRAME`	8	Number of reference frame types (including intra type)
`BLOCK_SIZE_GROUPS`	4	Number of contexts when decoding `y_mode`
`BLOCK_SIZES`	22	Number of different block sizes used
`BLOCK_INVALID`	22	Sentinel value to mark partition choices that are not allowed
`MAX_SB_SIZE`	128	Maximum size of a superblock in luma samples
`MI_SIZE`	4	Smallest size of a mode info block in luma samples
`MI_SIZE_LOG2`	2	Base 2 logarithm of smallest size of a mode info block
`MAX_TILE_WIDTH`	4096	Maximum width of a tile in units of luma samples
`MAX_TILE_AREA`	4096 * 2304	Maximum area of a tile in units of luma samples
`MAX_TILE_ROWS`	64	Maximum number of tile rows
`MAX_TILE_COLS`	64	Maximum number of tile columns

Symbol name	Value	Description
INTRABC_DELAY_PIXELS	256	Number of horizontal luma samples before intra block copy can be used
INTRABC_DELAY_SB64	4	Number of 64 by 64 blocks before intra block copy can be used
NUM_REF_FRAMES	8	Number of frames that can be stored for future reference
IS_INTER_CONTEXTS	4	Number of contexts for is_inter
REF_CONTEXTS	3	Number of contexts for single_ref , comp_ref , comp_bwdref , uni_comp_ref , uni_comp_ref_p1 and uni_comp_ref_p2
MAX_SEGMENTS	8	Number of segments allowed in segmentation map
SEGMENT_ID_CONTEXTS	3	Number of contexts for segment_id
SEG_LVL_ALT_Q	0	Index for quantizer segment feature
SEG_LVL_ALT_LF_Y_V	1	Index for vertical luma loop filter segment feature
SEG_LVL_REF_FRAME	5	Index for reference frame segment feature
SEG_LVL_SKIP	6	Index for skip segment feature
SEG_LVL_GLOBALMV	7	Index for global mv feature
SEG_LVL_MAX	8	Number of segment features
PLANE_TYPES	2	Number of different plane types (luma or chroma)
TX_SIZE_CONTEXTS	3	Number of contexts for transform size
INTERP_FILTERS	3	Number of values for interp_filter
INTERP_FILTER_CONTEXTS	16	Number of contexts for interp_filter
SKIP_MODE_CONTEXTS	3	Number of contexts for decoding skip_mode
SKIP_CONTEXTS	3	Number of contexts for decoding skip
PARTITION_CONTEXTS	4	Number of contexts when decoding partition
TX_SIZES	5	Number of square transform sizes
TX_SIZES_ALL	19	Number of transform sizes (including non-square sizes)
TX_MODES	3	Number of values for tx_mode
DCT_DCT	0	Inverse transform rows with DCT and columns with DCT

Symbol name	Value	Description
`ADST_DCT`	1	Inverse transform rows with `DCT` and columns with `ADST`
`DCT_ADST`	2	Inverse transform rows with `ADST` and columns with `DCT`
`ADST_ADST`	3	Inverse transform rows with `ADST` and columns with `ADST`
`FLIPADST_DCT`	4	Inverse transform rows with `DCT` and columns with `FLIPADST`
`DCT_FLIPADST`	5	Inverse transform rows with `FLIPADST` and columns with `DCT`
`FLIPADST_FLIPADST`	6	Inverse transform rows with `FLIPADST` and columns with `FLIPADST`
`ADST_FLIPADST`	7	Inverse transform rows with `FLIPADST` and columns with `ADST`
`FLIPADST_ADST`	8	Inverse transform rows with `ADST` and columns with `FLIPADST`
`IDTX`	9	Inverse transform rows with identity and columns with identity
`V_DCT`	10	Inverse transform rows with identity and columns with `DCT`
`H_DCT`	11	Inverse transform rows with `DCT` and columns with identity
`V_ADST`	12	Inverse transform rows with identity and columns with `ADST`
`H_ADST`	13	Inverse transform rows with `ADST` and columns with identity
`V_FLIPADST`	14	Inverse transform rows with identity and columns with `FLIPADST`
`H_FLIPADST`	15	Inverse transform rows with `FLIPADST` and columns with identity
`TX_TYPES`	16	Number of inverse transform types
`MB_MODE_COUNT`	17	Number of values for `YMode`
`INTRA_MODES`	13	Number of values for `y_mode`

Symbol name	Value	Description
UV_INTRA_MODES_CFL_NOT_ALLOWED	13	Number of values for uv_mode when chroma from luma is not allowed
UV_INTRA_MODES_CFL_ALLOWED	14	Number of values for uv_mode when chroma from luma is allowed
COMPOUND_MODES	8	Number of values for compound_mode
COMPOUND_MODE_CONTEXTS	8	Number of contexts for compound_mode
COMP_NEWMV_CTXS	5	Number of new mv values used when constructing context for compound_mode
NEW_MV_CONTEXTS	6	Number of contexts for new_mv
ZERO_MV_CONTEXTS	2	Number of contexts for zero_mv
REF_MV_CONTEXTS	6	Number of contexts for ref_mv
DRL_MODE_CONTEXTS	3	Number of contexts for drl_mode
MV_CONTEXTS	2	Number of contexts for decoding motion vectors including one for intra block copy
MV_INTRABC_CONTEXT	1	Motion vector context used for intra block copy
MV_JOINTS	4	Number of values for mv_joint
MV_CLASSES	11	Number of values for mv_class
CLASS0_SIZE	2	Number of values for mv_class0_bit
MV_OFFSET_BITS	10	Maximum number of bits for decoding motion vectors
MAX_LOOP_FILTER	63	Maximum value used for loop filtering
REF_SCALE_SHIFT	14	Number of bits of precision when scaling reference frames
SUBPEL_BITS	4	Number of bits of precision when choosing an inter prediction filter kernel
SUBPEL_MASK	15	(1 << SUBPEL_BITS) - 1
SCALE_SUBPEL_BITS	10	Number of bits of precision when computing inter prediction locations
MV_BORDER	128	Value used when clipping motion vectors
PALETTE_COLOR_CONTEXTS	5	Number of values for color contexts

Symbol name	Value	Description
PALETTE_MAX_COLOR_CONTEXT_HASH	8	Number of mappings between color context hash and color context
PALETTE_BLOCK_SIZE_CONTEXTS	7	Number of values for palette block size
PALETTE_Y_MODE_CONTEXTS	3	Number of values for palette Y plane mode contexts
PALETTE_UV_MODE_CONTEXTS	2	Number of values for palette U and V plane mode contexts
PALETTE_SIZES	7	Number of values for palette_size
PALETTE_COLORS	8	Number of values for palette_color
PALETTE_NUM_NEIGHBORS	3	Number of neighbors considered within palette computation
DELTA_Q_SMALL	3	Value indicating alternative encoding of quantizer index delta values
DELTA_LF_SMALL	3	Value indicating alternative encoding of loop filter delta values
QM_TOTAL_SIZE	3344	Number of values in the quantizer matrix
MAX_ANGLE_DELTA	3	Maximum magnitude of AngleDeltaY and AngleDeltaUV
DIRECTIONAL_MODES	8	Number of directional intra modes
ANGLE_STEP	3	Number of degrees of step per unit increase in AngleDeltaY or AngleDeltaUV.
TX_SET_TYPES_INTRA	3	Number of intra transform set types
TX_SET_TYPES_INTER	4	Number of inter transform set types
WARPEDMODEL_PREC_BITS	16	Internal precision of warped motion models
IDENTITY	0	Warp model is just an identity transform
TRANSLATION	1	Warp model is a pure translation
ROTZOOM	2	Warp model is a rotation + symmetric zoom + translation
AFFINE	3	Warp model is a general affine transform
GM_ABS_TRANS_BITS	12	Number of bits encoded for translational components of global motion models, if part of a ROTZOOM or AFFINE model

Symbol name	Value	Description
GM_ABS_TRANS_ONLY_BITS	9	Number of bits encoded for translational components of global motion models, if part of a TRANSLATION model
GM_ABS_ALPHA_BITS	12	Number of bits encoded for non-translational components of global motion models
DIV_LUT_PREC_BITS	14	Number of fractional bits of entries in divisor lookup table
DIV_LUT_BITS	8	Number of fractional bits for lookup in divisor lookup table
DIV_LUT_NUM	257	Number of entries in divisor lookup table
MOTION_MODES	3	Number of values for motion modes
SIMPLE	0	Use translation or global motion compensation
OBMC	1	Use overlapped block motion compensation
LOCALWARP	2	Use local warp motion compensation
LEAST_SQUARES_SAMPLES_MAX	8	Largest number of samples used when computing a local warp
LS_MV_MAX	256	Largest motion vector difference to include in local warp computation
WARPEDMODEL_TRANS_CLAMP	1<<23	Clamping value used for translation components of warp
WARPEDMODEL_NONDIAGAFFINE_CLAMP	1<<13	Clamping value used for matrix components of warp
WARPEDPIXEL_PREC_SHIFTS	1<<6	Number of phases used in warped filtering
WARPEDDIFF_PREC_BITS	10	Number of extra bits of precision in warped filtering
GM_ALPHA_PREC_BITS	15	Number of fractional bits for sending non-translational warp model coefficients
GM_TRANS_PREC_BITS	6	Number of fractional bits for sending translational warp model coefficients
GM_TRANS_ONLY_PREC_BITS	3	Number of fractional bits used for pure translational warps
INTERINTRA_MODES	4	Number of inter intra modes
MASK_MASTER_SIZE	64	Size of MasterMask array

Symbol name	Value	Description
SEGMENT_ID_PREDICTED_CONTEXTS	3	Number of contexts for segment_id_predicted
IS_INTER_CONTEXTS	4	Number of contexts for is_inter
SKIP_CONTEXTS	3	Number of contexts for skip
FWD_REFS	4	Number of syntax elements for forward reference frames
BWD_REFS	3	Number of syntax elements for backward reference frames
SINGLE_REFS	7	Number of syntax elements for single reference frames
UNIDIR_COMP_REFS	4	Number of syntax elements for unidirectional compound reference frames
COMPOUND_TYPES	2	Number of values for compound_type
CFL_JOINT_SIGNS	8	Number of values for cfl_alpha_signs
CFL_ALPHABET_SIZE	16	Number of values for cfl_alpha_u and cfl_alpha_v
COMP_INTER_CONTEXTS	5	Number of contexts for comp_mode
COMP_REF_TYPE_CONTEXTS	5	Number of contexts for comp_ref_type
CFL_ALPHA_CONTEXTS	6	Number of contexts for cfl_alpha_u and cfl_alpha_v
INTRA_MODE_CONTEXTS	5	Number of each of left and above contexts for intra_frame_y_mode
COMP_GROUP_IDX_CONTEXTS	6	Number of contexts for comp_group_idx
COMPOUND_IDX_CONTEXTS	6	Number of contexts for compound_idx
INTRA_EDGE_KERNELS	3	Number of filter kernels for the intra edge filter
INTRA_EDGE_TAPS	5	Number of kernel taps for the intra edge filter
FRAME_LF_COUNT	4	Number of loop filter strength values
MAX_VARTX_DEPTH	2	Maximum depth for variable transform trees
TXFM_PARTITION_CONTEXTS	21	Number of contexts for txfm_split
REF_CAT_LEVEL	640	Bonus weight for close motion vectors
MAX_REF_MV_STACK_SIZE	8	Maximum number of motion vectors in the stack
MFMV_STACK_SIZE	3	Stack size for motion field motion vectors

Symbol name	Value	Description
MAX_TX_DEPTH	2	Maximum times the transform can be split
WEDGE_TYPES	16	Number of directions for the wedge mask process
FILTER_BITS	7	Number of bits used in Wiener filter coefficients
WIENER_COEFFS	3	Number of Wiener filter coefficients to read
SGRPROJ_PARAMS_BITS	4	Number of bits needed to specify self guided filter set
SGRPROJ_PRJ_SUBEXP_K	4	Controls how self guided deltas are read
SGRPROJ_PRJ_BITS	7	Precision bits during self guided restoration
SGRPROJ_RST_BITS	4	Restoration precision bits generated higher than source before projection
SGRPROJ_MTABLE_BITS	20	Precision of mtable division table
SGRPROJ_RECIP_BITS	12	Precision of division by n table
SGRPROJ_SGR_BITS	8	Internal precision bits for core selfguided_restoration
EC_PROB_SHIFT	6	Number of bits to reduce CDF precision during arithmetic coding
EC_MIN_PROB	4	Minimum probability assigned to each symbol during arithmetic coding
SELECT_SCREEN_CONTENT_TOOLS	2	Value that indicates the allow_screen_content_tools syntax element is coded
SELECT_INTEGER_MV	2	Value that indicates the force_integer_mv syntax element is coded
RESTORATION_TILESIZE_MAX	256	Maximum size of a loop restoration tile
MAX_FRAME_DISTANCE	31	Maximum distance when computing weighted prediction
MAX_OFFSET_WIDTH	8	Maximum horizontal offset of a projected motion vector
MAX_OFFSET_HEIGHT	0	Maximum vertical offset of a projected motion vector
WARP_PARAM_REDUCE_BITS	6	Rounding bitwidth for the parameters to the shear process

Symbol name	Value	Description
NUM_BASE_LEVELS	2	Number of quantizer base levels
COEFF_BASE_RANGE	12	The quantizer range above NUM_BASE_LEVELS above which the Exp-Golomb coding process is activated
BR_CDF_SIZE	4	Number of values for coeff_br
SIG_COEF_CONTEXTS_EOB	4	Number of contexts for coeff_base_eob
SIG_COEF_CONTEXTS_2D	26	Context offset for coeff_base for horizontal-only or vertical-only transforms.
SIG_COEF_CONTEXTS	42	Number of contexts for coeff_base
SIG_REF_DIFF_OFFSET_NUM	5	Maximum number of context samples to be used in determining the context index for coeff_base and coeff_base_eob .
SUPERRES_NUM	8	Numerator for upscaling ratio
SUPERRES_DENOM_MIN	9	Smallest denominator for upscaling ratio
SUPERRES_DENOM_BITS	3	Number of bits sent to specify denominator of upscaling ratio
SUPERRES_FILTER_BITS	6	Number of bits of fractional precision for upscaling filter selection
SUPERRES_FILTER_SHIFTS	1 << SUPERRES_FILTER_BITS	Number of phases of upscaling filters
SUPERRES_FILTER_TAPS	8	Number of taps of upscaling filters
SUPERRES_FILTER_OFFSET	3	Sample offset for upscaling filters
SUPERRES_SCALE_BITS	14	Number of fractional bits for computing position in upscaling
SUPERRES_SCALE_MASK	(1 << 14) - 1	Mask for computing position in upscaling
SUPERRES_EXTRA_BITS	8	Difference in precision between SUPERRES_SCALE_BITS and SUPERRES_FILTER_BITS
TXB_SKIP_CONTEXTS	13	Number of contexts for all_zero
EOB_COEF_CONTEXTS	9	Number of contexts for eob_extra
DC_SIGN_CONTEXTS	3	Number of contexts for dc_sign
LEVEL_CONTEXTS	21	Number of contexts for coeff_br

Symbol name	Value	Description
TX_CLASS_2D	0	Transform class for transform types performing non-identity transforms in both directions
TX_CLASS_HORIZ	1	Transform class for transforms performing only a horizontal non-identity transform
TX_CLASS_VERT	2	Transform class for transforms performing only a vertical non-identity transform
REFMVS_LIMIT	(1 << 12) - 1	Largest reference MV component that can be saved
INTRA_FILTER_SCALE_BITS	4	Scaling shift for intra filtering process
INTRA_FILTER_MODES	5	Number of types of intra filtering
COEFF_CDF_Q_CTXS	4	Number of selectable context types for the coeff( ) syntax structure
PRIMARY_REF_NONE	7	Value of primary_ref_frame indicating that there is no primary reference frame
BUFFER_POOL_MAX_SIZE	10	Number of frames in buffer pool

4. Conventions

4.1. General

The mathematical operators and their precedence rules used to describe this Specification are similar to those used in the C programming language. However, the operation of integer division with truncation is specifically defined.

In addition, a length 2 array used to hold a motion vector (indicated by the variable name ending with the letters `Mv` or `Mvs`) can be accessed using either array notation (e.g. `Mv[ 0 ]` and `Mv[ 1 ]`), or by just the name (e.g., `Mv`). The only operations defined when using the name are assignment and equality/inequality testing. Assignment of an array is represented using the notation `A = B` and is specified to mean the same as doing both the individual assignments `A[ 0 ] = B[ 0 ]` and `A[ 1 ] = B[ 1 ].` Equality testing of 2 motion vectors is represented using the notation `A == B` and is specified to mean the same as `(A[ 0 ] == B[ 0 ] && A[ 1 ] == B[ 1 ])`. Inequality testing is defined as `A != B` and is specified to mean the same as `(A[ 0 ] != B[ 0 ] || A[ 1 ] != B[ 1 ])`.

When a variable is said to be representable by a signed integer with `x` bits, it means that the variable is greater than or equal to `-(1 << (x-1))`, and that the variable is less than or equal to `(1 << (x-1))-1`.

The key words “must”, “must not”, “required”, “shall”, “shall not”, “should”, “should not”, “recommended”, “may”, and “optional” in this document are to be interpreted as described in RFC 2119.

4.2. Arithmetic operators

+	Addition
–	Subtraction (as a binary operator) or negation (as a unary prefix operator)
*	Multiplication
/	Integer division with truncation of the result toward zero. For example, `7/4` and `-7/-4` are truncated to `1` and `-7/4` and `7/-4` are truncated to `-1`.
a % b	Remainder from division of `a` by `b`. Both `a` and `b` are positive integers.
÷	Floating point (arithmetical) division.
ceil(x)	The smallest integer that is greater or equal than `x`.
floor(x)	The largest integer that is smaller or equal than `x`.

4.3. Logical operators

a && b	Logical AND operation between `a` and `b`
a || b	Logical OR operation between `a` and `b`
!	Logical NOT operation.

4.4. Relational operators

>	Greater than
>=	Greater than or equal to
<	Less than
<=	Less than or equal to
==	Equal to
!=	Not equal to

4.5. Bitwise operators

&	AND operation
|	OR operation
^	XOR operation
~	Negation operation
a >> b	Shift `a` in 2's complement binary integer representation format to the right by `b` bit positions. This operator is only used with `b` being a non-negative integer. Bits shifted into the MSBs as a result of the right shift have a value equal to the MSB of `a` prior to the shift operation.
a << b	Shift `a` in 2's complement binary integer representation format to the left by `b` bit positions. This operator is only used with `b` being a non-negative integer. Bits shifted into the LSBs as a result of the left shift have a value equal to `0`.

4.6. Assignment

=	Assignment operator
++	Increment, `x++` is equivalent to `x = x + 1`. When this operator is used for an array index, the variable value is obtained before the auto increment operation
- -	Decrement, i.e. `x--` is equivalent to `x = x - 1`. When this operator is used for an array index, the variable value is obtained before the auto decrement operation
+=	Addition assignment operator, for example `x += 3` corresponds to `x = x + 3`
-=	Subtraction assignment operator, for example `x -= 3` corresponds to `x = x - 3`

4.7. Mathematical functions

The following mathematical functions (Abs, Clip3, Clip1, Min, Max, Round2 and Round2Signed) are defined as follows:

$$\mathrm{Abs}\left(x\right) = \left\{ \begin{array}{ll} x; & x \geq 0 \\ -x; & x < 0 \end{array} \right\}$$

$$\mathrm{Clip1(x)} = \mathrm{Clip3}\left(0, 2^{\mathrm{BitDepth}} - 1, x\right)$$

$$\mathrm{Clip3}(x, y, z) = \left\{ \begin{array}{ll} x; & z < x \\ y; & z > y \\ z; & otherwise \end{array} \right\}$$

$$\mathrm{Min}(x, y) = \left\{ \begin{array}{ll} x; & x \leq y \\ y; & x > y \end{array} \right\}$$

$$\mathrm{Max}(x, y) = \left\{ \begin{array}{ll} x; & x \geq y \\ y; & x < y \end{array} \right\}$$

$$\mathrm{Round2}(x, n) = \left\lfloor \frac{x + \left(2^{n-1}\right)}{2^n} \right\rfloor$$

$$\mathrm{Round2Signed}(x, n) = \left\{ \begin{array}{ll} \mathrm{Round2}(x, n); & x \geq 0 \\ -\mathrm{Round2}(-x, n); & x < 0 \end{array} \right\}$$

The definition of Round2 uses standard mathematical power and division operations, not integer operations. An equivalent definition using integer operations is:

```
Round2( x, n ) {
  if ( n == 0 )
    return x
  return ( x + ( 1 << (n - 1) ) ) >> n
}
```

The FloorLog2(x) function is defined to be the floor of the base 2 logarithm of the input x.

The input x will always be an integer, and will always be greater than or equal to 1.

This function extracts the location of the most significant bit in x.

An equivalent definition (using the pseudo-code notation introduced in the following section) is:

```
FloorLog2( x ) {
  s = 0
  while ( x != 0 ) {
    x = x >> 1
    s++
  }
  return s - 1
}
```

The CeilLog2(x) function is defined to be the ceiling of the base 2 logarithm of the input x (when x is 0, it is defined to return 0).

The input x will always be an integer, and will always be greater than or equal to 0.

This function extracts the number of bits needed to code a value in the range 0 to x-1.

An equivalent definition (using the pseudo-code notation introduced in the following section) is:

```
CeilLog2( x ) {
  if ( x < 2 )
    return 0
  i = 1
  p = 2
  while ( p < x ) {
    i++
    p = p << 1
  }
  return i
}
```

4.8. Method of describing bitstream syntax

The description style of the syntax is similar to the C programming language. Syntax elements in the bitstream are represented in bold type. Each syntax element is described by its name (using only lower case letters with underscore characters) and a descriptor for its method of coded representation. The decoding process behaves according to the value of the syntax element and to the values of previously decoded syntax elements. When a value of a syntax element is used in the syntax tables or the text, it appears in regular (i.e. not bold) type. If the value of a syntax element is being computed (e.g. being written with a default value instead of being coded in the bitstream), it also appears in regular type (e.g. tile_size_minus_1).

In some cases the syntax tables may use the values of other variables derived from syntax elements values. Such variables appear in the syntax tables, or text, named by a mixture of lower case and upper case letter and without any underscore characters. Variables starting with an upper case letter are derived for the decoding of the current syntax

structure and all depending syntax structures. These variables may be used in the decoding process for later syntax structures. Variables starting with a lower case letter are only used within the process from which they are derived. (Single character variables are allowed.)

Constant values appear in all upper case letters with underscore characters (e.g. MI_SIZE).

Constant lookup tables appear as words (with the first letter of each word in upper case, and remaining letters in lower case) separated with underscore characters (e.g. Block_Width[…]).

Hexadecimal notation, indicated by prefixing the hexadecimal number by `0x`, may be used when the number of bits is an integer multiple of 4. For example, `0x1a` represents a bit string `0001 1010`.

Binary notation is indicated by prefixing the binary number by `0b`. For example, `0b00011010` represents a bit string `0001 1010`. Binary numbers may include underscore characters to enhance readability. If present, the underscore characters appear every 4 binary digits starting from the LSB. For example, `0b11010` may also be written as `0b1_1010`.

A value equal to 0 represents a FALSE condition in a test statement. The value TRUE is represented by any value not equal to 0.

The following table lists examples of the syntax specification format. When `syntax_element` appears (with bold face font), it specifies that this syntax element is parsed from the bitstream.

	Type
/* A statement can be a syntax element with associated	
descriptor or can be an expression used to specify its	
existence, type, and value, as in the following	
examples */	
syntax_element	f(1)
/* A group of statements enclosed in brackets is a	
compound statement and is treated functionally as a single	
statement. */	
{	
statement	
…	
}	
/* A “while” structure specifies that the statement is	
to be evaluated repeatedly while the condition remains	
true. */	
while (condition)	
statement	
/* A “do .. while” structure executes the statement once,	
and then tests the condition. It repeatedly evaluates the	
statement while the condition remains true. */	

```
do
    statement
while ( condition )

/* An “if .. else” structure tests the condition first. If
it is true, the primary statement is evaluated. Otherwise,
the alternative statement is evaluated. If the alternative
statement is unnecessary to be evaluated, the “else” and
corresponding alternative statement can be omitted. */

if ( condition )
    primary statement
else
    alternative statement

/* A “for” structure evaluates the initial statement at the
beginning then tests the condition. If it is true, the primary
and subsequent statements are evaluated until the condition
becomes false. */

for ( initial statement; condition; subsequent statement )
    primary statement

/* The return statement in a syntax structure specifies
that the parsing of the syntax structure will be terminated
without processing any additional information after this stage.
When a value immediately follows a return statement, this value
shall also be returned as the output of this syntax structure. */

return x
```

4.9. Functions

Bitstream functions used for syntax description are specified in this section.

Other functions are included in the syntax tables. The convention is that a section is called syntax if it causes syntax elements to be read from the bitstream, either directly or indirectly through subprocesses. The remaining sections are called functions.

The specification of these functions makes use of a bitstream position indicator. This bitstream position indicator locates the position of the bit that is going to be read next.

get_position( ): Return the value of the bitstream position indicator.

init_symbol(sz): Initialize the arithmetic decode process for the Symbol decoder with a size of sz bytes as specified in section 8.2.2.

exit_symbol( ): Exit the arithmetic decode process as described in section 8.2.4 (this includes reading trailing bits).

4.10. Descriptors

4.10.1. General

The following descriptors specify the parsing of syntax elements. Lower case descriptors specify syntax elements that are represented by an integer number of bits in the bitstream; upper case descriptors specify syntax elements that are represented by arithmetic coding.

4.10.2. f(n)

Unsigned n-bit number appearing directly in the bitstream. The bits are read from high to low order. The parsing process specified in section 8.1 is invoked and the syntax element is set equal to the return value.

4.10.3. uvlc()

Variable length unsigned n-bit number appearing directly in the bitstream. The parsing process for this descriptor is specified below:

uvlc() {	Type
leadingZeros = 0	
while (1) {	
done	f(1)
if (done)	
break	
leadingZeros++	
}	
if (leadingZeros >= 32) {	
return (1 << 32) - 1	
}	
value	f(leadingZeros)
return value + (1 << leadingZeros) - 1	
}	

4.10.4. le(n)

Unsigned little-endian n-byte number appearing directly in the bitstream. The parsing process for this descriptor is specified below:

le(n) {	Type
t = 0	
for (i = 0; i < n; i++) {	
byte	f(8)
t += (byte << (i * 8))	
}	
return t	
}	

Note: This syntax element will only be present when the bitstream position is byte aligned.

4.10.5. leb128()

Unsigned integer represented by a variable number of little-endian bytes.

> **Note:** This syntax element will only be present when the bitstream position is byte aligned.

In this encoding, the most significant bit of each byte is equal to 1 to signal that more bytes should be read, or equal to 0 to signal the end of the encoding.

A variable Leb128Bytes is set equal to the number of bytes read during this process.

The parsing process for this descriptor is specified below:

leb128() {	Type
value = 0	
Leb128Bytes = 0	
for (i = 0; i < 8; i++) {	
leb128_byte	f(8)
value |= ((leb128_byte & 0x7f) << (i*7))	
Leb128Bytes += 1	
if (!(leb128_byte & 0x80)) {	
break	
}	
}	
return value	
}	

It is a requirement of bitstream conformance that the value returned from the leb128 parsing process is less than or equal to (1 << 32) - 1.

leb128_byte contains 8 bits read from the bitstream. The bottom 7 bits are used to compute the variable value. The most significant bit is used to indicate that there are more bytes to be read.

It is a requirement of bitstream conformance that the most significant bit of leb128_byte is equal to 0 if i is equal to 7. (This ensures that this syntax descriptor never uses more than 8 bytes.)

> **Note:** There are multiple ways of encoding the same value depending on how many leading zero bits are encoded. There is no requirement that this syntax descriptor uses the most compressed representation. This can be useful for encoder implementations by allowing a fixed amount of space to be filled in later when the value becomes known.

4.10.6. su(n)

Signed integer converted from an n bits unsigned integer in the bitstream. (The unsigned integer corresponds to the bottom n bits of the signed integer.) The parsing process for this descriptor is specified below:

su(n) {	Type
value	f(n)
signMask = 1 << (n - 1)	
if (value & signMask)	
value = value - 2 * signMask	
return value	
}	

4.10.7. ns(n)

Unsigned encoded integer with maximum number of values n (i.e. output in range 0..n-1).

This descriptor is similar to f(CeilLog2(n)), but reduces wastage incurred when encoding non-power of two value ranges by encoding 1 fewer bits for the lower part of the value range. For example, when n is equal to 5, the encodings are as follows (full binary encodings are also presented for comparison):

Value	Full binary encoding	ns(n) encoding
0	000	00
1	001	01
2	010	10
3	011	110
4	100	111

The parsing process for this descriptor is specified as:

ns(n) {	Type
w = FloorLog2(n) + 1	
m = (1 << w) - n	
v	f(w - 1)
if (v < m)	
return v	
extra_bit	f(1)
return (v << 1) - m + extra_bit	
}	

The abbreviation ns stands for non-symmetric. This encoding is non-symmetric because the values are not all coded with the same number of bits.

4.10.8. L(n)

Unsigned arithmetic encoded n-bit number encoded as n flags (a “literal”). The flags are read from high to low order. The syntax element is set equal to the return value of read_literal(n) (see section 8.2.5 for a specification of this process).

4.10.9. S()

An arithmetic encoded symbol coded from a small alphabet of at most 16 entries.

The symbol is decoded based on a context sensitive CDF (see section 8.3 for the specification of this process).

4.10.10. NS(n)

Unsigned arithmetic encoded integer with maximum number of values n (i.e. output in range 0..n-1).

This descriptor is the same as ns(n) except the underlying bits are coded arithmetically.

The parsing process for this descriptor is specified as:

NS(n) {	Type
w = FloorLog2(n) + 1	
m = (1 << w) - n	
v	L(w - 1)
if (v < m)	
return v	
extra_bit	L(1)
return (v << 1) - m + extra_bit	
}	

5. Syntax structures

5.1. General

This section presents the syntax structures in a tabular form. The meaning of each of the syntax elements is presented in Section 6.

5.2. Low overhead bitstream format

This specification defines a low-overhead bitstream format as a sequence of the OBU syntactical elements defined in this section. When using this format, obu_has_size_field must be equal to 1. For applications requiring a format where it is easier to skip through frames or temporal units, a length-delimited bitstream format is defined in Annex B.

Derived specifications, such as container formats enabling storage of AV1 videos together with audio or subtitles, should indicate which of these formats they rely on. Other methods of packing OBUs into a bitstream format are also allowed.

5.3. OBU syntax

5.3.1. General OBU syntax

open_bitstream_unit(sz) {	Type
obu_header()	
if (obu_has_size_field) {	
obu_size	leb128()
} else {	
obu_size = sz - 1 - obu_extension_flag	
}	
startPosition = get_position( )	
if (obu_type != OBU_SEQUENCE_HEADER &&	
obu_type != OBU_TEMPORAL_DELIMITER &&	
OperatingPointIdc != 0 &&	
obu_extension_flag == 1)	
{	
inTemporalLayer = (OperatingPointIdc >> temporal_id) & 1	
inSpatialLayer = (OperatingPointIdc >> (spatial_id + 8)) & 1	
if (!inTemporalLayer || ! inSpatialLayer) {	
drop_obu( )	
return	
}	
}	
if (obu_type == OBU_SEQUENCE_HEADER)	
sequence_header_obu( )	
else if (obu_type == OBU_TEMPORAL_DELIMITER)	
temporal_delimiter_obu( )	
else if (obu_type == OBU_FRAME_HEADER)	
frame_header_obu( )	
else if (obu_type == OBU_REDUNDANT_FRAME_HEADER)	
frame_header_obu( )	

```
    else if ( obu_type == OBU_TILE_GROUP )
        tile_group_obu( obu_size )
    else if ( obu_type == OBU_METADATA )
        metadata_obu( )
    else if ( obu_type == OBU_FRAME )
        frame_obu( obu_size )
    else if ( obu_type == OBU_TILE_LIST )
        tile_list_obu( )
    else if ( obu_type == OBU_PADDING )
        padding_obu( )
    else
        reserved_obu( )
    currentPosition = get_position( )
    payloadBits = currentPosition - startPosition
    if ( obu_size > 0 && obu_type != OBU_TILE_GROUP &&
         obu_type != OBU_TILE_LIST &&
         obu_type != OBU_FRAME ) {
        trailing_bits( obu_size * 8 - payloadBits )
    }
}
```

5.3.2. OBU header syntax

obu_header() {	Type
obu_forbidden_bit	f(1)
obu_type	f(4)
obu_extension_flag	f(1)
obu_has_size_field	f(1)
obu_reserved_1bit	f(1)
if (obu_extension_flag == 1)	
obu_extension_header()	
}	

5.3.3. OBU extension header syntax

obu_extension_header() {	Type
temporal_id	f(3)
spatial_id	f(2)
extension_header_reserved_3bits	f(3)
}	

5.3.4. Trailing bits syntax

trailing_bits(nbBits) {	Type
trailing_one_bit	f(1)
nbBits--	
while (nbBits > 0) {	
trailing_zero_bit	f(1)
nbBits--	
}	

}	

5.3.5. Byte alignment syntax

byte_alignment( ) {	Type
while (get_position( ) & 7)	
zero_bit	f(1)
}	

5.4. Reserved OBU syntax

reserved_obu( ) {	Type
}	

Note: Reserved OBUs do not have a defined syntax. The obu_type reserved values are reserved for future use. Decoders should ignore the entire OBU if they do not understand the obu_type. Ignoring the OBU can be done based on obu_size. The last byte of the valid content of the payload data for this OBU type is considered to be the last byte that is not equal to zero. This rule is to prevent the dropping of valid bytes by systems that interpret trailing zero bytes as a continuation of the trailing bits in an OBU. This implies that when any payload data is present for this OBU type, at least one byte of the payload data (including the trailing bit) shall not be equal to 0.

5.5. Sequence header OBU syntax

5.5.1. General sequence header OBU syntax

sequence_header_obu( ) {	Type
seq_profile	f(3)
still_picture	f(1)
reduced_still_picture_header	f(1)
if (reduced_still_picture_header) {	
timing_info_present_flag = 0	
decoder_model_info_present_flag = 0	
initial_display_delay_present_flag = 0	
operating_points_cnt_minus_1 = 0	
operating_point_idc[0] = 0	
seq_level_idx[0]	f(5)
seq_tier[0] = 0	
decoder_model_present_for_this_op[0] = 0	
initial_display_delay_present_for_this_op[0] = 0	
} else {	
timing_info_present_flag	f(1)
if (timing_info_present_flag) {	
timing_info( )	
decoder_model_info_present_flag	f(1)
if (decoder_model_info_present_flag) {	
decoder_model_info( )	
}	

} else {	
decoder_model_info_present_flag = 0	
}	
initial_display_delay_present_flag	f(1)
operating_points_cnt_minus_1	f(5)
for (i = 0; i <= operating_points_cnt_minus_1; i++) {	
operating_point_idc[i]	f(12)
seq_level_idx[i]	f(5)
if (seq_level_idx[i] > 7) {	
seq_tier[i]	f(1)
} else {	
seq_tier[i] = 0	
}	
if (decoder_model_info_present_flag) {	
decoder_model_present_for_this_op[i]	f(1)
if (decoder_model_present_for_this_op[i]) {	
operating_parameters_info(i)	
}	
} else {	
decoder_model_present_for_this_op[i] = 0	
}	
if (initial_display_delay_present_flag) {	
initial_display_delay_present_for_this_op[i]	f(1)
if (initial_display_delay_present_for_this_op[i]) {	
initial_display_delay_minus_1[i]	f(4)
}	
}	
}	
}	
operatingPoint = choose_operating_point( )	
OperatingPointIdc = operating_point_idc[operatingPoint]	
frame_width_bits_minus_1	f(4)
frame_height_bits_minus_1	f(4)
n = frame_width_bits_minus_1 + 1	
max_frame_width_minus_1	f(n)
n = frame_height_bits_minus_1 + 1	
max_frame_height_minus_1	f(n)
if (reduced_still_picture_header)	
frame_id_numbers_present_flag = 0	
else	
frame_id_numbers_present_flag	f(1)
if (frame_id_numbers_present_flag) {	
delta_frame_id_length_minus_2	f(4)
additional_frame_id_length_minus_1	f(3)
}	
use_128x128_superblock	f(1)
enable_filter_intra	f(1)
enable_intra_edge_filter	f(1)
if (reduced_still_picture_header) {	

enable_interintra_compound = 0	
enable_masked_compound = 0	
enable_warped_motion = 0	
enable_dual_filter = 0	
enable_order_hint = 0	
enable_jnt_comp = 0	
enable_ref_frame_mvs = 0	
seq_force_screen_content_tools = SELECT_SCREEN_CONTENT_TOOLS	
seq_force_integer_mv = SELECT_INTEGER_MV	
OrderHintBits = 0	
} else {	
enable_interintra_compound	f(1)
enable_masked_compound	f(1)
enable_warped_motion	f(1)
enable_dual_filter	f(1)
enable_order_hint	f(1)
if (enable_order_hint) {	
enable_jnt_comp	f(1)
enable_ref_frame_mvs	f(1)
} else {	
enable_jnt_comp = 0	
enable_ref_frame_mvs = 0	
}	
seq_choose_screen_content_tools	f(1)
if (seq_choose_screen_content_tools) {	
seq_force_screen_content_tools = SELECT_SCREEN_CONTENT_TOOLS	
} else {	
seq_force_screen_content_tools	f(1)
}	
if (seq_force_screen_content_tools > 0) {	
seq_choose_integer_mv	f(1)
if (seq_choose_integer_mv) {	
seq_force_integer_mv = SELECT_INTEGER_MV	
} else {	
seq_force_integer_mv	f(1)
}	
} else {	
seq_force_integer_mv = SELECT_INTEGER_MV	
}	
if (enable_order_hint) {	
order_hint_bits_minus_1	f(3)
OrderHintBits = order_hint_bits_minus_1 + 1	
} else {	
OrderHintBits = 0	
}	
}	
enable_superres	f(1)
enable_cdef	f(1)

enable_restoration	f(1)
color_config( )	
film_grain_params_present	f(1)
}	

5.5.2. Color config syntax

color_config( ) {	Type
high_bitdepth	f(1)
if (seq_profile == 2 && high_bitdepth) {	
twelve_bit	f(1)
BitDepth = twelve_bit ? 12 : 10	
} else if (seq_profile <= 2) {	
BitDepth = high_bitdepth ? 10 : 8	
}	
if (seq_profile == 1) {	
mono_chrome = 0	
} else {	
mono_chrome	f(1)
}	
NumPlanes = mono_chrome ? 1 : 3	
color_description_present_flag	f(1)
if (color_description_present_flag) {	
color_primaries	f(8)
transfer_characteristics	f(8)
matrix_coefficients	f(8)
} else {	
color_primaries = CP_UNSPECIFIED	
transfer_characteristics = TC_UNSPECIFIED	
matrix_coefficients = MC_UNSPECIFIED	
}	
if (mono_chrome) {	
color_range	f(1)
subsampling_x = 1	
subsampling_y = 1	
chroma_sample_position = CSP_UNKNOWN	
separate_uv_delta_q = 0	
return	
} else if (color_primaries == CP_BT_709 &&	
transfer_characteristics == TC_SRGB &&	
matrix_coefficients == MC_IDENTITY) {	
color_range = 1	
subsampling_x = 0	
subsampling_y = 0	
} else {	
color_range	f(1)
if (seq_profile == 0) {	
subsampling_x = 1	
subsampling_y = 1	

} else if (seq_profile == 1) {	
subsampling_x = 0	
subsampling_y = 0	
} else {	
if (BitDepth == 12) {	
subsampling_x	f(1)
if (subsampling_x)	
subsampling_y	f(1)
else	
subsampling_y = 0	
} else {	
subsampling_x = 1	
subsampling_y = 0	
}	
}	
if (subsampling_x && subsampling_y) {	
chroma_sample_position	f(2)
}	
}	
separate_uv_delta_q	f(1)
}	

5.5.3. Timing info syntax

timing_info( ) {	Type
num_units_in_display_tick	f(32)
time_scale	f(32)
equal_picture_interval	f(1)
if (equal_picture_interval)	
num_ticks_per_picture_minus_1	uvlc()
}	

5.5.4. Decoder model info syntax

decoder_model_info( ) {	Type
buffer_delay_length_minus_1	f(5)
num_units_in_decoding_tick	f(32)
buffer_removal_time_length_minus_1	f(5)
frame_presentation_time_length_minus_1	f(5)
}	

5.5.5. Operating parameters info syntax

operating_parameters_info(op) {	Type
n = buffer_delay_length_minus_1 + 1	
decoder_buffer_delay[op]	f(n)
encoder_buffer_delay[op]	f(n)
low_delay_mode_flag[op]	f(1)
}	

5.6. Temporal delimiter obu syntax

temporal_delimiter_obu( ) {	Type
SeenFrameHeader = 0	
}	

Note: The temporal delimiter has an empty payload.

5.7. Padding OBU syntax

padding_obu( ) {	Type
for (i = 0; i < obu_padding_length; i++)	
obu_padding_byte	f(8)
}	

Note: obu_padding_length is not coded in the bitstream but can be computed based on obu_size minus the number of trailing bytes. In practice, though, since this is padding data meant to be skipped, decoders do not need to determine either that length nor the number of trailing bytes. They can ignore the entire OBU. Ignoring the OBU can be done based on obu_size. The last byte of the valid content of the payload data for this OBU type is considered to be the last byte that is not equal to zero. This rule is to prevent the dropping of valid bytes by systems that interpret trailing zero bytes as a continuation of the trailing bits in an OBU. This implies that when any payload data is present for this OBU type, at least one byte of the payload data (including the trailing bit) shall not be equal to 0.

5.8. Metadata OBU syntax

5.8.1. General metadata OBU syntax

metadata_obu( ) {	Type
metadata_type	leb128()
if (metadata_type == METADATA_TYPE_ITUT_T35)	
metadata_itut_t35( )	
else if (metadata_type == METADATA_TYPE_HDR_CLL)	
metadata_hdr_cll( )	
else if (metadata_type == METADATA_TYPE_HDR_MDCV)	
metadata_hdr_mdcv( )	
else if (metadata_type == METADATA_TYPE_SCALABILITY)	
metadata_scalability( )	
else if (metadata_type == METADATA_TYPE_TIMECODE)	
metadata_timecode( )	
}	

Note: The exact syntax of metadata_obu is not defined in this specification when metadata_type is equal to a value reserved for future use or a user private value. Decoders should ignore the entire OBU if they do not understand the metadata_type. The last byte of the valid content of the data is considered to be the last byte that is not equal to zero. This rule is to prevent the dropping of valid bytes by systems that interpret trailing zero bytes as a padding continuation of the trailing bits in an OBU. This implies that when any payload data is present for this OBU type, at least one byte of the payload data (including the trailing bit) shall not be equal to 0.

5.8.2. Metadata ITUT T35 syntax

metadata_itut_t35( ) {	Type
itu_t_t35_country_code	f(8)
if (itu_t_t35_country_code == 0xFF) {	
itu_t_t35_country_code_extension_byte	f(8)
}	
itu_t_t35_payload_bytes	
}	

Note: The exact syntax of itu_t_t35_payload_bytes is not defined in this specification. External specifications can define the syntax. Decoders should ignore the entire OBU if they do not understand it. The last byte of the valid content of the data is considered to be the last byte that is not equal to zero. This rule is to prevent the dropping of valid bytes by systems that interpret trailing zero bytes as a padding continuation of the trailing bits in an OBU. This implies that when any payload data is present for this OBU type, at least one byte of the payload data (including the trailing bit) shall not be equal to 0.

5.8.3. Metadata high dynamic range content light level syntax

metadata_hdr_cll( ) {	Type
max_cll	f(16)
max_fall	f(16)
}	

5.8.4. Metadata high dynamic range mastering display color volume syntax

metadata_hdr_mdcv( ) {	Type
for (i = 0; i < 3; i++) {	
primary_chromaticity_x[i]	f(16)
primary_chromaticity_y[i]	f(16)
}	
white_point_chromaticity_x	f(16)
white_point_chromaticity_y	f(16)
luminance_max	f(32)
luminance_min	f(32)
}	

5.8.5. Metadata scalability syntax

metadata_scalability( ) {	Type
scalability_mode_idc	f(8)
if (scalability_mode_idc == SCALABILITY_SS)	
scalability_structure( )	
}	

5.8.6. Scalability structure syntax

scalability_structure( ) {	Type
spatial_layers_cnt_minus_1	f(2)
spatial_layer_dimensions_present_flag	f(1)
spatial_layer_description_present_flag	f(1)
temporal_group_description_present_flag	f(1)
scalability_structure_reserved_3bits	f(3)
if (spatial_layer_dimensions_present_flag) {	
for (i = 0; i <= spatial_layers_cnt_minus_1 ; i++) {	
spatial_layer_max_width[i]	f(16)
spatial_layer_max_height[i]	f(16)
}	
}	
if (spatial_layer_description_present_flag) {	
for (i = 0; i <= spatial_layers_cnt_minus_1; i++)	
spatial_layer_ref_id[i]	f(8)
}	
if (temporal_group_description_present_flag) {	
temporal_group_size	f(8)
for (i = 0; i < temporal_group_size; i++) {	
temporal_group_temporal_id[i]	f(3)
temporal_group_temporal_switching_up_point_flag[i]	f(1)
temporal_group_spatial_switching_up_point_flag[i]	f(1)
temporal_group_ref_cnt[i]	f(3)
for (j = 0; j < temporal_group_ref_cnt[i]; j++) {	
temporal_group_ref_pic_diff[i][j]	f(8)
}	
}	
}	
}	

5.8.7. Metadata timecode syntax

metadata_timecode( ) {	Type
counting_type	f(5)
full_timestamp_flag	f(1)
discontinuity_flag	f(1)
cnt_dropped_flag	f(1)
n_frames	f(9)
if (full_timestamp_flag) {	
seconds_value	f(6)

minutes_value	f(6)
hours_value	f(5)
} else {	
seconds_flag	f(1)
if (seconds_flag) {	
seconds_value	f(6)
minutes_flag	f(1)
if (minutes_flag) {	
minutes_value	f(6)
hours_flag	f(1)
if (hours_flag) {	
hours_value	f(5)
}	
}	
}	
}	
time_offset_length	f(5)
if (time_offset_length > 0) {	
time_offset_value	f(time_offset_length)
}	
}	

5.9. Frame header OBU syntax

5.9.1. General frame header OBU syntax

frame_header_obu( ) {	Type
if (SeenFrameHeader == 1) {	
frame_header_copy()	
} else {	
SeenFrameHeader = 1	
uncompressed_header( )	
if (show_existing_frame) {	
decode_frame_wrapup( )	
SeenFrameHeader = 0	
} else {	
TileNum = 0	
SeenFrameHeader = 1	
}	
}	
}	

5.9.2. Uncompressed header syntax

uncompressed_header( ) {	Type
if (frame_id_numbers_present_flag) {	
idLen = (additional_frame_id_length_minus_1 +	
delta_frame_id_length_minus_2 + 3)	
}	

allFrames = (1 << NUM_REF_FRAMES) - 1	
if (reduced_still_picture_header) {	
show_existing_frame = 0	
frame_type = KEY_FRAME	
FrameIsIntra = 1	
show_frame = 1	
showable_frame = 0	
} else {	
show_existing_frame	f(1)
if (show_existing_frame == 1) {	
frame_to_show_map_idx	f(3)
if (decoder_model_info_present_flag && !equal_picture_interval) {	
temporal_point_info( )	
}	
refresh_frame_flags = 0	
if (frame_id_numbers_present_flag) {	
display_frame_id	f(idLen)
}	
frame_type = RefFrameType[frame_to_show_map_idx]	
if (frame_type == KEY_FRAME) {	
refresh_frame_flags = allFrames	
}	
if (film_grain_params_present) {	
load_grain_params(frame_to_show_map_idx)	
}	
return	
}	
frame_type	f(2)
FrameIsIntra = (frame_type == INTRA_ONLY_FRAME ||	
frame_type == KEY_FRAME)	
show_frame	f(1)
if (show_frame && decoder_model_info_present_flag && !equal_picture_interval) {	
temporal_point_info( )	
}	
if (show_frame) {	
showable_frame = frame_type != KEY_FRAME	
} else {	
showable_frame	f(1)
}	
if (frame_type == SWITCH_FRAME ||	
(frame_type == KEY_FRAME && show_frame))	
error_resilient_mode = 1	
else	
error_resilient_mode	f(1)
}	
if (frame_type == KEY_FRAME && show_frame) {	
for (i = 0; i < NUM_REF_FRAMES; i++) {	
RefValid[i] = 0	
RefOrderHint[i] = 0	

}
for (i = 0; i < REFS_PER_FRAME; i++) {
OrderHints[LAST_FRAME + i] = 0
}	

}	
disable_cdf_update	f(1)
if (seq_force_screen_content_tools == SELECT_SCREEN_CONTENT_TOOLS) {	
allow_screen_content_tools	f(1)
} else {	
allow_screen_content_tools = seq_force_screen_content_tools	
}	
if (allow_screen_content_tools) {	
if (seq_force_integer_mv == SELECT_INTEGER_MV) {	
force_integer_mv	f(1)
} else {	
force_integer_mv = seq_force_integer_mv	
}	
} else {	
force_integer_mv = 0	
}	
if (FrameIsIntra) {	
force_integer_mv = 1	
}	
if (frame_id_numbers_present_flag) {	
PrevFrameID = current_frame_id	
current_frame_id	f(idLen)
mark_ref_frames(idLen)	
} else {	
current_frame_id = 0	
}	
if (frame_type == SWITCH_FRAME)	
frame_size_override_flag = 1	
else if (reduced_still_picture_header)	
frame_size_override_flag = 0	
else	
frame_size_override_flag	f(1)
order_hint	f(OrderHintBits)
OrderHint = order_hint	
if (FrameIsIntra || error_resilient_mode) {	
primary_ref_frame = PRIMARY_REF_NONE	
} else {	
primary_ref_frame	f(3)
}	
if (decoder_model_info_present_flag) {	
buffer_removal_time_present_flag	f(1)
if (buffer_removal_time_present_flag) {	
for (opNum = 0; opNum <= operating_points_cnt_minus_1; opNum++) {	
if (decoder_model_present_for_this_op[opNum]) {	
opPtIdc = operating_point_idc[opNum]	

inTemporalLayer = (opPtIdc >> temporal_id) & 1	
inSpatialLayer = (opPtIdc >> (spatial_id + 8)) & 1	
if (opPtIdc == 0 || (inTemporalLayer && inSpatialLayer)) {	
n = buffer_removal_time_length_minus_1 + 1	
buffer_removal_time[opNum]	f(n)
}	
}	
}	
}	
}	
allow_high_precision_mv = 0	
use_ref_frame_mvs = 0	
allow_intrabc = 0	
if (frame_type == SWITCH_FRAME ||	
(frame_type == KEY_FRAME && show_frame)) {	
refresh_frame_flags = allFrames	
} else {	
refresh_frame_flags	f(8)
}	
if (!FrameIsIntra || refresh_frame_flags != allFrames) {	
if (error_resilient_mode && enable_order_hint) {	
for (i = 0; i < NUM_REF_FRAMES; i++) {	
ref_order_hint[i]	f(OrderHintBits)
if (ref_order_hint[i] != RefOrderHint[i]) {	
RefValid[i] = 0	
}	
}	
}	
}	
if (FrameIsIntra) {	
frame_size( )	
render_size( )	
if (allow_screen_content_tools && UpscaledWidth == FrameWidth) {	
allow_intrabc	f(1)
}	
} else {	
if (!enable_order_hint) {	
frame_refs_short_signaling = 0	
} else {	
frame_refs_short_signaling	f(1)
if (frame_refs_short_signaling) {	
last_frame_idx	f(3)
gold_frame_idx	f(3)
set_frame_refs()	
}	
}	
for (i = 0; i < REFS_PER_FRAME; i++) {	
if (!frame_refs_short_signaling)	
ref_frame_idx[i]	f(3)

if (frame_id_numbers_present_flag) {	
n = delta_frame_id_length_minus_2 + 2	
delta_frame_id_minus_1	f(n)
DeltaFrameId = delta_frame_id_minus_1 + 1	
expectedFrameId[i] = ((current_frame_id + (1 << idLen) -	
DeltaFrameId) % (1 << idLen))	
}	
}	
if (frame_size_override_flag && !error_resilient_mode) {	
frame_size_with_refs( )	
} else {	
frame_size( )	
render_size( )	
}	
if (force_integer_mv) {	
allow_high_precision_mv = 0	
} else {	
allow_high_precision_mv	f(1)
}	
read_interpolation_filter( )	
is_motion_mode_switchable	f(1)
if (error_resilient_mode || !enable_ref_frame_mvs) {	
use_ref_frame_mvs = 0	
} else {	
use_ref_frame_mvs	f(1)
}	
for (i = 0; i < REFS_PER_FRAME; i++) {	
refFrame = LAST_FRAME + i	
hint = RefOrderHint[ref_frame_idx[i]]	
OrderHints[refFrame] = hint	
if (!enable_order_hint) {	
RefFrameSignBias[refFrame] = 0	
} else {	
RefFrameSignBias[refFrame] = get_relative_dist(hint, OrderHint) > 0	
}	
}	
}	
if (reduced_still_picture_header || disable_cdf_update)	
disable_frame_end_update_cdf = 1	
else	
disable_frame_end_update_cdf	f(1)
if (primary_ref_frame == PRIMARY_REF_NONE) {	
init_non_coeff_cdfs( )	
setup_past_independence( )	
} else {	
load_cdfs(ref_frame_idx[primary_ref_frame])	
load_previous( )	
}	
if (use_ref_frame_mvs == 1)	

```
        motion_field_estimation( )
    tile_info( )
    quantization_params( )
    segmentation_params( )
    delta_q_params( )
    delta_lf_params( )
    if ( primary_ref_frame == PRIMARY_REF_NONE ) {
        init_coeff_cdfs( )
    } else {
        load_previous_segment_ids( )
    }
    CodedLossless = 1
    for ( segmentId = 0; segmentId < MAX_SEGMENTS; segmentId++ ) {
        qindex = get_qindex( 1, segmentId )
        LosslessArray[ segmentId ] = qindex == 0 && DeltaQYDc == 0 &&
                                     DeltaQUAc == 0 && DeltaQUDc == 0 &&
                                     DeltaQVAc == 0 && DeltaQVDc == 0
        if ( !LosslessArray[ segmentId ] )
            CodedLossless = 0
        if ( using_qmatrix ) {
            if ( LosslessArray[ segmentId ] ) {
                SegQMLevel[ 0 ][ segmentId ] = 15
                SegQMLevel[ 1 ][ segmentId ] = 15
                SegQMLevel[ 2 ][ segmentId ] = 15
            } else {
                SegQMLevel[ 0 ][ segmentId ] = qm_y
                SegQMLevel[ 1 ][ segmentId ] = qm_u
                SegQMLevel[ 2 ][ segmentId ] = qm_v
            }
        }
    }
    AllLossless = CodedLossless && ( FrameWidth == UpscaledWidth )
    loop_filter_params( )
    cdef_params( )
    lr_params( )
    read_tx_mode( )
    frame_reference_mode( )
    skip_mode_params( )
    if ( FrameIsIntra ||
         error_resilient_mode ||
         !enable_warped_motion )
        allow_warped_motion = 0
    else
        allow_warped_motion                                    f(1)
    reduced_tx_set                                             f(1)
    global_motion_params( )
    film_grain_params( )
}
```

5.9.3. Get relative distance function

This function computes the distance between two order hints by sign extending the result of subtracting the values.

get_relative_dist(a, b) {	Type
if (!enable_order_hint)	
return 0	
diff = a - b	
m = 1 << (OrderHintBits - 1)	
diff = (diff & (m - 1)) - (diff & m)	
return diff	
}	

5.9.4. Reference frame marking function

mark_ref_frames(idLen) {	Type
diffLen = delta_frame_id_length_minus_2 + 2	
for (i = 0; i < NUM_REF_FRAMES; i++) {	
if (current_frame_id > (1 << diffLen)) {	
if (RefFrameId[i] > current_frame_id ||	
RefFrameId[i] < (current_frame_id - (1 << diffLen)))	
RefValid[i] = 0	
} else {	
if (RefFrameId[i] > current_frame_id &&	
RefFrameId[i] < ((1 << idLen) +	
current_frame_id -	
(1 << diffLen)))	
RefValid[i] = 0	
}	
}	
}	

5.9.5. Frame size syntax

frame_size( ) {	Type
if (frame_size_override_flag) {	
n = frame_width_bits_minus_1 + 1	
frame_width_minus_1	f(n)
n = frame_height_bits_minus_1 + 1	
frame_height_minus_1	f(n)
FrameWidth = frame_width_minus_1 + 1	
FrameHeight = frame_height_minus_1 + 1	
} else {	
FrameWidth = max_frame_width_minus_1 + 1	
FrameHeight = max_frame_height_minus_1 + 1	
}	
superres_params( )	
compute_image_size( )	
}	

5.9.6. Render size syntax

render_size( ) {	Type
render_and_frame_size_different	f(1)
if (render_and_frame_size_different == 1) {	
render_width_minus_1	f(16)
render_height_minus_1	f(16)
RenderWidth = render_width_minus_1 + 1	
RenderHeight = render_height_minus_1 + 1	
} else {	
RenderWidth = UpscaledWidth	
RenderHeight = FrameHeight	
}	
}	

5.9.7. Frame size with refs syntax

frame_size_with_refs( ) {	Type
for (i = 0; i < REFS_PER_FRAME; i++) {	
found_ref	f(1)
if (found_ref == 1) {	
UpscaledWidth = RefUpscaledWidth[ref_frame_idx[i]]	
FrameWidth = UpscaledWidth	
FrameHeight = RefFrameHeight[ref_frame_idx[i]]	
RenderWidth = RefRenderWidth[ref_frame_idx[i]]	
RenderHeight = RefRenderHeight[ref_frame_idx[i]]	
break	
}	
}	
if (found_ref == 0) {	
frame_size( )	
render_size( )	
} else {	
superres_params( )	
compute_image_size( )	
}	
}	

5.9.8. Superres params syntax

superres_params() {	Type
if (enable_superres)	
use_superres	f(1)
else	
use_superres = 0	
if (use_superres) {	
coded_denom	f(SUPERRES_DENOM_BITS)
SuperresDenom = coded_denom + SUPERRES_DENOM_MIN	
} else {	
SuperresDenom = SUPERRES_NUM	

}	
UpscaledWidth = FrameWidth	
FrameWidth = (UpscaledWidth * SUPERRES_NUM +	
(SuperresDenom / 2)) / SuperresDenom	
}	

5.9.9. Compute image size function

compute_image_size( ) {	Type
MiCols = 2 * ((FrameWidth + 7) >> 3)	
MiRows = 2 * ((FrameHeight + 7) >> 3)	
}	

5.9.10. Interpolation filter syntax

read_interpolation_filter( ) {	Type
is_filter_switchable	f(1)
if (is_filter_switchable == 1) {	
interpolation_filter = SWITCHABLE	
} else {	
interpolation_filter	f(2)
}	
}	

5.9.11. Loop filter params syntax

loop_filter_params( ) {	Type
if (CodedLossless || allow_intrabc) {	
loop_filter_level[0] = 0	
loop_filter_level[1] = 0	
loop_filter_ref_deltas[INTRA_FRAME] = 1	
loop_filter_ref_deltas[LAST_FRAME] = 0	
loop_filter_ref_deltas[LAST2_FRAME] = 0	
loop_filter_ref_deltas[LAST3_FRAME] = 0	
loop_filter_ref_deltas[BWDREF_FRAME] = 0	
loop_filter_ref_deltas[GOLDEN_FRAME] = -1	
loop_filter_ref_deltas[ALTREF_FRAME] = -1	
loop_filter_ref_deltas[ALTREF2_FRAME] = -1	
for (i = 0; i < 2; i++) {	
loop_filter_mode_deltas[i] = 0	
}	
return	
}	
loop_filter_level[0]	f(6)
loop_filter_level[1]	f(6)
if (NumPlanes > 1) {	
if (loop_filter_level[0] || loop_filter_level[1]) {	
loop_filter_level[2]	f(6)
loop_filter_level[3]	f(6)
}	

}	
loop_filter_sharpness	f(3)
loop_filter_delta_enabled	f(1)
if (loop_filter_delta_enabled == 1) {	
loop_filter_delta_update	f(1)
if (loop_filter_delta_update == 1) {	
for (i = 0; i < TOTAL_REFS_PER_FRAME; i++) {	
update_ref_delta	f(1)
if (update_ref_delta == 1)	
loop_filter_ref_deltas[i]	su(1+6)
}	
for (i = 0; i < 2; i++) {	
update_mode_delta	f(1)
if (update_mode_delta == 1)	
loop_filter_mode_deltas[i]	su(1+6)
}	
}	
}	
}	

5.9.12. Quantization params syntax

quantization_params( ) {	Type
base_q_idx	f(8)
DeltaQYDc = read_delta_q( )	
if (NumPlanes > 1) {	
if (separate_uv_delta_q)	
diff_uv_delta	f(1)
else	
diff_uv_delta = 0	
DeltaQUDc = read_delta_q( )	
DeltaQUAc = read_delta_q( )	
if (diff_uv_delta) {	
DeltaQVDc = read_delta_q( )	
DeltaQVAc = read_delta_q( )	
} else {	
DeltaQVDc = DeltaQUDc	
DeltaQVAc = DeltaQUAc	
}	
} else {	
DeltaQUDc = 0	
DeltaQUAc = 0	
DeltaQVDc = 0	
DeltaQVAc = 0	
}	
using_qmatrix	f(1)
if (using_qmatrix) {	
qm_y	f(4)
qm_u	f(4)

if (!separate_uv_delta_q)	
qm_v = qm_u	
else	
qm_v	f(4)
}	
}	

5.9.13. Delta quantizer syntax

read_delta_q( ) {	Type
delta_coded	f(1)
if (delta_coded) {	
delta_q	su(1+6)
} else {	
delta_q = 0	
}	
return delta_q	
}	

5.9.14. Segmentation params syntax

segmentation_params( ) {	Type
segmentation_enabled	f(1)
if (segmentation_enabled == 1) {	
if (primary_ref_frame == PRIMARY_REF_NONE) {	
segmentation_update_map = 1	
segmentation_temporal_update = 0	
segmentation_update_data = 1	
} else {	
segmentation_update_map	f(1)
if (segmentation_update_map == 1)	
segmentation_temporal_update	f(1)
segmentation_update_data	f(1)
}	
if (segmentation_update_data == 1) {	
for (i = 0; i < MAX_SEGMENTS; i++) {	
for (j = 0; j < SEG_LVL_MAX; j++) {	
feature_value = 0	
feature_enabled	f(1)
FeatureEnabled[i][j] = feature_enabled	
clippedValue = 0	
if (feature_enabled == 1) {	
bitsToRead = Segmentation_Feature_Bits[j]	
limit = Segmentation_Feature_Max[j]	
if (Segmentation_Feature_Signed[j] == 1) {	
feature_value	su(1+bitsToRead)
clippedValue = Clip3(-limit, limit, feature_value)	
} else {	
feature_value	f(bitsToRead)
clippedValue = Clip3(0, limit, feature_value)	

```
                        }
                    }
                    FeatureData[ i ][ j ] = clippedValue
                }
            }
        }
    } else {
        for ( i = 0; i < MAX_SEGMENTS; i++ ) {
            for ( j = 0; j < SEG_LVL_MAX; j++ ) {
                FeatureEnabled[ i ][ j ] = 0
                FeatureData[ i ][ j ] = 0
            }
        }
    }
    SegIdPreSkip = 0
    LastActiveSegId = 0
    for ( i = 0; i < MAX_SEGMENTS; i++ ) {
        for ( j = 0; j < SEG_LVL_MAX; j++ ) {
            if ( FeatureEnabled[ i ][ j ] ) {
                LastActiveSegId = i
                if ( j >= SEG_LVL_REF_FRAME ) {
                    SegIdPreSkip = 1
                }
            }
        }
    }
}
```

The constant lookup tables used in this syntax are defined as:

```
Segmentation_Feature_Bits[ SEG_LVL_MAX ]   = { 8, 6, 6, 6, 6, 3, 0, 0 }
Segmentation_Feature_Signed[ SEG_LVL_MAX ] = { 1, 1, 1, 1, 1, 0, 0, 0 }
Segmentation_Feature_Max[ SEG_LVL_MAX ] = {
  255, MAX_LOOP_FILTER, MAX_LOOP_FILTER,
  MAX_LOOP_FILTER, MAX_LOOP_FILTER, 7,
  0, 0 }
```

5.9.15. Tile info syntax

tile_info ( ) {	Type
sbCols = use_128x128_superblock ? ((MiCols + 31) >> 5) : ((MiCols + 15) >> 4)	
sbRows = use_128x128_superblock ? ((MiRows + 31) >> 5) : ((MiRows + 15) >> 4)	
sbShift = use_128x128_superblock ? 5 : 4	
sbSize = sbShift + 2	
maxTileWidthSb = MAX_TILE_WIDTH >> sbSize	
maxTileAreaSb = MAX_TILE_AREA >> (2 * sbSize)	
minLog2TileCols = tile_log2(maxTileWidthSb, sbCols)	
maxLog2TileCols = tile_log2(1, Min(sbCols, MAX_TILE_COLS))	

maxLog2TileRows = tile_log2(1, Min(sbRows, MAX_TILE_ROWS))	
minLog2Tiles = Max(minLog2TileCols,	
tile_log2(maxTileAreaSb, sbRows * sbCols))	
uniform_tile_spacing_flag	f(1)
if (uniform_tile_spacing_flag) {	
TileColsLog2 = minLog2TileCols	
while (TileColsLog2 < maxLog2TileCols) {	
increment_tile_cols_log2	f(1)
if (increment_tile_cols_log2 == 1)	
TileColsLog2++	
else	
break	
}	
tileWidthSb = (sbCols + (1 << TileColsLog2) - 1) >> TileColsLog2	
i = 0	
for (startSb = 0; startSb < sbCols; startSb += tileWidthSb) {	
MiColStarts[i] = startSb << sbShift	
i += 1	
}	
MiColStarts[i] = MiCols	
TileCols = i	
minLog2TileRows = Max(minLog2Tiles - TileColsLog2, 0)	
TileRowsLog2 = minLog2TileRows	
while (TileRowsLog2 < maxLog2TileRows) {	
increment_tile_rows_log2	f(1)
if (increment_tile_rows_log2 == 1)	
TileRowsLog2++	
else	
break	
}	
tileHeightSb = (sbRows + (1 << TileRowsLog2) - 1) >> TileRowsLog2	
i = 0	
for (startSb = 0; startSb < sbRows; startSb += tileHeightSb) {	
MiRowStarts[i] = startSb << sbShift	
i += 1	
}	
MiRowStarts[i] = MiRows	
TileRows = i	
} else {	
widestTileSb = 0	
startSb = 0	
for (i = 0; startSb < sbCols; i++) {	
MiColStarts[i] = startSb << sbShift	
maxWidth = Min(sbCols - startSb, maxTileWidthSb)	
width_in_sbs_minus_1	ns(maxWidth)
sizeSb = width_in_sbs_minus_1 + 1	
widestTileSb = Max(sizeSb, widestTileSb)	

startSb += sizeSb	
}	
MiColStarts[i] = MiCols	
TileCols = i	
TileColsLog2 = tile_log2(1, TileCols)	
if (minLog2Tiles > 0)	
maxTileAreaSb = (sbRows * sbCols) >> (minLog2Tiles + 1)	
else	
maxTileAreaSb = sbRows * sbCols	
maxTileHeightSb = Max(maxTileAreaSb / widestTileSb, 1)	
startSb = 0	
for (i = 0; startSb < sbRows; i++) {	
MiRowStarts[i] = startSb << sbShift	
maxHeight = Min(sbRows - startSb, maxTileHeightSb)	
height_in_sbs_minus_1	ns(maxHeight)
sizeSb = height_in_sbs_minus_1 + 1	
startSb += sizeSb	
}	
MiRowStarts[i] = MiRows	
TileRows = i	
TileRowsLog2 = tile_log2(1, TileRows)	
}	
if (TileColsLog2 > 0 || TileRowsLog2 > 0) {	
context_update_tile_id	f(TileRowsLog2 + TileColsLog2)
tile_size_bytes_minus_1	f(2)
TileSizeBytes = tile_size_bytes_minus_1 + 1	
} else {	
context_update_tile_id = 0	
}	
}	

5.9.16. Tile size calculation function

tile_log2 returns the smallest value for k such that blkSize << k is greater than or equal to target.

tile_log2(blkSize, target) {	**Type**
for (k = 0; (blkSize << k) < target; k++) {	
}	
return k	
}	

5.9.17. Quantizer index delta parameters syntax

delta_q_params( ) {	**Type**
delta_q_res = 0	
delta_q_present = 0	

if (base_q_idx > 0) {	
delta_q_present	f(1)
}	
if (delta_q_present) {	
delta_q_res	f(2)
}	
}	

5.9.18. Loop filter delta parameters syntax

delta_lf_params( ) {	Type
delta_lf_present = 0	
delta_lf_res = 0	
delta_lf_multi = 0	
if (delta_q_present) {	
if (!allow_intrabc)	
delta_lf_present	f(1)
if (delta_lf_present) {	
delta_lf_res	f(2)
delta_lf_multi	f(1)
}	
}	
}	

5.9.19. CDEF params syntax

cdef_params( ) {	Type
if (CodedLossless || allow_intrabc ||	
!enable_cdef) {	
cdef_bits = 0	
cdef_y_pri_strength[0] = 0	
cdef_y_sec_strength[0] = 0	
cdef_uv_pri_strength[0] = 0	
cdef_uv_sec_strength[0] = 0	
CdefDamping = 3	
return	
}	
cdef_damping_minus_3	f(2)
CdefDamping = cdef_damping_minus_3 + 3	
cdef_bits	f(2)
for (i = 0; i < (1 << cdef_bits); i++) {	
cdef_y_pri_strength[i]	f(4)
cdef_y_sec_strength[i]	f(2)
if (cdef_y_sec_strength[i] == 3)	
cdef_y_sec_strength[i] += 1	
if (NumPlanes > 1) {	
cdef_uv_pri_strength[i]	f(4)
cdef_uv_sec_strength[i]	f(2)
if (cdef_uv_sec_strength[i] == 3)	
cdef_uv_sec_strength[i] += 1	

} } }	

5.9.20. Loop restoration params syntax

lr_params( ) {	Type
if (AllLossless || allow_intrabc ||	
!enable_restoration) {	
FrameRestorationType[0] = RESTORE_NONE	
FrameRestorationType[1] = RESTORE_NONE	
FrameRestorationType[2] = RESTORE_NONE	
UsesLr = 0	
return	
}	
UsesLr = 0	
usesChromaLr = 0	
for (i = 0; i < NumPlanes; i++) {	
lr_type	f(2)
FrameRestorationType[i] = Remap_Lr_Type[lr_type]	
if (FrameRestorationType[i] != RESTORE_NONE) {	
UsesLr = 1	
if (i > 0) {	
usesChromaLr = 1	
}	
}	
}	
if (UsesLr) {	
if (use_128x128_superblock) {	
lr_unit_shift	f(1)
lr_unit_shift++	
} else {	
lr_unit_shift	f(1)
if (lr_unit_shift) {	
lr_unit_extra_shift	f(1)
lr_unit_shift += lr_unit_extra_shift	
}	
}	
LoopRestorationSize[0] = RESTORATION_TILESIZE_MAX >> (2 - lr_unit_shift)	
if (subsampling_x && subsampling_y && usesChromaLr) {	
lr_uv_shift	f(1)
} else {	
lr_uv_shift = 0	
}	
LoopRestorationSize[1] = LoopRestorationSize[0] >> lr_uv_shift	
LoopRestorationSize[2] = LoopRestorationSize[0] >> lr_uv_shift	
}	
}	

where Remap_Lr_Type is a constant lookup table specified as:

```
Remap_Lr_Type[4] = {
  RESTORE_NONE, RESTORE_SWITCHABLE, RESTORE_WIENER, RESTORE_SGRPROJ
}
```

5.9.21. TX mode syntax

read_tx_mode( ) {	Type
if (CodedLossless == 1) {	
TxMode = ONLY_4X4	
} else {	
tx_mode_select	f(1)
if (tx_mode_select) {	
TxMode = TX_MODE_SELECT	
} else {	
TxMode = TX_MODE_LARGEST	
}	
}	
}	

5.9.22. Skip mode params syntax

skip_mode_params( ) {	Type
if (FrameIsIntra || !reference_select || !enable_order_hint) {	
skipModeAllowed = 0	
} else {	
forwardIdx = -1	
backwardIdx = -1	
for (i = 0; i < REFS_PER_FRAME; i++) {	
refHint = RefOrderHint[ref_frame_idx[i]]	
if (get_relative_dist(refHint, OrderHint) < 0) {	
if (forwardIdx < 0 ||	
get_relative_dist(refHint, forwardHint) > 0) {	
forwardIdx = i	
forwardHint = refHint	
}	
} else if (get_relative_dist(refHint, OrderHint) > 0) {	
if (backwardIdx < 0 ||	
get_relative_dist(refHint, backwardHint) < 0) {	
backwardIdx = i	
backwardHint = refHint	
}	
}	
}	
if (forwardIdx < 0) {	
skipModeAllowed = 0	
} else if (backwardIdx >= 0) {	
skipModeAllowed = 1	
SkipModeFrame[0] = LAST_FRAME + Min(forwardIdx, backwardIdx)	

SkipModeFrame[1] = LAST_FRAME + Max(forwardIdx, backwardIdx)	
} else {	
secondForwardIdx = -1	
for (i = 0; i < REFS_PER_FRAME; i++) {	
refHint = RefOrderHint[ref_frame_idx[i]]	
if (get_relative_dist(refHint, forwardHint) < 0) {	
if (secondForwardIdx < 0 ||	
get_relative_dist(refHint, secondForwardHint) > 0) {	
secondForwardIdx = i	
secondForwardHint = refHint	
}	
}	
}	
if (secondForwardIdx < 0) {	
skipModeAllowed = 0	
} else {	
skipModeAllowed = 1	
SkipModeFrame[0] = LAST_FRAME + Min(forwardIdx, secondForwardIdx)	
SkipModeFrame[1] = LAST_FRAME + Max(forwardIdx, secondForwardIdx)	
}	
}	
}	
if (skipModeAllowed) {	
skip_mode_present	f(1)
} else {	
skip_mode_present = 0	
}	
}	

5.9.23. Frame reference mode syntax

frame_reference_mode( ) {	Type
if (FrameIsIntra) {	
reference_select = 0	
} else {	
reference_select	f(1)
}	
}	

5.9.24. Global motion params syntax

global_motion_params( ) {	Type
for (ref = LAST_FRAME; ref <= ALTREF_FRAME; ref++) {	
GmType[ref] = IDENTITY	
for (i = 0; i < 6; i++) {	
gm_params[ref][i] = ((i % 3 == 2) ?	
1 << WARPEDMODEL_PREC_BITS : 0)	
}	
}	
if (FrameIsIntra)	

return	
for (ref = LAST_FRAME; ref <= ALTREF_FRAME; ref++) {	
is_global	f(1)
if (is_global) {	
is_rot_zoom	f(1)
if (is_rot_zoom) {	
type = ROTZOOM	
} else {	
is_translation	f(1)
type = is_translation ? TRANSLATION : AFFINE	
}	
} else {	
type = IDENTITY	
}	
GmType[ref] = type	
if (type >= ROTZOOM) {	
read_global_param(type,ref,2)	
read_global_param(type,ref,3)	
if (type == AFFINE) {	
read_global_param(type,ref,4)	
read_global_param(type,ref,5)	
} else {	
gm_params[ref][4] = -gm_params[ref][3]	
gm_params[ref][5] = gm_params[ref][2]	
}	
}	
if (type >= TRANSLATION) {	
read_global_param(type,ref,0)	
read_global_param(type,ref,1)	
}	
}	
}	

5.9.25. Global param syntax

read_global_param(type, ref, idx) {	Type
absBits = GM_ABS_ALPHA_BITS	
precBits = GM_ALPHA_PREC_BITS	
if (idx < 2) {	
if (type == TRANSLATION) {	
absBits = GM_ABS_TRANS_ONLY_BITS - !allow_high_precision_mv	
precBits = GM_TRANS_ONLY_PREC_BITS - !allow_high_precision_mv	
} else {	
absBits = GM_ABS_TRANS_BITS	
precBits = GM_TRANS_PREC_BITS	
}	
}	
precDiff = WARPEDMODEL_PREC_BITS - precBits	

```
    round = (idx % 3) == 2 ? (1 << WARPEDMODEL_PREC_BITS) : 0
    sub = (idx % 3) == 2 ? (1 << precBits) : 0
    mx = (1 << absBits)
    r = (PrevGmParams[ref][idx] >> precDiff) - sub
    gm_params[ref][idx] =
        (decode_signed_subexp_with_ref( -mx, mx + 1, r )<< precDiff) + round
}
```

Note: When force_integer_mv is equal to 1, some fractional bits are still read for the translation components. However, these fractional bits will be discarded during the Setup Global MV process.

5.9.26. Decode signed subexp with ref syntax

decode_signed_subexp_with_ref(low, high, r) {	Type
`    x = decode_unsigned_subexp_with_ref(high - low, r - low)`	
`    return x + low`	
`}`	

Note: decode_signed_subexp_with_ref will return a value in the range low to high - 1 (inclusive).

5.9.27. Decode unsigned subexp with ref syntax

decode_unsigned_subexp_with_ref(mx, r) {	Type
`    v = decode_subexp( mx )`	
`    if ( (r << 1) <= mx ) {`	
`        return inverse_recenter(r, v)`	
`    } else {`	
`        return mx - 1 - inverse_recenter(mx - 1 - r, v)`	
`    }`	
`}`	

Note: decode_unsigned_subexp_with_ref will return a value in the range 0 to mx - 1 (inclusive).

5.9.28. Decode subexp syntax

decode_subexp(numSyms) {	Type
`    i = 0`	
`    mk = 0`	
`    k = 3`	
`    while ( 1 ) {`	
`        b2 = i ? k + i - 1 : k`	
`        a = 1 << b2`	
`        if ( numSyms <= mk + 3 * a ) {`	
`            subexp_final_bits`	`ns(numSyms - mk)`
`            return subexp_final_bits + mk`	
`        } else {`	

subexp_more_bits	f(1)
if (subexp_more_bits) {	
i++	
mk += a	
} else {	
subexp_bits	f(b2)
return subexp_bits + mk	
}	
}	
}	
}	

5.9.29. Inverse recenter function

inverse_recenter(r, v) {	Type
if (v > 2 * r)	
return v	
else if (v & 1)	
return r - ((v + 1) >> 1)	
else	
return r + (v >> 1)	
}	

5.9.30. Film grain params syntax

film_grain_params( ) {	Type
if (!film_grain_params_present ||	
(!show_frame && !showable_frame)) {	
reset_grain_params()	
return	
}	
apply_grain	f(1)
if (!apply_grain) {	
reset_grain_params()	
return	
}	
grain_seed	f(16)
if (frame_type == INTER_FRAME)	
update_grain	f(1)
else	
update_grain = 1	
if (!update_grain) {	
film_grain_params_ref_idx	f(3)
tempGrainSeed = grain_seed	
load_grain_params(film_grain_params_ref_idx)	
grain_seed = tempGrainSeed	
return	
}	
num_y_points	f(4)
for (i = 0; i < num_y_points; i++) {	

point_y_value[i]	f(8)
point_y_scaling[i]	f(8)
}	
if (mono_chrome) {	
chroma_scaling_from_luma = 0	
} else {	
chroma_scaling_from_luma	f(1)
}	
if (mono_chrome || chroma_scaling_from_luma ||	
(subsampling_x == 1 && subsampling_y == 1 &&	
num_y_points == 0)	
) {	
num_cb_points = 0	
num_cr_points = 0	
} else {	
num_cb_points	f(4)
for (i = 0; i < num_cb_points; i++) {	
point_cb_value[i]	f(8)
point_cb_scaling[i]	f(8)
}	
num_cr_points	f(4)
for (i = 0; i < num_cr_points; i++) {	
point_cr_value[i]	f(8)
point_cr_scaling[i]	f(8)
}	
}	
grain_scaling_minus_8	f(2)
ar_coeff_lag	f(2)
numPosLuma = 2 * ar_coeff_lag * (ar_coeff_lag + 1)	
if (num_y_points) {	
numPosChroma = numPosLuma + 1	
for (i = 0; i < numPosLuma; i++)	
ar_coeffs_y_plus_128[i]	f(8)
} else {	
numPosChroma = numPosLuma	
}	
if (chroma_scaling_from_luma || num_cb_points) {	
for (i = 0; i < numPosChroma; i++)	
ar_coeffs_cb_plus_128[i]	f(8)
}	
if (chroma_scaling_from_luma || num_cr_points) {	
for (i = 0; i < numPosChroma; i++)	
ar_coeffs_cr_plus_128[i]	f(8)
}	
ar_coeff_shift_minus_6	f(2)
grain_scale_shift	f(2)
if (num_cb_points) {	
cb_mult	f(8)
cb_luma_mult	f(8)

cb_offset	f(9)
}	
if (num_cr_points) {	
cr_mult	f(8)
cr_luma_mult	f(8)
cr_offset	f(9)
}	
overlap_flag	f(1)
clip_to_restricted_range	f(1)
}	

5.9.31. Temporal point info syntax

temporal_point_info( ) {	Type
n = frame_presentation_time_length_minus_1 + 1	
frame_presentation_time	f(n)
}	

5.10. Frame OBU syntax

frame_obu(sz) {	Type
startBitPos = get_position( )	
frame_header_obu( )	
byte_alignment( )	
endBitPos = get_position( )	
headerBytes = (endBitPos - startBitPos) / 8	
sz -= headerBytes	
tile_group_obu(sz)	
}	

5.11. Tile group OBU syntax

5.11.1. General tile group OBU syntax

tile_group_obu(sz) {	Type
NumTiles = TileCols * TileRows	
startBitPos = get_position( )	
tile_start_and_end_present_flag = 0	
if (NumTiles > 1)	
tile_start_and_end_present_flag	f(1)
if (NumTiles == 1 || !tile_start_and_end_present_flag) {	
tg_start = 0	
tg_end = NumTiles - 1	
} else {	
tileBits = TileColsLog2 + TileRowsLog2	
tg_start	f(tileBits)
tg_end	f(tileBits)
}	
byte_alignment( )	

endBitPos = get_position( )	
headerBytes = (endBitPos - startBitPos) / 8	
sz -= headerBytes	
for (TileNum = tg_start; TileNum <= tg_end; TileNum++) {	
tileRow = TileNum / TileCols	
tileCol = TileNum % TileCols	
lastTile = TileNum == tg_end	
if (lastTile) {	
tileSize = sz	
} else {	
tile_size_minus_1	le(TileSizeBytes)
tileSize = tile_size_minus_1 + 1	
sz -= tileSize + TileSizeBytes	
}	
MiRowStart = MiRowStarts[tileRow]	
MiRowEnd = MiRowStarts[tileRow + 1]	
MiColStart = MiColStarts[tileCol]	
MiColEnd = MiColStarts[tileCol + 1]	
CurrentQIndex = base_q_idx	
init_symbol(tileSize)	
decode_tile( )	
exit_symbol( )	
}	
if (tg_end == NumTiles - 1) {	
if (!disable_frame_end_update_cdf) {	
frame_end_update_cdf( )	
}	
decode_frame_wrapup( )	
SeenFrameHeader = 0	
}	
}	

5.11.2. Decode tile syntax

decode_tile( ) {	**Type**
clear_above_context( )	
for (i = 0; i < FRAME_LF_COUNT; i++)	
DeltaLF[i] = 0	
for (plane = 0; plane < NumPlanes; plane++) {	
for (pass = 0; pass < 2; pass++) {	
RefSgrXqd[plane][pass] = Sgrproj_Xqd_Mid[pass]	
for (i = 0; i < WIENER_COEFFS; i++) {	
RefLrWiener[plane][pass][i] = Wiener_Taps_Mid[i]	
}	
}	
}	
sbSize = use_128x128_superblock ? BLOCK_128X128 : BLOCK_64X64	
sbSize4 = Num_4x4_Blocks_Wide[sbSize]	

```
    for ( r = MiRowStart; r < MiRowEnd; r += sbSize4 ) {
        clear_left_context( )
        for ( c = MiColStart; c < MiColEnd; c += sbSize4 ) {
            ReadDeltas = delta_q_present
            clear_cdef( r, c )
            clear_block_decoded_flags( r, c, sbSize4 )
            read_lr( r, c, sbSize )
            decode_partition( r, c, sbSize )
        }
    }
}
```

where Sgrproj_Xqd_Mid and Wiener_Taps_Mid are constant lookup tables specified as:

```
Wiener_Taps_Mid[3] = {  3,  -7,  15 }

Sgrproj_Xqd_Mid[2] = { -32,  31 }
```

5.11.3. Clear block decoded flags function

```
clear_block_decoded_flags( r, c, sbSize4 ) {                    Type
    for ( plane = 0; plane < NumPlanes; plane++ ) {
        subX = (plane > 0) ? subsampling_x : 0
        subY = (plane > 0) ? subsampling_y : 0
        sbWidth4 = ( MiColEnd - c ) >> subX
        sbHeight4 = ( MiRowEnd - r ) >> subY
        for ( y = -1; y <= ( sbSize4 >> subY ); y++ )
            for ( x = -1; x <= ( sbSize4 >> subX ); x++ ) {
                if ( y < 0 && x < sbWidth4 )
                    BlockDecoded[ plane ][ y ][ x ] = 1
                else if ( x < 0 && y < sbHeight4 )
                    BlockDecoded[ plane ][ y ][ x ] = 1
                else
                    BlockDecoded[ plane ][ y ][ x ] = 0
            }
        BlockDecoded[ plane ][ sbSize4 >> subY ][ -1 ] = 0
    }
}
```

5.11.4. Decode partition syntax

```
decode_partition( r, c, bSize ) {                               Type
    if ( r >= MiRows || c >= MiCols )
        return 0
    AvailU = is_inside( r - 1, c )
    AvailL = is_inside( r, c - 1 )
    num4x4 = Num_4x4_Blocks_Wide[ bSize ]
    halfBlock4x4 = num4x4 >> 1
```

quarterBlock4x4 = halfBlock4x4 >> 1	
hasRows = (r + halfBlock4x4) < MiRows	
hasCols = (c + halfBlock4x4) < MiCols	
if (bSize < BLOCK_8X8) {	
partition = PARTITION_NONE	
} else if (hasRows && hasCols) {	
partition	S()
} else if (hasCols) {	
split_or_horz	S()
partition = split_or_horz ? PARTITION_SPLIT : PARTITION_HORZ	
} else if (hasRows) {	
split_or_vert	S()
partition = split_or_vert ? PARTITION_SPLIT : PARTITION_VERT	
} else {	
partition = PARTITION_SPLIT	
}	
subSize = Partition_Subsize[partition][bSize]	
splitSize = Partition_Subsize[PARTITION_SPLIT][bSize]	
if (partition == PARTITION_NONE) {	
decode_block(r, c, subSize)	
} else if (partition == PARTITION_HORZ) {	
decode_block(r, c, subSize)	
if (hasRows)	
decode_block(r + halfBlock4x4, c, subSize)	
} else if (partition == PARTITION_VERT) {	
decode_block(r, c, subSize)	
if (hasCols)	
decode_block(r, c + halfBlock4x4, subSize)	
} else if (partition == PARTITION_SPLIT) {	
decode_partition(r, c, subSize)	
decode_partition(r, c + halfBlock4x4, subSize)	
decode_partition(r + halfBlock4x4, c, subSize)	
decode_partition(r + halfBlock4x4, c + halfBlock4x4, subSize)	
} else if (partition == PARTITION_HORZ_A) {	
decode_block(r, c, splitSize)	
decode_block(r, c + halfBlock4x4, splitSize)	
decode_block(r + halfBlock4x4, c, subSize)	
} else if (partition == PARTITION_HORZ_B) {	
decode_block(r, c, subSize)	
decode_block(r + halfBlock4x4, c, splitSize)	
decode_block(r + halfBlock4x4, c + halfBlock4x4, splitSize)	
} else if (partition == PARTITION_VERT_A) {	
decode_block(r, c, splitSize)	
decode_block(r + halfBlock4x4, c, splitSize)	
decode_block(r, c + halfBlock4x4, subSize)	
} else if (partition == PARTITION_VERT_B) {	
decode_block(r, c, subSize)	
decode_block(r, c + halfBlock4x4, splitSize)	
decode_block(r + halfBlock4x4, c + halfBlock4x4, splitSize)	

```
    } else if ( partition == PARTITION_HORZ_4 ) {
        decode_block( r + quarterBlock4x4 * 0, c, subSize )
        decode_block( r + quarterBlock4x4 * 1, c, subSize )
        decode_block( r + quarterBlock4x4 * 2, c, subSize )
        if ( r + quarterBlock4x4 * 3 < MiRows )
            decode_block( r + quarterBlock4x4 * 3, c, subSize )
    } else {
        decode_block( r, c + quarterBlock4x4 * 0, subSize )
        decode_block( r, c + quarterBlock4x4 * 1, subSize )
        decode_block( r, c + quarterBlock4x4 * 2, subSize )
        if ( c + quarterBlock4x4 * 3 < MiCols )
            decode_block( r, c + quarterBlock4x4 * 3, subSize )
    }
}
```

5.11.5. Decode block syntax

decode_block(r, c, subSize) {	Type
MiRow = r	
MiCol = c	
MiSize = subSize	
bw4 = Num_4x4_Blocks_Wide[subSize]	
bh4 = Num_4x4_Blocks_High[subSize]	
if (bh4 == 1 && subsampling_y && (MiRow & 1) == 0)	
HasChroma = 0	
else if (bw4 == 1 && subsampling_x && (MiCol & 1) == 0)	
HasChroma = 0	
else	
HasChroma = NumPlanes > 1	
AvailU = is_inside(r - 1, c)	
AvailL = is_inside(r, c - 1)	
AvailUChroma = AvailU	
AvailLChroma = AvailL	
if (HasChroma) {	
if (subsampling_y && bh4 == 1)	
AvailUChroma = is_inside(r - 2, c)	
if (subsampling_x && bw4 == 1)	
AvailLChroma = is_inside(r, c - 2)	
} else {	
AvailUChroma = 0	
AvailLChroma = 0	
}	
mode_info( )	
palette_tokens( )	
read_block_tx_size( )	
if (skip)	
reset_block_context(bw4, bh4)	
isCompound = RefFrame[1] > INTRA_FRAME	

```
    for ( y = 0; y < bh4; y++ ) {
        for ( x = 0; x < bw4; x++ ) {
            YModes [ r + y ][ c + x ] = YMode
            if ( RefFrame[ 0 ] == INTRA_FRAME && HasChroma )
                UVModes [ r + y ][ c + x ] = UVMode
            for ( refList = 0; refList < 2; refList++ )
                RefFrames[ r + y ][ c + x ][ refList ] = RefFrame[ refList ]
            if ( is_inter ) {
                if ( !use_intrabc ) {
                  CompGroupIdxs[ r + y ][ c + x ] = comp_group_idx
                  CompoundIdxs[ r + y ][ c + x ] = compound_idx
                }
                for ( dir = 0; dir < 2; dir++ ) {
                    InterpFilters[ r + y ][ c + x ][ dir ] = interp_filter[ dir ]
                }
                for ( refList = 0; refList < 1 + isCompound; refList++ ) {
                    Mvs[ r + y ][ c + x ][ refList ] = Mv[ refList ]
                }
            }
        }
    }
    compute_prediction( )
    residual( )
    for ( y = 0; y < bh4; y++ ) {
        for ( x = 0; x < bw4; x++ ) {
            IsInters[ r + y ][ c + x ] = is_inter
            SkipModes[ r + y ][ c + x ] = skip_mode
            Skips[ r + y ][ c + x ] = skip
            TxSizes[ r + y ][ c + x ] = TxSize
            MiSizes[ r + y ][ c + x ] = MiSize
            SegmentIds[ r + y ][ c + x ] = segment_id
            PaletteSizes[ 0 ][ r + y ][ c + x ] = PaletteSizeY
            PaletteSizes[ 1 ][ r + y ][ c + x ] = PaletteSizeUV
            for ( i = 0; i < PaletteSizeY; i++ )
                PaletteColors[ 0 ][ r + y ][ c + x ][ i ] = palette_colors_y[ i ]
            for ( i = 0; i < PaletteSizeUV; i++ )
                PaletteColors[ 1 ][ r + y ][ c + x ][ i ] = palette_colors_u[ i ]
            for ( i = 0; i < FRAME_LF_COUNT; i++ )
                DeltaLFs[ r + y ][ c + x ][ i ] = DeltaLF[ i ]
        }
    }
}
```

where reset_block_context( ) is specified as:

```
reset_block_context( bw4, bh4 ) {
    for ( plane = 0; plane < 1 + 2 * HasChroma; plane++ ) {
        subX = (plane > 0) ? subsampling_x : 0
        subY = (plane > 0) ? subsampling_y : 0
        for ( i = MiCol >> subX; i < ( ( MiCol + bw4 ) >> subX ); i++) {
            AboveLevelContext[ plane ][ i ] = 0
            AboveDcContext[ plane ][ i ] = 0
        }
        for ( i = MiRow >> subY; i < ( ( MiRow + bh4 ) >> subY ); i++) {
            LeftLevelContext[ plane ][ i ] = 0
            LeftDcContext[ plane ][ i ] = 0
        }
    }
}
```

5.11.6. Mode info syntax

mode_info( ) {	Type
if (FrameIsIntra)	
intra_frame_mode_info( )	
else	
inter_frame_mode_info( )	
}	

5.11.7. Intra frame mode info syntax

intra_frame_mode_info( ) {	Type
skip = 0	
if (SegIdPreSkip)	
intra_segment_id( )	
skip_mode = 0	
read_skip( )	
if (!SegIdPreSkip)	
intra_segment_id( )	
read_cdef( )	
read_delta_qindex( )	
read_delta_lf( )	
ReadDeltas = 0	
RefFrame[0] = INTRA_FRAME	
RefFrame[1] = NONE	
if (allow_intrabc) {	
use_intrabc	S()
} else {	
use_intrabc = 0	
}	
if (use_intrabc) {	
is_inter = 1	
YMode = DC_PRED	

UVMode = DC_PRED	
motion_mode = SIMPLE	
compound_type = COMPOUND_AVERAGE	
PaletteSizeY = 0	
PaletteSizeUV = 0	
interp_filter[0] = BILINEAR	
interp_filter[1] = BILINEAR	
find_mv_stack(0)	
assign_mv(0)	
} else {	
is_inter = 0	
intra_frame_y_mode	S()
YMode = intra_frame_y_mode	
intra_angle_info_y( )	
if (HasChroma) {	
uv_mode	S()
UVMode = uv_mode	
if (UVMode == UV_CFL_PRED) {	
read_cfl_alphas( )	
}	
intra_angle_info_uv( )	
}	
PaletteSizeY = 0	
PaletteSizeUV = 0	
if (MiSize >= BLOCK_8X8 &&	
Block_Width[MiSize] <= 64 &&	
Block_Height[MiSize] <= 64 &&	
allow_screen_content_tools) {	
palette_mode_info( )	
}	
filter_intra_mode_info( )	
}	
}	

5.11.8. Intra segment ID syntax

intra_segment_id( ) {	Type
if (segmentation_enabled)	
read_segment_id( )	
else	
segment_id = 0	
Lossless = LosslessArray[segment_id]	
}	

5.11.9. Read segment ID syntax

read_segment_id( ) {	Type
if (AvailU && AvailL)	
prevUL = SegmentIds[MiRow - 1][MiCol - 1]	
else	

prevUL = -1	
if (AvailU)	
prevU = SegmentIds[MiRow - 1][MiCol]	
else	
prevU = -1	
if (AvailL)	
prevL = SegmentIds[MiRow][MiCol - 1]	
else	
prevL = -1	
if (prevU == -1)	
pred = (prevL == -1) ? 0 : prevL	
else if (prevL == -1)	
pred = prevU	
else	
pred = (prevUL == prevU) ? prevU : prevL	
if (skip) {	
segment_id = pred	
} else {	
segment_id	S()
segment_id = neg_deinterleave(segment_id, pred,	
LastActiveSegId + 1)	
}	
}	

where neg_deinterleave is a function defined as:

```
neg_deinterleave(diff, ref, max) {
  if ( !ref )
    return diff
  if ( ref >= (max - 1) )
    return max - diff - 1
  if ( 2 * ref < max ) {
    if ( diff <= 2 * ref ) {
      if ( diff & 1 )
        return ref + ((diff + 1) >> 1)
      else
        return ref - (diff >> 1)
    }
    return diff
  } else {
    if ( diff <= 2 * (max - ref - 1) ) {
      if ( diff & 1 )
        return ref + ((diff + 1) >> 1)
      else
        return ref - (diff >> 1)
    }
    return max - (diff + 1)
  }
}
```

5.11.10. Skip mode syntax

read_skip_mode( ) {	Type
if (seg_feature_active(SEG_LVL_SKIP) ||	
seg_feature_active(SEG_LVL_REF_FRAME) ||	
seg_feature_active(SEG_LVL_GLOBALMV) ||	
!skip_mode_present ||	
Block_Width[MiSize] < 8 ||	
Block_Height[MiSize] < 8) {	
skip_mode = 0	
} else {	
skip_mode	S()
}	
}	

5.11.11. Skip syntax

read_skip( ) {	Type
if (SegIdPreSkip && seg_feature_active(SEG_LVL_SKIP)) {	
skip = 1	
} else {	
skip	S()
}	
}	

5.11.12. Quantizer index delta syntax

read_delta_qindex( ) {	Type
sbSize = use_128x128_superblock ? BLOCK_128X128 : BLOCK_64X64	
if (MiSize == sbSize && skip)	
return	
if (ReadDeltas) {	
delta_q_abs	S()
if (delta_q_abs == DELTA_Q_SMALL) {	
delta_q_rem_bits	L(3)
delta_q_rem_bits++	
delta_q_abs_bits	L(delta_q_rem_bits)
delta_q_abs = delta_q_abs_bits + (1 << delta_q_rem_bits) + 1	
}	
if (delta_q_abs) {	
delta_q_sign_bit	L(1)
reducedDeltaQIndex = delta_q_sign_bit ? -delta_q_abs : delta_q_abs	
CurrentQIndex = Clip3(1, 255,	
CurrentQIndex + (reducedDeltaQIndex << delta_q_res))	
}	
}	
}	

5.11.13. Loop filter delta syntax

read_delta_lf( ) {	Type
sbSize = use_128x128_superblock ? BLOCK_128X128 : BLOCK_64X64	
if (MiSize == sbSize && skip)	
return	
if (ReadDeltas && delta_lf_present) {	
frameLfCount = 1	
if (delta_lf_multi) {	
frameLfCount = (NumPlanes > 1) ? FRAME_LF_COUNT : (FRAME_LF_COUNT - 2)	
}	
for (i = 0; i < frameLfCount; i++) {	
delta_lf_abs	S()
if (delta_lf_abs == DELTA_LF_SMALL) {	
delta_lf_rem_bits	L(3)
n = delta_lf_rem_bits + 1	
delta_lf_abs_bits	L(n)
deltaLfAbs = delta_lf_abs_bits +	
(1 << n) + 1	
} else {	
deltaLfAbs = delta_lf_abs	
}	
if (deltaLfAbs) {	
delta_lf_sign_bit	L(1)
reducedDeltaLfLevel = delta_lf_sign_bit ?	
-deltaLfAbs :	
deltaLfAbs	
DeltaLF[i] = Clip3(-MAX_LOOP_FILTER, MAX_LOOP_FILTER, DeltaLF[i] +	
(reducedDeltaLfLevel << delta_lf_res))	
}	
}	
}	
}	

5.11.14. Segmentation feature active function

seg_feature_active_idx(idx, feature) {	Type
return segmentation_enabled && FeatureEnabled[idx][feature]	
}	
seg_feature_active(feature) {	
return seg_feature_active_idx(segment_id, feature)	
}	

5.11.15. TX size syntax

read_tx_size(allowSelect) {	Type
if (Lossless) {	
TxSize = TX_4X4	
return	

}
maxRectTxSize = Max_Tx_Size_Rect[MiSize]
maxTxDepth = Max_Tx_Depth[MiSize]
TxSize = maxRectTxSize
if (MiSize > BLOCK_4X4 && allowSelect && TxMode == TX_MODE_SELECT) {
tx_depth
for (i = 0; i < tx_depth; i++)
TxSize = Split_Tx_Size[TxSize]
}
}
}
	
	S()

The Max_Tx_Depth table specifies the maximum transform depth for each block size:

```
Max_Tx_Depth[ BLOCK_SIZES ] = {
    0, 1, 1, 1,
    2, 2, 2, 3,
    3, 3, 4, 4,
    4, 4, 4, 4,
    2, 2, 3, 3,
    4, 4
}
```

Note: Max_Tx_Depth contains the number of times the transform must be split to reach a 4x4 transform size. This number can be greater than MAX_TX_DEPTH. However, it is impossible to encode a transform depth greater than MAX_TX_DEPTH because tx_depth can only encode values in the range 0 to 2

5.11.16. Block TX size syntax

read_block_tx_size( ) {	Type

bw4 = Num_4x4_Blocks_Wide[MiSize]
bh4 = Num_4x4_Blocks_High[MiSize]
if (TxMode == TX_MODE_SELECT &&
MiSize > BLOCK_4X4 && is_inter &&
!skip && !Lossless) {
maxTxSz = Max_Tx_Size_Rect[MiSize]
txW4 = Tx_Width[maxTxSz] / MI_SIZE
txH4 = Tx_Height[maxTxSz] / MI_SIZE
for (row = MiRow; row < MiRow + bh4; row += txH4)
for (col = MiCol; col < MiCol + bw4; col += txW4)
read_var_tx_size(row, col, maxTxSz, 0)
} else {
read_tx_size(!skip || !is_inter)
for (row = MiRow; row < MiRow + bh4; row++)
for (col = MiCol; col < MiCol + bw4; col++)
InterTxSizes[row][col] = TxSize
}

}	

5.11.17. Var TX size syntax

read_var_tx_size is used to read a transform size tree.

read_var_tx_size(row, col, txSz, depth) {	Type
if (row >= MiRows || col >= MiCols)	
return	
if (txSz == TX_4X4 || depth == MAX_VARTX_DEPTH) {	
txfm_split = 0	
} else {	
txfm_split	S()
}	
w4 = Tx_Width[txSz] / MI_SIZE	
h4 = Tx_Height[txSz] / MI_SIZE	
if (txfm_split) {	
subTxSz = Split_Tx_Size[txSz]	
stepW = Tx_Width[subTxSz] / MI_SIZE	
stepH = Tx_Height[subTxSz] / MI_SIZE	
for (i = 0; i < h4; i += stepH)	
for (j = 0; j < w4; j += stepW)	
read_var_tx_size(row + i, col + j, subTxSz, depth+1)	
} else {	
for (i = 0; i < h4; i++)	
for (j = 0; j < w4; j++)	
InterTxSizes[row + i][col + j] = txSz	
TxSize = txSz	
}	
}	

5.11.18. Inter frame mode info syntax

inter_frame_mode_info( ) {	Type
use_intrabc = 0	
LeftRefFrame[0] = AvailL ? RefFrames[MiRow][MiCol-1][0] : INTRA_FRAME	
AboveRefFrame[0] = AvailU ? RefFrames[MiRow-1][MiCol][0] : INTRA_FRAME	
LeftRefFrame[1] = AvailL ? RefFrames[MiRow][MiCol-1][1] : NONE	
AboveRefFrame[1] = AvailU ? RefFrames[MiRow-1][MiCol][1] : NONE	
LeftIntra = LeftRefFrame[0] <= INTRA_FRAME	
AboveIntra = AboveRefFrame[0] <= INTRA_FRAME	
LeftSingle = LeftRefFrame[1] <= INTRA_FRAME	
AboveSingle = AboveRefFrame[1] <= INTRA_FRAME	
skip = 0	
inter_segment_id(1)	
read_skip_mode( )	
if (skip_mode)	
skip = 1	
else	
read_skip( )	

```
    if ( !SegIdPreSkip )
        inter_segment_id( 0 )
    Lossless = LosslessArray[ segment_id ]
    read_cdef( )
    read_delta_qindex( )
    read_delta_lf( )
    ReadDeltas = 0
    read_is_inter( )
    if ( is_inter )
        inter_block_mode_info( )
    else
        intra_block_mode_info( )
}
```

5.11.19. Inter segment ID syntax

This is called before (preSkip equal to 1) and after (preSkip equal to 0) the skip syntax element has been read.

inter_segment_id(preSkip) {	Type
`    if ( segmentation_enabled ) {`	
`        predictedSegmentId = get_segment_id( )`	
`        if ( segmentation_update_map ) {`	
`            if ( preSkip && !SegIdPreSkip ) {`	
`                segment_id = 0`	
`                return`	
`            }`	
`            if ( !preSkip ) {`	
`                if ( skip ) {`	
`                    seg_id_predicted = 0`	
`                    for ( i = 0; i < Num_4x4_Blocks_Wide[ MiSize ]; i++ )`	
`                        AboveSegPredContext[ MiCol + i ] = seg_id_predicted`	
`                    for ( i = 0; i < Num_4x4_Blocks_High[ MiSize ]; i++ )`	
`                        LeftSegPredContext[ MiRow + i ] = seg_id_predicted`	
`                    read_segment_id( )`	
`                    return`	
`                }`	
`            }`	
`            if ( segmentation_temporal_update == 1 ) {`	
`                seg_id_predicted`	S()
`                if ( seg_id_predicted )`	
`                    segment_id = predictedSegmentId`	
`                else`	
`                    read_segment_id( )`	
`                for ( i = 0; i < Num_4x4_Blocks_Wide[ MiSize ]; i++ )`	
`                    AboveSegPredContext[ MiCol + i ] = seg_id_predicted`	
`                for ( i = 0; i < Num_4x4_Blocks_High[ MiSize ]; i++ )`	
`                    LeftSegPredContext[ MiRow + i ] = seg_id_predicted`	
`            } else {`	
`                read_segment_id( )`	

```
            }
        } else {
            segment_id = predictedSegmentId
        }
    } else {
        segment_id = 0
    }
}
```

5.11.20. Is inter syntax

```
read_is_inter( ) {                                                                  Type
    if ( skip_mode ) {
        is_inter = 1
    } else if ( seg_feature_active ( SEG_LVL_REF_FRAME ) ) {
        is_inter = FeatureData[ segment_id ][ SEG_LVL_REF_FRAME ] != INTRA_FRAME
    } else if ( seg_feature_active ( SEG_LVL_GLOBALMV ) ) {
        is_inter = 1
    } else {
        is_inter                                                                    S()
    }
}
```

5.11.21. Get segment ID function

The predicted segment id is the smallest value found in the on-screen region of the segmentation map covered by the current block.

```
get_segment_id( ) {                                                                 Type
    bw4 = Num_4x4_Blocks_Wide[ MiSize ]
    bh4 = Num_4x4_Blocks_High[ MiSize ]
    xMis = Min( MiCols - MiCol, bw4 )
    yMis = Min( MiRows - MiRow, bh4 )
    seg = 7
    for ( y = 0; y < yMis; y++ )
        for ( x = 0; x < xMis; x++ )
            seg = Min( seg, PrevSegmentIds[ MiRow + y ][ MiCol + x ] )
    return seg
}
```

5.11.22. Intra block mode info syntax

```
intra_block_mode_info( ) {                                                          Type
    RefFrame[ 0 ] = INTRA_FRAME
    RefFrame[ 1 ] = NONE
    y_mode                                                                          S()
    YMode = y_mode
    intra_angle_info_y( )
    if ( HasChroma ) {
        uv_mode                                                                     S()
```

```
        UVMode = uv_mode
        if ( UVMode == UV_CFL_PRED ) {
            read_cfl_alphas( )
        }
        intra_angle_info_uv( )
    }
    PaletteSizeY = 0
    PaletteSizeUV = 0
    if ( MiSize >= BLOCK_8X8 &&
         Block_Width[ MiSize ] <= 64  &&
         Block_Height[ MiSize ] <= 64 &&
         allow_screen_content_tools )
        palette_mode_info( )
    filter_intra_mode_info( )
}
```

5.11.23. Inter block mode info syntax

inter_block_mode_info( ) {	Type
PaletteSizeY = 0	
PaletteSizeUV = 0	
read_ref_frames( )	
isCompound = RefFrame[1] > INTRA_FRAME	
find_mv_stack(isCompound)	
if (skip_mode) {	
YMode = NEAREST_NEARESTMV	
} else if (seg_feature_active(SEG_LVL_SKIP) ||	
seg_feature_active(SEG_LVL_GLOBALMV)) {	
YMode = GLOBALMV	
} else if (isCompound) {	
compound_mode	S()
YMode = NEAREST_NEARESTMV + compound_mode	
} else {	
new_mv	S()
if (new_mv == 0) {	
YMode = NEWMV	
} else {	
zero_mv	S()
if (zero_mv == 0) {	
YMode = GLOBALMV	
} else {	
ref_mv	S()
YMode = (ref_mv == 0) ? NEARESTMV : NEARMV	
}	
}	
}	
RefMvIdx = 0	
if (YMode == NEWMV || YMode == NEW_NEWMV) {	
for (idx = 0; idx < 2; idx++) {	

`            if ( NumMvFound > idx + 1 ) {`	
`                drl_mode`	S()
`                if ( drl_mode == 0 ) {`	
`                  RefMvIdx = idx`	
`                  break`	
`                }`	
`                RefMvIdx = idx + 1`	
`            }`	
`        }`	
`    } else if ( has_nearmv( ) ) {`	
`        RefMvIdx = 1`	
`        for ( idx = 1; idx < 3; idx++ ) {`	
`            if ( NumMvFound > idx + 1 ) {`	
`                drl_mode`	S()
`                if ( drl_mode == 0 ) {`	
`                    RefMvIdx = idx`	
`                    break`	
`                }`	
`                RefMvIdx = idx + 1`	
`            }`	
`        }`	
`    }`	
`    assign_mv( isCompound )`	
`    read_interintra_mode( isCompound )`	
`    read_motion_mode( isCompound )`	
`    read_compound_type( isCompound )`	
`    if ( interpolation_filter == SWITCHABLE ) {`	
`        for ( dir = 0; dir < ( enable_dual_filter ? 2 : 1 ); dir++ ) {`	
`            if ( needs_interp_filter( ) ) {`	
`                interp_filter[ dir ]`	S()
`            } else {`	
`                interp_filter[ dir ] = EIGHTTAP`	
`            }`	
`        }`	
`        if ( !enable_dual_filter )`	
`            interp_filter[ 1 ] = interp_filter[ 0 ]`	
`    } else {`	
`        for ( dir = 0; dir < 2; dir++ )`	
`            interp_filter[ dir ] = interpolation_filter`	
`    }`	
`}`	

The function has_nearmv is defined as:

```
has_nearmv( ) {
    return (YMode == NEARMV || YMode == NEAR_NEARMV
            || YMode == NEAR_NEWMV || YMode == NEW_NEARMV)
}
```

The function needs_interp_filter is defined as:

```
needs_interp_filter( ) {
    large = (Min(Block_Width[MiSize], Block_Height[MiSize]) >= 8)
    if ( skip_mode || motion_mode == LOCALWARP ) {
        return 0
    } else if ( large && YMode == GLOBALMV ) {
        return GmType[ RefFrame[ 0 ] ] == TRANSLATION
    } else if ( large && YMode == GLOBAL_GLOBALMV ) {
        return GmType[ RefFrame[ 0 ] ] == TRANSLATION || GmType[ RefFrame[ 1 ] ] == TRANSLATION
    } else {
        return 1
    }
}
```

5.11.24. Filter intra mode info syntax

filter_intra_mode_info( ) {	Type
use_filter_intra = 0	
if (enable_filter_intra &&	
YMode == DC_PRED && PaletteSizeY == 0 &&	
Max(Block_Width[MiSize], Block_Height[MiSize]) <= 32) {	
use_filter_intra	S()
if (use_filter_intra) {	
filter_intra_mode	S()
}	
}	
}	

5.11.25. Ref frames syntax

read_ref_frames( ) {	Type
if (skip_mode) {	
RefFrame[0] = SkipModeFrame[0]	
RefFrame[1] = SkipModeFrame[1]	
} else if (seg_feature_active(SEG_LVL_REF_FRAME)) {	
RefFrame[0] = FeatureData[segment_id][SEG_LVL_REF_FRAME]	
RefFrame[1] = NONE	
} else if (seg_feature_active(SEG_LVL_SKIP) ||	
seg_feature_active(SEG_LVL_GLOBALMV)) {	
RefFrame[0] = LAST_FRAME	
RefFrame[1] = NONE	
} else {	
bw4 = Num_4x4_Blocks_Wide[MiSize]	
bh4 = Num_4x4_Blocks_High[MiSize]	
if (reference_select && (Min(bw4, bh4) >= 2))	
comp_mode	S()
else	

comp_mode = SINGLE_REFERENCE	
if (comp_mode == COMPOUND_REFERENCE) {	
comp_ref_type	S()
if (comp_ref_type == UNIDIR_COMP_REFERENCE) {	
uni_comp_ref	S()
if (uni_comp_ref) {	
RefFrame[0] = BWDREF_FRAME	
RefFrame[1] = ALTREF_FRAME	
} else {	
uni_comp_ref_p1	S()
if (uni_comp_ref_p1) {	
uni_comp_ref_p2	S()
if (uni_comp_ref_p2) {	
RefFrame[0] = LAST_FRAME	
RefFrame[1] = GOLDEN_FRAME	
} else {	
RefFrame[0] = LAST_FRAME	
RefFrame[1] = LAST3_FRAME	
}	
} else {	
RefFrame[0] = LAST_FRAME	
RefFrame[1] = LAST2_FRAME	
}	
}	
} else {	
comp_ref	S()
if (comp_ref == 0) {	
comp_ref_p1	S()
RefFrame[0] = comp_ref_p1 ?	
LAST2_FRAME : LAST_FRAME	
} else {	
comp_ref_p2	S()
RefFrame[0] = comp_ref_p2 ?	
GOLDEN_FRAME : LAST3_FRAME	
}	
comp_bwdref	S()
if (comp_bwdref == 0) {	
comp_bwdref_p1	S()
RefFrame[1] = comp_bwdref_p1 ?	
ALTREF2_FRAME : BWDREF_FRAME	
} else {	
RefFrame[1] = ALTREF_FRAME	
}	
}	
} else {	
single_ref_p1	S()
if (single_ref_p1) {	
single_ref_p2	S()
if (single_ref_p2 == 0) {	

single_ref_p6	S()
RefFrame[0] = single_ref_p6 ?	
ALTREF2_FRAME : BWDREF_FRAME	
} else {	
RefFrame[0] = ALTREF_FRAME	
}	
} else {	
single_ref_p3	S()
if (single_ref_p3) {	
single_ref_p5	S()
RefFrame[0] = single_ref_p5 ?	
GOLDEN_FRAME : LAST3_FRAME	
} else {	
single_ref_p4	S()
RefFrame[0] = single_ref_p4 ?	
LAST2_FRAME : LAST_FRAME	
}	
}	
RefFrame[1] = NONE	
}	
}	
}	

5.11.26. Assign MV syntax

assign_mv(isCompound) {	Type
for (i = 0; i < 1 + isCompound; i++) {	
if (use_intrabc) {	
compMode = NEWMV	
} else {	
compMode = get_mode(i)	
}	
if (use_intrabc) {	
PredMv[0] = RefStackMv[0][0]	
if (PredMv[0][0] == 0 && PredMv[0][1] == 0) {	
PredMv[0] = RefStackMv[1][0]	
}	
if (PredMv[0][0] == 0 && PredMv[0][1] == 0) {	
sbSize = use_128x128_superblock ? BLOCK_128X128 : BLOCK_64X64	
sbSize4 = Num_4x4_Blocks_High[sbSize]	
if (MiRow - sbSize4 < MiRowStart) {	
PredMv[0][0] = 0	
PredMv[0][1] = -(sbSize4 * MI_SIZE + INTRABC_DELAY_PIXELS) * 8	
} else {	
PredMv[0][0] = -(sbSize4 * MI_SIZE * 8)	
PredMv[0][1] = 0	
}	
}	
} else if (compMode == GLOBALMV) {	

```
            PredMv[ i ] = GlobalMvs[ i ]
        } else {
            pos = ( compMode == NEARESTMV ) ? 0 : RefMvIdx
            if ( compMode == NEWMV && NumMvFound <= 1 )
                pos = 0
            PredMv[ i ] = RefStackMv[ pos ][ i ]
        }
        if ( compMode == NEWMV ) {
            read_mv( i )
        } else {
            Mv[ i ] = PredMv[ i ]
        }
    }
}
```

5.11.27. Read motion mode syntax

read_motion_mode(isCompound) {	Type
if (skip_mode) {	
motion_mode = SIMPLE	
return	
}	
if (!is_motion_mode_switchable) {	
motion_mode = SIMPLE	
return	
}	
if (Min(Block_Width[MiSize],	
Block_Height[MiSize]) < 8) {	
motion_mode = SIMPLE	
return	
}	
if (!force_integer_mv &&	
(YMode == GLOBALMV || YMode == GLOBAL_GLOBALMV)) {	
if (GmType[RefFrame[0]] > TRANSLATION) {	
motion_mode = SIMPLE	
return	
}	
}	
if (isCompound || RefFrame[1] == INTRA_FRAME || !has_overlappable_candidates( )) {	
motion_mode = SIMPLE	
return	
}	
find_warp_samples()	
if (force_integer_mv || NumSamples == 0 ||	
!allow_warped_motion || is_scaled(RefFrame[0])) {	
use_obmc	S()
motion_mode = use_obmc ? OBMC : SIMPLE	
} else {	
motion_mode	S()

}	
}	

where is_scaled is a function that determines whether a reference frame uses scaling and is specified as:

```
is_scaled( refFrame ) {
  refIdx = ref_frame_idx[ refFrame - LAST_FRAME ]
  xScale = ( ( RefUpscaledWidth[ refIdx ] << REF_SCALE_SHIFT ) + ( FrameWidth / 2 ) ) / FrameWidth
  yScale = ( ( RefFrameHeight[ refIdx ] << REF_SCALE_SHIFT ) + ( FrameHeight / 2 ) ) / FrameHeight
  noScale = 1 << REF_SCALE_SHIFT
  return xScale != noScale || yScale != noScale
}
```

5.11.28. Read inter intra syntax

read_interintra_mode(isCompound) {	Type
if (!skip_mode && enable_interintra_compound && !isCompound &&	
MiSize >= BLOCK_8X8 && MiSize <= BLOCK_32X32) {	
interintra	S()
if (interintra) {	
interintra_mode	S()
RefFrame[1] = INTRA_FRAME	
AngleDeltaY = 0	
AngleDeltaUV = 0	
use_filter_intra = 0	
wedge_interintra	S()
if (wedge_interintra) {	
wedge_index	S()
wedge_sign = 0	
}	
}	
} else {	
interintra = 0	
}	
}	

5.11.29. Read compound type syntax

read_compound_type(isCompound) {	Type
comp_group_idx = 0	
compound_idx = 1	
if (skip_mode) {	
compound_type = COMPOUND_AVERAGE	
return	
}	
if (isCompound) {	
n = Wedge_Bits[MiSize]	
if (enable_masked_compound) {	

comp_group_idx	S()
}	
if (comp_group_idx == 0) {	
if (enable_jnt_comp) {	
compound_idx	S()
compound_type = compound_idx ? COMPOUND_AVERAGE :	
COMPOUND_DISTANCE	
} else {	
compound_type = COMPOUND_AVERAGE	
}	
} else {	
if (n == 0) {	
compound_type = COMPOUND_DIFFWTD	
} else {	
compound_type	S()
}	
}	
if (compound_type == COMPOUND_WEDGE) {	
wedge_index	S()
wedge_sign	L(1)
} else if (compound_type == COMPOUND_DIFFWTD) {	
mask_type	L(1)
}	
} else {	
if (interintra) {	
compound_type = wedge_interintra ? COMPOUND_WEDGE : COMPOUND_INTRA	
} else {	
compound_type = COMPOUND_AVERAGE	
}	
}	
}	

5.11.30. Get mode function

get_mode(refList) {	Type
if (refList == 0) {	
if (YMode < NEAREST_NEARESTMV)	
compMode = YMode	
else if (YMode == NEW_NEWMV || YMode == NEW_NEARESTMV || YMode == NEW_NEARMV)	
compMode = NEWMV	
else if (YMode == NEAREST_NEARESTMV || YMode == NEAREST_NEWMV)	
compMode = NEARESTMV	
else if (YMode == NEAR_NEARMV || YMode == NEAR_NEWMV)	
compMode = NEARMV	
else	
compMode = GLOBALMV	
} else {	
if (YMode == NEW_NEWMV || YMode == NEAREST_NEWMV || YMode == NEAR_NEWMV)	
compMode = NEWMV	

```
        else if ( YMode == NEAREST_NEARESTMV || YMode == NEW_NEARESTMV )
            compMode = NEARESTMV
        else if ( YMode == NEAR_NEARMV || YMode == NEW_NEARMV )
            compMode = NEARMV
        else
            compMode = GLOBALMV
    }
    return compMode
}
```

5.11.31. MV syntax

read_mv(ref) {	Type
diffMv[0] = 0	
diffMv[1] = 0	
if (use_intrabc) {	
MvCtx = MV_INTRABC_CONTEXT	
} else {	
MvCtx = 0	
}	
mv_joint	S()
if (mv_joint == MV_JOINT_HZVNZ || mv_joint == MV_JOINT_HNZVNZ)	
diffMv[0] = read_mv_component(0)	
if (mv_joint == MV_JOINT_HNZVZ || mv_joint == MV_JOINT_HNZVNZ)	
diffMv[1] = read_mv_component(1)	
Mv[ref][0] = PredMv[ref][0] + diffMv[0]	
Mv[ref][1] = PredMv[ref][1] + diffMv[1]	
}	

5.11.32. MV component syntax

read_mv_component(comp) {	Type
mv_sign	S()
mv_class	S()
if (mv_class == MV_CLASS_0) {	
mv_class0_bit	S()
if (force_integer_mv)	
mv_class0_fr = 3	
else	
mv_class0_fr	S()
if (allow_high_precision_mv)	
mv_class0_hp	S()
else	
mv_class0_hp = 1	
mag = ((mv_class0_bit << 3) |	
(mv_class0_fr << 1) |	
mv_class0_hp) + 1	
} else {	
d = 0	
for (i = 0; i < mv_class; i++) {	

mv_bit	S()
d |= mv_bit << i	
}	
mag = CLASS0_SIZE << (mv_class + 2)	
if (force_integer_mv)	
mv_fr = 3	
else	
mv_fr	S()
if (allow_high_precision_mv)	
mv_hp	S()
else	
mv_hp = 1	
mag += ((d << 3) | (mv_fr << 1) | mv_hp) + 1	
}	
return mv_sign ? -mag : mag	
}	

5.11.33. Compute prediction syntax

compute_prediction() {	Type
sbMask = use_128x128_superblock ? 31 : 15	
subBlockMiRow = MiRow & sbMask	
subBlockMiCol = MiCol & sbMask	
for (plane = 0; plane < 1 + HasChroma * 2; plane++) {	
planeSz = get_plane_residual_size(MiSize, plane)	
num4x4W = Num_4x4_Blocks_Wide[planeSz]	
num4x4H = Num_4x4_Blocks_High[planeSz]	
log2W = MI_SIZE_LOG2 + Mi_Width_Log2[planeSz]	
log2H = MI_SIZE_LOG2 + Mi_Height_Log2[planeSz]	
subX = (plane > 0) ? subsampling_x : 0	
subY = (plane > 0) ? subsampling_y : 0	
baseX = (MiCol >> subX) * MI_SIZE	
baseY = (MiRow >> subY) * MI_SIZE	
candRow = (MiRow >> subY) << subY	
candCol = (MiCol >> subX) << subX	
IsInterIntra = (is_inter && RefFrame[1] == INTRA_FRAME)	
if (IsInterIntra) {	
if (interintra_mode == II_DC_PRED) mode = DC_PRED	
else if (interintra_mode == II_V_PRED) mode = V_PRED	
else if (interintra_mode == II_H_PRED) mode = H_PRED	
else mode = SMOOTH_PRED	
predict_intra(plane, baseX, baseY,	
plane == 0 ? AvailL : AvailLChroma,	
plane == 0 ? AvailU : AvailUChroma,	
BlockDecoded[plane]	
[(subBlockMiRow >> subY) - 1]	
[(subBlockMiCol >> subX) + num4x4W],	
BlockDecoded[plane]	

```
                                    [ ( subBlockMiRow >> subY ) + num4x4H ]
                                    [ ( subBlockMiCol >> subX ) - 1 ],
                            mode,
                            log2W, log2H )
        }
        if ( is_inter ) {
            predW = Block_Width[ MiSize ] >> subX
            predH = Block_Height[ MiSize ] >> subY
            someUseIntra = 0
            for ( r = 0; r < (num4x4H << subY); r++ )
                for ( c = 0; c < (num4x4W << subX); c++ )
                    if ( RefFrames[ candRow + r ][ candCol + c ][ 0 ] == INTRA_FRAME )
                        someUseIntra = 1
            if ( someUseIntra ) {
                predW = num4x4W * 4
                predH = num4x4H * 4
                candRow = MiRow
                candCol = MiCol
            }
            r = 0
            for ( y = 0; y < num4x4H * 4; y += predH ) {
                c = 0
                for ( x = 0; x < num4x4W * 4; x += predW ) {
                    predict_inter( plane, baseX + x, baseY + y,
                                   predW, predH,
                                   candRow + r, candCol + c)
                    c++
                }
                r++
            }
        }
    }
}
```

5.11.34. Residual syntax

residual( ) {	Type
sbMask = use_128x128_superblock ? 31 : 15	
widthChunks = Max(1, Block_Width[MiSize] >> 6)	
heightChunks = Max(1, Block_Height[MiSize] >> 6)	
miSizeChunk = (widthChunks > 1 || heightChunks > 1) ? BLOCK_64X64 : MiSize	
for (chunkY = 0; chunkY < heightChunks; chunkY++) {	
for (chunkX = 0; chunkX < widthChunks; chunkX++) {	
miRowChunk = MiRow + (chunkY << 4)	
miColChunk = MiCol + (chunkX << 4)	
subBlockMiRow = miRowChunk & sbMask	

```
            subBlockMiCol = miColChunk & sbMask

            for ( plane = 0; plane < 1 + HasChroma * 2; plane++ ) {
                txSz = Lossless ? TX_4X4 : get_tx_size( plane, TxSize )
                stepX = Tx_Width[ txSz ] >> 2
                stepY = Tx_Height[ txSz ] >> 2
                planeSz = get_plane_residual_size( miSizeChunk, plane )
                num4x4W = Num_4x4_Blocks_Wide[ planeSz ]
                num4x4H = Num_4x4_Blocks_High[ planeSz ]
                subX = (plane > 0) ? subsampling_x : 0
                subY = (plane > 0) ? subsampling_y : 0
                baseX = (miColChunk >> subX) * MI_SIZE
                baseY = (miRowChunk >> subY) * MI_SIZE
                if ( is_inter && !Lossless && !plane ) {
                    transform_tree( baseX, baseY, num4x4W * 4, num4x4H * 4 )
                } else {
                    baseXBlock = (MiCol >> subX) * MI_SIZE
                    baseYBlock = (MiRow >> subY) * MI_SIZE
                    for ( y = 0; y < num4x4H; y += stepY )
                        for ( x = 0; x < num4x4W; x += stepX )
                            transform_block( plane, baseXBlock, baseYBlock, txSz,
                                             x + ( ( chunkX << 4 ) >> subX ),
                                             y + ( ( chunkY << 4 ) >> subY ) )
                }
            }
        }
    }
}
```

5.11.35. Transform block syntax

```
transform_block(plane, baseX, baseY, txSz, x, y) {                    Type
    startX = baseX + 4 * x
    startY = baseY + 4 * y
    subX = (plane > 0) ? subsampling_x : 0
    subY = (plane > 0) ? subsampling_y : 0
    row = ( startY << subY ) >> MI_SIZE_LOG2
    col = ( startX << subX ) >> MI_SIZE_LOG2
    sbMask = use_128x128_superblock ? 31 : 15
    subBlockMiRow = row & sbMask
    subBlockMiCol = col & sbMask
    stepX = Tx_Width[ txSz ] >> MI_SIZE_LOG2
    stepY = Tx_Height[ txSz ] >> MI_SIZE_LOG2
    maxX = (MiCols * MI_SIZE) >> subX
    maxY = (MiRows * MI_SIZE) >> subY
    if ( startX >= maxX || startY >= maxY ) {
        return
    }
    if ( !is_inter ) {
```

```
        if ( ( ( plane == 0 ) && PaletteSizeY ) ||
             ( ( plane != 0 ) && PaletteSizeUV ) ) {
            predict_palette( plane, startX, startY, x, y, txSz )
        } else {
            isCfl = (plane > 0 && UVMode == UV_CFL_PRED)
            if ( plane == 0 ) {
                mode = YMode
            } else {
                mode = ( isCfl ) ? DC_PRED : UVMode
            }
            log2W = Tx_Width_Log2[ txSz ]
            log2H = Tx_Height_Log2[ txSz ]
            predict_intra( plane, startX, startY,
                           ( plane == 0 ? AvailL : AvailLChroma ) || x > 0,
                           ( plane == 0 ? AvailU : AvailUChroma ) || y > 0,
                           BlockDecoded[ plane ]
                                        [ ( subBlockMiRow >> subY ) - 1 ]
                                        [ ( subBlockMiCol >> subX ) + stepX ],
                           BlockDecoded[ plane ]
                                        [ ( subBlockMiRow >> subY ) + stepY ]
                                        [ ( subBlockMiCol >> subX ) - 1 ],
                           mode,
                           log2W, log2H )
            if ( isCfl ) {
                predict_chroma_from_luma( plane, startX, startY, txSz )
            }
        }

        if ( plane == 0 ) {
            MaxLumaW = startX + stepX * 4
            MaxLumaH = startY + stepY * 4
        }
    }
    if ( !skip ) {
        eob = coeffs( plane, startX, startY, txSz )
        if ( eob > 0 )
            reconstruct( plane, startX, startY, txSz )
    }
    for ( i = 0; i < stepY; i++ ) {
        for ( j = 0; j < stepX; j++ ) {
            LoopfilterTxSizes[ plane ]
                              [ (row >> subY) + i ]
                              [ (col >> subX) + j ] = txSz
            BlockDecoded[ plane ]
                        [ ( subBlockMiRow >> subY ) + i ]
                        [ ( subBlockMiCol >> subX ) + j ] = 1
        }
    }
}
```

5.11.36. Transform tree syntax

transform_tree is used to read a number of transform blocks arranged in a transform tree.

transform_tree(startX, startY, w, h) {	Type
maxX = MiCols * MI_SIZE	
maxY = MiRows * MI_SIZE	
if (startX >= maxX || startY >= maxY) {	
return	
}	
row = startY >> MI_SIZE_LOG2	
col = startX >> MI_SIZE_LOG2	
lumaTxSz = InterTxSizes[row][col]	
lumaW = Tx_Width[lumaTxSz]	
lumaH = Tx_Height[lumaTxSz]	
if (w <= lumaW && h <= lumaH) {	
txSz = find_tx_size(w, h)	
transform_block(0, startX, startY, txSz, 0, 0)	
} else {	
if (w > h) {	
transform_tree(startX, startY, w/2, h)	
transform_tree(startX + w / 2, startY, w/2, h)	
} else if (w < h) {	
transform_tree(startX, startY, w, h/2)	
transform_tree(startX, startY + h/2, w, h/2)	
} else {	
transform_tree(startX, startY, w/2, h/2)	
transform_tree(startX + w/2, startY, w/2, h/2)	
transform_tree(startX, startY + h/2, w/2, h/2)	
transform_tree(startX + w/2, startY + h/2, w/2, h/2)	
}	
}	
}	

where find_tx_size finds the transform size matching the given dimensions and is defined as:

```
find_tx_size( w, h ) {
    for ( txSz = 0; txSz < TX_SIZES_ALL; txSz++ )
        if ( Tx_Width[ txSz ] == w && Tx_Height[ txSz ] == h )
            break
    return txSz
}
```

5.11.37. Get TX size function

get_tx_size(plane, txSz) {	Type
if (plane == 0)	
return txSz	

```
    uvTx = Max_Tx_Size_Rect[ get_plane_residual_size( MiSize, plane ) ]
    if ( Tx_Width[ uvTx ] == 64 || Tx_Height[ uvTx ] == 64 ){
        if ( Tx_Width[ uvTx ] == 16 ) {
            return TX_16X32
        }
        if ( Tx_Height[ uvTx ] == 16 ) {
            return TX_32X16
        }
        return TX_32X32
    }
    return uvTx
}
```

5.11.38. Get plane residual size function

The get_plane_residual_size returns the size of a residual block for the specified plane. (The residual block will always have width and height at least equal to 4.)

```
get_plane_residual_size( subsize, plane ) {
    subx = plane > 0 ? subsampling_x : 0
    suby = plane > 0 ? subsampling_y : 0
    return Subsampled_Size[ subsize ][ subx ][ suby ]
}
```

Type

The Subsampled_Size table is defined as:

```
Subsampled_Size[ BLOCK_SIZES ][ 2 ][ 2 ] = {
  { { BLOCK_4X4,    BLOCK_4X4},      {BLOCK_4X4,     BLOCK_4X4} },
  { { BLOCK_4X8,    BLOCK_4X4},      {BLOCK_INVALID, BLOCK_4X4} },
  { { BLOCK_8X4,    BLOCK_INVALID},  {BLOCK_4X4,     BLOCK_4X4} },
  { { BLOCK_8X8,    BLOCK_8X4},      {BLOCK_4X8,     BLOCK_4X4} },
  { {BLOCK_8X16,    BLOCK_8X8},      {BLOCK_INVALID, BLOCK_4X8} },
  { {BLOCK_16X8,    BLOCK_INVALID},  {BLOCK_8X8,     BLOCK_8X4} },
  { {BLOCK_16X16,   BLOCK_16X8},     {BLOCK_8X16,    BLOCK_8X8} },
  { {BLOCK_16X32,   BLOCK_16X16},    {BLOCK_INVALID, BLOCK_8X16} },
  { {BLOCK_32X16,   BLOCK_INVALID},  {BLOCK_16X16,   BLOCK_16X8} },
  { {BLOCK_32X32,   BLOCK_32X16},    {BLOCK_16X32,   BLOCK_16X16} },
  { {BLOCK_32X64,   BLOCK_32X32},    {BLOCK_INVALID, BLOCK_16X32} },
  { {BLOCK_64X32,   BLOCK_INVALID},  {BLOCK_32X32,   BLOCK_32X16} },
  { {BLOCK_64X64,   BLOCK_64X32},    {BLOCK_32X64,   BLOCK_32X32} },
  { {BLOCK_64X128,  BLOCK_64X64},    {BLOCK_INVALID, BLOCK_32X64} },
  { {BLOCK_128X64,  BLOCK_INVALID},  {BLOCK_64X64,   BLOCK_64X32} },
  { {BLOCK_128X128, BLOCK_128X64},   {BLOCK_64X128,  BLOCK_64X64} },
  { {BLOCK_4X16,    BLOCK_4X8},      {BLOCK_INVALID, BLOCK_4X8} },
  { {BLOCK_16X4,    BLOCK_INVALID},  {BLOCK_8X4,     BLOCK_8X4} },
  { {BLOCK_8X32,    BLOCK_8X16},     {BLOCK_INVALID, BLOCK_4X16} },
  { {BLOCK_32X8,    BLOCK_INVALID},  {BLOCK_16X8,    BLOCK_16X4} },
  { {BLOCK_16X64,   BLOCK_16X32},    {BLOCK_INVALID, BLOCK_8X32} },
  { {BLOCK_64X16,   BLOCK_INVALID},  {BLOCK_32X16,   BLOCK_32X8} },
}
```

5.11.39. Coefficients syntax

coeffs(plane, startX, startY, txSz) {	Type
x4 = startX >> 2	
y4 = startY >> 2	
w4 = Tx_Width[txSz] >> 2	
h4 = Tx_Height[txSz] >> 2	
txSzCtx = (Tx_Size_Sqr[txSz] + Tx_Size_Sqr_Up[txSz] + 1) >> 1	
ptype = plane > 0	
segEob = (txSz == TX_16X64 || txSz == TX_64X16) ? 512 :	
Min(1024, Tx_Width[txSz] * Tx_Height[txSz])	
for (c = 0; c < segEob; c++)	
Quant[c] = 0	
for (i = 0; i < 64; i++)	
for (j = 0; j < 64; j++)	
Dequant[i][j] = 0	
eob = 0	
culLevel = 0	
dcCategory = 0	
all_zero	S()

if (all_zero) {	
c = 0	
if (plane == 0) {	
for (i = 0; i < w4; i++) {	
for (j = 0; j < h4; j++) {	
TxTypes[y4 + j][x4 + i] = DCT_DCT	
}	
}	
}	
} else {	
if (plane == 0)	
transform_type(x4, y4, txSz)	
PlaneTxType = compute_tx_type(plane, txSz, x4, y4)	
scan = get_scan(txSz)	
eobMultisize = Min(Tx_Width_Log2[txSz], 5) + Min(Tx_Height_Log2[txSz], 5) - 4	
if (eobMultisize == 0) {	
eob_pt_16	S()
eobPt = eob_pt_16 + 1	
} else if (eobMultisize == 1) {	
eob_pt_32	S()
eobPt = eob_pt_32 + 1	
} else if (eobMultisize == 2) {	
eob_pt_64	S()
eobPt = eob_pt_64 + 1	
} else if (eobMultisize == 3) {	
eob_pt_128	S()
eobPt = eob_pt_128 + 1	
} else if (eobMultisize == 4) {	
eob_pt_256	S()
eobPt = eob_pt_256 + 1	
} else if (eobMultisize == 5) {	
eob_pt_512	S()
eobPt = eob_pt_512 + 1	
} else {	
eob_pt_1024	S()
eobPt = eob_pt_1024 + 1	
}	
eob = (eobPt < 2) ? eobPt : ((1 << (eobPt - 2)) + 1)	
eobShift = Max(-1, eobPt - 3)	
if (eobShift >= 0) {	
eob_extra	S()
if (eob_extra) {	
eob += (1 << eobShift)	
}	
for (i = 1; i < Max(0, eobPt - 2); i++) {	
eobShift = Max(0, eobPt - 2) - 1 - i	

eob_extra_bit	L(1)
if (eob_extra_bit) {	
eob += (1 << eobShift)	
}	
}	
}	
for (c = eob - 1; c >= 0; c--) {	
pos = scan[c]	
if (c == (eob - 1)) {	
coeff_base_eob	S()
level = coeff_base_eob + 1	
} else {	
coeff_base	S()
level = coeff_base	
}	
if (level > NUM_BASE_LEVELS) {	
for (idx = 0;	
idx < COEFF_BASE_RANGE / (BR_CDF_SIZE - 1);	
idx++) {	
coeff_br	S()
level += coeff_br	
if (coeff_br < (BR_CDF_SIZE - 1))	
break	
}	
}	
Quant[pos] = level	
}	
for (c = 0; c < eob; c++) {	
pos = scan[c]	
if (Quant[pos] != 0) {	
if (c == 0) {	
dc_sign	S()
sign = dc_sign	
} else {	
sign_bit	L(1)
sign = sign_bit	
}	
} else {	
sign = 0	
}	
if (Quant[pos] >	
(NUM_BASE_LEVELS + COEFF_BASE_RANGE)) {	
length = 0	
do {	
length++	
golomb_length_bit	L(1)
} while (!golomb_length_bit)	

```
                x = 1                                                                   
                for ( i = length - 2; i >= 0; i-- ) {                                   
                    golomb_data_bit                                                     L(1)
                    x = ( x << 1 ) | golomb_data_bit                                    
                }                                                                       
               Quant[ pos ] = x + COEFF_BASE_RANGE + NUM_BASE_LEVELS                    
            }                                                                           
            if ( pos == 0 && Quant[ pos ] > 0 ) {                                       
                dcCategory = sign ? 1 : 2                                               
            }                                                                           
            Quant[ pos ] = Quant[ pos ] & 0xFFFFF                                       
            culLevel += Quant[ pos ]                                                    
            if ( sign )                                                                 
                Quant[ pos ] = - Quant[ pos ]                                           
        }                                                                               
        culLevel = Min( 63, culLevel )                                                  
    }                                                                                   
                                                                                        
    for ( i = 0; i < w4; i++ ) {                                                        
        AboveLevelContext[ plane ][ x4 + i ] = culLevel                                 
        AboveDcContext[ plane ][ x4 + i ] = dcCategory                                  
    }                                                                                   
    for ( i = 0; i < h4; i++ ) {                                                        
        LeftLevelContext[ plane ][ y4 + i ] = culLevel                                  
        LeftDcContext[ plane ][ y4 + i ] = dcCategory                                   
    }                                                                                   
                                                                                        
    return eob                                                                          
}                                                                                       
```

5.11.40. Compute transform type function

```
compute_tx_type( plane, txSz, blockX, blockY ) {                                        Type
    txSzSqrUp = Tx_Size_Sqr_Up[ txSz ]                                                  
                                                                                        
    if ( Lossless || txSzSqrUp > TX_32X32 )                                             
        return DCT_DCT                                                                  
                                                                                        
    txSet = get_tx_set( txSz )                                                          
                                                                                        
    if ( plane == 0 ) {                                                                 
        return TxTypes[ blockY ][ blockX ]                                              
    }                                                                                   
                                                                                        
    if ( is_inter ) {                                                                   
        x4 = Max( MiCol, blockX << subsampling_x )                                      
        y4 = Max( MiRow, blockY << subsampling_y )                                      
        txType = TxTypes[ y4 ][ x4 ]                                                    
        if ( !is_tx_type_in_set( txSet, txType ) )                                      
```

```
            return DCT_DCT
        return txType
    }

    txType = Mode_To_Txfm[ UVMode ]
    if ( !is_tx_type_in_set( txSet, txType ) )
        return DCT_DCT
    return txType
}

is_tx_type_in_set( txSet, txType ) {
    return is_inter ? Tx_Type_In_Set_Inter[ txSet ][ txType ] :
                      Tx_Type_In_Set_Intra[ txSet ][ txType ]
}
```

where the tables Tx_Type_In_Set_Inter and Tx_Type_In_Set_Intra are specified as follows:

```
Tx_Type_In_Set_Intra[ TX_SET_TYPES_INTRA ][ TX_TYPES ] = {
  {
    1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
  },
  {
    1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0, 0,
  },
  {
    1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0,
  }
}

Tx_Type_In_Set_Inter[ TX_SET_TYPES_INTER ][ TX_TYPES ] = {
  {
    1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
  },
  {
    1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
  },
  {
    1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0,
  },
  {
    1, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0,
  }
}
```

5.11.41. Get scan function

get_mrow_scan(txSz) {	Type
if (txSz == TX_4X4)	
return Mrow_Scan_4x4	

```
    else if ( txSz == TX_4X8 )
        return Mrow_Scan_4x8
    else if ( txSz == TX_8X4 )
        return Mrow_Scan_8x4
    else if ( txSz == TX_8X8 )
        return Mrow_Scan_8x8
    else if ( txSz == TX_8X16 )
        return Mrow_Scan_8x16
    else if ( txSz == TX_16X8 )
        return Mrow_Scan_16x8
    else if ( txSz == TX_16X16 )
        return Mrow_Scan_16x16
    else if ( txSz == TX_4X16 )
        return Mrow_Scan_4x16
    return Mrow_Scan_16x4
}

get_mcol_scan( txSz ) {
    if ( txSz == TX_4X4 )
        return Mcol_Scan_4x4
    else if ( txSz == TX_4X8 )
        return Mcol_Scan_4x8
    else if ( txSz == TX_8X4 )
        return Mcol_Scan_8x4
    else if ( txSz == TX_8X8 )
        return Mcol_Scan_8x8
    else if ( txSz == TX_8X16 )
        return Mcol_Scan_8x16
    else if ( txSz == TX_16X8 )
        return Mcol_Scan_16x8
    else if ( txSz == TX_16X16 )
        return Mcol_Scan_16x16
    else if ( txSz == TX_4X16 )
        return Mcol_Scan_4x16
    return Mcol_Scan_16x4
}

get_default_scan( txSz ) {
    if ( txSz == TX_4X4 )
        return Default_Scan_4x4
    else if ( txSz == TX_4X8 )
        return Default_Scan_4x8
    else if ( txSz == TX_8X4 )
        return Default_Scan_8x4
    else if ( txSz == TX_8X8 )
        return Default_Scan_8x8
    else if ( txSz == TX_8X16 )
        return Default_Scan_8x16
    else if ( txSz == TX_16X8 )
```

```
        return Default_Scan_16x8
    else if ( txSz == TX_16X16 )
        return Default_Scan_16x16
    else if ( txSz == TX_16X32 )
        return Default_Scan_16x32
    else if ( txSz == TX_32X16 )
        return Default_Scan_32x16
    else if ( txSz == TX_4X16 )
        return Default_Scan_4x16
    else if ( txSz == TX_16X4 )
        return Default_Scan_16x4
    else if ( txSz == TX_8X32 )
        return Default_Scan_8x32
    else if ( txSz == TX_32X8 )
        return Default_Scan_32x8
    return Default_Scan_32x32
}

get_scan( txSz ) {
    if ( txSz == TX_16X64 ) {
        return Default_Scan_16x32
    }
    if ( txSz == TX_64X16 ) {
        return Default_Scan_32x16
    }
    if ( Tx_Size_Sqr_Up[ txSz ] == TX_64X64 ) {
        return Default_Scan_32x32
    }

    if ( PlaneTxType == IDTX ) {
        return get_default_scan( txSz )
    }

    preferRow = ( PlaneTxType == V_DCT ||
                  PlaneTxType == V_ADST ||
                  PlaneTxType == V_FLIPADST )

    preferCol = ( PlaneTxType == H_DCT ||
                  PlaneTxType == H_ADST ||
                  PlaneTxType == H_FLIPADST )

    if ( preferRow ) {
        return get_mrow_scan( txSz )
    } else if ( preferCol ) {
        return get_mcol_scan( txSz )
    }
    return get_default_scan( txSz )
}
```

5.11.42. Intra angle info luma syntax

intra_angle_info_y( ) {	Type
AngleDeltaY = 0	
if (MiSize >= BLOCK_8X8) {	
if (is_directional_mode(YMode)) {	
angle_delta_y	S()
AngleDeltaY = angle_delta_y - MAX_ANGLE_DELTA	
}	
}	
}	

5.11.43. Intra angle info chroma syntax

intra_angle_info_uv( ) {	Type
AngleDeltaUV = 0	
if (MiSize >= BLOCK_8X8) {	
if (is_directional_mode(UVMode)) {	
angle_delta_uv	S()
AngleDeltaUV = angle_delta_uv - MAX_ANGLE_DELTA	
}	
}	
}	

5.11.44. Is directional mode function

is_directional_mode(mode) {	Type
if ((mode >= V_PRED) && (mode <= D67_PRED)) {	
return 1	
}	
return 0	
}	

5.11.45. Read CFL alphas syntax

read_cfl_alphas() {	Type
cfl_alpha_signs	S()
signU = (cfl_alpha_signs + 1) / 3	
signV = (cfl_alpha_signs + 1) % 3	
if (signU != CFL_SIGN_ZERO) {	
cfl_alpha_u	S()
CflAlphaU = 1 + cfl_alpha_u	
if (signU == CFL_SIGN_NEG)	
CflAlphaU = -CflAlphaU	
} else {	
CflAlphaU = 0	
}	
if (signV != CFL_SIGN_ZERO) {	
cfl_alpha_v	S()
CflAlphaV = 1 + cfl_alpha_v	

if (signV == CFL_SIGN_NEG)	
CflAlphaV = -CflAlphaV	
} else {	
CflAlphaV = 0	
}	

5.11.46. Palette mode info syntax

palette_mode_info( ) {	Type
bsizeCtx = Mi_Width_Log2[MiSize] + Mi_Height_Log2[MiSize] - 2	
if (YMode == DC_PRED) {	
has_palette_y	S()
if (has_palette_y) {	
palette_size_y_minus_2	S()
PaletteSizeY = palette_size_y_minus_2 + 2	
cacheN = get_palette_cache(0)	
idx = 0	
for (i = 0; i < cacheN && idx < PaletteSizeY; i++) {	
use_palette_color_cache_y	L(1)
if (use_palette_color_cache_y) {	
palette_colors_y[idx] = PaletteCache[i]	
idx++	
}	
}	
if (idx < PaletteSizeY) {	
palette_colors_y[idx]	L(BitDepth)
idx++	
}	
if (idx < PaletteSizeY) {	
minBits = BitDepth - 3	
palette_num_extra_bits_y	L(2)
paletteBits = minBits + palette_num_extra_bits_y	
}	
while (idx < PaletteSizeY) {	
palette_delta_y	L(paletteBits)
palette_delta_y++	
palette_colors_y[idx] =	
Clip1(palette_colors_y[idx - 1] +	
palette_delta_y)	
range = (1 << BitDepth) - palette_colors_y[idx] - 1	
paletteBits = Min(paletteBits, CeilLog2(range))	
idx++	
}	
sort(palette_colors_y, 0, PaletteSizeY - 1)	
}	
}	
if (HasChroma && UVMode == DC_PRED) {	
has_palette_uv	S()
if (has_palette_uv) {	

palette_size_uv_minus_2	S()
PaletteSizeUV = palette_size_uv_minus_2 + 2	
cacheN = get_palette_cache(1)	
idx = 0	
for (i = 0; i < cacheN && idx < PaletteSizeUV; i++) {	
use_palette_color_cache_u	L(1)
if (use_palette_color_cache_u) {	
palette_colors_u[idx] = PaletteCache[i]	
idx++	
}	
}	
if (idx < PaletteSizeUV) {	
palette_colors_u[idx]	L(BitDepth)
idx++	
}	
if (idx < PaletteSizeUV) {	
minBits = BitDepth - 3	
palette_num_extra_bits_u	L(2)
paletteBits = minBits + palette_num_extra_bits_u	
}	
while (idx < PaletteSizeUV) {	
palette_delta_u	L(paletteBits)
palette_colors_u[idx] =	
Clip1(palette_colors_u[idx - 1] +	
palette_delta_u)	
range = (1 << BitDepth) - palette_colors_u[idx]	
paletteBits = Min(paletteBits, CeilLog2(range))	
idx++	
}	
sort(palette_colors_u, 0, PaletteSizeUV - 1)	
delta_encode_palette_colors_v	L(1)
if (delta_encode_palette_colors_v) {	
minBits = BitDepth - 4	
maxVal = 1 << BitDepth	
palette_num_extra_bits_v	L(2)
paletteBits = minBits + palette_num_extra_bits_v	
palette_colors_v[0]	L(BitDepth)
for (idx = 1; idx < PaletteSizeUV; idx++) {	
palette_delta_v	L(paletteBits)
if (palette_delta_v) {	
palette_delta_sign_bit_v	L(1)
if (palette_delta_sign_bit_v) {	
palette_delta_v = -palette_delta_v	
}	
}	
val = palette_colors_v[idx - 1] + palette_delta_v	
if (val < 0) val += maxVal	
if (val >= maxVal) val -= maxVal	

```
                    palette_colors_v[ idx ] = Clip1( val )
                }
            } else {
                for ( idx = 0; idx < PaletteSizeUV; idx++ ) {
                    palette_colors_v[ idx ]                    L(BitDepth)
                }
            }
        }
    }
}
```

The function sort(arr, i1, i2) sorts a subarray of the array arr in-place into ascending order. The subarray to be sorted is between indices i1 and i2 inclusive.

> **Note:** The palette colors are generated in ascending order. The palette cache is also in ascending order. This means that the sort function can be replaced in implementations by a merge of two sorted lists.

where the function get_palette_cache, which merges the above and left palettes to form a cache, is specified as follows:

```
get_palette_cache( plane ) {                                   Type
    aboveN = 0
    if ( ( MiRow * MI_SIZE ) % 64 ) {
        aboveN = PaletteSizes[ plane ][ MiRow - 1 ][ MiCol ]
    }
    leftN = 0
    if ( AvailL ) {
        leftN = PaletteSizes[ plane ][ MiRow ][ MiCol - 1 ]
    }
    aboveIdx = 0
    leftIdx = 0
    n = 0
    while ( aboveIdx < aboveN  && leftIdx < leftN ) {
        aboveC = PaletteColors[ plane ][ MiRow - 1 ][ MiCol ][ aboveIdx ]
        leftC = PaletteColors[ plane ][ MiRow ][ MiCol - 1 ][ leftIdx ]
        if ( leftC < aboveC ) {
            if ( n == 0 || leftC != PaletteCache[ n - 1 ] ) {
                PaletteCache[ n ] = leftC
                n++
            }
            leftIdx++
        } else {
            if ( n == 0 || aboveC != PaletteCache[ n - 1 ] ) {
                PaletteCache[ n ] = aboveC
                n++
            }
            aboveIdx++
            if ( leftC == aboveC ) {
                leftIdx++
```

```
            }
        }
    }
    while ( aboveIdx < aboveN ) {
        val = PaletteColors[ plane ][ MiRow - 1 ][ MiCol ][ aboveIdx ]
        aboveIdx++
        if ( n == 0 || val != PaletteCache[ n - 1 ] ) {
            PaletteCache[ n ] = val
            n++
        }
    }
    while ( leftIdx < leftN ) {
        val = PaletteColors[ plane ][ MiRow ][ MiCol - 1 ][ leftIdx ]
        leftIdx++
        if ( n == 0 || val != PaletteCache[ n - 1 ] ) {
            PaletteCache[ n ] = val
            n++
        }
    }
    return n
}
```

Note: get_palette_cache is equivalent to sorting the available palette colors from above and left together and removing any duplicates.

5.11.47. Transform type syntax

transform_type(x4, y4, txSz) {	Type
set = get_tx_set(txSz)	
if (set > 0 &&	
(segmentation_enabled ? get_qindex(1, segment_id) : base_q_idx) > 0) {	
if (is_inter) {	
inter_tx_type	S()
if (set == TX_SET_INTER_1)	
TxType = Tx_Type_Inter_Inv_Set1[inter_tx_type]	
else if (set == TX_SET_INTER_2)	
TxType = Tx_Type_Inter_Inv_Set2[inter_tx_type]	
else	
TxType = Tx_Type_Inter_Inv_Set3[inter_tx_type]	
} else {	
intra_tx_type	S()
if (set == TX_SET_INTRA_1)	
TxType = Tx_Type_Intra_Inv_Set1[intra_tx_type]	
else	
TxType = Tx_Type_Intra_Inv_Set2[intra_tx_type]	
}	
} else {	

```
        TxType = DCT_DCT
    }
    for ( i = 0; i < ( Tx_Width[ txSz ] >> 2 ); i++ ) {
        for ( j = 0; j < ( Tx_Height[ txSz ] >> 2 ); j++ ) {
            TxTypes[ y4 + j ][ x4 + i ] = TxType
        }
    }
}
```

where the inversion tables used in the function are specified as follows:

```
Tx_Type_Intra_Inv_Set1[ 7 ]  = { IDTX, DCT_DCT, V_DCT, H_DCT, ADST_ADST, ADST_DCT, DCT_ADST }
Tx_Type_Intra_Inv_Set2[ 5 ]  = { IDTX, DCT_DCT, ADST_ADST, ADST_DCT, DCT_ADST }
Tx_Type_Inter_Inv_Set1[ 16 ] = { IDTX, V_DCT, H_DCT, V_ADST, H_ADST, V_FLIPADST, H_FLIPADST,
                                 DCT_DCT, ADST_DCT, DCT_ADST, FLIPADST_DCT, DCT_FLIPADST, ADST_ADST,
                                 FLIPADST_FLIPADST, ADST_FLIPADST, FLIPADST_ADST }
Tx_Type_Inter_Inv_Set2[ 12 ] = { IDTX, V_DCT, H_DCT, DCT_DCT, ADST_DCT, DCT_ADST, FLIPADST_DCT,
                                 DCT_FLIPADST, ADST_ADST, FLIPADST_FLIPADST, ADST_FLIPADST,
                                 FLIPADST_ADST }
Tx_Type_Inter_Inv_Set3[ 2 ]  = { IDTX, DCT_DCT }
```

5.11.48. Get transform set function

get_tx_set(txSz) {	Type
txSzSqr = Tx_Size_Sqr[txSz]	
txSzSqrUp = Tx_Size_Sqr_Up[txSz]	
if (txSzSqrUp > TX_32X32)	
return TX_SET_DCTONLY	
if (is_inter) {	
if (reduced_tx_set || txSzSqrUp == TX_32X32) return TX_SET_INTER_3	
else if (txSzSqr == TX_16X16) return TX_SET_INTER_2	
return TX_SET_INTER_1	
} else {	
if (txSzSqrUp == TX_32X32) return TX_SET_DCTONLY	
else if (reduced_tx_set) return TX_SET_INTRA_2	
else if (txSzSqr == TX_16X16) return TX_SET_INTRA_2	
return TX_SET_INTRA_1	
}	
}	

5.11.49. Palette tokens syntax

palette_tokens( ) {	Type
blockHeight = Block_Height[MiSize]	
blockWidth = Block_Width[MiSize]	
onscreenHeight = Min(blockHeight, (MiRows - MiRow) * MI_SIZE)	
onscreenWidth = Min(blockWidth, (MiCols - MiCol) * MI_SIZE)	

if (PaletteSizeY) {	
color_index_map_y	NS(PaletteSizeY)
ColorMapY[0][0] = color_index_map_y	
for (i = 1; i < onscreenHeight + onscreenWidth - 1; i++) {	
for (j = Min(i, onscreenWidth - 1);	
j >= Max(0, i - onscreenHeight + 1); j--) {	
get_palette_color_context(	
ColorMapY, (i - j), j, PaletteSizeY)	
palette_color_idx_y	S()
ColorMapY[i - j][j] = ColorOrder[palette_color_idx_y]	
}	
}	
for (i = 0; i < onscreenHeight; i++) {	
for (j = onscreenWidth; j < blockWidth; j++) {	
ColorMapY[i][j] = ColorMapY[i][onscreenWidth - 1]	
}	
}	
for (i = onscreenHeight; i < blockHeight; i++) {	
for (j = 0; j < blockWidth; j++) {	
ColorMapY[i][j] = ColorMapY[onscreenHeight - 1][j]	
}	
}	
}	
if (PaletteSizeUV) {	
color_index_map_uv	NS(PaletteSizeUV)
ColorMapUV[0][0] = color_index_map_uv	
blockHeight = blockHeight >> subsampling_y	
blockWidth = blockWidth >> subsampling_x	
onscreenHeight = onscreenHeight >> subsampling_y	
onscreenWidth = onscreenWidth >> subsampling_x	
if (blockWidth < 4) {	
blockWidth += 2	
onscreenWidth += 2	
}	
if (blockHeight < 4) {	
blockHeight += 2	
onscreenHeight += 2	
}	
for (i = 1; i < onscreenHeight + onscreenWidth - 1; i++) {	
for (j = Min(i, onscreenWidth - 1);	
j >= Max(0, i - onscreenHeight + 1); j--) {	
get_palette_color_context(	
ColorMapUV, (i - j), j, PaletteSizeUV)	
palette_color_idx_uv	S()
ColorMapUV[i - j][j] = ColorOrder[palette_color_idx_uv]	
}	
}	

```
        for ( i = 0; i < onscreenHeight; i++ ) {
            for ( j = onscreenWidth; j < blockWidth; j++ ) {
                ColorMapUV[ i ][ j ] = ColorMapUV[ i ][ onscreenWidth - 1 ]
            }
        }
        for ( i = onscreenHeight; i < blockHeight; i++ ) {
            for ( j = 0; j < blockWidth; j++ ) {
                ColorMapUV[ i ][ j ] = ColorMapUV[ onscreenHeight - 1 ][ j ]
            }
        }
    }
}
```

5.11.50. Palette color context function

get_palette_color_context(colorMap, r, c, n) {	Type
`    for ( i = 0; i < PALETTE_COLORS; i++ ) {`	
`        scores[ i ] = 0`	
`        ColorOrder[i] = i`	
`    }`	
`    if ( c > 0 ) {`	
`        neighbor = colorMap[ r ][ c - 1 ]`	
`        scores[ neighbor ] += 2`	
`    }`	
`    if ( ( r > 0 ) && ( c > 0 ) ) {`	
`        neighbor = colorMap[ r - 1 ][ c - 1 ]`	
`        scores[ neighbor ] += 1`	
`    }`	
`    if ( r > 0 ) {`	
`        neighbor = colorMap[ r - 1 ][ c ]`	
`        scores[ neighbor ] += 2`	
`    }`	
`    for ( i = 0; i < PALETTE_NUM_NEIGHBORS; i++ ) {`	
`        maxScore = scores[ i ]`	
`        maxIdx = i`	
`        for ( j = i + 1; j < n; j++ ) {`	
`            if ( scores[ j ] > maxScore ) {`	
`                maxScore = scores[ j ]`	
`                maxIdx = j`	
`            }`	
`        }`	
`        if ( maxIdx != i ) {`	
`            maxScore = scores[ maxIdx ]`	
`            maxColorOrder = ColorOrder[ maxIdx ]`	
`            for ( k = maxIdx; k > i; k-- ) {`	
`                scores[ k ] = scores[ k - 1 ]`	
`                ColorOrder[ k ] = ColorOrder[ k - 1 ]`	
`            }`	
`            scores[ i ] = maxScore`	

```
            ColorOrder[ i ] = maxColorOrder
        }
    }
    ColorContextHash = 0
    for ( i = 0; i < PALETTE_NUM_NEIGHBORS; i++ ) {
        ColorContextHash += scores[ i ] * Palette_Color_Hash_Multipliers[ i ]
    }
}
```

5.11.51. Is inside function

is_inside determines whether a candidate position is inside the current tile.

```
is_inside( candidateR, candidateC ) {                    Type
    return ( candidateC >= MiColStart &&
             candidateC < MiColEnd &&
             candidateR >= MiRowStart &&
             candidateR < MiRowEnd )
}
```

5.11.52. Is inside filter region function

is_inside_filter_region determines whether a candidate position is inside the region that is being used for CDEF filtering.

```
is_inside_filter_region( candidateR, candidateC ) {      Type
    colStart = 0
    colEnd = MiCols
    rowStart = 0
    rowEnd = MiRows
    return (candidateC >= colStart &&
            candidateC < colEnd &&
            candidateR >= rowStart &&
            candidateR < rowEnd)
}
```

5.11.53. Clamp MV row function

```
clamp_mv_row( mvec, border ) {                           Type
    bh4 = Num_4x4_Blocks_High[ MiSize ]
    mbToTopEdge = -((MiRow * MI_SIZE) * 8)
    mbToBottomEdge = ((MiRows - bh4 - MiRow) * MI_SIZE) * 8
    return Clip3( mbToTopEdge - border, mbToBottomEdge + border, mvec )
}
```

5.11.54. Clamp MV col function

```
clamp_mv_col( mvec, border ) {                           Type
    bw4 = Num_4x4_Blocks_Wide[ MiSize ]
    mbToLeftEdge = -((MiCol * MI_SIZE) * 8)
    mbToRightEdge = ((MiCols - bw4 - MiCol) * MI_SIZE) * 8
```

```
    return Clip3( mbToLeftEdge - border, mbToRightEdge + border, mvec )
}
```

5.11.55. Clear CDEF function

```
clear_cdef( r, c ) {                                                    Type
    cdef_idx[ r ][ c ] = -1
    if ( use_128x128_superblock ) {
        cdefSize4 = Num_4x4_Blocks_Wide[ BLOCK_64X64 ]
        cdef_idx[ r ][ c + cdefSize4 ] = -1
        cdef_idx[ r + cdefSize4][ c ] = -1
        cdef_idx[ r + cdefSize4][ c + cdefSize4 ] = -1
    }
}
```

5.11.56. Read CDEF syntax

```
read_cdef( ) {                                                          Type
    if ( skip || CodedLossless || !enable_cdef || allow_intrabc) {
        return
    }
    cdefSize4 = Num_4x4_Blocks_Wide[ BLOCK_64X64 ]
    cdefMask4 = ~(cdefSize4 - 1)
    r = MiRow & cdefMask4
    c = MiCol & cdefMask4
    if ( cdef_idx[ r ][ c ] == -1 ) {
        cdef_idx[ r ][ c ]                                              L(cdef_bits)
        w4 = Num_4x4_Blocks_Wide[ MiSize ]
        h4 = Num_4x4_Blocks_High[ MiSize ]
        for ( i = r; i < r + h4 ; i += cdefSize4 ) {
            for ( j = c; j < c + w4 ; j += cdefSize4 ) {
                cdef_idx[ i ][ j ] = cdef_idx[ r ][ c ]
            }
        }
    }
}
```

5.11.57. Read loop restoration syntax

```
read_lr( r, c, bSize ) {                                                Type
    if ( allow_intrabc ) {
        return
    }
    w = Num_4x4_Blocks_Wide[ bSize ]
    h = Num_4x4_Blocks_High[ bSize ]
    for ( plane = 0; plane < NumPlanes; plane++ ) {
        if ( FrameRestorationType[ plane ] != RESTORE_NONE ) {
            subX = (plane == 0) ? 0 : subsampling_x
            subY = (plane == 0) ? 0 : subsampling_y
            unitSize = LoopRestorationSize[ plane ]
```

```
            unitRows = count_units_in_frame( unitSize, Round2( FrameHeight, subY) )
            unitCols = count_units_in_frame( unitSize, Round2( UpscaledWidth, subX) )
            unitRowStart = ( r * ( MI_SIZE >> subY) +
                                    unitSize - 1 ) / unitSize
            unitRowEnd = Min( unitRows, ( (r + h) * ( MI_SIZE >> subY) +
                                    unitSize - 1 ) / unitSize)
            if ( use_superres ) {
                numerator = (MI_SIZE >> subX) * SuperresDenom
                denominator = unitSize * SUPERRES_NUM
            } else {
                numerator = MI_SIZE >> subX
                denominator = unitSize
            }
            unitColStart = ( c * numerator + denominator - 1 ) / denominator
            unitColEnd = Min( unitCols, ( (c + w) * numerator +
                            denominator - 1 ) / denominator)
            for ( unitRow = unitRowStart; unitRow < unitRowEnd; unitRow++ ) {
                for ( unitCol = unitColStart; unitCol < unitColEnd; unitCol++ ) {
                    read_lr_unit(plane, unitRow, unitCol)
                }
            }
        }
    }
}
```

where count_units_in_frame is a function specified as:

```
count_units_in_frame(unitSize, frameSize) {
    return Max((frameSize + (unitSize >> 1)) / unitSize, 1)
}
```

5.11.58. Read loop restoration unit syntax

read_lr_unit(plane, unitRow, unitCol) {	Type
if (FrameRestorationType[plane] == RESTORE_WIENER) {	
use_wiener	S()
restoration_type = use_wiener ? RESTORE_WIENER : RESTORE_NONE	
} else if (FrameRestorationType[plane] == RESTORE_SGRPROJ) {	
use_sgrproj	S()
restoration_type = use_sgrproj ? RESTORE_SGRPROJ : RESTORE_NONE	
} else {	
restoration_type	S()
}	
LrType[plane][unitRow][unitCol] = restoration_type	
if (restoration_type == RESTORE_WIENER) {	
for (pass = 0; pass < 2; pass++) {	
if (plane) {	
firstCoeff = 1	

LrWiener[plane]	
[unitRow][unitCol][pass][0] = 0	
} else {	
firstCoeff = 0	
}	
for (j = firstCoeff; j < 3; j++) {	
min = Wiener_Taps_Min[j]	
max = Wiener_Taps_Max[j]	
k = Wiener_Taps_K[j]	
v = decode_signed_subexp_with_ref_bool(	
min, max + 1, k, RefLrWiener[plane][pass][j])	
LrWiener[plane]	
[unitRow][unitCol][pass][j] = v	
RefLrWiener[plane][pass][j] = v	
}	
}	
} else if (restoration_type == RESTORE_SGRPROJ) {	
lr_sgr_set	L(SGRPROJ_PARAMS_BITS)
LrSgrSet[plane][unitRow][unitCol] = lr_sgr_set	
for (i = 0; i < 2; i++) {	
radius = Sgr_Params[lr_sgr_set][i * 2]	
min = Sgrproj_Xqd_Min[i]	
max = Sgrproj_Xqd_Max[i]	
if (radius) {	
v = decode_signed_subexp_with_ref_bool(	
min, max + 1, SGRPROJ_PRJ_SUBEXP_K,	
RefSgrXqd[plane][i])	
} else {	
v = 0	
if (i == 1) {	
v = Clip3(min, max, (1 << SGRPROJ_PRJ_BITS) -	
RefSgrXqd[plane][0])	
}	
}	
LrSgrXqd[plane][unitRow][unitCol][i] = v	
RefSgrXqd[plane][i] = v	
}	
}	
}	

where Wiener_Taps_Min, Wiener_Taps_Max, ,Wiener_Taps_K, Sgrproj_Xqd_Min, and Sgrproj_Xqd_Max are constant lookup tables:

```
Wiener_Taps_Min[3] = { -5, -23, -17 }
Wiener_Taps_Max[3] = { 10,   8,  46 }
Wiener_Taps_K[3] = { 1, 2, 3 }

Sgrproj_Xqd_Min[2] = { -96, -32 }
Sgrproj_Xqd_Max[2] = {  31,  95 }
```

Sgr_Params is a constant lookup table defined in section 7.17.3 and decode_signed_subexp_with_ref_bool is a function specified as follows:

decode_signed_subexp_with_ref_bool(low, high, k, r) {	Type
x = decode_unsigned_subexp_with_ref_bool(high - low, k, r - low)	
return x + low	
}	
decode_unsigned_subexp_with_ref_bool(mx, k, r) {	
v = decode_subexp_bool(mx, k)	
if ((r << 1) <= mx) {	
return inverse_recenter(r, v)	
} else {	
return mx - 1 - inverse_recenter(mx - 1 - r, v)	
}	
}	
decode_subexp_bool(numSyms, k) {	
i = 0	
mk = 0	
while (1) {	
b2 = i ? k + i - 1 : k	
a = 1 << b2	
if (numSyms <= mk + 3 * a) {	
subexp_unif_bools	NS(numSyms - mk)
return subexp_unif_bools + mk	
} else {	
subexp_more_bools	L(1)
if (subexp_more_bools) {	
i++	
mk += a	
} else {	
subexp_bools	L(b2)
return subexp_bools + mk	
}	
}	
}	
}	

Note: The decode_signed_subexp_with_ref_bool function is the same as the decode_signed_subexp_with_ref function except that the bits used to represent the symbol are arithmetic coded instead of being read directly from the bitstream.

5.12. Tile list OBU syntax

5.12.1. General tile list OBU syntax

tile_list_obu( ) {	Type
output_frame_width_in_tiles_minus_1	f(8)
output_frame_height_in_tiles_minus_1	f(8)
tile_count_minus_1	f(16)
for (tile = 0; tile <= tile_count_minus_1; tile++)	
tile_list_entry( )	
}	

5.12.2. Tile list entry syntax

tile_list_entry( ) {	Type
anchor_frame_idx	f(8)
anchor_tile_row	f(8)
anchor_tile_col	f(8)
tile_data_size_minus_1	f(16)
N = 8 * (tile_data_size_minus_1 + 1)	
coded_tile_data	f(N)
}	

6. Syntax structures semantics

6.1. General

This section specifies the meaning of the syntax elements read in the syntax structures.

Important variables and function calls are also described.

6.2. OBU semantics

6.2.1. General OBU semantics

An ordered series of OBUs is presented to the decoding process. Each OBU is given to the decoding process as a string of bytes along with a variable sz that identifies the total number of bytes in the OBU.

If the syntax element obu_has_size_field (in the OBU header) is equal to 1, then the variable sz will be unused and does not have to be provided.

obu_size contains the size in bytes of the OBU not including the bytes within obu_header or the obu_size syntax element.

Methods of framing the OBUs (i.e. of identifying the series of OBUs and their size and payload data) in a delivery or container format may be established in a manner outside the scope of this Specification. One simple method is described in Annex B.

OBU data starts on the first (most significant) bit and ends on the last bit of the given bytes. The payload of an OBU lies between the first bit of the given bytes and the last bit before the first trailing bit. Trailing bits are always present, unless the OBU consists of only the header. Trailing bits achieve byte alignment when the payload of an OBU is not byte aligned. The trailing bits may also used for additional byte padding, and if used are taken into account in the sz value. In all cases, the pattern used for the trailing bits guarantees that all OBUs (except header-only OBUs) end with the same pattern: one bit set to one, optionally followed by zeros.

> **Note:** As a validity check for malformed encoded data and for operation in environments in which losses and errors can occur, decoders may detect an error if the end of the parsed data is not directly followed by the correct trailing bits pattern or if the parsing of the OBU header and payload leads to the consumption of bits within the trailing bits (except for tile group data which is allowed to read a small distance into the trailing bits as described in section 8.2.4).

drop_obu( ) is a function call that indicates when the decoding process should ignore an OBU because it is not contained in the selected operating point. When an OBU is not in the selected operating point the contents have no effect on the decoding process.

When this function is called, the bitstream position indicator should be advanced by obu_size * 8 bits.

6.2.2. OBU header semantics

OBUs are structured with a header and a payload. The header identifies the type of the payload using the obu_type header parameter.

obu_forbidden_bit must be set to 0.

> **Note:** This ensures that MPEG2 transport is possible by preventing emulation of MPEG2 transport stream ids.

obu_type specifies the type of data structure contained in the OBU payload:

obu_type	Name of obu_type
0	Reserved
1	OBU_SEQUENCE_HEADER
2	OBU_TEMPORAL_DELIMITER
3	OBU_FRAME_HEADER
4	OBU_TILE_GROUP
5	OBU_METADATA
6	OBU_FRAME
7	OBU_REDUNDANT_FRAME_HEADER
8	OBU_TILE_LIST
9-14	Reserved
15	OBU_PADDING

Reserved units are for future use and shall be ignored by AV1 decoder.

obu_extension_flag indicates if the optional obu_extension_header is present.

obu_has_size_field equal to 1 indicates that the obu_size syntax element will be present. obu_has_size_field equal to 0 indicates that the obu_size syntax element will not be present.

obu_reserved_1bit must be set to 0. The value is ignored by a decoder.

6.2.3. OBU extension header semantics

temporal_id specifies the temporal level of the data contained in the OBU. When temporal_id is not present, temporal_id is inferred to be equal to 0.

spatial_id specifies the spatial level of the data contained in the OBU. When spatial_id is not present, spatial_id is inferred to be equal to 0.

> **Note:** The term “spatial” refers to the fact that the enhancement here occurs in the spatial dimension: either as an increase in spatial resolution, or an increase in spatial fidelity (increased SNR).

Tile group OBU data associated with spatial_id and temporal_id equal to 0 are referred to as the base layer, whereas tile group OBU data that are associated with spatial_id greater than 0 or temporal_id greater than 0 are referred to as enhancement layer(s).

Coded video data of a temporal level with temporal_id T and spatial level with spatial_id S are only allowed to reference previously coded video data of temporal_id T’ and spatial_id S’, where T’ <= T and S’ <= S.

extension_header_reserved_3bits must be set to 0. The value is ignored by a decoder.

6.2.4. Trailing bits semantics

> **Note:** Tile group OBUs, tile List OBUs, and frame OBUs do end with trailing bits, but for these cases, the trailing bits are consumed by the exit_symbol process.

trailing_one_bit shall be equal to 1.

When the syntax element trailing_one_bit is read, it is a requirement that nbBits is greater than zero.

trailing_zero_bit shall be equal to 0 and is inserted into the bitstream to align the bit position to a multiple of 8 bits and add optional zero padding bytes to the OBU.

6.2.5. Byte alignment semantics

zero_bit shall be equal to 0 and is inserted into the bitstream to align the bit position to a multiple of 8 bits.

6.3. Reserved OBU semantics

The reserved OBU allows the extension of this specification with additional OBU types in a way that allows older decoders to ignore them.

6.4. Sequence header OBU semantics

6.4.1. General sequence header OBU semantics

seq_profile specifies the features that can be used in the coded video sequence.

seq_profile	Bit depth	Monochrome support	Chroma subsampling
0	8 or 10	Yes	YUV 4:2:0
1	8 or 10	No	YUV 4:4:4
2	8 or 10	Yes	YUV 4:2:2

seq_profile	Bit depth	Monochrome support	Chroma subsampling
2	12	Yes	YUV 4:2:0, YUV 4:2:2, YUV 4:4:4

It is a requirement of bitstream conformance that seq_profile is not greater than 2 (values 3 to 7 are reserved).

Monochrome can only be signaled when seq_profile is equal to 0 or 2.

AV1 profiles are defined in Annex A.

still_picture equal to 1 specifies that the coded video sequence contains only one coded frame. still_picture equal to 0 specifies that the coded video sequence contains one or more coded frames.

reduced_still_picture_header specifies that the syntax elements not needed by a still picture are omitted.

If reduced_still_picture_header is equal to 1, it is a requirement of bitstream conformance that still_picture is equal to 1.

> **Note:** It is allowed to have still_picture equal to 1 and reduced_still_picture_header equal to 0. This allows a video frame to be converted to a still picture by changing a single bit.

timing_info_present_flag specifies whether timing info is present in the coded video sequence.

decoder_model_info_present_flag specifies whether decoder model information is present in the coded video sequence.

initial_display_delay_present_flag specifies whether initial display delay information is present in the coded video sequence.

operating_points_cnt_minus_1 indicates the number of operating points minus 1 present in the coded video sequence.

An operating point specifies which spatial and temporal layers should be decoded.

operating_point_idc[i] contains a bitmask that indicates which spatial and temporal layers should be decoded for operating point i. Bit k is equal to 1 if temporal layer k should be decoded (for k between 0 and 7). Bit j+8 is equal to 1 if spatial layer j should be decoded (for j between 0 and 3).

However, if operating_point_idc[i] is equal to 0 then the coded video sequence has no scalability information in OBU extension headers and the operating point applies to the entire coded video sequence. This means that all OBUs must be decoded.

It is a requirement of bitstream conformance that operating_point_idc[i] is not equal to operating_point_idc[j] for j = 0..(i - 1).

> **Note:** This constraint means it is not allowed for two operating points to have the same value of operating_point_idc.

If operating_point_idc[op] is not equal to 0 for any value of op from 0 to operating_points_cnt_minus_1, it is a requirement of bitstream conformance that obu_extension_flag is equal to 1.

seq_level_idx[i] specifies the level that the coded video sequence conforms to when operating point i is selected.

> **Note:** Encoders should select the lowest level that is satisfied by the operating point to maximize the number of decoders that can decode the stream, but this is not a requirement of bitstream conformance.

seq_tier[i] specifies the tier that the coded video sequence conforms to when operating point i is selected.

decoder_model_present_for_this_op[i] equal to one indicates that there is a decoder model associated with operating point i. decoder_model_present_for_this_op[i] equal to zero indicates that there is not a decoder model associated with operating point i.

initial_display_delay_present_for_this_op[i] equal to 1 indicates that initial_display_delay_minus_1 is specified for operating point i. initial_display_delay_present_for_this_op[i] equal to 0 indicates that initial_display_delay_minus_1 is not specified for operating point i.

initial_display_delay_minus_1[i] plus 1 specifies, for operating point i, the number of decoded frames that should be present in the buffer pool before the first presentable frame is displayed. This will ensure that all presentable frames in the sequence can be decoded at or before the time that they are scheduled for display. If not signaled then initial_display_delay_minus_1[i] = BUFFER_POOL_MAX_SIZE - 1.

choose_operating_point( ) is a function call that indicates that the operating point should be selected.

The implementation of this function depends on the capabilities of the chosen implementation. The order of operating points indicates the preferred order for producing an output: a decoder should select the earliest operating point in the list that meets its decoding capabilities as expressed by the level associated with each operating point.

A decoder must return a value from choose_operating_point between 0 and operating_points_cnt_minus_1, or abandon the decoding process if no level within the decoder's capabilities can be found.

> **Note:** To help with conformance testing, decoders may allow the operating point to be explicitly signaled by external means.

> **Note:** A decoder may need to change the operating point selection when a new coded video sequence begins.

OperatingPointIdc specifies the value of operating_point_idc for the selected operating point.

It is a requirement of bitstream conformance that if OperatingPointIdc is equal to 0, then obu_extension_flag is equal to 0 for all OBUs that follow this sequence header until the next sequence header.

frame_width_bits_minus_1 specifies the number of bits minus 1 used for transmitting the frame width syntax elements.

frame_height_bits_minus_1 specifies the number of bits minus 1 used for transmitting the frame height syntax elements.

max_frame_width_minus_1 specifies the maximum frame width minus 1 for the frames represented by this sequence header.

max_frame_height_minus_1 specifies the maximum frame height minus 1 for the frames represented by this sequence header.

frame_id_numbers_present_flag specifies whether frame id numbers are present in the coded video sequence.

> **Note:** The frame id numbers (represented in display_frame_id, current_frame_id, and RefFrameId[i]) are not needed by the decoding process, but allow decoders to spot when frames have been missed and take an appropriate action.

additional_frame_id_length_minus_1 is used to calculate the number of bits used to encode the frame_id syntax element.

delta_frame_id_length_minus_2 specifies the number of bits minus 2 used to encode delta_frame_id syntax elements.

use_128x128_superblock, when equal to 1, indicates that superblocks contain 128x128 luma samples. When equal to 0, it indicates that superblocks contain 64x64 luma samples. (The number of contained chroma samples depends on subsampling_x and subsampling_y.)

enable_filter_intra equal to 1 specifies that the use_filter_intra syntax element may be present. enable_filter_intra equal to 0 specifies that the use_filter_intra syntax element will not be present.

enable_intra_edge_filter specifies whether the intra edge filtering process should be enabled.

enable_interintra_compound equal to 1 specifies that the mode info for inter blocks may contain the syntax element interintra. enable_interintra_compound equal to 0 specifies that the syntax element interintra will not be present.

enable_masked_compound equal to 1 specifies that the mode info for inter blocks may contain the syntax element compound_type. enable_masked_compound equal to 0 specifies that the syntax element compound_type will not be present.

enable_warped_motion equal to 1 indicates that the allow_warped_motion syntax element may be present. enable_warped_motion equal to 0 indicates that the allow_warped_motion syntax element will not be present.

enable_order_hint equal to 1 indicates that tools based on the values of order hints may be used. enable_order_hint equal to 0 indicates that tools based on order hints are disabled.

enable_dual_filter equal to 1 indicates that the inter prediction filter type may be specified independently in the horizontal and vertical directions. If the flag is equal to 0, only one filter type may be specified, which is then used in both directions.

enable_jnt_comp equal to 1 indicates that the distance weights process may be used for inter prediction.

enable_ref_frame_mvs equal to 1 indicates that the use_ref_frame_mvs syntax element may be present. enable_ref_frame_mvs equal to 0 indicates that the use_ref_frame_mvs syntax element will not be present.

seq_choose_screen_content_tools equal to 0 indicates that the seq_force_screen_content_tools syntax element will be present. seq_choose_screen_content_tools equal to 1 indicates that seq_force_screen_content_tools should be set equal to SELECT_SCREEN_CONTENT_TOOLS.

seq_force_screen_content_tools equal to SELECT_SCREEN_CONTENT_TOOLS indicates that the allow_screen_content_tools syntax element will be present in the frame header. Otherwise, seq_force_screen_content_tools contains the value for allow_screen_content_tools.

seq_choose_integer_mv equal to 0 indicates that the seq_force_integer_mv syntax element will be present. seq_choose_integer_mv equal to 1 indicates that seq_force_integer_mv should be set equal to SELECT_INTEGER_MV.

seq_force_integer_mv equal to SELECT_INTEGER_MV indicates that the force_integer_mv syntax element will be present in the frame header (providing allow_screen_content_tools is equal to 1). Otherwise, seq_force_integer_mv contains the value for force_integer_mv.

order_hint_bits_minus_1 is used to compute OrderHintBits.

OrderHintBits specifies the number of bits used for the order_hint syntax element.

enable_superres equal to 1 specifies that the use_superres syntax element will be present in the uncompressed header. enable_superres equal to 0 specifies that the use_superres syntax element will not be present (instead use_superres will be set to 0 in the uncompressed header without being read).

> **Note:** It is allowed to set enable_superres equal to 1 even when use_superres is not equal to 1 for any frame in the coded video sequence.

enable_cdef equal to 1 specifies that cdef filtering may be enabled. enable_cdef equal to 0 specifies that cdef filtering is disabled.

> **Note:** It is allowed to set enable_cdef equal to 1 even when cdef filtering is not used on any frame in the coded video sequence.

enable_restoration equal to 1 specifies that loop restoration filtering may be enabled. enable_restoration equal to 0 specifies that loop restoration filtering is disabled.

> **Note:** It is allowed to set enable_restoration equal to 1 even when loop restoration is not used on any frame in the coded video sequence.

film_grain_params_present specifies whether film grain parameters are present in the coded video sequence.

6.4.2. Color config semantics

high_bitdepth and **twelve_bit** are syntax elements which, together with seq_profile, determine the bit depth.

mono_chrome equal to 1 indicates that the video does not contain U and V color planes. mono_chrome equal to 0 indicates that the video contains Y, U, and V color planes.

color_description_present_flag equal to 1 specifies that color_primaries, transfer_characteristics, and matrix_coefficients are present. color_description_present_flag equal to 0 specifies that color_primaries, transfer_characteristics and matrix_coefficients are not present.

color_primaries is an integer that is defined by the “Color primaries” section of ISO/IEC 23091-4/ITU-T H.273.

color_primaries	Name of color primaries	Description
1	CP_BT_709	BT.709
2	CP_UNSPECIFIED	Unspecified
4	CP_BT_470_M	BT.470 System M (historical)
5	CP_BT_470_B_G	BT.470 System B, G (historical)
6	CP_BT_601	BT.601
7	CP_SMPTE_240	SMPTE 240
8	CP_GENERIC_FILM	Generic film (color filters using illuminant C)
9	CP_BT_2020	BT.2020, BT.2100
10	CP_XYZ	SMPTE 428 (CIE 1921 XYZ)
11	CP_SMPTE_431	SMPTE RP 431-2
12	CP_SMPTE_432	SMPTE EG 432-1
22	CP_EBU_3213	EBU Tech. 3213-E

transfer_characteristics is an integer that is defined by the “Transfer characteristics” section of ISO/IEC 23091-4/ITU-T H.273.

transfer_characteristics	Name of transfer characteristics	Description
0	TC_RESERVED_0	For future use
1	TC_BT_709	BT.709
2	TC_UNSPECIFIED	Unspecified
3	TC_RESERVED_3	For future use
4	TC_BT_470_M	BT.470 System M (historical)

transfer_characteristics	Name of transfer characteristics	Description
5	TC_BT_470_B_G	BT.470 System B, G (historical)
6	TC_BT_601	BT.601
7	TC_SMPTE_240	SMPTE 240 M
8	TC_LINEAR	Linear
9	TC_LOG_100	Logarithmic (100 : 1 range)
10	TC_LOG_100_SQRT10	Logarithmic (100 * Sqrt(10) : 1 range)
11	TC_IEC_61966	IEC 61966-2-4
12	TC_BT_1361	BT.1361
13	TC_SRGB	sRGB or sYCC
14	TC_BT_2020_10_BIT	BT.2020 10-bit systems
15	TC_BT_2020_12_BIT	BT.2020 12-bit systems
16	TC_SMPTE_2084	SMPTE ST 2084, ITU BT.2100 PQ
17	TC_SMPTE_428	SMPTE ST 428
18	TC_HLG	BT.2100 HLG, ARIB STD-B67

matrix_coefficients is an integer that is defined by the “Matrix coefficients” section of ISO/IEC 23091-4/ITU-T H.273.

matrix_coefficients	Name of matrix coefficients	Description
0	MC_IDENTITY	Identity matrix
1	MC_BT_709	BT.709
2	MC_UNSPECIFIED	Unspecified
3	MC_RESERVED_3	For future use
4	MC_FCC	US FCC 73.628
5	MC_BT_470_B_G	BT.470 System B, G (historical)
6	MC_BT_601	BT.601
7	MC_SMPTE_240	SMPTE 240 M
8	MC_SMPTE_YCGCO	YCgCo
9	MC_BT_2020_NCL	BT.2020 non-constant luminance, BT.2100 YCbCr
10	MC_BT_2020_CL	BT.2020 constant luminance
11	MC_SMPTE_2085	SMPTE ST 2085 YDzDx

matrix_coefficients	Name of matrix coefficients	Description
12	MC_CHROMAT_NCL	Chromaticity-derived non-constant luminance
13	MC_CHROMAT_CL	Chromaticity-derived constant luminance
14	MC_ICTCP	BT.2100 ICtCp

color_range is a binary value that is associated with the VideoFullRangeFlag variable specified in ISO/IEC 23091-4/ITU-T H.273. color range equal to 0 shall be referred to as the studio swing representation and color range equal to 1 shall be referred to as the full swing representation for all intents relating to this specification.

> **Note:** Note that this specification does not enforce the range when signaled as Studio swing. Therefore the application should perform additional clamping and color conversion operations according to the specified range.

subsampling_x, **subsampling_y** specify the chroma subsampling format:

subsampling_x	subsampling_y	mono_chrome	Description
0	0	0	YUV 4:4:4
1	0	0	YUV 4:2:2
1	1	0	YUV 4:2:0
1	1	1	Monochrome 4:0:0

If matrix_coefficients is equal to MC_IDENTITY, it is a requirement of bitstream conformance that subsampling_x is equal to 0 and subsampling_y is equal to 0.

chroma_sample_position specifies the sample position for subsampled streams:

chroma_sample_position	Name of chroma sample position	Description
0	CSP_UNKNOWN	Unknown (in this case the source video transfer function must be signaled outside the AV1 bitstream)
1	CSP_VERTICAL	Horizontally co-located with (0, 0) luma sample, vertical position in the middle between two luma samples
2	CSP_COLOCATED	co-located with (0, 0) luma sample
3	CSP_RESERVED	

separate_uv_delta_q equal to 1 indicates that the U and V planes may have separate delta quantizer values. separate_uv_delta_q equal to 0 indicates that the U and V planes will share the same delta quantizer value.

6.4.3. Timing info semantics

num_units_in_display_tick is the number of time units of a clock operating at the frequency time_scale Hz that corresponds to one increment of a clock tick counter. A display clock tick, in seconds, is equal to num_units_in_display_tick divided by time_scale:

```
DispCT = num_units_in_display_tick ÷ time_scale
```

> **Note:** The ÷ operator represents standard mathematical division (in contrast to the / operator which represents integer division).

It is a requirement of bitstream conformance that num_units_in_display_tick is greater than 0.

time_scale is the number of time units that pass in one second.

It is a requirement of bitstream conformance that time_scale is greater than 0.

equal_picture_interval equal to 1 indicates that pictures should be displayed according to their output order with the number of ticks between two consecutive pictures (without dropping frames) specified by num_ticks_per_picture_minus_1 + 1. equal_picture_interval equal to 0 indicates that the interval between two consecutive pictures is not specified.

num_ticks_per_picture_minus_1 plus 1 specifies the number of clock ticks corresponding to output time between two consecutive pictures in the output order.

It is a requirement of bitstream conformance that the value of num_ticks_per_picture_minus_1 shall be in the range of 0 to (1 << 32) − 2, inclusive.

> **Note:** The frame rate, when specified explicitly, applies to the top temporal layer of the bitstream. If bitstream is expected to be manipulated, e.g. by intermediate network elements, then the resulting frame rate may not match the specified one. In this case, an encoder is advised to use explicit time codes or some mechanisms that convey picture timing information outside the bitstream.

6.4.4. Decoder model info semantics

buffer_delay_length_minus_1 plus 1 specifies the length of the decoder_buffer_delay and the encoder_buffer_delay syntax elements, in bits.

num_units_in_decoding_tick is the number of time units of a decoding clock operating at the frequency time_scale Hz that corresponds to one increment of a clock tick counter:

```
DecCT = num_units_in_decoding_tick ÷ time_scale
```

> **Note:** The ÷ operator represents standard mathematical division (in contrast to the / operator which represents integer division).

num_units_in_decoding_tick shall be greater than 0. DecCT represents the expected time to decode a single frame or a common divisor of the expected times to decode frames of different sizes and dimensions present in the coded video sequence.

buffer_removal_time_length_minus_1 plus 1 specifies the length of the buffer_removal_time syntax element, in bits.

frame_presentation_time_length_minus_1 plus 1 specifies the length of the frame_presentation_time syntax element, in bits.

6.4.5. Operating parameters info semantics

decoder_buffer_delay[op] specifies the time interval between the arrival of the first bit in the smoothing buffer and the subsequent removal of the data that belongs to the first coded frame for operating point op, measured in units of 1/90000 seconds. The length of decoder_buffer_delay is specified by buffer_delay_length_minus_1 + 1, in bits.

encoder_buffer_delay[op] specifies, in combination with decoder_buffer_delay[op] syntax element, the first bit arrival time of frames to be decoded to the smoothing buffer. encoder_buffer_delay is measured in units of 1/90000 seconds.

For a video sequence that includes one or more random access points the sum of decoder_buffer_delay and encoder_buffer_delay shall be kept constant.

low_delay_mode_flag[op] equal to 1 indicates that the smoothing buffer operates in low-delay mode for operating point op. In low-delay mode late decode times and buffer underflow are both permitted. low_delay_mode_flag[op] equal to 0 indicates that the smoothing buffer operates in strict mode, where buffer underflow is not allowed.

6.5. Temporal delimiter OBU semantics

SeenFrameHeader is a variable used to mark whether the frame header for the current frame has been received. It is initialized to zero.

6.6. Padding OBU semantics

Multiple padding units can be present, each padding with an arbitrary number of bytes.

obu_padding_byte is a padding byte. Padding bytes may have arbitrary values and have no effect on the decoding process.

6.7. Metadata OBU semantics

6.7.1. General metadata OBU semantics

metadata_type indicates the type of metadata:

metadata_type	Name of metadata_type
0	Reserved for AOM use
1	METADATA_TYPE_HDR_CLL
2	METADATA_TYPE_HDR_MDCV
3	METADATA_TYPE_SCALABILITY
4	METADATA_TYPE_ITUT_T35
5	METADATA_TYPE_TIMECODE
6-31	Unregistered user private
32 and greater	Reserved for AOM use

6.7.2. Metadata ITUT T35 semantics

itu_t_t35_country_code shall be a byte having a value specified as a country code by Annex A of Recommendation ITU-T T.35.

itu_t_t35_country_code_extension_byte shall be a byte having a value specified as a country code by Annex B of Recommendation ITU-T T.35.

itu_t_t35_payload_bytes shall be bytes containing data registered as specified in Recommendation ITU-T T.35.

The ITU-T T.35 terminal provider code and terminal provider oriented code shall be contained in the first one or more bytes of the itu_t_t35_payload_bytes, in the format specified by the Administration that issued the terminal provider code. Any remaining bytes in itu_t_t35_payload_bytes data shall be data having syntax and semantics as specified by the entity identified by the ITU-T T.35 country code and terminal provider code.

6.7.3. Metadata high dynamic range content light level semantics

max_cll specifies the maximum content light level as specified in CEA-861.3, Appendix A.

max_fall specifies the maximum frame-average light level as specified in CEA-861.3, Appendix A.

6.7.4. Metadata high dynamic range mastering display color volume semantics

primary_chromaticity_x[i] specifies a 0.16 fixed-point X chromaticity coordinate as defined by CIE 1931, where i = 0,1,2 specifies Red, Green, Blue respectively.

primary_chromaticity_y[i] specifies a 0.16 fixed-point Y chromaticity coordinate as defined by CIE 1931, where i = 0,1,2 specifies Red, Green, Blue respectively.

white_point_chromaticity_x specifies a 0.16 fixed-point white X chromaticity coordinate as defined by CIE 1931.

white_point_chromaticity_y specifies a 0.16 fixed-point white Y chromaticity coordinate as defined by CIE 1931.

luminance_max is a 24.8 fixed-point maximum luminance, represented in candelas per square meter.

luminance_min is a 18.14 fixed-point minimum luminance, represented in candelas per square meter.

6.7.5. Metadata scalability semantics

> **Note:** The scalability metadata OBU is intended for use by intermediate processing entities that may perform selective layer elimination. Its presence allows these entities to know the structure of the original coded video sequence without having to decode individual frames. If the received bitstream has been modified by an intermediate processing entity, then some of the layers and/or individual frames may be absent from the bitstream.

If scalability metadata is present it should be placed between the first sequence header and the first frame header of a coded video sequence. The information present in a scalability metadata OBU applies to the entire coded video sequence in which it is contained, and only that sequence. Redundant copies of a scalability metadata OBU may occur in any temporal unit of a coded video sequence.

scalability_mode_idc indicates the picture prediction structure of the coded video sequence.

scalability_mode_idc	Name of scalability_mode_idc
0	SCALABILITY_L1T2
1	SCALABILITY_L1T3
2	SCALABILITY_L2T1
3	SCALABILITY_L2T2
4	SCALABILITY_L2T3
5	SCALABILITY_S2T1
6	SCALABILITY_S2T2
7	SCALABILITY_S2T3
8	SCALABILITY_L2T1h
9	SCALABILITY_L2T2h
10	SCALABILITY_L2T3h
11	SCALABILITY_S2T1h
12	SCALABILITY_S2T2h
13	SCALABILITY_S2T3h
14	SCALABILITY_SS

scalability_mode_idc	Name of scalability_mode_idc
15	SCALABILITY_L3T1
16	SCALABILITY_L3T2
17	SCALABILITY_L3T3
18	SCALABILITY_S3T1
19	SCALABILITY_S3T2
20	SCALABILITY_S3T3
21	SCALABILITY_L3T2_KEY
22	SCALABILITY_L3T3_KEY
23	SCALABILITY_L4T5_KEY
24	SCALABILITY_L4T7_KEY
25	SCALABILITY_L3T2_KEY_SHIFT
26	SCALABILITY_L3T3_KEY_SHIFT
27	SCALABILITY_L4T5_KEY_SHIFT
28	SCALABILITY_L4T7_KEY_SHIFT
29-255	reserved

The scalability metadata provides two mechanisms for describing the underlying picture prediction structure of the bitstream:

1. Selection among a set of preconfigured structures, or modes, covering a number of cases that have found wide use in applications.
2. A facility for specifying picture prediction structures to accommodate a variety of special cases.

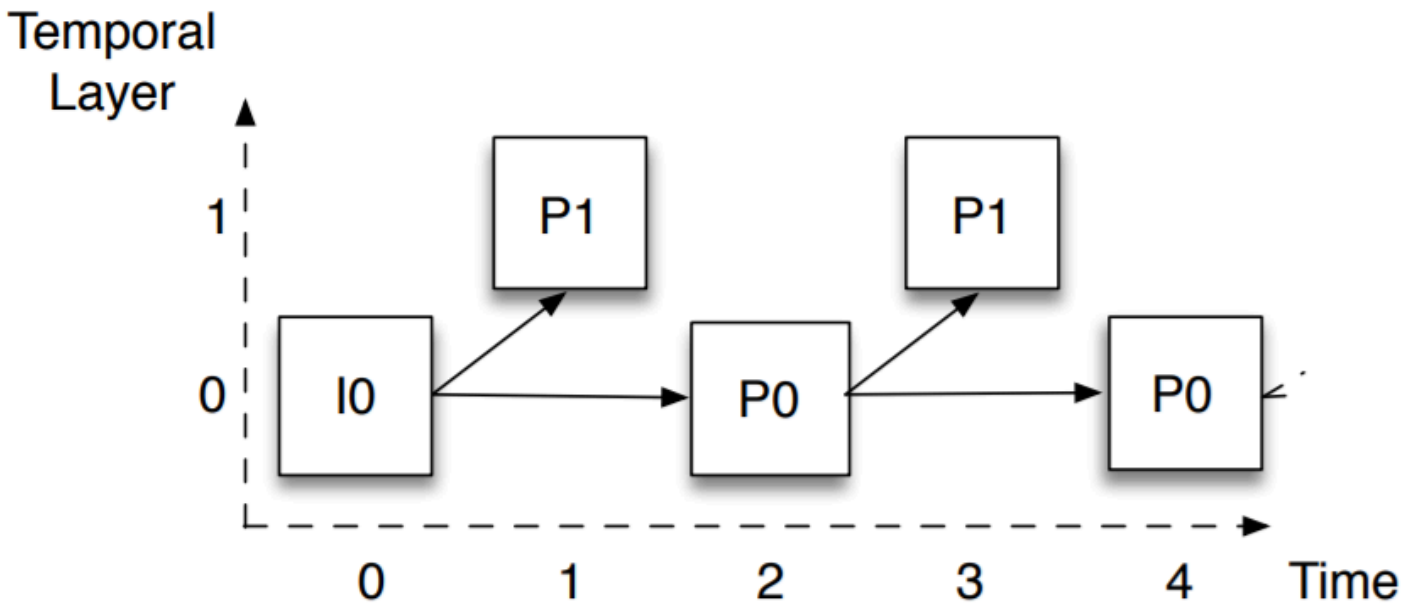
The preconfigured modes are described below. The mechanism for describing alternative structures is described in scalability_structure() below.

All predefined modes follow a dyadic, hierarchical picture prediction structure. They support up to three temporal layers, in combinations with one or two spatial layers. The second spatial layer may have twice or one and a half times the resolution of the base layer in each dimension, depending on the mode. There is also support for a spatial layer that uses no inter-layer prediction (i.e., the second spatial layer does not use its corresponding base layer as a reference) and a spatial layer that uses inter-layer prediction only at key frames. The following table lists the predefined scalability structures.

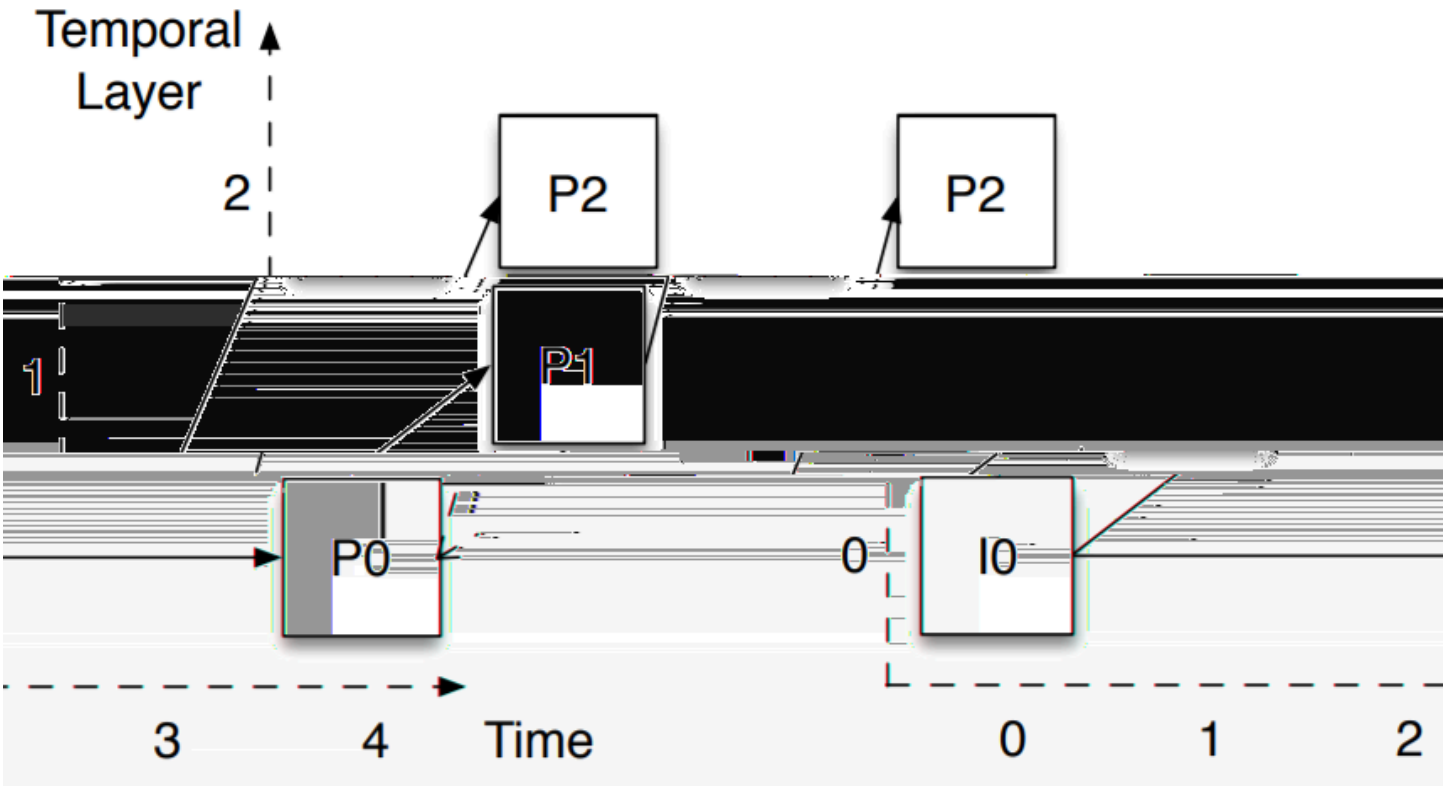
Name of scalability_mode_idc	Spatial Layers	Resolution Ratio	Temporal Layers	Inter-layer dependency
SCALABILITY_L1T2	1		2	

Name of scalability_mode_idc	Spatial Layers	Resolution Ratio	Temporal Layers	Inter-layer dependency
SCALABILITY_L1T3	1		3	
SCALABILITY_L2T1	2	2:1	1	Yes
SCALABILITY_L2T2	2	2:1	2	Yes
SCALABILITY_L2T3	2	2:1	3	Yes
SCALABILITY_S2T1	2	2:1	1	No
SCALABILITY_S2T2	2	2:1	2	No
SCALABILITY_S2T3	2	2:1	3	No
SCALABILITY_L2T1h	2	1.5:1	1	Yes
SCALABILITY_L2T2h	2	1.5:1	2	Yes
SCALABILITY_L2T3h	2	1.5:1	3	Yes
SCALABILITY_S2T1h	2	1.5:1	1	No
SCALABILITY_S2T2h	2	1.5:1	2	No
SCALABILITY_S2T3h	2	1.5:1	3	No
SCALABILITY_L3T1	3	2:1	1	Yes
SCALABILITY_L3T2	3	2:1	2	Yes
SCALABILITY_L3T3	3	2:1	3	Yes
SCALABILITY_S3T1	3	2:1	1	No
SCALABILITY_S3T2	3	2:1	2	No
SCALABILITY_S3T3	3	2:1	3	No
SCALABILITY_L3T2_KEY	3	2:1	2	Yes
SCALABILITY_L3T3_KEY	3	2:1	3	Yes
SCALABILITY_L4T5_KEY	4	2:1	5	Yes
SCALABILITY_L4T7_KEY	4	2:1	7	Yes
SCALABILITY_L3T2_KEY_SHIFT	3	2:1	2	Yes
SCALABILITY_L3T3_KEY_SHIFT	3	2:1	3	Yes
SCALABILITY_L4T5_KEY_SHIFT	4	2:1	5	Yes
SCALABILITY_L4T7_KEY_SHIFT	4	2:1	7	Yes

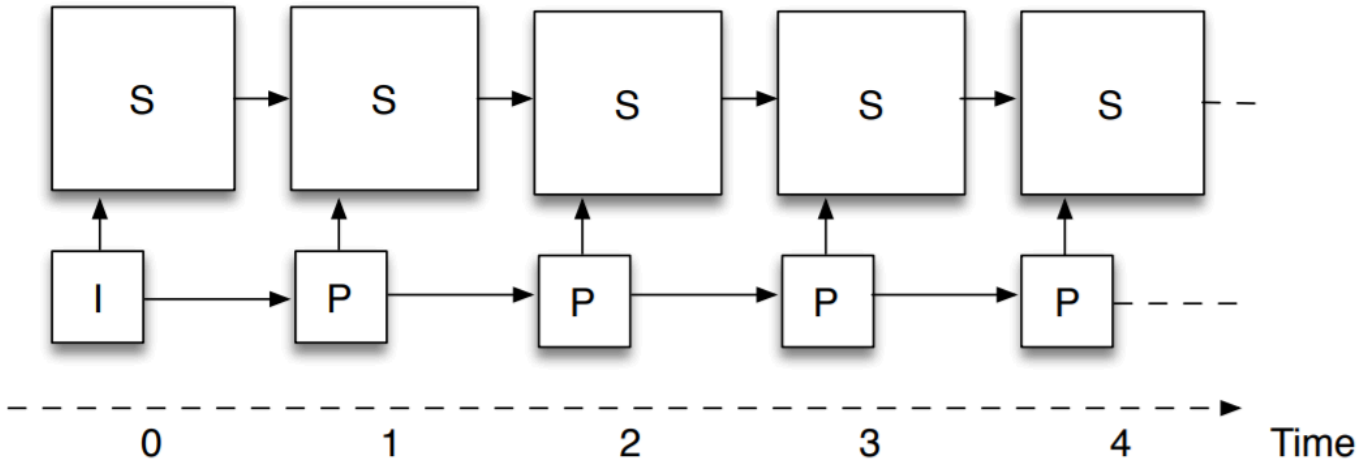
The following figures show the picture prediction structures for certain modes:


Temporal
Layer
1
0
P1
P1
I0
P0
P0
0
1
2
3
4
Time

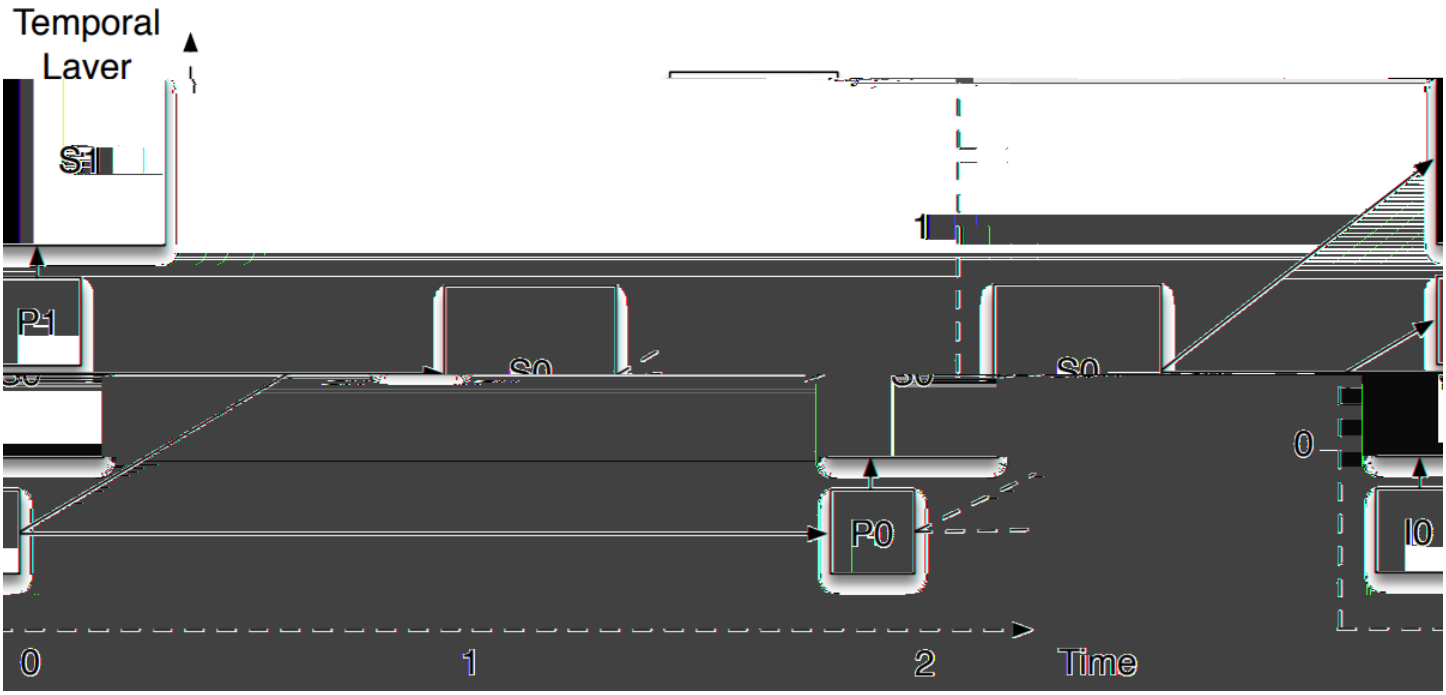
L1T2


Temporal
Layer
2
1
P2
P2
P1
P0
0
I0
3
4
Time
0
1
2

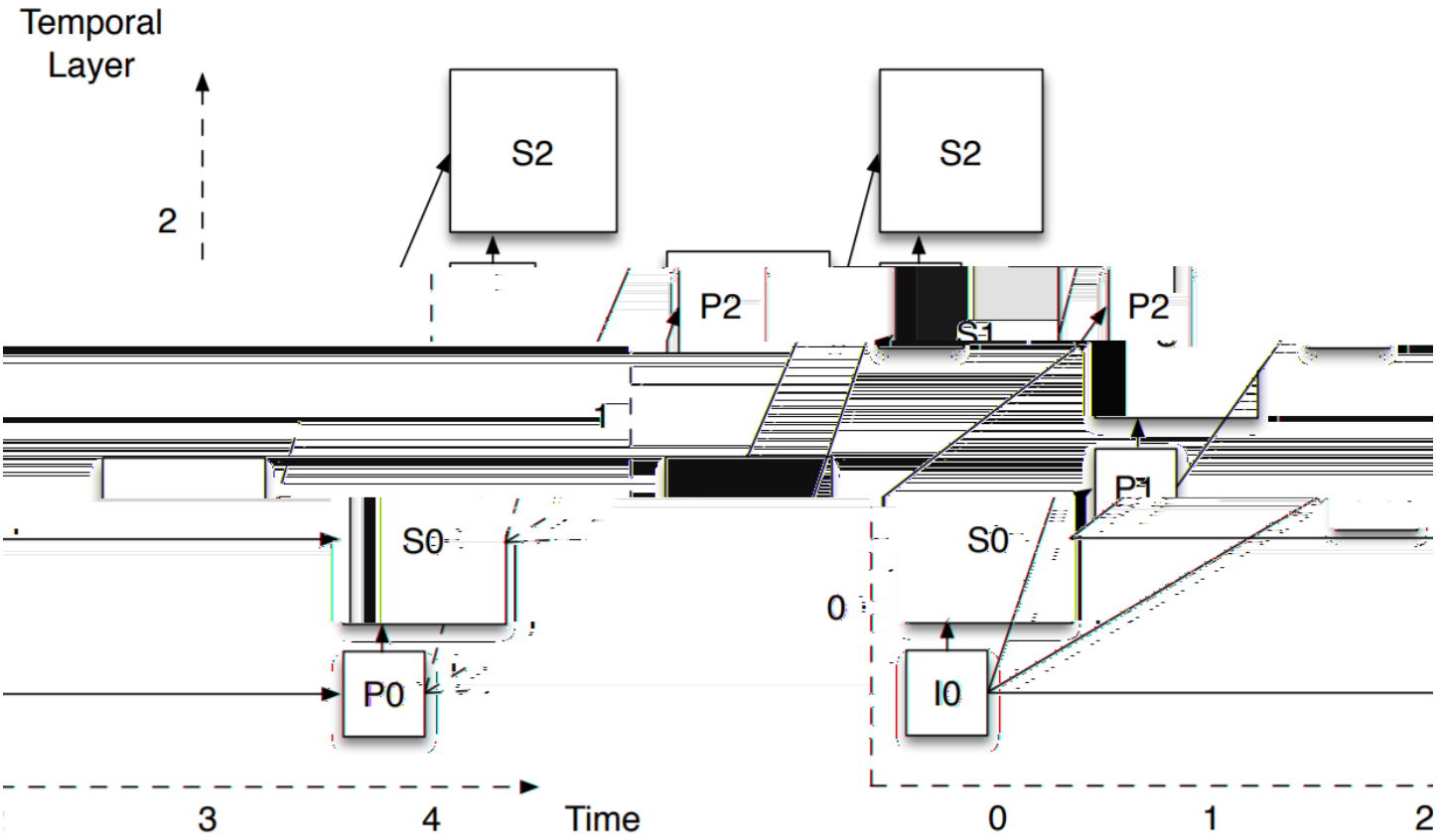
L1T3



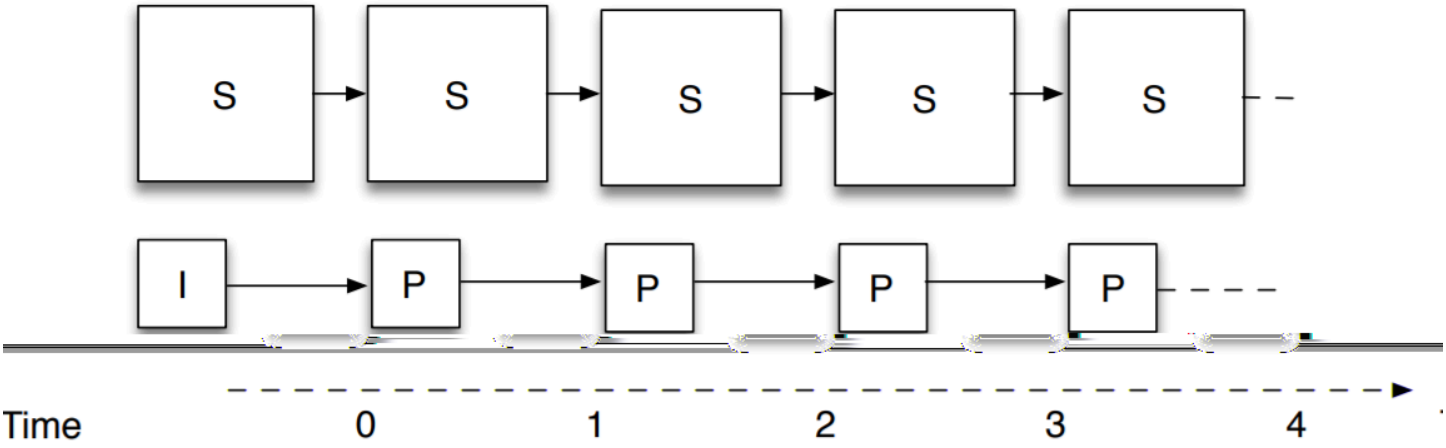
L2T1



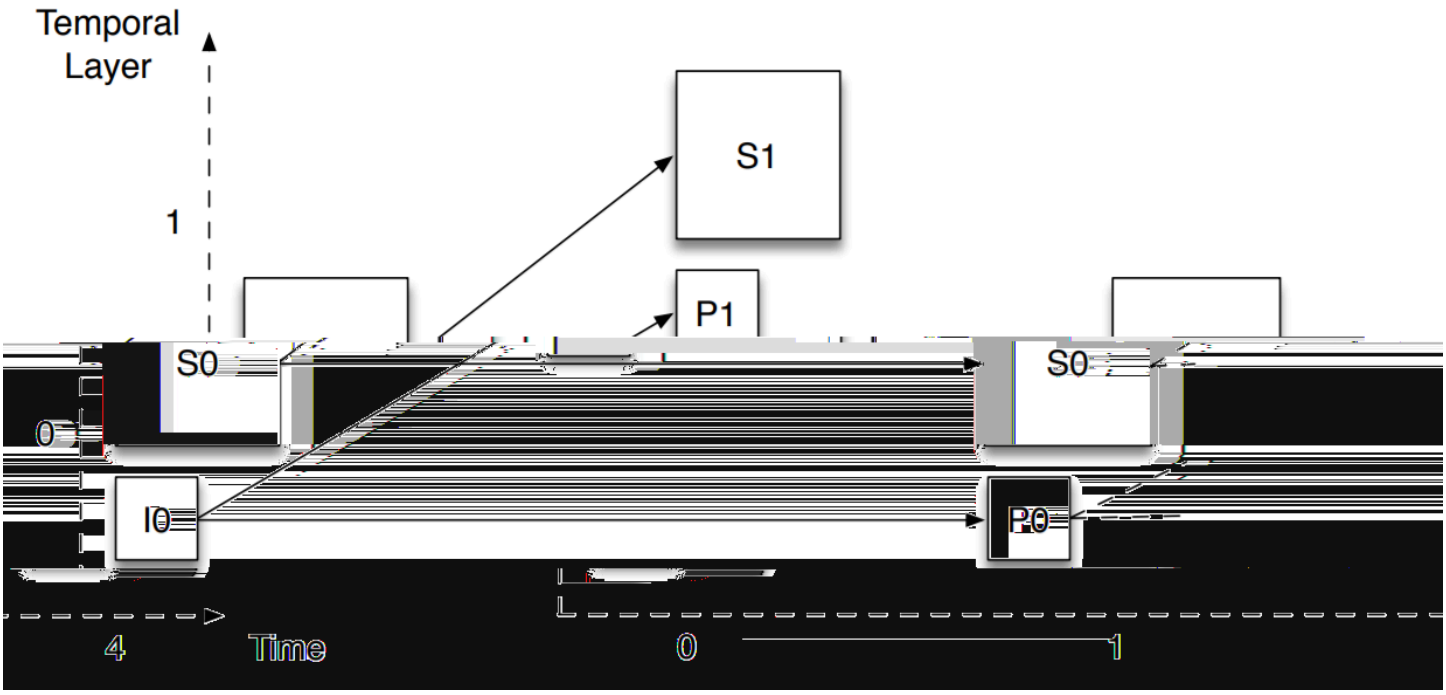
L2T2


Temporal
Layer
2
1
0
S2
S2
P2
P2
S1
P1
S0
S0
P0
I0
3
4
Time
0
1
2

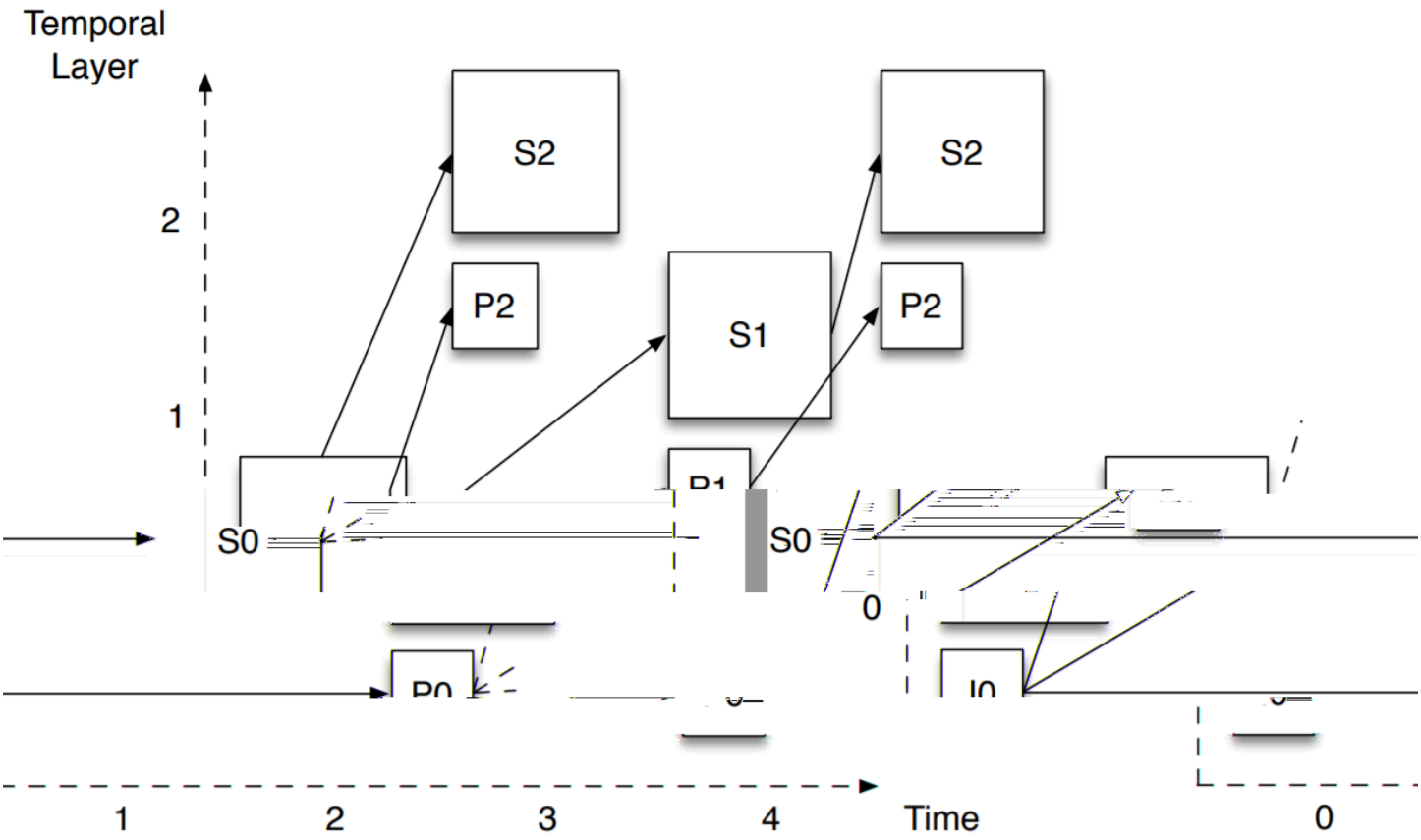
L2T3


S
S
S
S
S
I
P
P
P
P
Time
0
1
2
3
4

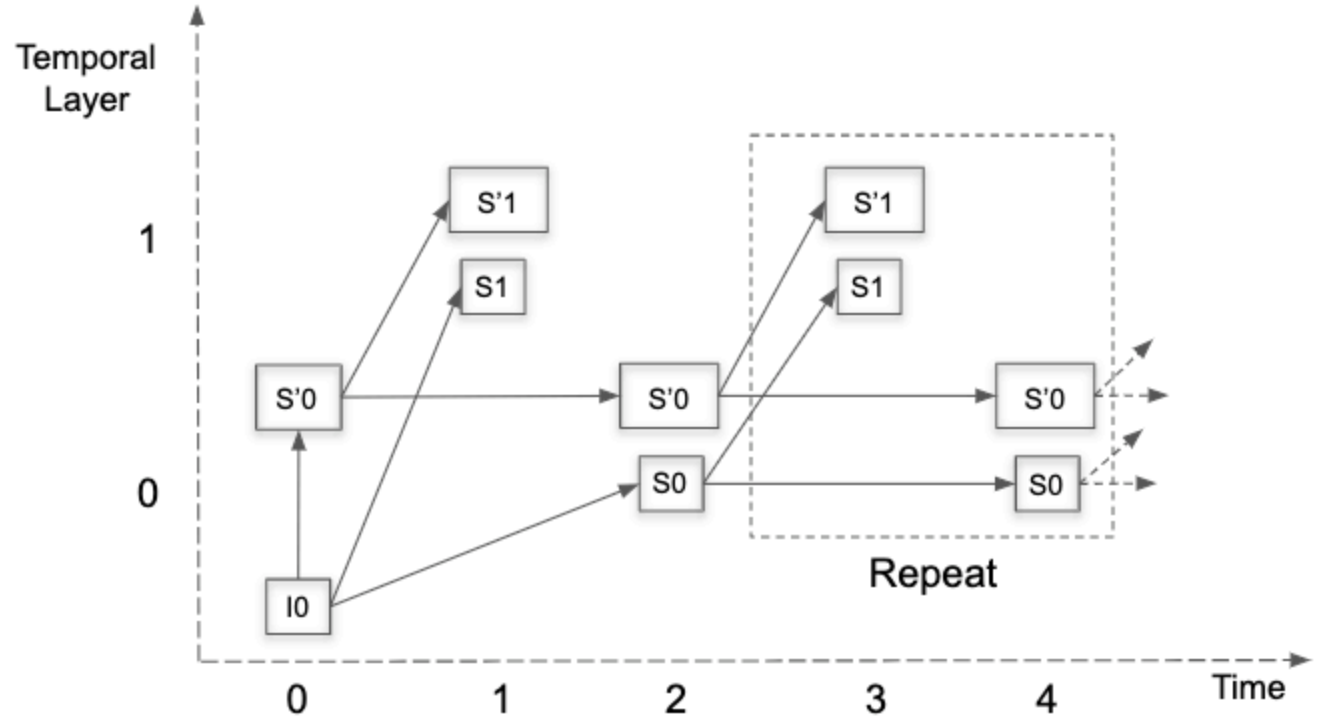
S2T1



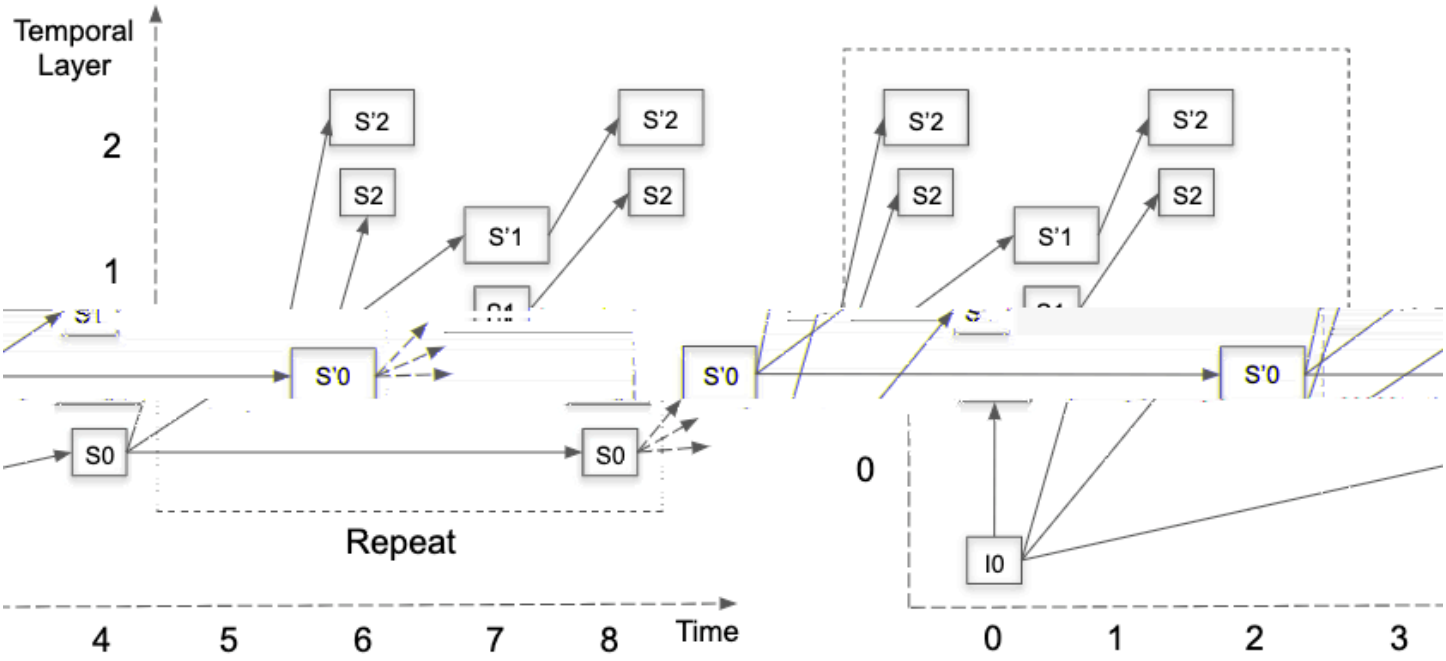
S2T2



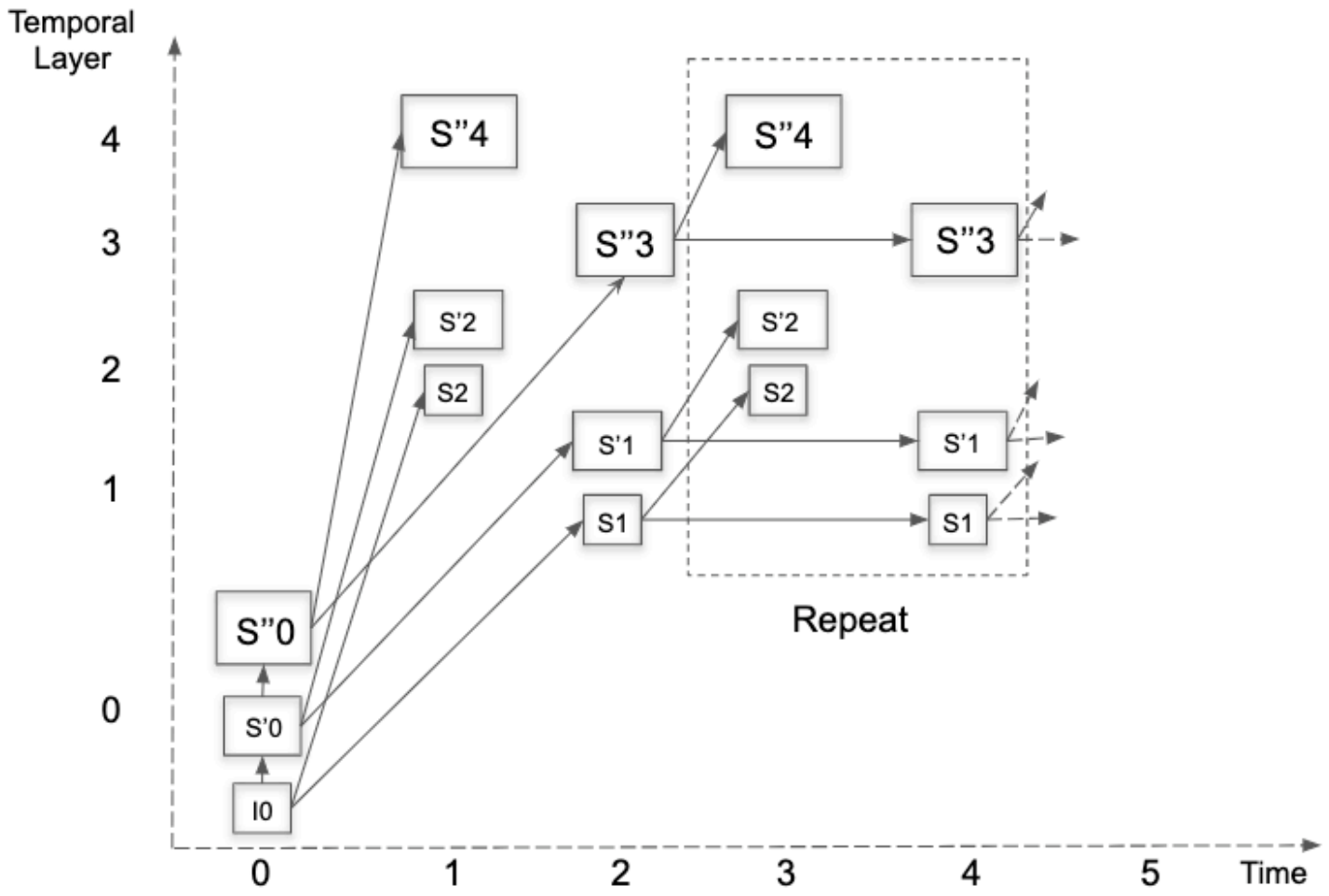
S2T3



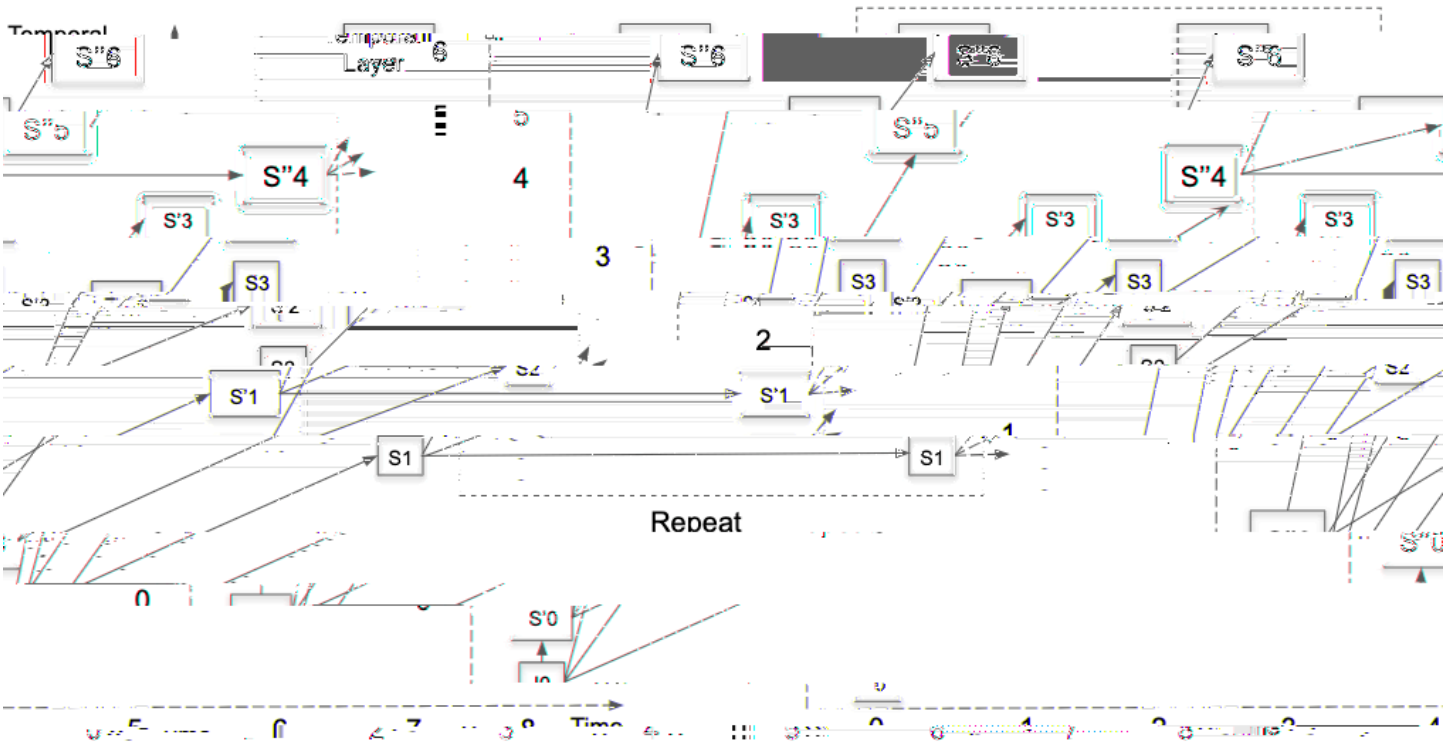
L3T2_KEY



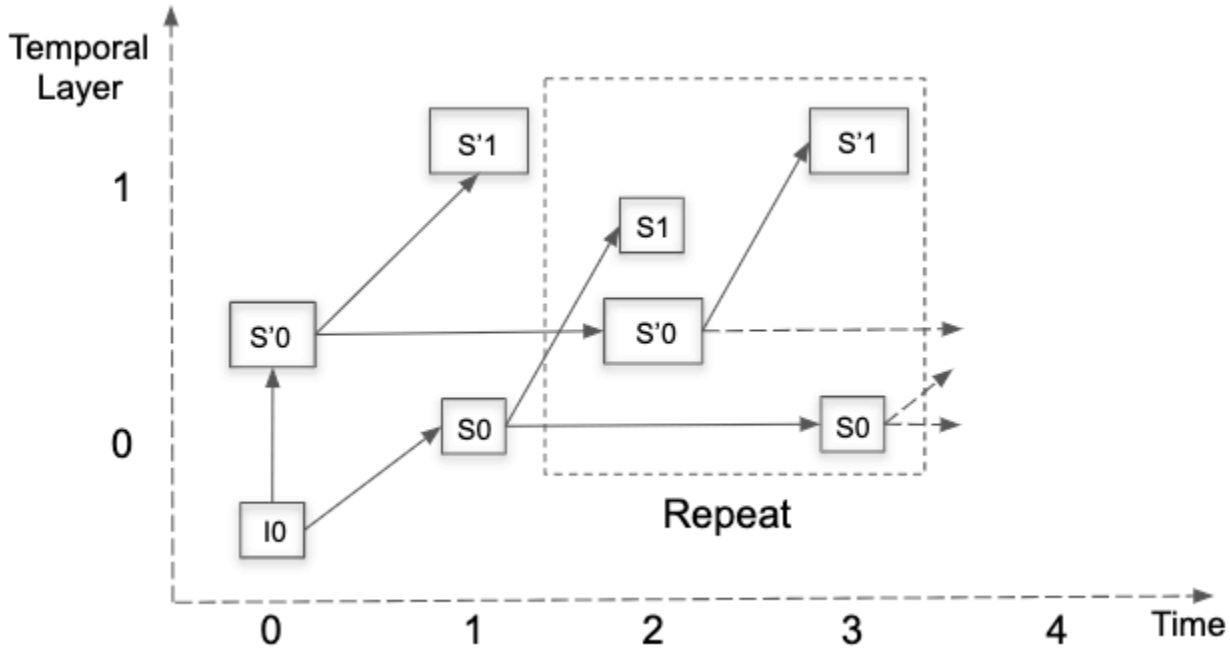
L3T3_KEY


Temporal Layer
4
3
2
1
0
S"4
S"3
S'2
S2
S'1
S1
S"0
S'0
I0
S"4
S"3
S'2
S2
S'1
S1
Repeat
0
1
2
3
4
5
Time

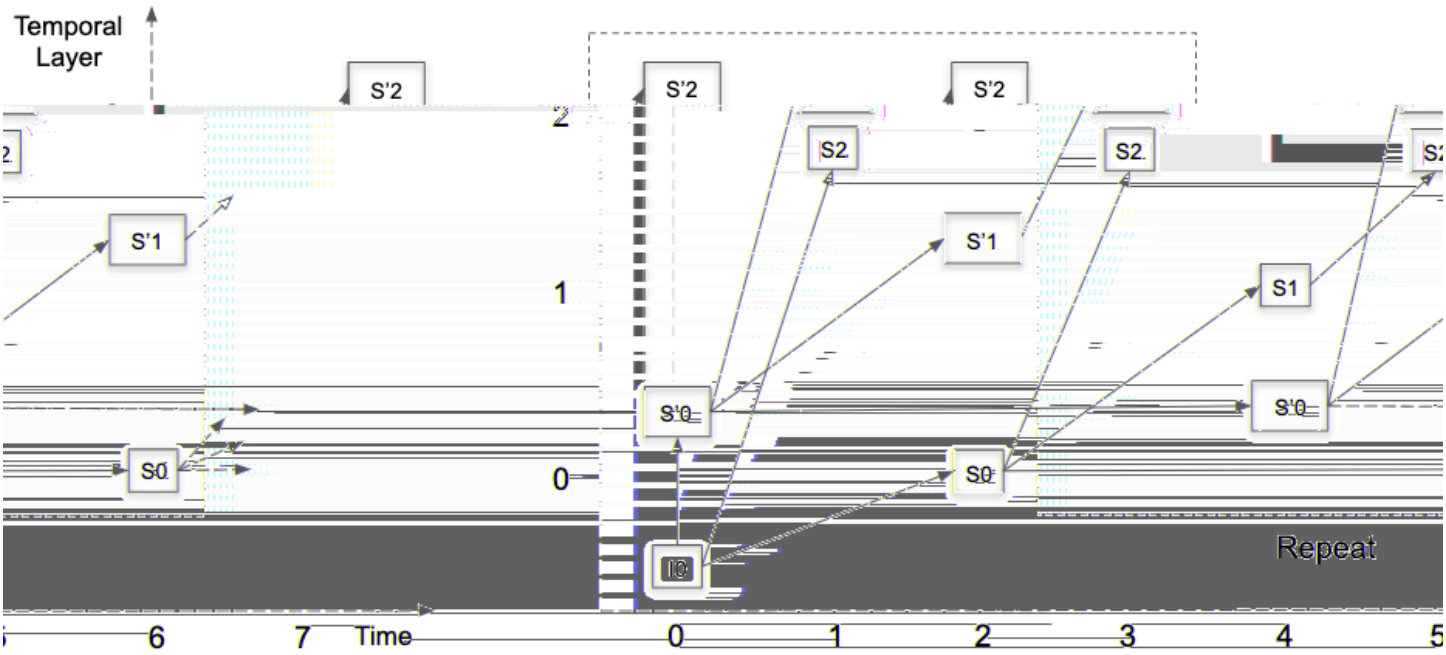
L4T5_KEY



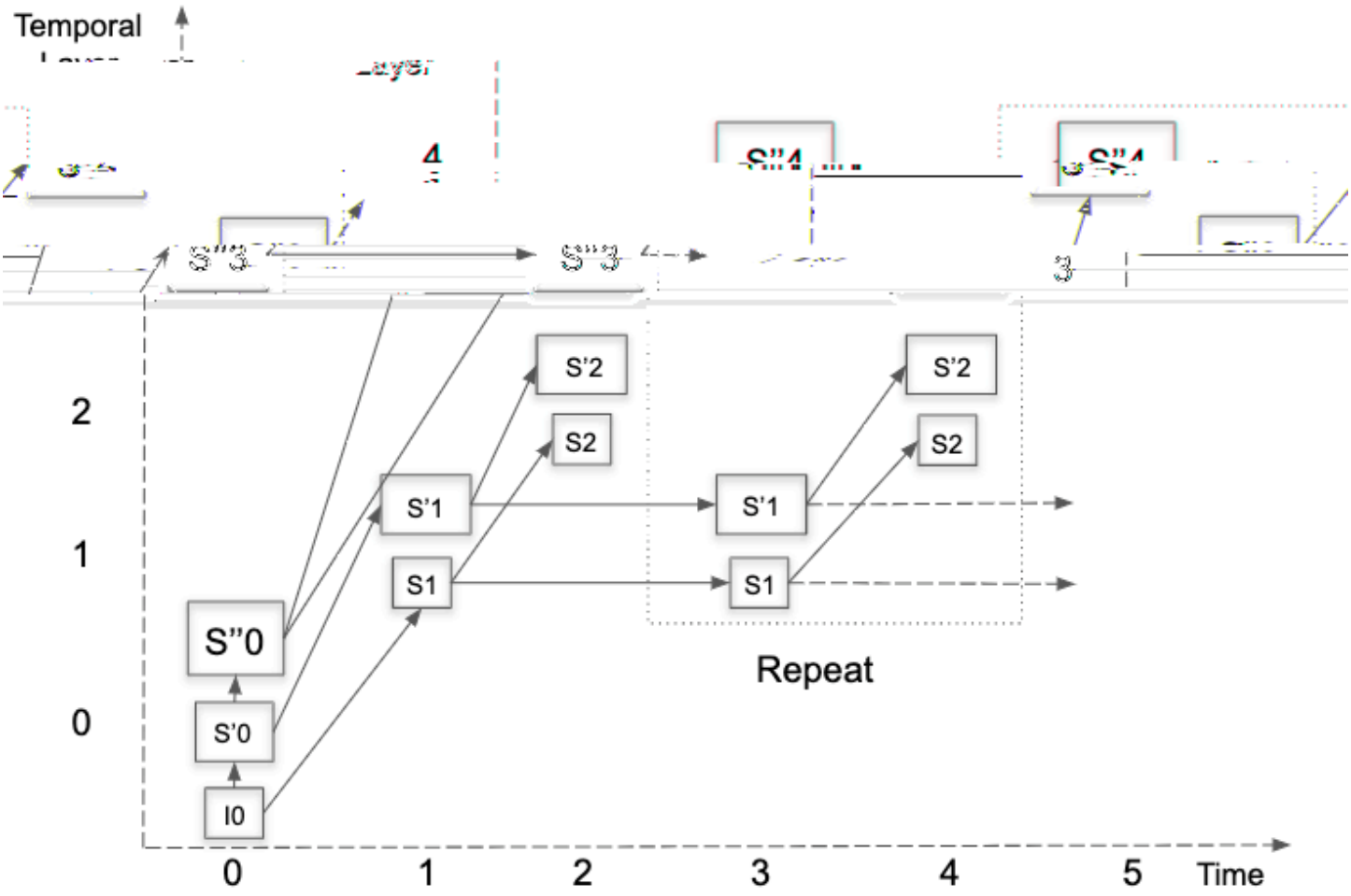
L4T7_KEY



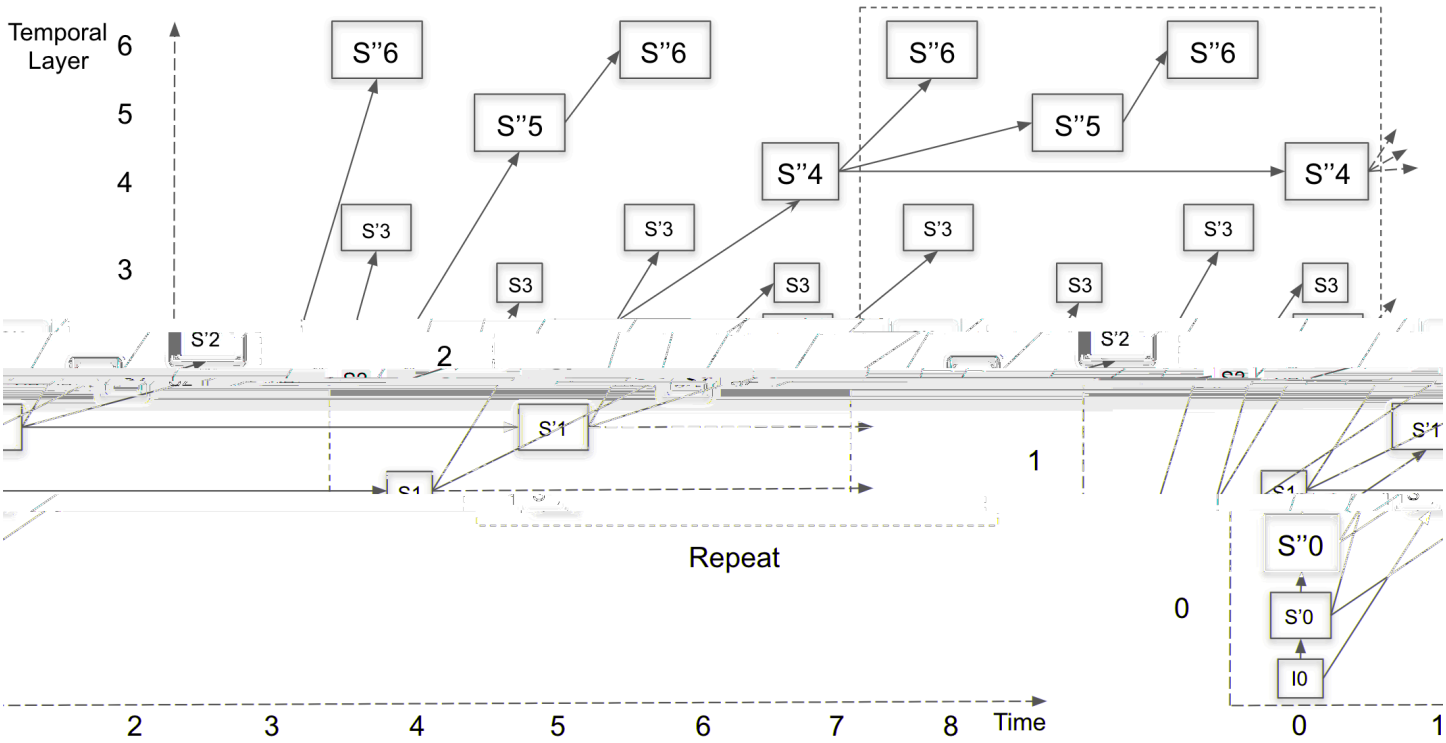
L3T2_KEY_SHIFT



L3T3_KEY_SHIFT



L4T5_KEY_SHIFT



L4T7_KEY_SHIFT

6.7.6. Scalability structure semantics

6.7.6.1. General

> **Note:** The scalability_structure is intended for use by intermediate processing entities that may perform selective layer elimination. Its presence allows these entities to know the structure of the video bitstream without have to decode individual frames. Scalability structures should be placed immediately after the sequence header so that these entities are informed of the scalability structure of the video sequence as early as possible.

spatial_layers_cnt_minus_1 indicates the number of spatial layers present in the coded video sequence minus one.

spatial_layer_description_present_flag indicates when set to 1 that the spatial_layer_ref_id is present for each of the (spatial_layers_cnt_minus_1 + 1) layers, or that it is not present when set to 0.

spatial_layer_dimensions_present_flag indicates when set to 1 that the spatial_layer_max_width and spatial_layer_max_height parameters are present for each of the (spatial_layers_cnt_minus_1 + 1) layers, or that it they are not present when set to 0.

temporal_group_description_present_flag indicates when set to 1 that the temporal dependency information is present, or that it is not when set to 0. When any temporal unit in a coded video sequence contains OBU extension headers that have temporal_id values that are not equal to each other, temporal_group_description_present_flag must be equal to 0.

scalability_structure_reserved_3bits must be set to zero and be ignored by decoders.

spatial_layer_max_width[i] specifies the maximum frame width for the frames with spatial_id equal to i. This number must not be larger than max_frame_width_minus_1 + 1.

spatial_layer_max_height[i] specifies the maximum frame height for the frames with spatial_id equal to i. This number must not be larger than max_frame_height_minus_1 + 1.

spatial_layer_ref_id[i] specifies the spatial_id value of the frame within the current temporal unit that the frame of layer i uses for reference. If no frame within the current temporal unit is used for reference the value must be equal to 255.

temporal_group_size indicates the number of pictures in a temporal picture group. If the temporal_group_size is greater than 0, then the scalability structure data allows the inter-picture temporal dependency structure of the coded video sequence to be specified. If the temporal_group_size is greater than 0, then for temporal_group_size pictures in the temporal group, each picture's temporal layer id (temporal_id), switch up points (temporal_group_temporal_switching_up_point_flag and temporal_group_spatial_switching_up_point_flag), and the reference picture indices (temporal_group_ref_pic_diff) are specified.

The first picture specified in a temporal group must have temporal_id equal to 0.

If the parameter temporal_group_size is not present or set to 0, then either there is only one temporal layer or there is no fixed inter-picture temporal dependency present in the coded video sequence.

Note that for a given picture, all frames follow the same inter-picture temporal dependency structure. However, the frame rate of each layer can be different from each other. The specified dependency structure in the scalability structure data must be for the highest frame rate layer.

temporal_group_temporal_id[i] specifies the temporal_id value for the i-th picture in the temporal group.

temporal_group_temporal_switching_up_point_flag[i] is set to 1 if subsequent (in decoding order) pictures with a temporal_id higher than temporal_group_temporal_id[i] do not depend on any picture preceding the current picture (in coding order) with temporal_id higher than temporal_group_temporal_id[i].

> **Note:** This condition ensures that switching up to a higher frame rate is possible at the current picture.

temporal_group_spatial_switching_up_point_flag[i]] is set to 1 if spatial layers of the current picture in the temporal group (i.e., pictures with a spatial_id higher than zero) do not depend on any picture preceding the current picture in the temporal group.

temporal_group_ref_cnt[i] indicates the number of reference pictures used by the i-th picture in the temporal group.

temporal_group_ref_pic_diff[i][j] indicates, for the i-th picture in the temporal group, the temporal distance between the i-th picture and the j-th reference picture used by the i-th picture. The temporal distance is measured in frames, counting only frames of identical spatial_id values.

Note: The scalability structure description does not allow different temporal prediction structures across non-temporal layers (i.e., layers with different spatial_id values). It also only allows for a single reference picture for inter-layer prediction.

The following sections contain the value of these syntax elements for certain predefined modes. Prediction structures having scalability_mode_idc values in the range 21 to 28, inclusive, cannot be described using temporal group description syntax and are not described in the sections that follow.

6.7.6.2. L1T2 (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	0
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	2
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	2
1	temporal_group_temporal_id[1]	1
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[0][0]	1

6.7.6.3. L1T3 (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	0
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	4
0	temporal_group_temporal_id[0]	0

	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	4
1	temporal_group_temporal_id[1]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1
2	temporal_group_temporal_id[2]	1
	temporal_group_temporal_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[2]	1
	temporal_group_ref_pic_diff[2][0]	2
3	temporal_group_temporal_id[3]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[3]	1
	temporal_group_ref_pic_diff[3][0]	1

6.7.6.4. L2T1 / L2T1h (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	0
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	1
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0

	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	1

6.7.6.5. L2T2 / L2T2h (Informative)

Layer	Spatial Layers Description	Value
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	0
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	2
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	2
1	temporal_group_temporal_id[1]	1
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1

6.7.6.6. L2T3 / L2T3h (Informative)

Layer	Spatial Layers Description	Value
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	0
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	4

0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	4
1	temporal_group_temporal_id[1]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1
2	temporal_group_temporal_id[2]	1
	temporal_group_temporal_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[2]	1
	temporal_group_ref_pic_diff[2][0]	2
3	temporal_group_temporal_id[3]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[3]	1
	temporal_group_ref_pic_diff[3][0]	1

6.7.6.7. S2T1 / S2T1h (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	255
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	1
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1

	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	1

6.7.6.8. S2T2 / S2T2h (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	255
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	2
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	2
1	temporal_group_temporal_id[1]	1
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1

6.7.6.9. S2T3 / S2T3h (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	255
Picture	**Temporal Group Description**	**Value**

	temporal_group_size	4
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	4
1	temporal_group_temporal_id[1]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1
2	temporal_group_temporal_id[2]	1
	temporal_group_temporal_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[2]	1
	temporal_group_ref_pic_diff[2][0]	2
3	temporal_group_temporal_id[3]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[3]	1
	temporal_group_ref_pic_diff[3][0]	1

6.7.6.10. L3T1 (Informative)

LayerSpatial Layers DescriptionValue

	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	0
2	spatial_layer_ref_id[1]	1

Picture	**Temporal Group Description**	**Value**
	temporal_group_size	1
0	temporal_group_temporal_id[0]	0

	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	1

6.7.6.11. L3T2 (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	0
2	spatial_layer_ref_id[1]	1
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	2
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	2
1	temporal_group_temporal_id[1]	1
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1

6.7.6.12. L3T3 (Informative)

Layer	**Spatial Layers Description**	**Value**
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	0

2	spatial_layer_ref_id[1]	1
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	4
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	4
1	temporal_group_temporal_id[1]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1
2	temporal_group_temporal_id[2]	1
	temporal_group_temporal_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[2]	1
	temporal_group_ref_pic_diff[2][0]	2
3	temporal_group_temporal_id[3]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[3]	1
	temporal_group_ref_pic_diff[3][0]	1

6.7.6.13. S3T1 (Informative)

LayerSpatial Layers DescriptionValue

	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	255
2	spatial_layer_ref_id[1]	255

Picture	Temporal Group Description	Value
	temporal_group_size	1
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	1

6.7.6.14. S3T2 (Informative)

Layer	Spatial Layers Description	Value
	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	255
2	spatial_layer_ref_id[1]	255
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	2
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	2
1	temporal_group_temporal_id[1]	1
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1

6.7.6.15. S3T3 (Informative)

Layer	Spatial Layers Description	Value

	spatial_layers_cnt_minus_1	1
0	spatial_layer_ref_id[0]	255
1	spatial_layer_ref_id[1]	255
2	spatial_layer_ref_id[1]	255
Picture	**Temporal Group Description**	**Value**
	temporal_group_size	4
0	temporal_group_temporal_id[0]	0
	temporal_group_temporal_switching_up_point_flag[0]	1
	temporal_group_spatial_switching_up_point_flag[0]	0
	temporal_group_ref_cnt[0]	1
	temporal_group_ref_pic_diff[0][0]	4
1	temporal_group_temporal_id[1]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[1]	1
	temporal_group_ref_pic_diff[1][0]	1
2	temporal_group_temporal_id[2]	1
	temporal_group_temporal_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[2]	1
	temporal_group_ref_pic_diff[2][0]	2
3	temporal_group_temporal_id[3]	2
	temporal_group_temporal_switching_up_point_flag[1]	1
	temporal_group_spatial_switching_up_point_flag[1]	0
	temporal_group_ref_cnt[3]	1
	temporal_group_ref_pic_diff[3][0]	1

6.7.7. Metadata timecode semantics

counting_type specifies the method of dropping values of the n_frames syntax element as specified in the table below. counting_type should be the same for all pictures in the coded video sequence.

counting_type	Meaning
0	no dropping of n_frames count values and no use of time_offset_value
1	no dropping of n_frames count values
2	dropping of individual zero values of n_frames count
3	dropping of individual values of n_frames count equal to maxFps − 1
4	dropping of the two lowest (value 0 and 1) n_frames counts when seconds_value is equal to 0 and minutes_value is not an integer multiple of 10
5	dropping of unspecified individual n_frames count values
6	dropping of unspecified numbers of unspecified n_frames count values
7..31	reserved

full_timestamp_flag equal to 1 indicates that the the seconds_value, minutes_value, hours_value syntax elements will be present. full_timestamp_flag equal to 0 indicates that there are flags to control the presence of these syntax elements.

When timing_info_present_flag is equal to 1, the contents of the clock timestamp indicate a time of origin, capture, or ideal display. This indicated time is computed as follows:

```
if ( equal_picture_interval ) {
  ticksPerPicture = num_ticks_per_picture_minus_1 + 1
} else {
  ticksPerPicture = 1
}
ss = ( ( hours_value * 60 + minutes_value) * 60 + seconds_value )
clockTimestamp = ss * time_scale + n_frames * ticksPerPicture + time_offset_value
```

clockTimestamp is in units of clock ticks of a clock with clock frequency equal to time_scale Hz, relative to some unspecified point in time for which clockTimestamp would be equal to 0.

discontinuity_flag equal to 0 indicates that the difference between the current value of clockTimestamp and the value of clockTimestamp computed from the previous set of timestamp syntax elements in output order can be interpreted as the time difference between the times of origin or capture of the associated frames or fields. discontinuity_flag equal to 1 indicates that the difference between the current value of clockTimestamp and the value of clockTimestamp computed from the previous set of clock timestamp syntax elements in output order should not be interpreted as the time difference between the times of origin or capture of the associated frames or fields.

When timing_info_present_flag is equal to 1 and discontinuity_flag is equal to 0, the value of clockTimestamp shall be greater than or equal to the value of clockTimestamp for the previous set of clock timestamp syntax elements in output order.

cnt_dropped_flag specifies the skipping of one or more values of n_frames using the counting method specified by counting_type.

n_frames is used to compute clockTimestamp. When timing_info_present_flag is equal to 1, n_frames shall be less than maxFps, where maxFps is specified by maxFps = ceil(time_scale / (2 * num_units_in_display_tick)).

seconds_flag equal to 1 specifies that seconds_value and minutes_flag are present when full_timestamp_flag is equal to 0. seconds_flag equal to 0 specifies that seconds_value and minutes_flag are not present.

seconds_value is used to compute clockTimestamp and shall be in the range of 0 to 59. When seconds_value is not present, its value is inferred to be equal to the value of seconds_value for the previous set of clock timestamp syntax elements in decoding order, and it is required that such a previous seconds_value shall have been present.

minutes_flag equal to 1 specifies that minutes_value and hours_flag are present when full_timestamp_flag is equal to 0 and seconds_flag is equal to 1. minutes_flag equal to 0 specifies that minutes_value and hours_flag are not present.

minutes_value specifies the value of mm used to compute clockTimestamp and shall be in the range of 0 to 59, inclusive. When minutes_value is not present, its value is inferred to be equal to the value of minutes_value for the previous set of clock timestamp syntax elements in decoding order, and it is required that such a previous minutes_value shall have been present.

hours_flag equal to 1 specifies that hours_value is present when full_timestamp_flag is equal to 0 and seconds_flag is equal to 1 and minutes_flag is equal to 1.

hours_value is used to compute clockTimestamp and shall be in the range of 0 to 23, inclusive. When hours_value is not present, its value is inferred to be equal to the value of hours_value for the previous set of clock timestamp syntax elements in decoding order, and it is required that such a previous hours_value shall have been present.

time_offset_length greater than 0 specifies the length in bits of the time_offset_value syntax element. time_offset_length equal to 0 specifies that the time_offset_value syntax element is not present. time_offset_length should be the same for all pictures in the coded video sequence.

time_offset_value is used to compute clockTimestamp. The number of bits used to represent time_offset_value is equal to time_offset_length. When time_offset_value is not present, its value is inferred to be equal to 0.

6.8. Frame header OBU semantics

6.8.1. General frame header OBU semantics

It is a requirement of bitstream conformance that a sequence header OBU has been received before a frame header OBU.

frame_header_copy is a function call that indicates that a copy of the previous frame_header_obu should be inserted at this point.

> **Note:** Bitstreams may contain several copies of the frame_header_obu interspersed with tile_group_obu to allow for greater error resilience. However, the copies must contain identical contents to the original frame_header_obu.

If obu_type is equal to OBU_FRAME_HEADER, it is a requirement of bitstream conformance that SeenFrameHeader is equal to 0.

If obu_type is equal to OBU_REDUNDANT_FRAME_HEADER, it is a requirement of bitstream conformance that SeenFrameHeader is equal to 1.

> **Note:** These requirements ensure that the first frame header for a frame has obu_type equal to OBU_FRAME_HEADER, while later copies of this frame header (if present) have obu_type equal to OBU_REDUNDANT_FRAME_HEADER.

TileNum is a variable giving the index (zero-based) of the current tile.

decode_frame_wrapup is a function call that indicates that the decode frame wrapup process specified in section 7.4 should be invoked.

6.8.2. Uncompressed header semantics

show_existing_frame equal to 1, indicates the frame indexed by frame_to_show_map_idx is to be output; show_existing_frame equal to 0 indicates that further processing is required.

If obu_type is equal to OBU_FRAME, it is a requirement of bitstream conformance that show_existing_frame is equal to 0.

frame_to_show_map_idx specifies the frame to be output. It is only available if show_existing_frame is 1.

display_frame_id provides the frame id number for the frame to output. It is a requirement of bitstream conformance that whenever display_frame_id is read, the value matches RefFrameId[frame_to_show_map_idx] (the value of current_frame_id at the time that the frame indexed by frame_to_show_map_idx was stored), and that RefValid[frame_to_show_map_idx] is equal to 1.

It is a requirement of bitstream conformance that the number of bits needed to read display_frame_id does not exceed 16. This is equivalent to the constraint that idLen <= 16.

frame_type specifies the type of the frame:

frame_type	Name of frame_type
0	KEY_FRAME
1	INTER_FRAME
2	INTRA_ONLY_FRAME
3	SWITCH_FRAME

show_frame equal to 1 specifies that this frame should be immediately output once decoded. show_frame equal to 0 specifies that this frame should not be immediately output. (It may be output later if a later uncompressed header uses show_existing_frame equal to 1).

showable_frame equal to 1 specifies that the frame may be output using the show_existing_frame mechanism. showable_frame equal to 0 specifies that this frame will not be output using the show_existing_frame mechanism.

It is a requirement of bitstream conformance that when show_existing_frame is used to show a previous frame, that the value of showable_frame for the previous frame was equal to 1.

It is a requirement of bitstream conformance that when show_existing_frame is used to show a previous frame with RefFrameType[frame_to_show_map_idx] equal to KEY_FRAME, that the frame is output via the show_existing_frame mechanism at most once.

> **Note:** This requirement also forbids storing a frame with frame_type equal to KEY_FRAME into multiple reference frames and then using show_existing_frame for each reference frame.

error_resilient_mode equal to 1 indicates that error resilient mode is enabled; error_resilient_mode equal to 0 indicates that error resilient mode is disabled.

> **Note:** Error resilient mode allows the syntax of a frame to be parsed independently of previously decoded frames.

disable_cdf_update specifies whether the CDF update in the symbol decoding process should be disabled.

current_frame_id specifies the frame id number for the current frame. Frame id numbers are additional information that do not affect the decoding process, but provide decoders with a way of detecting missing reference frames so that appropriate action can be taken.

If frame_type is not equal to KEY_FRAME or show_frame is equal to 0, it is a requirement of bitstream conformance that all of the following conditions are true:

- current_frame_id is not equal to PrevFrameID,
- DiffFrameID is less than 1 << (idLen - 1)

where DiffFrameID is specified as follows:

- If current_frame_id is greater than PrevFrameID, DiffFrameID is equal to current_frame_id - PrevFrameID.
- Otherwise, DiffFrameID is equal to (1 << idLen) + current_frame_id - PrevFrameID.

frame_size_override_flag equal to 0 specifies that the frame size is equal to the size in the sequence header. frame_size_override_flag equal to 1 specifies that the frame size will either be specified as the size of one of the reference frames, or computed from the frame_width_minus_1 and frame_height_minus_1 syntax elements.

order_hint is used to compute OrderHint.

OrderHint specifies OrderHintBits least significant bits of the expected output order for this frame.

> **Note:** There is no requirement that OrderHint should reflect the true output order. As a guideline, the motion vector prediction is expected to be more accurate if the true output order is used for frames that will be shown later. If a frame is never to be shown (e.g. it has been constructed as an average of several frames for reference purposes), the encoder is free to choose whichever value of OrderHint will give the best compression.

primary_ref_frame specifies which reference frame contains the CDF values and other state that should be loaded at the start of the frame.

> **Note:** It is allowed for primary_ref_frame to be coded as PRIMARY_REF_NONE, this will cause default values to be used for the CDF values and other state.

buffer_removal_time_present_flag equal to 1 specifies that buffer_removal_time is present. buffer_removal_time_present_flag equal to 0 specifies that buffer_removal_time is not present.

buffer_removal_time[opNum] specifies the frame removal time in units of DecCT clock ticks counted from the removal time of the last random access point for operating point opNum. buffer_removal_time is signaled as a fixed length unsigned integer with a length in bits given by buffer_removal_time_length_minus_1 + 1.

buffer_removal_time is the remainder of a modulo 1 << (buffer_removal_time_length_minus_1 + 1) counter.

allow_screen_content_tools equal to 1 indicates that intra blocks may use palette encoding; allow_screen_content_tools equal to 0 indicates that palette encoding is never used.

allow_intrabc equal to 1 indicates that intra block copy may be used in this frame. allow_intrabc equal to 0 indicates that intra block copy is not allowed in this frame.

> **Note:** intra block copy is only allowed in intra frames, and disables all loop filtering. force_integer_mv will be equal to 1 for intra frames, so only integer offsets are allowed in block copy mode.

force_integer_mv equal to 1 specifies that motion vectors will always be integers. force_integer_mv equal to 0 specifies that motion vectors can contain fractional bits.

ref_order_hint[i] specifies the expected output order hint for each reference frame.

> **Note:** The values in the ref_order_hint array are provided to allow implementations to gracefully handle cases when some frames have been lost.

> **Note:** When scalability is used, the values in RefOrderHint during the decode process may depend on the selected operating point.

refresh_frame_flags contains a bitmask that specifies which reference frame slots will be updated with the current frame after it is decoded.

If frame_type is equal to INTRA_ONLY_FRAME, it is a requirement of bitstream conformance that refresh_frame_flags is not equal to 0xff.

> **Note:** This restriction encourages encoders to correctly label random access points (by forcing frame_type to be equal to KEY_FRAME when an intra frame is used to reset the decoding process).

See section 7.20 for details of the frame update process.

frame_refs_short_signaling equal to 1 indicates that only two reference frames are explicitly signaled. frame_refs_short_signaling equal to 0 indicates that all reference frames are explicitly signaled.

last_frame_idx specifies the reference frame to use for LAST_FRAME.

gold_frame_idx specifies the reference frame to use for GOLDEN_FRAME.

set_frame_refs is a function call that indicates the conceptual point where the ref_frame_idx values are computed (in the case when frame_refs_short_signaling is equal to 1, these syntax elements are computed instead of being explicitly signaled). When this function is called, the set frame refs process specified in section 7.8 is invoked.

ref_frame_idx[i] specifies which reference frames are used by inter frames. It is a requirement of bitstream conformance that RefValid[ref_frame_idx[i]] is equal to 1, and that the selected reference frames match the current frame in bit depth, profile, chroma subsampling, and color space.

> **Note:** Syntax elements indicate a reference (such as LAST_FRAME, ALTREF_FRAME). These references are looked up in the ref_frame_idx array to find which reference frame should be used during inter prediction. There is no requirement that the values in ref_frame_idx should be distinct.

RefFrameSignBias specifies the intended direction of the motion vector in time for each reference frame. A sign bias equal to 0 indicates that the reference frame is a forwards reference (i.e. the reference frame is expected to be output before the current frame); a sign bias equal to 1 indicates that the reference frame is a backwards reference.

> **Note:** The sign bias is just an indication that can improve the accuracy of motion vector prediction and is not constrained to reflect the actual output order of pictures.

delta_frame_id_minus_1 is used to calculate DeltaFrameId.

DeltaFrameId specifies the distance to the frame id for the reference frame.

RefFrameId[i] specifies the frame id for each reference frame.

expectedFrameId[i] specifies the frame id for each frame used for reference. It is a requirement of bitstream conformance that whenever expectedFrameId[i] is calculated, the value matches RefFrameId[ref_frame_idx[i]] (this contains the value of current_frame_id at the time that the frame indexed by ref_frame_idx was stored).

allow_high_precision_mv equal to 0 specifies that motion vectors are specified to quarter pel precision; allow_high_precision_mv equal to 1 specifies that motion vectors are specified to eighth pel precision.

is_motion_mode_switchable equal to 0 specifies that only the SIMPLE motion mode will be used.

use_ref_frame_mvs equal to 1 specifies that motion vector information from a previous frame can be used when decoding the current frame. use_ref_frame_mvs equal to 0 specifies that this information will not be used.

disable_frame_end_update_cdf equal to 1 indicates that the end of frame CDF update is disabled; disable_frame_end_update_cdf equal to 0 indicates that the end of frame CDF update is enabled.

> **Note:** It can be useful to disable the CDF update because it means the next frame can start to be decoded as soon as the frame headers of the current frame have been processed.

motion_field_estimation is a function call which indicates that the motion field estimation process in section 7.9 should be invoked.

OrderHints specifies the expected output order for each reference frame.

CodedLossless is a variable that is equal to 1 when all segments use lossless encoding. This indicates that the frame is fully lossless at the coded resolution of FrameWidth by FrameHeight. In this case, the loop filter and CDEF filter are disabled.

It is a requirement of bitstream conformance that delta_q_present is equal to 0 when CodedLossless is equal to 1.

AllLossless is a variable that is equal to 1 when CodedLossless is equal to 1 and FrameWidth is equal to UpscaledWidth. This indicates that the frame is fully lossless at the upscaled resolution. In this case, the loop filter, CDEF filter, and loop restoration are disabled.

allow_warped_motion equal to 1 indicates that the syntax element motion_mode may be present. allow_warped_motion equal to 0 indicates that the syntax element motion_mode will not be present (this means that LOCALWARP cannot be signaled if allow_warped_motion is equal to 0).

reduced_tx_set equal to 1 specifies that the frame is restricted to a reduced subset of the full set of transform types.

setup_past_independence is a function call that indicates that this frame can be decoded without dependence on previous coded frames. When this function is invoked the following takes place:

- FeatureData[i][j] and FeatureEnabled[i][j] are set equal to 0 for i = 0..MAX_SEGMENTS-1 and j = 0..SEG_LVL_MAX-1.
- PrevSegmentIds[row][col] is set equal to 0 for row = 0..MiRows-1 and col = 0..MiCols-1.

- GmType[ref] is set equal to IDENTITY for ref = LAST_FRAME..ALTREF_FRAME.
- PrevGmParams[ref][i] is set equal to ((i % 3 == 2) ? 1 << WARPEDMODEL_PREC_BITS : 0) for ref = LAST_FRAME..ALTREF_FRAME, for i = 0..5.
- loop_filter_delta_enabled is set equal to 1.
- loop_filter_ref_deltas[INTRA_FRAME] is set equal to 1.
- loop_filter_ref_deltas[LAST_FRAME] is set equal to 0.
- loop_filter_ref_deltas[LAST2_FRAME] is set equal to 0.
- loop_filter_ref_deltas[LAST3_FRAME] is set equal to 0.
- loop_filter_ref_deltas[BWDREF_FRAME] is set equal to 0.
- loop_filter_ref_deltas[GOLDEN_FRAME] is set equal to -1.
- loop_filter_ref_deltas[ALTREF_FRAME] is set equal to -1.
- loop_filter_ref_deltas[ALTREF2_FRAME] is set equal to -1.
- loop_filter_mode_deltas[i] is set equal to 0 for i = 0..1.

init_non_coeff_cdfs is a function call that indicates that the CDF tables which are not used in the coeff( ) syntax structure should be initialised. When this function is invoked, the following steps apply:

- YModeCdf is set to a copy of Default_Y_Mode_Cdf
- UVModeCflNotAllowedCdf is set to a copy of Default_Uv_Mode_Cfl_Not_Allowed_Cdf
- UVModeCflAllowedCdf is set to a copy of Default_Uv_Mode_Cfl_Allowed_Cdf
- AngleDeltaCdf is set to a copy of Default_Angle_Delta_Cdf
- IntrabcCdf is set to a copy of Default_Intrabc_Cdf
- PartitionW8Cdf is set to a copy of Default_Partition_W8_Cdf
- PartitionW16Cdf is set to a copy of Default_Partition_W16_Cdf
- PartitionW32Cdf is set to a copy of Default_Partition_W32_Cdf
- PartitionW64Cdf is set to a copy of Default_Partition_W64_Cdf
- PartitionW128Cdf is set to a copy of Default_Partition_W128_Cdf
- SegmentIdCdf is set to a copy of Default_Segment_Id_Cdf

- SegmentIdPredictedCdf is set to a copy of Default_Segment_Id_Predicted_Cdf
- Tx8x8Cdf is set to a copy of Default_Tx_8x8_Cdf
- Tx16x16Cdf is set to a copy of Default_Tx_16x16_Cdf
- Tx32x32Cdf is set to a copy of Default_Tx_32x32_Cdf
- Tx64x64Cdf is set to a copy of Default_Tx_64x64_Cdf
- TxfmSplitCdf is set to a copy of Default_Txfm_Split_Cdf
- FilterIntraModeCdf is set to a copy of Default_Filter_Intra_Mode_Cdf
- FilterIntraCdf is set to a copy of Default_Filter_Intra_Cdf
- InterpFilterCdf is set to a copy of Default_Interp_Filter_Cdf
- MotionModeCdf is set to a copy of Default_Motion_Mode_Cdf
- NewMvCdf is set to a copy of Default_New_Mv_Cdf
- ZeroMvCdf is set to a copy of Default_Zero_Mv_Cdf
- RefMvCdf is set to a copy of Default_Ref_Mv_Cdf
- CompoundModeCdf is set to a copy of Default_Compound_Mode_Cdf
- DrlModeCdf is set to a copy of Default_Drl_Mode_Cdf
- IsInterCdf is set to a copy of Default_Is_Inter_Cdf
- CompModeCdf is set to a copy of Default_Comp_Mode_Cdf
- SkipModeCdf is set to a copy of Default_Skip_Mode_Cdf
- SkipCdf is set to a copy of Default_Skip_Cdf
- CompRefCdf is set to a copy of Default_Comp_Ref_Cdf
- CompBwdRefCdf is set to a copy of Default_Comp_Bwd_Ref_Cdf
- SingleRefCdf is set to a copy of Default_Single_Ref_Cdf
- MvJointCdf[i] is set to a copy of Default_Mv_Joint_Cdf for i = 0..MV_CONTEXTS-1
- MvClassCdf[i] is set to a copy of Default_Mv_Class_Cdf for i = 0..MV_CONTEXTS-1
- MvClass0BitCdf[i][comp] is set to a copy of Default_Mv_Class0_Bit_Cdf for i = 0..MV_CONTEXTS-1 and comp = 0..1

- MvFrCdf[i] is set to a copy of Default_Mv_Fr_Cdf for i = 0..MV_CONTEXTS-1
- MvClass0FrCdf[i] is set to a copy of Default_Mv_Class0_Fr_Cdf for i = 0..MV_CONTEXTS-1
- MvClass0HpCdf[i][comp] is set to a copy of Default_Mv_Class0_Hp_Cdf for i = 0..MV_CONTEXTS-1 and comp = 0..1
- MvSignCdf[i][comp] is set to a copy of Default_Mv_Sign_Cdf for i = 0..MV_CONTEXTS-1 and comp = 0..1
- MvBitCdf[i][comp] is set to a copy of Default_Mv_Bit_Cdf for i = 0..MV_CONTEXTS-1 and comp = 0..1
- MvHpCdf[i][comp] is set to a copy of Default_Mv_Hp_Cdf for i = 0..MV_CONTEXTS-1 and comp = 0..1
- PaletteYModeCdf is set to a copy of Default_Palette_Y_Mode_Cdf
- PaletteUVModeCdf is set to a copy of Default_Palette_Uv_Mode_Cdf
- PaletteYSizeCdf is set to a copy of Default_Palette_Y_Size_Cdf
- PaletteUVSizeCdf is set to a copy of Default_Palette_Uv_Size_Cdf
- PaletteSize2YColorCdf is set to a copy of Default_Palette_Size_2_Y_Color_Cdf
- PaletteSize2UVColorCdf is set to a copy of Default_Palette_Size_2_Uv_Color_Cdf
- PaletteSize3YColorCdf is set to a copy of Default_Palette_Size_3_Y_Color_Cdf
- PaletteSize3UVColorCdf is set to a copy of Default_Palette_Size_3_Uv_Color_Cdf
- PaletteSize4YColorCdf is set to a copy of Default_Palette_Size_4_Y_Color_Cdf
- PaletteSize4UVColorCdf is set to a copy of Default_Palette_Size_4_Uv_Color_Cdf
- PaletteSize5YColorCdf is set to a copy of Default_Palette_Size_5_Y_Color_Cdf
- PaletteSize5UVColorCdf is set to a copy of Default_Palette_Size_5_Uv_Color_Cdf
- PaletteSize6YColorCdf is set to a copy of Default_Palette_Size_6_Y_Color_Cdf
- PaletteSize6UVColorCdf is set to a copy of Default_Palette_Size_6_Uv_Color_Cdf
- PaletteSize7YColorCdf is set to a copy of Default_Palette_Size_7_Y_Color_Cdf
- PaletteSize7UVColorCdf is set to a copy of Default_Palette_Size_7_Uv_Color_Cdf
- PaletteSize8YColorCdf is set to a copy of Default_Palette_Size_8_Y_Color_Cdf
- PaletteSize8UVColorCdf is set to a copy of Default_Palette_Size_8_Uv_Color_Cdf
- DeltaQCdf is set to a copy of Default_Delta_Q_Cdf

- DeltaLFCdf is set to a copy of Default_Delta_Lf_Cdf
- DeltaLFMultiCdf[i] is set to a copy of Default_Delta_Lf_Cdf for i = 0..FRAME_LF_COUNT-1
- IntraTxTypeSet1Cdf is set to a copy of Default_Intra_Tx_Type_Set1_Cdf
- IntraTxTypeSet2Cdf is set to a copy of Default_Intra_Tx_Type_Set2_Cdf
- InterTxTypeSet1Cdf is set to a copy of Default_Inter_Tx_Type_Set1_Cdf
- InterTxTypeSet2Cdf is set to a copy of Default_Inter_Tx_Type_Set2_Cdf
- InterTxTypeSet3Cdf is set to a copy of Default_Inter_Tx_Type_Set3_Cdf
- UseObmcCdf is set to a copy of Default_Use_Obmc_Cdf
- InterIntraCdf is set to a copy of Default_Inter_Intra_Cdf
- CompRefTypeCdf is set to a copy of Default_Comp_Ref_Type_Cdf
- CflSignCdf is set to a copy of Default_Cfl_Sign_Cdf
- UniCompRefCdf is set to a copy of Default_Uni_Comp_Ref_Cdf
- WedgeInterIntraCdf is set to a copy of Default_Wedge_Inter_Intra_Cdf
- CompGroupIdxCdf is set to a copy of Default_Comp_Group_Idx_Cdf
- CompoundIdxCdf is set to a copy of Default_Compound_Idx_Cdf
- CompoundTypeCdf is set to a copy of Default_Compound_Type_Cdf
- InterIntraModeCdf is set to a copy of Default_Inter_Intra_Mode_Cdf
- WedgeIndexCdf is set to a copy of Default_Wedge_Index_Cdf
- CflAlphaCdf is set to a copy of Default_Cfl_Alpha_Cdf
- UseWienerCdf is set to a copy of Default_Use_Wiener_Cdf
- UseSgrprojCdf is set to a copy of Default_Use_Sgrproj_Cdf
- RestorationTypeCdf is set to a copy of Default_Restoration_Type_Cdf

init_coeff_cdfs( ) is a function call that indicates that the CDF tables used in the coeff( ) syntax structure should be initialised. When this function is invoked, the following steps apply:

- The variable idx is derived as follows:
    - If base_q_idx is less than or equal to 20, idx is set equal to 0.

    - Otherwise, if base_q_idx is less than or equal to 60, idx is set equal to 1.
    - Otherwise, if base_q_idx is less than or equal to 120, idx is set equal to 2.
    - Otherwise, idx is set equal to 3.
- The cumulative distribution function arrays are reset to default values as follows:
    - TxbSkipCdf is set to a copy of Default_Txb_Skip_Cdf[idx].
    - EobPt16Cdf is set to a copy of Default_Eob_Pt_16_Cdf[idx].
    - EobPt32Cdf is set to a copy of Default_Eob_Pt_32_Cdf[idx].
    - EobPt64Cdf is set to a copy of Default_Eob_Pt_64_Cdf[idx].
    - EobPt128Cdf is set to a copy of Default_Eob_Pt_128_Cdf[idx].
    - EobPt256Cdf is set to a copy of Default_Eob_Pt_256_Cdf[idx].
    - EobPt512Cdf is set to a copy of Default_Eob_Pt_512_Cdf[idx].
    - EobPt1024Cdf is set to a copy of Default_Eob_Pt_1024_Cdf[idx].
    - EobExtraCdf is set to a copy of Default_Eob_Extra_Cdf[idx].
    - DcSignCdf is set to a copy of Default_Dc_Sign_Cdf[idx].
    - CoeffBaseEobCdf is set to a copy of Default_Coeff_Base_Eob_Cdf[idx].
    - CoeffBaseCdf is set to a copy of Default_Coeff_Base_Cdf[idx].
    - CoeffBrCdf is set to a copy of Default_Coeff_Br_Cdf[idx].

load_cdfs(ctx) is a function call that indicates that the CDF tables are loaded from frame context number ctx in the range 0 to (NUM_REF_FRAMES - 1). When this function is invoked, a copy of each CDF array mentioned in the semantics for init_coeff_cdfs and init_non_coeff_cdfs is loaded from an area of memory indexed by ctx. (The memory contents of these frame contexts have been initialized by previous calls to save_cdfs). Once the CDF arrays have been loaded, the last entry in each array, representing the symbol count for that context, is set to 0.

load_previous( ) is a function call that indicates that information from a previous frame may be loaded for use in decoding the current frame. When this function is invoked the following ordered steps apply:

1. The variable prevFrame is set equal to ref_frame_idx[primary_ref_frame].
2. PrevGmParams is set equal to SavedGmParams[prevFrame].
3. The function load_loop_filter_params(prevFrame) specified in section 7.21 is invoked.
4. The function load_segmentation_params(prevFrame) specified in section 7.21 is invoked.

load_previous_segment_ids( ) is a function call that indicates that a segment map from a previous frame may be loaded for use in decoding the current frame. When this function is invoked the segment map contained in PrevSegmentIds is set as follows:

1. The variable prevFrame is set equal to ref_frame_idx[primary_ref_frame].

2. If segmentation_enabled is equal to 1, RefMiCols[prevFrame] is equal to MiCols, and RefMiRows[prevFrame] is equal to MiRows, PrevSegmentIds[row][col] is set equal to SavedSegmentIds[prevFrame][row][col] for row = 0..MiRows-1, for col = 0..MiCols-1.

   Otherwise, PrevSegmentIds[row][col] is set equal to 0 for row = 0..MiRows-1, for col = 0..MiCols-1.

6.8.3. Reference frame marking semantics

RefValid is an array which is indexed by a reference picture slot number. A value of 1 in the array signifies that the corresponding reference picture slot is valid for use as a reference picture, while a value of 0 signifies that the corresponding reference picture slot is not valid for use as a reference picture.

> **Note:** RefValid is only used to define valid bitstreams when frame_id_numbers_present_flag is equal to 1. Frames are marked as invalid when they are too far in the past to be referenced by the frame id mechanism.

6.8.4. Frame size semantics

frame_width_minus_1 plus one is the width of the frame in luma samples.

frame_height_minus_1 plus one is the height of the frame in luma samples.

It is a requirement of bitstream conformance that frame_width_minus_1 is less than or equal to max_frame_width_minus_1.

It is a requirement of bitstream conformance that frame_height_minus_1 is less than or equal to max_frame_height_minus_1.

If FrameIsIntra is equal to 0 (indicating that this frame may use inter prediction), the requirements described in the frame size with refs semantics of section 6.8.6 must also be satisfied.

6.8.5. Render size semantics

The render size is provided as a hint to the application about the desired display size. It has no effect on the decoding process.

render_and_frame_size_different equal to 0 means that the render width and height are inferred from the frame width and height. render_and_frame_size_different equal to 1 means that the render width and height are explicitly coded.

> **Note:** It is allowed for the bitstream to explicitly code the render dimensions in the bitstream even if they are an exact match for the frame dimensions.

render_width_minus_1 plus one is the render width of the frame in luma samples.

render_height_minus_1 plus one is the render height of the frame in luma samples.

6.8.6. Frame size with refs semantics

For inter frames, the frame size is either set equal to the size of a reference frame, or can be sent explicitly.

found_ref equal to 1 indicates that the frame dimensions can be inferred from reference frame i where i is the loop counter in the syntax parsing process for frame_size_with_refs. found_ref equal to 0 indicates that the frame dimensions are not inferred from reference frame i.

Once the FrameWidth and FrameHeight have been computed for an inter frame, it is a requirement of bitstream conformance that for all values of i in the range 0..(REFS_PER_FRAME - 1), all the following conditions are true:

- 2 * FrameWidth >= RefUpscaledWidth[ref_frame_idx[i]]
- 2 * FrameHeight >= RefFrameHeight[ref_frame_idx[i]]
- FrameWidth <= 16 * RefUpscaledWidth[ref_frame_idx[i]]
- FrameHeight <= 16 * RefFrameHeight[ref_frame_idx[i]]

Note: This is a requirement even if all the blocks in an inter frame are coded using intra prediction.

6.8.7. Superres params semantics

use_superres equal to 0 indicates that no upscaling is needed. use_superres equal to 1 indicates that upscaling is needed.

coded_denom is used to compute the amount of upscaling.

SuperresDenom is the denominator of a fraction that specifies the ratio between the superblock width before and after upscaling. The numerator of this fraction is equal to the constant SUPERRES_NUM.

6.8.8. Compute image size semantics

MiCols is the number of 4x4 block columns in the frame.

MiRows is the number of 4x4 block rows in the frame.

6.8.9. Interpolation filter semantics

is_filter_switchable equal to 1 indicates that the filter selection is signaled at the block level; is_filter_switchable equal to 0 indicates that the filter selection is signaled at the frame level.

interpolation_filter specifies the filter selection used for performing inter prediction:

interpolation_filter	Name of interpolation_filter
0	EIGHTTAP
1	EIGHTTAP_SMOOTH
2	EIGHTTAP_SHARP
3	BILINEAR
4	SWITCHABLE

6.8.10. Loop filter semantics

loop_filter_level is an array containing loop filter strength values. Different loop filter strength values from the array are used depending on the image plane being filtered, and the edge direction (vertical or horizontal) being filtered.

loop_filter_sharpness indicates the sharpness level. The loop_filter_level and loop_filter_sharpness together determine when a block edge is filtered, and by how much the filtering can change the sample values.

The loop filter process is described in section 7.14.

loop_filter_delta_enabled equal to 1 means that the filter level depends on the mode and reference frame used to predict a block. loop_filter_delta_enabled equal to 0 means that the filter level does not depend on the mode and reference frame.

loop_filter_delta_update equal to 1 means that additional syntax elements are present that specify which mode and reference frame deltas are to be updated. loop_filter_delta_update equal to 0 means that these syntax elements are not present.

update_ref_delta equal to 1 means that the syntax element loop_filter_ref_delta is present; update_ref_delta equal to 0 means that this syntax element is not present.

loop_filter_ref_deltas contains the adjustment needed for the filter level based on the chosen reference frame. If this syntax element is not present, it maintains its previous value.

update_mode_delta equal to 1 means that the syntax element loop_filter_mode_deltas is present; update_mode_delta equal to 0 means that this syntax element is not present.

loop_filter_mode_deltas contains the adjustment needed for the filter level based on the chosen mode. If this syntax element is not present in the, it maintains its previous value.

> **Note:** The previous values for loop_filter_mode_deltas and loop_filter_ref_deltas are intially set by the setup_past_independence function and can be subsequently modified by these syntax elements being coded in a previous frame.

6.8.11. Quantization params semantics

The residual is specified via decoded coefficients which are adjusted by one of four quantization parameters before the inverse transform is applied. The choice depends on the plane (Y or UV) and coefficient position (DC/AC coefficient). The Dequantization process is specified in section 7.12.

base_q_idx indicates the base frame qindex. This is used for Y AC coefficients and as the base value for the other quantizers.

DeltaQYDc indicates the Y DC quantizer relative to base_q_idx.

diff_uv_delta equal to 1 indicates that the U and V delta quantizer values are coded separately. diff_uv_delta equal to 0 indicates that the U and V delta quantizer values share a common value.

DeltaQUDc indicates the U DC quantizer relative to base_q_idx.

DeltaQUAc indicates the U AC quantizer relative to base_q_idx.

DeltaQVDc indicates the V DC quantizer relative to base_q_idx.

DeltaQVAc indicates the V AC quantizer relative to base_q_idx.

using_qmatrix specifies that the quantizer matrix will be used to compute quantizers.

qm_y specifies the level in the quantizer matrix that should be used for luma plane decoding.

qm_u specifies the level in the quantizer matrix that should be used for chroma U plane decoding.

qm_v specifies the level in the quantizer matrix that should be used for chroma V plane decoding.

6.8.12. Delta quantizer semantics

delta_coded specifies that the delta_q syntax element is present.

delta_q specifies an offset (relative to base_q_idx) for a particular quantization parameter.

6.8.13. Segmentation params semantics

AV1 provides a means of segmenting the image and then applying various adjustments at the segment level.

Up to 8 segments may be specified for any given frame. For each of these segments it is possible to specify:

1. A quantizer (absolute value or delta).
2. A loop filter strength (absolute value or delta).
3. A prediction reference frame.
4. A block skip mode that implies both the use of a (0,0) motion vector and that no residual will be coded.

Each of these data values for each segment may be individually updated at the frame level. Where a value is not updated in a given frame, the value from the previous frame persists. The exceptions to this are key frames, intra only frames or other frames where independence from past frame values is required (for example to enable error resilience). In such cases all values are reset as described in the semantics for setup_past_independence.

The segment affiliation (the segmentation map) is stored at the resolution of 4x4 blocks. If no explicit update is coded for a block's segment affiliation, then it persists from frame to frame (until reset by a call to setup_past_independence).

SegIdPreSkip equal to 1 indicates that the segment id will be read before the skip syntax element. SegIdPreSkip equal to 0 indicates that the skip syntax element will be read first.

LastActiveSegId indicates the highest numbered segment id that has some enabled feature. This is used when decoding the segment id to only decode choices corresponding to used segments.

segmentation_enabled equal to 1 indicates that this frame makes use of the segmentation tool; segmentation_enabled equal to 0 indicates that the frame does not use segmentation.

segmentation_update_map equal to 1 indicates that the segmentation map are updated during the decoding of this frame. segmentation_update_map equal to 0 means that the segmentation map from the previous frame is used.

segmentation_temporal_update equal to 1 indicates that the updates to the segmentation map are coded relative to the existing segmentation map. segmentation_temporal_update equal to 0 indicates that the new segmentation map is coded without reference to the existing segmentation map.

segmentation_update_data equal to 1 indicates that new parameters are about to be specified for each segment. segmentation_update_data equal to 0 indicates that the segmentation parameters should keep their existing values.

feature_enabled equal to 0 indicates that the corresponding feature is unused and has value equal to 0. feature_enabled equal to 1 indicates that the feature value is coded.

feature_value specifies the feature data for a segment feature.

6.8.14. Tile info semantics

uniform_tile_spacing_flag equal to 1 means that the tiles are uniformly spaced across the frame. (In other words, all tiles are the same size except for the ones at the right and bottom edge which can be smaller.) uniform_tile_spacing_flag equal to 0 means that the tile sizes are coded.

increment_tile_cols_log2 is used to compute TileColsLog2.

TileColsLog2 specifies the base 2 logarithm of the desired number of tiles across the frame.

TileCols specifies the number of tiles across the frame. It is a requirement of bitstream conformance that TileCols is less than or equal to MAX_TILE_COLS.

increment_tile_rows_log2 is used to compute TileRowsLog2.

TileRowsLog2 specifies the base 2 logarithm of the desired number of tiles down the frame.

> **Note:** For small frame sizes the actual number of tiles in the frame may be smaller than the desired number because the tile size is rounded up to a multiple of the maximum superblock size.

TileRows specifies the number of tiles down the frame. It is a requirement of bitstream conformance that TileRows is less than or equal to MAX_TILE_ROWS.

tileWidthSb is used to specify the width of each tile in units of superblocks. It is a requirement of bitstream conformance that tileWidthSb is less than maxTileWidthSb.

tileHeightSb is used to specify the height of each tile in units of superblocks. It is a requirement of bitstream conformance that tileWidthSb * tileHeightSb is less than maxTileAreaSb.

If uniform_tile_spacing_flag is equal to 0, it is a requirement of bitstream conformance that startSb is equal to sbCols when the loop writing MiColStarts exits.

If uniform_tile_spacing_flag is equal to 0, it is a requirement of bitstream conformance that startSb is equal to sbRows when the loop writing MiRowStarts exits.

> **Note:** The requirements on startSb ensure that the sizes of each tile add up to the full size of the frame when measured in superblocks.

MiColStarts is an array specifying the start column (in units of 4x4 luma samples) for each tile across the image.

MiRowStarts is an array specifying the start row (in units of 4x4 luma samples) for each tile down the image.

width_in_sbs_minus_1 specifies the width of a tile minus 1 in units of superblocks.

height_in_sbs_minus_1 specifies the height of a tile minus 1 in units of superblocks.

maxTileHeightSb specifies the maximum height (in units of superblocks) that can be used for a tile (to avoid making tiles with too much area).

context_update_tile_id specifies which tile to use for the CDF update. It is a requirement of bitstream conformance that context_update_tile_id is less than TileCols * TileRows.

tile_size_bytes_minus_1 is used to compute TileSizeBytes.

TileSizeBytes specifies the number of bytes needed to code each tile size.

6.8.15. Quantizer index delta parameters semantics

delta_q_present specifies whether quantizer index delta values are present.

delta_q_res specifies the left shift which should be applied to decoded quantizer index delta values.

6.8.16. Loop filter delta parameters semantics

delta_lf_present specifies whether loop filter delta values are present.

delta_lf_res specifies the left shift which should be applied to decoded loop filter delta values.

delta_lf_multi equal to 1 specifies that separate loop filter deltas are sent for horizontal luma edges, vertical luma edges, the U edges, and the V edges. delta_lf_multi equal to 0 specifies that the same loop filter delta is used for all edges.

6.8.17. Global motion params semantics

is_global specifies whether global motion parameters are present for a particular reference frame.

is_rot_zoom specifies whether a particular reference frame uses rotation and zoom global motion.

is_translation specifies whether a particular reference frame uses translation global motion.

6.8.18. Global param semantics

absBits is used to compute the range of values that can be used for gm_params[ref][idx]. The values allowed are in the range -(1 << absBits) to (1 << absBits).

precBits specifies the number of fractional bits used for representing gm_params[ref][idx]. All global motion parameters are stored in the model with WARPEDMODEL_PREC_BITS fractional bits, but the parameters are encoded with less precision.

6.8.19. Decode subexp semantics

subexp_final_bits provide the final bits that are read once the appropriate range has been determined.

subexp_more_bits equal to 0 specifies that the parameter is in the range mk to mk+a-1. subexp_more_bits equal to 1 specifies that the parameter is greater than mk+a-1.

subexp_bits specifies the value of the parameter minus mk.

6.8.20. Film grain params semantics

apply_grain equal to 1 specifies that film grain should be added to this frame. apply_grain equal to 0 specifies that film grain should not be added.

reset_grain_params() is a function call that indicates that all the syntax elements read in film_grain_params should be set equal to 0.

grain_seed specifies the starting value for the pseudo-random numbers used during film grain synthesis.

update_grain equal to 1 means that a new set of parameters should be sent. update_grain equal to 0 means that the previous set of parameters should be used.

film_grain_params_ref_idx indicates which reference frame contains the film grain parameters to be used for this frame.

It is a requirement of bitstream conformance that film_grain_params_ref_idx is equal to ref_frame_idx[j] for some value of j in the range 0 to REFS_PER_FRAME - 1.

> **Note:** This requirement means that film grain can only be predicted from the frames that the current frame is using as reference frames.

load_grain_params(idx) is a function call that indicates that all the syntax elements read in film_grain_params should be set equal to the values stored in an area of memory indexed by idx.

tempGrainSeed is a temporary variable that is used to avoid losing the value of grain_seed when load_grain_params is called. When update_grain is equal to 0, a previous set of parameters should be used for everything except grain_seed.

num_y_points specifies the number of points for the piece-wise linear scaling function of the luma component.

It is a requirement of bitstream conformance that num_y_points is less than or equal to 14.

point_y_value[i] represents the x (luma value) coordinate for the i-th point of the piecewise linear scaling function for luma component. The values are signaled on the scale of 0..255. (In case of 10 bit video, these values correspond to luma values divided by 4. In case of 12 bit video, these values correspond to luma values divided by 16.)

If i is greater than 0, it is a requirement of bitstream conformance that point_y_value[i] is greater than point_y_value[i - 1] (this ensures the x coordinates are specified in increasing order).

point_y_scaling[i] represents the scaling (output) value for the i-th point of the piecewise linear scaling function for luma component.

chroma_scaling_from_luma specifies that the chroma scaling is inferred from the luma scaling.

num_cb_points specifies the number of points for the piece-wise linear scaling function of the cb component.

It is a requirement of bitstream conformance that num_cb_points is less than or equal to 10.

> **Note:** When chroma_scaling_from_luma is equal to 1, it is still allowed for num_y_points to take values up to 14. This means that the chroma scaling also needs to support up to 14 points.

point_cb_value[i] represents the x coordinate for the i-th point of the piece-wise linear scaling function for cb component. The values are signaled on the scale of 0..255.

If i is greater than 0, it is a requirement of bitstream conformance that point_cb_value[i] is greater than point_cb_value[i - 1].

point_cb_scaling[i] represents the scaling (output) value for the i-th point of the piecewise linear scaling function for cb component.

num_cr_points specifies represents the number of points for the piece-wise linear scaling function of the cr component.

It is a requirement of bitstream conformance that num_cr_points is less than or equal to 10.

If subsampling_x is equal to 1 and subsampling_y is equal to 1 and num_cb_points is equal to 0, it is a requirement of bitstream conformance that num_cr_points is equal to 0.

If subsampling_x is equal to 1 and subsampling_y is equal to 1 and num_cb_points is not equal to 0, it is a requirement of bitstream conformance that num_cr_points is not equal to 0.

> **Note:** These requirements ensure that for 4:2:0 chroma subsampling, film grain noise will be applied to both chroma components, or to neither. There is no restriction for 4:2:2 or 4:4:4 chroma subsampling.

point_cr_value[i] represents the x coordinate for the i-th point of the piece-wise linear scaling function for cr component. The values are signaled on the scale of 0..255.

If i is greater than 0, it is a requirement of bitstream conformance that point_cr_value[i] is greater than point_cr_value[i - 1].

point_cr_scaling[i] represents the scaling (output) value for the i-th point of the piecewise linear scaling function for cr component.

grain_scaling_minus_8 represents the shift – 8 applied to the values of the chroma component. The grain_scaling_minus_8 can take values of 0..3 and determines the range and quantization step of the standard deviation of film grain.

ar_coeff_lag specifies the number of auto-regressive coefficients for luma and chroma.

ar_coeffs_y_plus_128[i] specifies auto-regressive coefficients used for the Y plane.

ar_coeffs_cb_plus_128[i] specifies auto-regressive coefficients used for the U plane.

ar_coeffs_cr_plus_128[i] specifies auto-regressive coefficients used for the V plane.

ar_coeff_shift_minus_6 specifies the range of the auto-regressive coefficients. Values of 0, 1, 2, and 3 correspond to the ranges for auto-regressive coefficients of [-2, 2), [-1, 1), [-0.5, 0.5) and [-0.25, 0.25) respectively.

grain_scale_shift specifies how much the Gaussian random numbers should be scaled down during the grain synthesis process.

cb_mult represents a multiplier for the cb component used in derivation of the input index to the cb component scaling function.

cb_luma_mult represents a multiplier for the average luma component used in derivation of the input index to the cb component scaling function.

cb_offset represents an offset used in derivation of the input index to the cb component scaling function.

cr_mult represents a multiplier for the cr component used in derivation of the input index to the cr component scaling function.

cr_luma_mult represents a multiplier for the average luma component used in derivation of the input index to the cr component scaling function.

cr_offset represents an offset used in derivation of the input index to the cr component scaling function.

overlap_flag equal to 1 indicates that the overlap between film grain blocks shall be applied. overlap_flag equal to 0 indicates that the overlap between film grain blocks shall not be applied.

clip_to_restricted_range equal to 1 indicates that clipping to the restricted (studio) range shall be applied to the sample values after adding the film grain (see the semantics for color_range for an explanation of studio swing). clip_to_restricted_range equal to 0 indicates that clipping to the full range shall be applied to the sample values after adding the film grain.

6.8.21. TX mode semantics

tx_mode_select is used to compute TxMode.

TxMode specifies how the transform size is determined:

TxMode	Name of TxMode
0	ONLY_4X4
1	TX_MODE_LARGEST
2	TX_MODE_SELECT

For tx_mode equal to TX_MODE_LARGEST, the inverse transform will use the largest transform size that fits inside the block.

For tx_mode equal to ONLY_4X4, the inverse transform will use only 4x4 transforms.

For tx_mode equal to TX_MODE_SELECT, the choice of transform size is specified explicitly for each block.

6.8.22. Skip mode params semantics

SkipModeFrame[list] specifies the frames to use for compound prediction when skip_mode is equal to 1.

skip_mode_present equal to 1 specifies that the syntax element skip_mode will be present. skip_mode_present equal to 0 specifies that skip_mode will not be used for this frame.

Note: Skip mode tries to use the closest forward and backward references (as measured by values in the RefOrderHint array). If no backward reference is found, then the second closest forward reference is used. If no forward reference is found, then skip mode is disabled. (Forward prediction is when a frame is used for reference that is considered to be output before the current frame, backward prediction is when a frame is used that has not yet been output.)

6.8.23. Frame reference mode semantics

reference_select equal to 1 specifies that the mode info for inter blocks contains the syntax element comp_mode that indicates whether to use single or compound reference prediction. Reference_select equal to 0 specifies that all inter blocks will use single prediction.

6.8.24. Temporal point info semantics

frame_presentation_time specifies the presentation time of the frame in clock ticks DispCT counted from the removal time of the last random access point for the operating point that is being decoded. The syntax element is signaled as a fixed length unsigned integer with a length in bits given by frame_presentation_time_length_minus_1 + 1. The frame_presentation_time is the remainder of a modulo 1 << (frame_presentation_time_length_minus_1 + 1) counter.

6.9. Frame OBU semantics

A frame OBU consists of a frame header OBU and a tile group OBU packed into a single OBU.

Note: The intention is to provide a more compact way of coding the common use case where the frame header is immediately followed by tile group data.

6.10. Tile group OBU semantics

6.10.1. General tile group OBU semantics

NumTiles specifies the total number of tiles in the frame.

tile_start_and_end_present_flag specifies whether tg_start and tg_end are present. If tg_start and tg_end are not present, this tile group covers the entire frame.

If obu_type is equal to OBU_FRAME, it is a requirement of bitstream conformance that the value of tile_start_and_end_present_flag is equal to 0.

tg_start specifies the zero-based index of the first tile in the current tile group.

It is a requirement of bitstream conformance that the value of tg_start is equal to the value of TileNum at the point that tile_group_obu is invoked.

tg_end specifies the zero-based index of the last tile in the current tile group.

It is a requirement of bitstream conformance that the value of tg_end is greater than or equal to tg_start.

It is a requirement of bitstream conformance that the value of tg_end for the last tile group in each frame is equal to NumTiles - 1.

> **Note:** These requirements ensure that conceptually all tile groups are present and received in order for the purposes of specifying the decode process.

frame_end_update_cdf is a function call that indicates that the frame CDF arrays are set equal to the saved CDFs. This process is described in section 7.7.

tile_size_minus_1 is used to compute tileSize.

tileSize specifies the size in bytes of the next coded tile.

> **Note:** This size includes any padding bytes if added by the exit process for the Symbol decoder. The size does not include the bytes used for tile_size_minus_1 or syntax elements sent before tile_size_minus_1. For the last tile in the tile group, tileSize is computed instead of being read and includes the OBU trailing bits.

decode_frame_wrapup is a function call that indicates that the decode frame wrapup process specified in section 7.4 should be invoked.

6.10.2. Decode tile semantics

clear_left_context is a function call that indicates that some arrays used to determine the probabilities are zeroed. When this function is invoked the arrays LeftLevelContext, LeftDcContext, and LeftSegPredContext are set equal to 0.

> **Note:** LeftLevelContext[plane][i], LeftDcContext[plane][i], and LeftSegPredContext[i] need to be set to 0 for i = 0..MiRows-1, for plane = 0..2.

clear_above_context is a function call that indicates that some arrays used to determine the probabilities are zeroed. When this function is invoked the arrays AboveLevelContext, AboveDcContext, and AboveSegPredContext are set equal to 0.

> **Note:** AboveLevelContext[plane][i], AboveDcContext[plane][i], and AboveSegPredContext[i] need to be set to 0 for i = 0..MiCols-1, for plane = 0..2.

ReadDeltas specifies whether the current block may read delta values for the quantizer index and loop filter. If the entire superblock is skipped the delta values are not read, otherwise delta values for the quantizer index and loop filter are read on the first block of a superblock. If delta_q_present is equal to 0, no delta values are read for the quantizer index. If delta_lf_present is equal to 0, no delta values are read for the loop filter.

6.10.3. Clear block decoded flags semantics

BlockDecoded is an array which stores one boolean value per 4x4 sample block per plane in the current superblock, plus a border of one 4x4 sample block on all sides of the superblock. Except for the borders, a value of 1 in BlockDecoded indicates that the corresponding 4x4 sample block has been decoded. The borders are used when computing above-right and below-left availability along the top and left edges of the superblock.

6.10.4. Decode partition semantics

partition specifies how a block is partitioned:

partition	Name of partition
0	PARTITION_NONE
1	PARTITION_HORZ
2	PARTITION_VERT
3	PARTITION_SPLIT
4	PARTITION_HORZ_A
5	PARTITION_HORZ_B
6	PARTITION_VERT_A
7	PARTITION_VERT_B
8	PARTITION_HORZ_4
9	PARTITION_VERT_4

The variable **subSize** is computed from partition and indicates the size of the component blocks within this block:

subSize	Name of subSize
0	BLOCK_4X4
1	BLOCK_4X8
2	BLOCK_8X4
3	BLOCK_8X8
4	BLOCK_8X16
5	BLOCK_16X8
6	BLOCK_16X16
7	BLOCK_16X32
8	BLOCK_32X16

subSize	Name of subSize
9	BLOCK_32X32
10	BLOCK_32X64
11	BLOCK_64X32
12	BLOCK_64X64
13	BLOCK_64X128
14	BLOCK_128X64
15	BLOCK_128X128
16	BLOCK_4X16
17	BLOCK_16X4
18	BLOCK_8X32
19	BLOCK_32X8
20	BLOCK_16X64
21	BLOCK_64X16

The dimensions of these blocks are given in width, height order (e.g. BLOCK_8X16 corresponds to a block that is 8 samples wide, and 16 samples high).

It is a requirement of bitstream conformance that get_plane_residual_size(subSize, 1) is not equal to BLOCK_INVALID every time subSize is computed.

> **Note:** This requirement prevents the UV blocks from being too tall or too wide (i.e. having aspect ratios outside the range 1:4 to 4:1). For example, when 4:2:2 chroma subsampling is used a luma partition of size 8x32 is invalid, as it implies a chroma partition of size 4x32, which results in an aspect ratio of 1:8.

split_or_vert is used to compute partition for blocks when only split or vert partitions are allowed because of overlap with the right hand edge of the frame.

split_or_horz is used to compute partition for blocks when only split or horz partitions are allowed because of overlap with the bottom edge of the frame.

6.10.5. Decode block semantics

MiRow is a variable holding the vertical location of the block in units of 4x4 luma samples.

MiCol is a variable holding the horizontal location of the block in units of 4x4 luma samples.

MiSize is a variable holding the size of the block with values having the same interpretation for the variable subSize.

HasChroma is a variable that specifies whether chroma information is coded for this block.

Variable **AvailU** is equal to 0 if the information from the block above cannot be used on the luma plane; AvailU is equal to 1 if the information from the block above can be used on the luma plane.

Variable **AvailL** is equal to 0 if the information from the block to the left can not be used on the luma plane; AvailL is equal to 1 if the information from the block to the left can be used on the luma plane.

> **Note:** Information from a block in a different tile can be used in some circumstances if the block is above, but not if the block is to the left.

Variables **AvailUChroma** and **AvailLChroma** have the same significance as AvailU and AvailL, but on the chroma planes.

6.10.6. Intra frame mode info semantics

This syntax is used when coding an intra block within an intra frame.

use_intrabc equal to 1 specifies that intra block copy should be used for this block. use_intrabc equal to 0 specifies that intra block copy should not be used.

intra_frame_y_mode specifies the direction of intra prediction filtering:

intra_frame_y_mode	Name of intra_frame_y_mode
0	DC_PRED
1	V_PRED
2	H_PRED
3	D45_PRED
4	D135_PRED
5	D113_PRED
6	D157_PRED
7	D203_PRED
8	D67_PRED
9	SMOOTH_PRED
10	SMOOTH_V_PRED
11	SMOOTH_H_PRED
12	PAETH_PRED

uv_mode specifies the chrominance intra prediction mode using values with the same interpretation as in the semantics for intra_frame_y_mode, with an additional mode UV_CFL_PRED.

uv_mode	Name of uv_mode
0	DC_PRED
1	V_PRED
2	H_PRED
3	D45_PRED
4	D135_PRED
5	D113_PRED
6	D157_PRED
7	D203_PRED
8	D67_PRED
9	SMOOTH_PRED
10	SMOOTH_V_PRED
11	SMOOTH_H_PRED
12	PAETH_PRED
13	UV_CFL_PRED

Note: Due to the way the uv_mode syntax element is read, uv_mode can only be read as UV_CFL_PRED when Max(Block_Width[MiSize], Block_Height[MiSize]) <= 32.

6.10.7. Intra segment ID semantics

Lossless is a variable which, if equal to 1, indicates that the block is coded using a special 4x4 transform designed for encoding frames that are bit-identical with the original frames.

6.10.8. Read segment ID semantics

segment_id specifies which segment is associated with the current intra block being decoded. It is first read from the stream, and then postprocessed based on the predicted segment id.

It is a requirement of bitstream conformance that the postprocessed value of segment_id (i.e. the value returned by neg_deinterleave) is in the range 0 to LastActiveSegId (inclusive of endpoints).

6.10.9. Inter segment ID semantics

seg_id_predicted equal to 1 specifies that the segment_id is taken from the segmentation map. seg_id_predicted equal to 0 specifies that the syntax element segment_id is parsed.

> **Note:** It is allowed for seg_id_predicted to be equal to 0 even if the value coded for the segment_id is equal to predictedSegmentId.

6.10.10. Skip mode semantics

skip_mode equal to 1 indicates that this block will use some default settings (that correspond to compound prediction) and so most of the mode info is skipped. skip_mode equal to 0 indicates that the mode info is not skipped.

6.10.11. Skip semantics

skip equal to 0 indicates that there may be some transform coefficients to read for this block; skip equal to 1 indicates that there are no transform coefficients.

6.10.12. Quantizer index delta semantics

delta_q_abs specifies the absolute value of the quantizer index delta value being decoded. If delta_q_abs is equal to DELTA_Q_SMALL, the value is encoded using delta_q_rem_bits and delta_q_abs_bits.

delta_q_rem_bits and **delta_q_abs_bits** encode the absolute value of the quantizer index delta value being decoded, where the absolute value of the quantizer index delta value is of the form:

```
(1 << delta_q_rem_bits) + delta_q_abs_bits + 1
```

delta_q_sign_bit equal to 0 indicates that the quantizer index delta value is positive; delta_q_sign_bit equal to 1 indicates that the quantizer index delta value is negative.

6.10.13. Loop filter delta semantics

delta_lf_abs specifies the absolute value of the loop filter delta value being decoded. If delta_lf_abs is equal to DELTA_LF_SMALL, the value is encoded using delta_lf_rem_bits and delta_lf_abs_bits.

delta_lf_rem_bits and **delta_lf_abs_bits** encode the absolute value of the loop filter delta value being decoded, where the absolute value of the loop filter delta value is of the form:

```
( 1 << ( delta_lf_rem_bits + 1 ) ) + delta_lf_abs_bits + 1
```

delta_lf_sign_bit equal to 0 indicates that the loop filter delta value is positive; delta_lf_sign_bit equal to 1 indicates that the loop filter delta value is negative.

6.10.14. CDEF params semantics

cdef_damping_minus_3 controls the amount of damping in the deringing filter.

cdef_bits specifies the number of bits needed to specify which CDEF filter to apply.

cdef_y_pri_strength and **cdef_uv_pri_strength** specify the strength of the primary filter.

cdef_y_sec_strength and **cdef_uv_sec_strength** specify the strength of the secondary filter.

6.10.15. Loop restoration params semantics

lr_type is used to compute FrameRestorationType.

FrameRestorationType specifies the type of restoration used for each plane as follows:

lr_type	FrameRestorationType	Name of FrameRestorationType
0	0	RESTORE_NONE
1	3	RESTORE_SWITCHABLE
2	1	RESTORE_WIENER
3	2	RESTORE_SGRPROJ

UsesLr indicates if any plane uses loop restoration.

lr_unit_shift specifies if the luma restoration size should be halved.

lr_unit_extra_shift specifies if the luma restoration size should be halved again.

lr_uv_shift is only present for 4:2:0 formats and specifies if the chroma size should be half the luma size.

LoopRestorationSize[plane] specifies the size of loop restoration units in units of samples in the current plane.

6.10.16. TX size semantics

tx_depth is used to compute TxSize. tx_depth is inverted with respect to TxSize, i.e. it specifies how much smaller the transform size should be made than the largest possible transform size for the block.

TxSize specifies the transform size to be used for this block:

TxSize	Name of TxSize
0	TX_4X4
1	TX_8X8
2	TX_16X16

TxSize	Name of TxSize
3	TX_32X32
4	TX_64X64
5	TX_4X8
6	TX_8X4
7	TX_8X16
8	TX_16X8
9	TX_16X32
10	TX_32X16
11	TX_32X64
12	TX_64X32
13	TX_4X16
14	TX_16X4
15	TX_8X32
16	TX_32X8
17	TX_16X64
18	TX_64X16

Note: TxSize is determined for skipped intra blocks because TxSize controls the granularity of the intra prediction.

6.10.17. Block TX size semantics

InterTxSizes is an array that holds the transform sizes within inter frames.

Note: TxSizes and InterTxSizes contain different values. All the values in TxSizes across a residual block will share the same value, while InterTxSizes can represent several different transform sizes within a residual block.

6.10.18. Var TX size semantics

txfm_split equal to 1 specifies that the block should be split into smaller transform sizes. txfm_split equal to 0 specifies that the block should not be split any more.

6.10.19. Transform type semantics

set specifies the transform set.

is_inter	set	Name of transform set
Don’t care	0	TX_SET_DCTONLY
0	1	TX_SET_INTRA_1
0	2	TX_SET_INTRA_2
1	1	TX_SET_INTER_1
1	2	TX_SET_INTER_2
1	3	TX_SET_INTER_3

The transform sets determine what subset of transform types can be used, according to the following table.

Transform type	TX_SET_ DCTONLY	TX_SET_ INTRA_1	TX_SET_ INTRA_2	TX_SET_ INTER_1	TX_SET_ INTER_2	TX_SET_ INTER_3
DCT_DCT	X	X	X	X	X	X
ADST_DCT		X	X	X	X	
DCT_ADST		X	X	X	X	
ADST_ADST		X	X	X	X	
FLIPADST_DCT				X	X	
DCT_FLIPADST				X	X	
FLIPADST_FLIPADST				X	X	
ADST_FLIPADST				X	X	
FLIPADST_ADST				X	X	
IDTX		X	X	X	X	X
V_DCT		X		X	X	
H_DCT		X		X	X	
V_ADST				X		
H_ADST				X		
V_FLIPADST				X		
H_FLIPADST				X		

inter_tx_type specifies the transform type for inter blocks.

intra_tx_type specifies the transform type for intra blocks.

6.10.20. Is inter semantics

is_inter equal to 0 specifies that the block is an intra block; is_inter equal to 1 specifies that the block is an inter block.

6.10.21. Intra block mode info semantics

This syntax is used when coding an intra block within an inter frame.

y_mode specifies the direction of luminance intra prediction using values with the same interpretation as for intra_frame_y_mode.

uv_mode specifies the chrominance intra prediction mode using values with the same interpretation as in the semantics for intra_frame_y_mode, with an additional mode UV_CFL_PRED.

> **Note:** Due to the way the uv_mode syntax element is read, uv_mode can only be read as UV_CFL_PRED when Max(Block_Width[MiSize], Block_Height[MiSize]) <= 32.

6.10.22. Inter block mode info semantics

This syntax is used when coding an inter block.

compound_mode specifies how the motion vector used by inter prediction is obtained when using compound prediction. An offset is added to compound_mode to compute YMode as follows:

YMode	Name of YMode
14	NEARESTMV
15	NEARMV
16	GLOBALMV
17	NEWMV
18	NEAREST_NEARESTMV
19	NEAR_NEARMV
20	NEAREST_NEWMV
21	NEW_NEARESTMV
22	NEAR_NEWMV
23	NEW_NEARMV
24	GLOBAL_GLOBALMV
25	NEW_NEWMV

> **Note:** The intra modes take values 0..13 so these YMode values start at 14.

new_mv equal to 0 means that a motion vector difference should be read.

zero_mv equal to 0 means that the motion vector should be set equal to default motion for the frame.

ref_mv equal to 0 means that the most likely motion vector should be used (called NEAREST), ref_mv equal to 1 means that the second most likely motion vector should be used (called NEAR).

interp_filter specifies the type of filter used in inter prediction. Values 0..3 are allowed with the same interpretation as for interpolation_filter. One filter type is specified for the vertical filter direction and one for the horizontal filter direction.

> **Note:** The syntax element interpolation_filter from the uncompressed header can specify the type of filter to be used for the whole frame. If it is set to SWITCHABLE then the interp_filter syntax element is read from the bitstream for every inter block.

RefMvIdx specifies which candidate in the RefStackMv should be used.

drl_mode is a bit sent for candidates in the motion vector stack to indicate if they should be used. drl_mode equal to 0 means to use the current value of idx. drl_mode equal to 1 says to continue searching. DRL stands for “Dynamic Reference List”.

6.10.23. Filter intra mode info semantics

use_filter_intra is a bit specifying whether or not intra filtering can be used.

filter_intra_mode specifies the type of intra filtering, and can take on any of the following values:

filter_intra_mode	Name of filter_intra_mode
0	FILTER_DC_PRED
1	FILTER_V_PRED
2	FILTER_H_PRED
3	FILTER_D157_PRED
4	FILTER_PAETH_PRED

6.10.24. Ref frames semantics

comp_mode specifies whether single or compound prediction is used:

comp_mode	Name of comp_mode
0	SINGLE_REFERENCE

comp_mode	Name of comp_mode
1	COMPOUND_REFERENCE

SINGLE_REFERENCE indicates that the inter block uses only a single reference frame to generate motion compensated prediction.

COMPOUND_REFERENCE indicates that the inter block uses compound mode.

There are two reference frame groups:

- Group 1: LAST_FRAME, LAST2_FRAME, LAST3_FRAME, and GOLDEN_FRAME.
- Group 2: BWDREF_FRAME, ALTREF2_FRAME, and ALTREF_FRAME.

Note: Encoders are free to assign these references to any of the reference frames (via the ref_frame_idx array). For example, there is no requirement of bitstream conformance that LAST_FRAME should indicate a frame that appears before the current frame in output order. Similarly, encoders can assign multiple references to the same reference frame.

comp_ref_type is used for compound prediction to specify whether both reference frames come from the same group or not:

comp_ref_type	Name of comp_ref_type	Description
0	UNIDIR_COMP_REFERENCE	Both reference frames from the same group
1	BIDIR_COMP_REFERENCE	One from Group 1 and one from Group 2

uni_comp_ref, **uni_comp_ref_p1**, and **uni_comp_ref_p2** specify which reference frames are in use when both come from the same group.

comp_ref, **comp_ref_p1**, and **comp_ref_p2** specify the first reference frame when the two reference frames come from different groups.

comp_bwdref and **comp_bwdref_p1** specify the second reference frame when the two reference frames come from different groups.

single_ref_p1, **single_ref_p2**, **single_ref_p3**, **single_ref_p4**, **single_ref_p5**, and **single_ref_p6** specify the reference frame when only a single reference frame is in use.

RefFrame[0] specifies which frame is used to compute the predicted samples for this block:

RefFrame[0]	Name of ref_frame
0	INTRA_FRAME

RefFrame[0]	Name of ref_frame
1	LAST_FRAME
2	LAST2_FRAME
3	LAST3_FRAME
4	GOLDEN_FRAME
5	BWDREF_FRAME
6	ALTREF2_FRAME
7	ALTREF_FRAME

RefFrame[1] specifies which additional frame is used in compound prediction:

RefFrame[1]	Name of ref_frame
-1	NONE (this block uses single prediction)
0	INTRA_FRAME (this block uses interintra prediction)
1	LAST_FRAME
2	LAST2_FRAME
3	LAST3_FRAME
4	GOLDEN_FRAME
5	BWDREF_FRAME
6	ALTREF2_FRAME
7	ALTREF_FRAME

Note: Not all combinations of RefFrame[0] and RefFrame[1] can be coded.

6.10.25. Assign mv semantics

It is a requirement of bitstream conformance that whenever assign_mv returns, the function is_mv_valid(isCompound) would return 1, where is_mv_valid is defined as:

```
is_mv_valid( isCompound ) {
    for ( i = 0; i < 1 + isCompound; i++ ) {
        for ( comp = 0; comp < 2; comp++ ) {
            if ( Abs( Mv[ i ][ comp ] ) >= ( 1 << 14 ) )
                return 0
        }
    }
    if ( !use_intrabc ) {
        return 1
    }
    bw = Block_Width[ MiSize ]
    bh = Block_Height[ MiSize ]
    if ( (Mv[ 0 ][ 0 ] & 7) || (Mv[ 0 ][ 1 ] & 7) ) {
        return 0
    }
    deltaRow = Mv[ 0 ][ 0 ] >> 3
    deltaCol = Mv[ 0 ][ 1 ] >> 3
    srcTopEdge = MiRow * MI_SIZE + deltaRow
    srcLeftEdge = MiCol * MI_SIZE + deltaCol
    srcBottomEdge = srcTopEdge + bh
    srcRightEdge = srcLeftEdge + bw
    if ( HasChroma ) {
        if ( bw < 8 && subsampling_x )
            srcLeftEdge -= 4
        if ( bh < 8 && subsampling_y )
            srcTopEdge -= 4
    }
    if ( srcTopEdge < MiRowStart * MI_SIZE ||
         srcLeftEdge < MiColStart * MI_SIZE ||
         srcBottomEdge > MiRowEnd * MI_SIZE ||
         srcRightEdge > MiColEnd * MI_SIZE ) {
        return 0
    }
    sbSize = use_128x128_superblock ? BLOCK_128X128 : BLOCK_64X64
    sbH = Block_Height[ sbSize ]
    activeSbRow = (MiRow * MI_SIZE) / sbH
    activeSb64Col = (MiCol * MI_SIZE) >> 6
    srcSbRow = (srcBottomEdge - 1) / sbH
    srcSb64Col = (srcRightEdge - 1) >> 6
    totalSb64PerRow = ((MiColEnd - MiColStart - 1) >> 4) + 1
    activeSb64 = activeSbRow * totalSb64PerRow + activeSb64Col
    srcSb64 = srcSbRow * totalSb64PerRow + srcSb64Col
    if ( srcSb64 >= activeSb64 - INTRABC_DELAY_SB64) {
        return 0
    }
    gradient = 1 + INTRABC_DELAY_SB64 + use_128x128_superblock
    wfOffset = gradient * (activeSbRow - srcSbRow)
    if ( srcSbRow > activeSbRow ||
         srcSb64Col >= activeSb64Col - INTRABC_DELAY_SB64 + wfOffset ) {
        return 0
```

```
    }
    return 1
}
```

Note: The purpose of this function is to limit the maximum size of motion vectors and also, if use_intrabc is equal to 1, to additionally constrain the motion vector in order that the data is fetched from parts of the tile that have already been decoded, and that are not too close to the current block (in order to make a pipelined decoder implementation feasible).

6.10.26. Read motion mode semantics

use_obmc equal to 1 means that OBMC should be used. use_obmc equal to 0 means that simple translation should be used.

motion_mode specifies the type of motion compensation to perform:

motion_mode	Name of motion_mode
0	SIMPLE
1	OBMC
2	LOCALWARP

Note: A motion_mode equal to SIMPLE is used for blocks requiring global motion.

6.10.27. Read inter intra semantics

interintra equal to 1 specifies that an inter prediction should be blended with an intra prediction.

interintra_mode specifies the type of intra prediction to be used:

interintra_mode	Name of interintra_mode
0	II_DC_PRED
1	II_V_PRED
2	II_H_PRED
3	II_SMOOTH_PRED

wedge_interintra equal to 1 specifies that wedge blending should be used. wedge_interintra equal to 0 specifies that intra blending should be used.

wedge_index is used to derive the direction and offset of the wedge mask used during blending.

6.10.28. Read compound type semantics

comp_group_idx equal to 0 indicates that the compound_idx syntax element should be read. comp_group_idx equal to 1 indicates that the compound_idx syntax element is not present.

compound_idx equal to 0 indicates that a distance based weighted scheme should be used for blending. compound_idx equal to 1 indicates that the averaging scheme should be used for blending.

compound_type specifies how the two predictions should be blended together:

compound_type	Name of compound_type
0	COMPOUND_WEDGE
1	COMPOUND_DIFFWTD
2	COMPOUND_AVERAGE
3	COMPOUND_INTRA
4	COMPOUND_DISTANCE

Note: COMPOUND_AVERAGE, COMPOUND_INTRA, and COMPOUND_DISTANCE cannot be directly signaled with the compound_type syntax element but are inferred from other syntax elements.

wedge_index is used to derive the direction and offset of the wedge mask used during blending.

wedge_sign specifies the sign of the wedge blend.

mask_type specifies the type of mask to be used during blending:

mask_type	Name of mask_type
0	UNIFORM_45
1	UNIFORM_45_INV

6.10.29. MV semantics

MvCtx is used to determine which CDFs to use for the motion vector syntax elements.

mv_joint specifies which components of the motion vector difference are non-zero:

mv_joint	Name of mv_joint	Changes row	Changes col
0	MV_JOINT_ZERO	No	No
1	MV_JOINT_HNZVZ	No	Yes
2	MV_JOINT_HZVNZ	Yes	No
3	MV_JOINT_HNZVNZ	Yes	Yes

The motion vector difference is added to the PredMv to compute the final motion vector in Mv.

6.10.30. MV component semantics

mv_sign equal to 0 means that the motion vector difference is positive; mv_sign equal to 1 means that the motion vector difference is negative.

mv_class specifies the class of the motion vector difference. A higher class means that the motion vector difference represents a larger update:

mv_class	Name of mv_class
0	MV_CLASS_0
1	MV_CLASS_1
2	MV_CLASS_2
3	MV_CLASS_3
4	MV_CLASS_4
5	MV_CLASS_5
6	MV_CLASS_6
7	MV_CLASS_7
8	MV_CLASS_8
9	MV_CLASS_9
10	MV_CLASS_10

mv_class0_bit specifies the integer part of the motion vector difference. This is only present for class 0 motion vector differences.

mv_class0_fr specifies the first 2 fractional bits of the motion vector difference. This is only present for class 0 motion vector differences.

mv_class0_hp specifies the third fraction bit of the motion vector difference. This is only present for class 0 motion vector differences.

mv_bit specifies bit i of the integer part of the motion vector difference.

mv_fr specifies the first 2 fractional bits of the motion vector difference.

mv_hp specifies the third fractional bit of the motion vector difference.

6.10.31. Compute prediction semantics

The prediction for inter and interintra blocks is triggered within compute_prediction. However, intra prediction is done at the transform block granularity so predict_intra is also called from transform_block.

predW and **predH** are variables containing the smallest size that can be used for inter prediction. (This size may be increased for chroma blocks if not all blocks use inter prediction.)

predict_inter is a function call that indicates the conceptual point where inter prediction happens. When this function is called, the inter prediction process specified in section 7.11.3 is invoked.

predict_intra is a function call that indicates the conceptual point where intra prediction happens. When this function is called, the intra prediction process specified in section 7.11.2 is invoked.

> **Note:** The predict_inter and predict_intra functions do not affect the syntax decode process.

someUseIntra is a variable that indicates if some of the blocks corresponding to this residual require intra prediction.

> **Note:** The chroma residual block size is always at least 4 in width and height. This means that no transform width or height smaller than 4 is required. As such, a chroma residual may actually cover several luma blocks. If any of these blocks are intra, a single prediction is performed for the entire chroma residual block based on the mode info of the bottom right luma block. However, if all the constituent blocks are inter blocks, a special case is triggered and inter prediction is done using the smaller chroma block size that corresponds to each of the luma blocks.

6.10.32. Residual semantics

The residual consists of a number of transform blocks.

If the block is wider or higher than 64 luma samples, then the residual is split into 64 by 64 chunks.

Within each chunk, the transform blocks are either sent in raster order (if use_inter is equal to 0 or LossLess is equal to 1), or within a recursive transform tree.

6.10.33. Transform block semantics

reconstruct is a function call that indicates the conceptual point where inverse transform and reconstruction happens. When this function is called, the reconstruction process specified in section 7.12.3 is invoked.

predict_palette is a function call that indicates the conceptual point where palette prediction happens. When this function is called, the palette prediction process specified in section 7.11.4 is invoked.

predict_chroma_from_luma is a function call that indicates the conceptual point where predicting chroma from luma happens. When this function is called, the predict chroma from luma process specified in section 7.11.5 is invoked.

MaxLumaW and **MaxLumaH** are needed for chroma from luma prediction and store the extent of luma samples that can be used for prediction.

LoopfilterTxSizes is an array that stores the transform size for each plane and position for use in loop filtering. LoopfilterTxSizes[plane][row][col] stores the transform size where row and col are in units of 4x4 samples.

> **Note:** The transform size is always equal for planes 1 and 2.

6.10.34. Coefficients semantics

TxTypes is an array which stores at a 4x4 luma sample granularity the transform type to be used.

> **Note:** The transform type is only read for luma transform blocks, the chroma uses the transform type for a corresponding luma block. Chroma blocks will only use transform types that have been written for the current residual block.

Quant is an array storing the quantised coefficients for the current transform block.

all_zero equal to 1 specifies that all coefficients are zero.

> **Note:** The transform type is only present when this is a luminance block and all_zero is equal to 0. If all_zero is equal to 1 for a luminance block, the transform type is set to DCT_DCT.

eob_extra and **eob_extra_bit** specify the position of the last non-zero coefficient by being used to compute the variable eob.

eob_pt_16, **eob_pt_32**, **eob_pt_64**, **eob_pt_128**, **eob_pt_256**, **eob_pt_512**, **eob_pt_1024**: syntax elements used to compute eob.

eob is a variable that indicates the index of the end of block. This index is equal to one plus the index of the last non-zero coefficient.

coeff_base_eob is a syntax element used to compute the base level of the last non-zero coefficient.

> **Note:** The base level is set to coeff_base_eob plus 1. Since this coefficient is known to be non-zero, only base levels of 1, 2, or 3 can be coded via coeff_base_eob.

coeff_base specifies the base level of a coefficient (this syntax element is used for all coefficients except the last non-zero coefficient).

> **Note:** The base level can take values of 0, 1, 2, or 3. If the base level is less than 3, then it contains the actual level of the coefficient. Otherwise, the syntax element coeff_br is used to optionally increase the level.

dc_sign specifies the sign of the DC coefficient.

sign_bit specifies the sign of a non-zero AC coefficient.

coeff_br specifies an increment to the coefficient.

> **Note:** Each quantized coefficient can use coeff_br to provide up to 4 increments. If an increment less than 3 is coded, it signifies that this was the final increment.

golomb_length_bit is used to compute the number of extra bits required to code the coefficient.

If length is equal to 20, it is a requirement of bitstream conformance that golomb_length_bit is equal to 1.

golomb_data_bit specifies the value of one of the extra bits.

AboveLevelContext and **LeftLevelContext** are arrays that store at a 4 sample granularity the cumulative sum of coefficient levels.

AboveDcContext and **LeftDcContext** are arrays that store at a 4 sample granularity 2 bits signaling the sign of the DC coefficient (zero being counted as a separate sign).

6.10.35. Intra angle info semantics

angle_delta_y specifies the offset to be applied to the intra prediction angle specified by the prediction mode in the luma plane, biased by MAX_ANGLE_DELTA so as to encode a positive value.

angle_delta_uv specifies the offset to be applied to the intra prediction angle specified by the prediction mode in the chroma plane biased by MAX_ANGLE_DELTA so as to encode a positive value.

AngleDeltaY is computed from angle_delta_y by removing the MAX_ANGLE_DELTA offset to produce the final luma angle offset value, which may be positive or negative.

AngleDeltaUV is computed from angle_delta_uv by removing the MAX_ANGLE_DELTA offset to produce the final chroma angle offset value, which may be positive or negative.

6.10.36. Read CFL alphas semantics

cfl_alpha_signs contains the sign of the alpha values for U and V packed together into a single syntax element with 8 possible values. (The combination of two zero signs is prohibited as it is redundant with DC Intra prediction.)

cfl_alpha_signs	Name of signU	Name of signV
0	CFL_SIGN_ZERO	CFL_SIGN_NEG

cfl_alpha_signs	Name of signU	Name of signV
1	CFL_SIGN_ZERO	CFL_SIGN_POS
2	CFL_SIGN_NEG	CFL_SIGN_ZERO
3	CFL_SIGN_NEG	CFL_SIGN_NEG
4	CFL_SIGN_NEG	CFL_SIGN_POS
5	CFL_SIGN_POS	CFL_SIGN_ZERO
6	CFL_SIGN_POS	CFL_SIGN_NEG
7	CFL_SIGN_POS	CFL_SIGN_POS

signU contains the sign of the alpha value for the U component:

signU	Name of signU
0	CFL_SIGN_ZERO
1	CFL_SIGN_NEG
2	CFL_SIGN_POS

signV contains the sign of the alpha value for the V component with the same interpretation as for signU.

cfl_alpha_u contains the absolute value of alpha minus one for the U component.

cfl_alpha_v contains the absolute value of alpha minus one for the V component.

CflAlphaU contains the signed value of the alpha component for the U component.

CflAlphaV contains the signed value of the alpha component for the V component.

6.10.37. Palette mode info semantics

has_palette_y is a boolean value specifying whether a palette is encoded for the Y plane.

has_palette_uv is a boolean value specifying whether a palette is encoded for the UV plane.

palette_size_y_minus_2 is used to compute PaletteSizeY.

PaletteSizeY is a variable holding the Y plane palette size.

palette_size_uv_minus_2 is used to compute PaletteSizeUV.

PaletteSizeUV is a variable holding the UV plane palette size.

use_palette_color_cache_y, if equal to 1, indicates that for a particular palette entry in the luma palette, the cached entry should be used.

use_palette_color_cache_u, if equal to 1, indicates that for a particular palette entry in the U chroma palette, the cached entry should be used.

palette_colors_y is an array holding the Y plane palette colors.

palette_colors_u is an array holding the U plane palette colors.

palette_colors_v is an array holding the V plane palette colors.

delta_encode_palette_colors_v, if equal to 1, indicates that the V chroma palette is encoded using delta encoding.

palette_num_extra_bits_y is used to calculate the number of bits used to store each palette delta value for the luma palette.

palette_num_extra_bits_u is used to calculate the number of bits used to store each palette delta value for the U chroma palette.

palette_num_extra_bits_v is used to calculate the number of bits used to store each palette delta value for the V chroma palette.

palette_delta_y is a delta value for the luma palette.

palette_delta_u is a delta value for the U chroma palette.

palette_delta_v is a delta value for the V chroma palette.

> **Note:** Luma and U delta values give a positive offset relative to the previous palette entry in the same plane. V delta values give a signed offset relative to the U palette entries.

palette_delta_sign_bit_v, if equal to 1, indicates that the decoded V chroma palette delta value should be negated.

6.10.38. Palette tokens semantics

color_index_map_y holds the index in palette_colors_y for the block's Y plane top left sample.

color_index_map_uv holds the index in palette_colors_u and palette_colors_v for the block's UV plane top left sample.

palette_color_idx_y holds the index in ColorOrder for a sample in the block's Y plane.

palette_color_idx_uv holds the index in ColorOrder for a sample in the block's UV plane.

6.10.39. Palette color context semantics

ColorOrder is an array holding the mapping from an encoded index to the palette. ColorOrder is ranked in order of frequency of occurrence of each color in the neighborhood of the current block, weighted by closeness to the current block.

ColorContextHash is a variable derived from the distribution of colors in the neighborhood of the current block, which is used to determine the probability context used to decode palette_color_idx_y and palette_color_idx_uv.

6.10.40. Read CDEF semantics

cdef_idx specifies which CDEF filtering parameters should be used for a particular 64 by 64 block. A value of -1 means that CDEF is disabled for that block.

6.10.41. Read loop restoration unit semantics

use_wiener specifies if the Wiener filter should be used.

use_sgrproj specifies if the self guided filter should be used.

restoration_type specifies the restoration filter that should be used with the same interpretation as FrameRestorationType.

lr_sgr_set specifies which set of parameters to use for the self guided filter.

subexp_more_bools equal to 0 specifies that the parameter is in the range mk to mk+a-1. subexp_more_bools equal to 1 specifies that the parameter is greater than mk+a-1.

subexp_unif_bools specifies the value of the parameter minus mk.

subexp_bools specifies the value of the parameter minus mk.

6.11. Tile list OBU semantics

6.11.1. General tile list OBU semantics

output_frame_width_in_tiles_minus_1 plus one is the width of the output frame, in tile units.

output_frame_height_in_tiles_minus_1 plus one is the height of the output frame, in tile units.

tile_count_minus_1 plus one is the number of tile_list_entry in the list.

It is a requirement of bitstream conformance that tile_count_minus_1 is less than or equal to 511.

6.11.2. Tile list entry semantics

anchor_frame_idx is the index into an array AnchorFrames of the frames that the tile uses for prediction. The AnchorFrames array is provided by external means and may change for each tile list OBU. The process for creating the AnchorFrames array is outside of the scope of this specification.

It is a requirement of bitstream conformance that anchor_frame_idx is less than or equal to 127.

anchor_tile_row is the row coordinate of the tile in the frame that it belongs, in tile units.

It is a requirement of bitstream conformance that anchor_tile_row is less than TileRows.

anchor_tile_col is the column coordinate of the tile in the frame that it belongs, in tile units.

It is a requirement of bitstream conformance that anchor_tile_col is less than TileCols.

tile_data_size_minus_1 plus one is the size of the coded tile data, coded_tile_data, in bytes.

coded_tile_data are the tile_data_size_minus_1 + 1 bytes of the coded tile.

7. Decoding process

7.1. Overview

AV1 contains two operating modes:

1. General decoding (input is a sequence of OBUs, output is decoded frames)
2. Large scale tile decoding (input is a tile list OBU plus additional side information, output is a decoded frame)

The general decoding process is specified in section 7.2.

The large scale tile decoding process is specified in section 7.3.

7.2. General decoding process

When film_grain_params_present is equal to 0, decoders shall produce output frames that are identical in all respects and have the same output order as those produced by the decoding process specified herein.

When film_grain_params_present is equal to 1, a decoder shall implement a film grain synthesis process that modifies the output arrays OutY, OutU, OutV. The reference film grain synthesis process is described in section 7.18.3.

When film_grain_params_present is equal to 1, a conformant decoder shall satisfy at least one of the following two options:

1. A conformant decoder shall produce output frames that are identical in all respects and have the same output order as those produced by the decoding process specified herein including applying the exact film grain synthesis process as specified in section 7.18.3.
2. A conformant decoder shall produce intermediate frames that are identical in all respects and have the same order as the frames produced by the process specified in section 7.18.2. In addition to that, a conformant decoder shall produce output frames that are in the same order and do not have perceptually significant differences with the frames produced by the reference film grain synthesis process specified in section 7.18.3 when applied to the input frames of the film grain synthesis process with the film grain parameters signaled for these frames. The decoder may also include optional processing steps which are applied to the intermediate frames produced by the process specified in section 7.18.2 and before the film grain synthesis process, resulting in the input frames of the film grain synthesis process. Such optional processing steps are beyond the scope of this specification. Otherwise, the intermediate frames are the input frames of the film grain synthesis process. The definition of “perceptually significant differences” is beyond the scope of this specification and may be specified, for example, by a service provider as part of their accreditation program. The film grain synthesis process applied by a conformant decoder should be feature complete with regards to the reference film grain synthesis process of section 7.18.3 including scaling strength of the film grain as a function of intensity according to the signaled parameters, same maximum AR lag, and similar modeling of correlation between luma and chroma and smoothing of transitions between blocks of grain when applicable.

Note: To ensure conformance, decoder manufacturers are advised to implement the film grain synthesis process as specified in section 7.18.3. One reason to choose the second conformance option is implementation of optional processing steps between the output of section 7.18.2 and the film grain synthesis process, in which case there could be minor differences in the output with the reference film grain synthesis process of section 7.18.3. Examples of these optional processing steps are algorithms improving output picture quality, such as de-banding filtering and coding artefacts removal.

Note: Some applications, such as transcoding from AV1 to AV1, may use intermediate output frames of section 7.18.2 for transcoding. In such cases, the original film grain synthesis information may be adapted and inserted in the transcoded bitstream.

The input to this process is a sequence of open bitstream units (OBUs).

The output from this process is a sequence of decoded frames.

For each OBU in turn the syntax elements are extracted as specified in section 5.3.

The syntax tables include function calls indicating when the remaining decode processes are triggered.

7.3. Large scale tile decoding process

7.3.1. General

The large scale tile decoding process is used to decode a random subset of tiles taken from a number of coded frames. The list of tiles is specified by a tile list OBU. One possible use case for this process is described in Annex D.

Note: A decoder is recommended to support decoding of tile list OBUs, but this is not a requirement for decoder conformance.

The inputs to this process are:

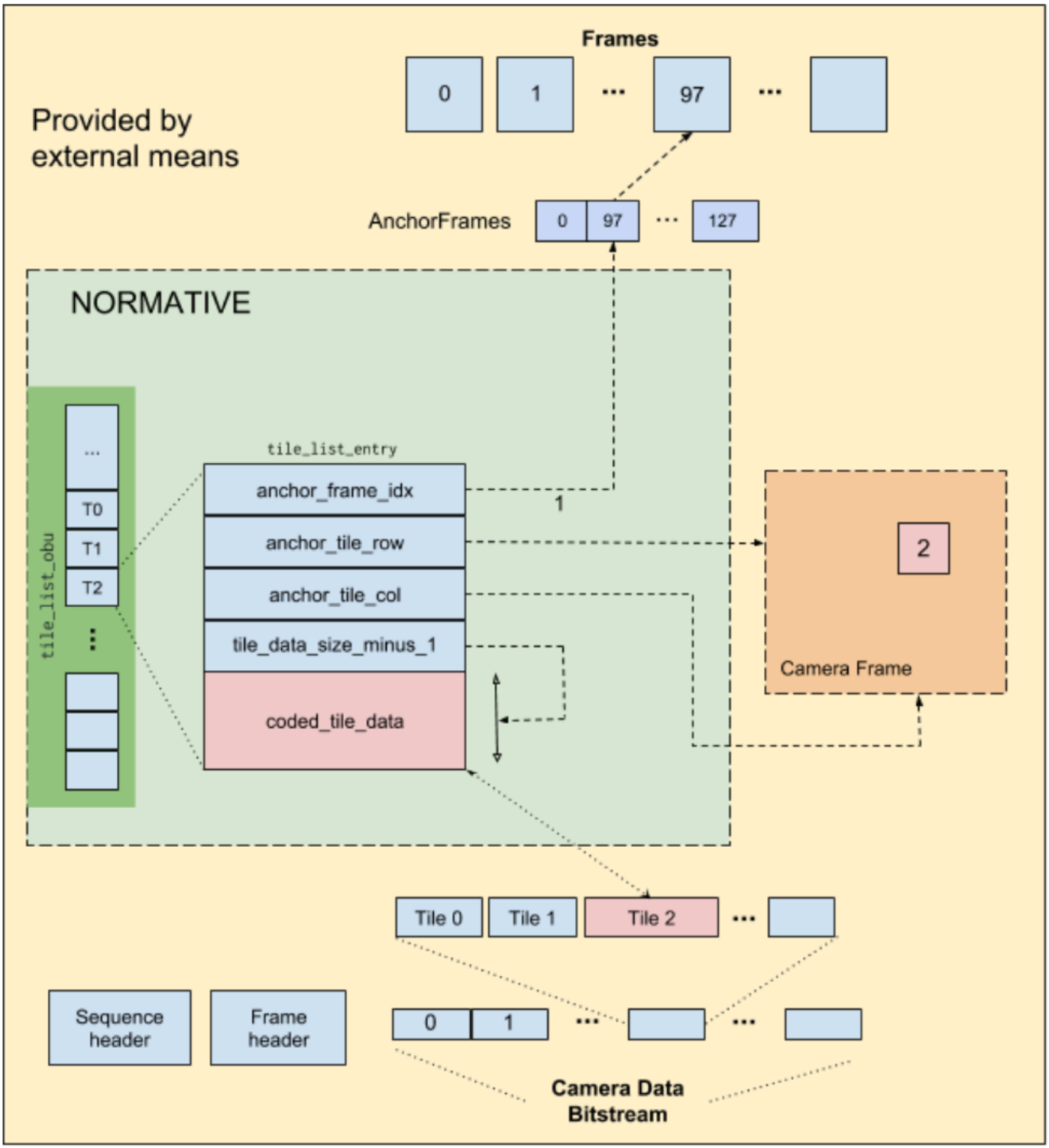
- contents of all syntax elements and variables produced when parsing a sequence header OBU,
- contents of all syntax elements and variables produced when parsing a frame header OBU (including CDF tables optionally loaded from a reference frame),
- an array AnchorFrames containing up to 128 frames,
- a tile list OBU.

The output from this process is:

- an output frame containing decoded tiles in raster order.

Note: The syntax elements from the sequence header and frame header may be produced by decoding a sequence header OBU and a frame header OBU, but this is not a requirement of decoder conformance. The AnchorFrames may be produced by decoding an AV1 bitstream, but this is not a requirement of bitstream conformance.

The following figure shows the arrangement of data required to decode a single tile list OBU. Those data shown on a green background are normatively defined in this specification. Data items shown on a yellow background are defined by a process or processes beyond the scope of this specification.



Application level overview

For each tile list entry in the tile list OBU, the following ordered steps are applied:

1. Parse the syntax elements within the tile_list_entry

2. Set the bitstream position indicator to point to the the start of the coded_tile_data syntax element
3. Set the variable last equal to ref_frame_idx[0]
4. Set FrameStore[last] equal to AnchorFrames[anchor_frame_idx]
5. RefValid[last] is set equal to 1.
6. RefUpscaledWidth[last] is set equal to UpscaledWidth.
7. RefFrameWidth[last] is set equal to FrameWidth.
8. RefFrameHeight[last] is set equal to FrameHeight.
9. RefMiCols[last] is set equal to MiCols.
10. RefMiRows[last] is set equal to MiRows.
11. RefSubsamplingX[last] is set equal to subsampling_x.
12. RefSubsamplingY[last] is set equal to subsampling_y.
13. RefBitDepth[last] is set equal to BitDepth.
14. Invoke the decode camera tile process specified in section 7.3.2 and write the decoded tiles into an output frame in raster order, in the order that they occur in the tile list OBU.

The output from this process is the output frame that is built up in the final step above.

The variable outputW is defined as (1 + output_frame_width_in_tiles_minus_1) * TileWidth.

The variable outputH is defined as (1 + output_frame_height_in_tiles_minus_1) * TileHeight.

The operation of writing a decoded tile (with zero-based index given by the variable tile) into the output frame in raster order is defined as follows:

```
destX = TileWidth * ( tile % (output_frame_width_in_tiles_minus_1 + 1) )
destY = TileHeight * ( tile / (output_frame_width_in_tiles_minus_1 + 1) )
w = TileWidth
h = TileHeight
for ( y = 0; y < h; y++ ) {
  for ( x = 0; x < w; x++ ) {
    OutputFrameY[ y + destY ][ x + destX ] = OutY[ y ][ x ]
  }
}
w = w >> subsampling_x
h = h >> subsampling_y
destX = destX >> subsampling_x
destY = destY >> subsampling_y
for ( y = 0; y < h; y++ ) {
  for ( x = 0; x < w; x++ ) {
    OutputFrameU[ y + destY ][ x + destX ] = OutU[ y ][ x ]
    OutputFrameV[ y + destY ][ x + destX ] = OutV[ y ][ x ]
  }
}
```

OutputFrameY (representing the luma plane of the output frame) is outputW samples across by outputH samples down.

OutputFrameU (representing the U plane of the output frame) is (outputW >> subsampling_x) samples across by (outputH >> subsampling_y) samples down.

OutputFrameV (representing the V plane of the output frame) is (outputW >> subsampling_x) samples across by (outputH >> subsampling_y) samples down.

The bitdepth of each output sample is given by BitDepth.

The output frame may not be fully covered with decoded tiles. The decoder should not modify samples in the output frame outside of the boundaries of the decoded tiles.

Decoders that support large scale tile decoding shall produce output frames that are identical in all respects as those produced by this decoding process.

It is a requirement of bitstream conformance that the following conditions are met:

- enable_superres is equal to 0
- enable_order_hint is equal to 0
- still_picture is equal to 0
- film_grain_params_present is equal to 0
- timing_info_present_flag is equal to 0
- decoder_model_info_present_flag is equal to 0

- initial_display_delay_present_flag is equal to 0
- enable_restoration is equal to 0
- enable_cdef is equal to 0
- mono_chrome is equal to 0
- TileHeight is equal to (use_128x128_superblock ? 128 : 64) for all tiles (i.e. the tile is exactly one superblock high)
- TileWidth is identical for all tiles and is an integer multiple of TileHeight (i.e. the tile is an integer number of superblocks wide)
- FrameWidth is equal to MiCols * MI_SIZE
- FrameHeight is equal to MiRows * MI_SIZE
- show_existing_frame is equal to 0
- frame_type is equal to INTER_FRAME
- show_frame is equal to 1
- error_resilient_mode is equal to 0
- disable_cdf_update is equal to 1
- disable_frame_end_update_cdf is equal to 1
- delta_lf_present is equal to 0
- delta_q_present is equal to 0
- frame_size_override_flag is equal to 0
- refresh_frame_flags is equal to 0
- use_ref_frame_mvs is equal to 0
- segmentation_temporal_update is equal to 0
- reference_select is equal to 0
- loop_filter_level[0] and loop_filter_level[1] are equal to 0
- tile_count_minus_1 + 1 is less than or equal to (output_frame_width_in_tiles_minus_1 + 1) * (output_frame_height_in_tiles_minus_1 + 1).

7.3.2. Decode camera tile process

This process decodes a single tile within a frame.

The output of this process are arrays OutY, OutU, OutV containing the decoded samples for the tile.

> **Note:** The decoding process defined here does not invoke the post-processing steps of deblock, cdef, superres, loop restoration and reference frame update. Implementations may choose to implement this process by using the general decode process with these tools disabled.

The process is specified as:

```
CurrentQIndex = base_q_idx
init_symbol( tile_data_size_minus_1 + 1 )
clear_above_context( )
sbSize = use_128x128_superblock ? BLOCK_128X128 : BLOCK_64X64
sbSize4 = Num_4x4_Blocks_Wide[ sbSize ]
MiRowStart = MiRowStarts[ anchor_tile_row ]
MiRowEnd = MiRowStarts[ anchor_tile_row + 1 ]
MiColStart = MiColStarts[ anchor_tile_col ]
MiColEnd = MiColStarts[ anchor_tile_col + 1 ]
for ( r = MiRowStart; r < MiRowEnd; r += sbSize4 ) {
    clear_left_context( )
    for ( c = MiColStart; c < MiColEnd; c += sbSize4 ) {
        ReadDeltas = delta_q_present
        clear_block_decoded_flags( c < ( MiColEnd - 1 ) )
        decode_partition( r, c, sbSize )
    }
}
exit_symbol( )
w = (MiColEnd - MiColStart) * MI_SIZE
h = (MiRowEnd - MiRowStart) * MI_SIZE
x0 = MiColStart * MI_SIZE
y0 = MiRowStart * MI_SIZE
subX = subsampling_x
subY = subsampling_y
xC0 = ( MiColStart * MI_SIZE ) >> subX
yC0 = ( MiRowStart * MI_SIZE ) >> subY
```

> **Note:** The intention is that the same decoding process for tile data can be used as for the general decoding process.

It is a requirement of bitstream conformance that the following conditions are met whenever the parsing process returns from the read_ref_frames syntax:

- RefFrame[0] = LAST_FRAME

- RefFrame[1] = NONE

Note: It is allowed to use intra blocks, they are not forbidden by this constraint because intra blocks do not invoke the read_ref_frames syntax.

Arrays OutY, OutU, OutV (representing the decoded samples for the tile) are specified as:

- The array OutY is w samples across by h samples down and the sample at location x samples across and y samples down is given by OutY[y][x] = CurrFrame[0][y0 + y][x0 + x] with x = 0..w - 1 and y = 0..h - 1.
- The array OutU is (w + subX) >> subX samples across by (h + subY) >> subY samples down and the sample at location x samples across and y samples down is given by OutU[y][x] = CurrFrame[1][yC0 + y][xC0 + x] with x = 0..(w >> subX) - 1 and y = 0..(h >> subY) - 1.
- The array OutV is (w + subX) >> subX samples across by (h + subY) >> subY samples down and the sample at location x samples across and y samples down is given by OutV[y][x] = CurrFrame[2][yC0 + y][xC0 + x] with x = 0..(w >> subX) - 1 and y = 0..(h >> subY) - 1.

The output of this process is arrays OutY, OutU, OutV representing the Y, U, and V samples.

7.4. Decode frame wrapup process

This process is triggered by a call to decode_frame_wrapup from within the syntax tables.

At this stage, all the tile level decode has been done, and this process performs any frame level decode that is required.

If show_existing_frame is equal to 0, the process first performs any post processing filtering by the following ordered steps:

1. If loop_filter_level[0] is not equal to 0 or loop_filter_level[1] is not equal to 0, the loop filter process specified in section 7.14 is invoked (this process modifies the contents of CurrFrame).
2. The CDEF process specified in section 7.15 is invoked (this process takes CurrFrame and produces CdefFrame).
3. The upscaling process specified in section 7.16 is invoked with CdefFrame as input and the output is assigned to UpscaledCdefFrame.
4. The upscaling process specified in section 7.16 is invoked with CurrFrame as input and the output is assigned to UpscaledCurrFrame.
5. The loop restoration process specified in section 7.17 is invoked (this process takes UpscaledCurrFrame and UpscaledCdefFrame and produces LrFrame).
6. The motion field motion vector storage process specified in section 7.19 is invoked.

7. If segmentation_enabled is equal to 1 and segmentation_update_map is equal to 0, SegmentIds[row][col] is set equal to PrevSegmentIds[row][col] for row = 0..MiRows-1, for col = 0..MiCols-1.

Otherwise (show_existing_frame is equal to 1), if frame_type is equal to KEY_FRAME, the reference frame loading process as specified in section 7.21 is invoked (this process loads frame state from the reference frames into the current frame state variables).

The following ordered steps now apply:

1. The reference frame update process as specified in section 7.20 is invoked (this process saves the current frame state into the reference frames).

2. If show_frame is equal to 1 or show_existing_frame is equal to 1, the output process as specified in section 7.18 is invoked (this will output the current frame or a saved frame).

Note: Although it is specified that all samples in CurrFrame are upscaled, at most 2 lines above and below each stripe (defined by StripeStartY and StripeEndY) will end up being read. Implementations may wish to avoid upscaling the unused lines.

7.5. Ordering of OBUs

A bitstream conforming to this specification consists of one or more coded video sequences.

A coded video sequence consists of one or more temporal units. A temporal unit consists of a series of OBUs starting from a temporal delimiter, optional sequence headers, optional metadata OBUs, a sequence of one or more frame headers, each followed by zero or more tile group OBUs as well as optional padding OBUs.

A new coded video sequence is defined to start at each temporal unit which satisfies both of the following conditions:

- A sequence header OBU appears before the first frame header.
- The first frame header has frame_type equal to KEY_FRAME, show_frame equal to 1, show_existing_frame equal to 0, and temporal_id equal to 0.

If scalability is not being used (OperatingPointIdc equal to 0), then all frames are part of the operating point. The following constraints must hold:

- The first frame header must have frame_type equal to KEY_FRAME and show_frame equal to 1.
- Each temporal unit must have exactly one shown frame.

If scalability is being used (OperatingPointIdc not equal to 0), then only a subset of frames are part of the operating point. For each operating point, the following constraints must hold:

- The first frame header that will be decoded must have frame_type equal to KEY_FRAME and show_frame equal to 1.

- Every layer that has a coded frame in a temporal unit must have exactly one shown frame that is the last frame of that layer in the temporal unit.

Note: A shown frame is either a frame with show_frame equal to 1, or with show_existing_frame equal to 1.

A frame header and its associated tile group OBUs within a temporal unit must use the same value of obu_extension_flag (i.e., either both include or both not include the optional OBU extension header).

All OBU extension headers that are contained in the same temporal unit and have the same spatial_id value must have the same temporal_id value.

If a coded video sequence contains at least one enhancement layer (OBUs with spatial_id greater than 0 or temporal_id greater than 0) then all frame headers and tile group OBUs associated with base (spatial_id equals 0 and temporal_id equals 0) and enhancement layer (spatial_id greater than 0 or temporal_id greater than 0) data must include the OBU extension header.

OBUs with spatial level IDs (spatial_id) greater than 0 must appear within a temporal unit in increasing order of the spatial level ID values.

The first temporal unit of a coded video sequence must contain one or more sequence header OBUs before the first frame header OBU.

Note: There is not a requirement that every temporal unit with a key frame also contains a sequence header, just that the sequence header has been sent before the first key frame. However, note that temporal units without sequence header OBUs are not considered to be random access points.

Sequence header OBUs may appear in any order within a coded video sequence. Within a particular coded video sequence, the contents of sequence_header_obu must be bit-identical each time the sequence header appears except for the contents of operating_parameters_info. A new coded video sequence is required if the sequence header parameters change. Any sequence header in a bitstream which changes the parameters must be contained in a temporal unit with temporal_id equal to zero.

If a temporal unit contains one or more sequence header OBUs, the first appearance of the sequence header OBU must be before the first frame header OBU.

One or more metadata and padding OBUs may appear in any order within an OBU sequence (unless constrained by semantics provided elsewhere in this specification). Specific metadata types may be required or recommended to be placed in specific locations, as identified in their corresponding definitions.

OBU types that are not defined in this specification can be ignored by a decoder.

Note: Some applications may choose to use bitstreams that are not fully conformant to the requirements described in this section. For example, a bitstream received in a streaming use case may never contain key frames, but instead rely on gradual intra refresh.

7.6. Random access decoding

7.6.1. General

In general, random access points are places in a bitstream where decoding can be started.

This section defines the types of random access point that must be supported by all conformant decoders.

The purpose of this section is to define a minimum level of functionality that must be supported, not a maximum. In other words, decoders may choose to support more types of random access point.

The random access points are defined in section 7.6.2.

The conformance requirements are specified in section 7.6.3.

The consequences for encoders are specified in section 7.6.4.

The consequences for decoders are specified in section 7.6.5.

7.6.2. Definitions

This section defines the following terms:

- key frame random access point,
- delayed random access point,
- key frame dependent recovery point.

A key frame random access point is defined as being a frame:

- with frame_type equal to KEY_FRAME
- with show_frame equal to 1
- that is contained in a temporal unit that also contains a sequence header OBU

A delayed random access point is defined as being a frame:

- with frame_type equal to KEY_FRAME
- with show_frame equal to 0
- that is contained in a temporal unit that also contains a sequence header OBU

A key frame dependent recovery point is defined as being a frame:

- with show_existing_frame equal to 1
- with frame_to_show_map_idx specifying a frame to output that was a delayed random access point

7.6.3. Conformance requirements

Informally, the requirement for decoder conformance is that decoding can start at any key frame random access point or delayed random access point. The rest of this section makes this requirement more precise.

Starting at a key frame random access point is trivial, because if the earlier temporal units are dropped, the remaining temporal units still constitute a valid bitstream.

Starting at a delayed random access point is harder to define because:

- if all temporal units before the key frame dependent recovery point are dropped, it is impossible to decode (because the relevant delayed random access point has been dropped)
- if all temporal units before the delayed random access point are dropped, it is unclear what should happen for frames between the delayed random access point and the key-frame dependent recovery point (some applications may wish these to be dropped, while others may wish them to be displayed)
- in either case, the remaining temporal units do not constitute a valid standalone bitstream (because it does not start with a shown key frame)

To support the different modes of operation, a conformant decoder is required to be able to decode bitstreams consisting of:

- a temporal unit containing a delayed random access point
- immediately followed by a temporal unit containing the associated key frame dependent recovery point
- followed by optional additional temporal units

This moves the responsibility for dropping the intermediate temporal units (between the delayed random access point and the key frame dependent recovery point) out of the normatively defined decoding process into application specific behavior. This allows applications to choose which behavior to use depending on the use case and capabilities of the specific decoder implementation.

> **Note:** In practice, decoder implementations are expected to be able to start decoding bitstreams from a delayed random access point when the intermediate temporal units are still present. The decoder should correctly produce all output frames from the next key frame or key frame dependent recovery point onwards, while the preceding frames are implementation defined. For example: a streaming decoder may choose to decode and display all frames even when the reference frames are not available (tolerating some errors in the output), a low latency decoder may choose to decode and display all frames that are guaranteed to be correct (e.g. an inter frame that only uses inter prediction from the delayed random access point), a media player decoder may choose to decode and display only frames starting from a key frame or key frame dependent recovery point (guaranteeing smooth playback once display starts).

7.6.4. Encoder consequences

Random access points introduce no additional conformance requirements on encoders.

Encoders are free to insert any number of random access points.

7.6.5. Decoder consequences

The conformance requirement means that conformant decoders must be able to start decoding at a delayed random access point partway through a valid bitstream.

This is almost the same as decoding a bitstream from the start - the only differences are that:

- The first frame has show_frame equal to 0.
- If frame_id_numbers_present_flag is equal to 1, for the first frame current_frame_id should not be compared to PrevFrameID (because PrevFrameID is uninitialized).

7.7. Frame end update CDF process

This process is triggered when the function frame_end_update_cdf is called from the tile group syntax table.

The frame CDF arrays are set equal to the saved CDF arrays as follows.

A copy is made of the saved CDF values for each of the CDF arrays mentioned in the semantics for init_coeff_cdfs and init_non_coeff_cdfs. The name of the destination for the copy is the name of the CDF array with no prefix. The name of the source for the copy is the name of the CDF array prefixed with “Saved”. For example, the array YModeCdf will be updated with values equal to the contents of SavedYModeCdf.

7.8. Set frame refs process

This process is triggered if the function set_frame_refs is called while reading the uncompressed header.

The syntax elements in the ref_frame_idx array are computed based on:

- the syntax elements last_frame_idx and gold_frame_idx,
- the values stored within the RefOrderHint array (these values represent the least significant bits of the expected output order of the frames).

The reference frames used for the LAST_FRAME and GOLDEN_FRAME references are sent explicitly and used to set the corresponding entries of ref_frame_idx as follows (the other entries are initialized to -1 and will be overwritten later in this process):

```
for ( i = 0; i < REFS_PER_FRAME; i++ )
  ref_frame_idx[ i ] = -1
ref_frame_idx[ LAST_FRAME - LAST_FRAME ] = last_frame_idx
ref_frame_idx[ GOLDEN_FRAME - LAST_FRAME ] = gold_frame_idx
```

An array usedFrame marking which reference frames have been used is prepared as follows:

```
for ( i = 0; i < NUM_REF_FRAMES; i++ )
  usedFrame[ i ] = 0
usedFrame[ last_frame_idx ] = 1
usedFrame[ gold_frame_idx ] = 1
```

A variable curFrameHint is set equal to 1 << (OrderHintBits - 1).

An array shiftedOrderHints (containing the expected output order shifted such that the current frame has hint equal to curFrameHint) is prepared as follows:

```
for ( i = 0; i < NUM_REF_FRAMES; i++ )
  shiftedOrderHints[ i ] = curFrameHint + get_relative_dist( RefOrderHint[ i ], OrderHint )
```

The variable lastOrderHint (representing the expected output order for LAST_FRAME) is set equal to shiftedOrderHints[last_frame_idx].

It is a requirement of bitstream conformance that lastOrderHint is strictly less than curFrameHint.

The variable goldOrderHint (representing the expected output order for GOLDEN_FRAME) is set equal to shiftedOrderHints[gold_frame_idx].

It is a requirement of bitstream conformance that goldOrderHint is strictly less than curFrameHint.

The ALTREF_FRAME reference is set to be a backward reference to the frame with highest output order as follows:

```
ref = find_latest_backward()
if ( ref >= 0 ) {
  ref_frame_idx[ ALTREF_FRAME - LAST_FRAME ] = ref
  usedFrame[ ref ] = 1
}
```

where find_latest_backward is defined as:

```
find_latest_backward() {
  ref = -1
  for ( i = 0; i < NUM_REF_FRAMES; i++ ) {
    hint = shiftedOrderHints[ i ]
    if ( !usedFrame[ i ] &&
         hint >= curFrameHint &&
         ( ref < 0 || hint >= latestOrderHint ) ) {
      ref = i
      latestOrderHint = hint
    }
  }
  return ref
}
```

The BWDREF_FRAME reference is set to be a backward reference to the closest frame as follows:

```
ref = find_earliest_backward()
if ( ref >= 0 ) {
  ref_frame_idx[ BWDREF_FRAME - LAST_FRAME ] = ref
  usedFrame[ ref ] = 1
}
```

where find_earliest_backward is defined as:

```
find_earliest_backward() {
  ref = -1
  for ( i = 0; i < NUM_REF_FRAMES; i++ ) {
    hint = shiftedOrderHints[ i ]
    if ( !usedFrame[ i ] &&
         hint >= curFrameHint &&
         ( ref < 0 || hint < earliestOrderHint ) ) {
      ref = i
      earliestOrderHint = hint
    }
  }
  return ref
}
```

The ALTREF2_FRAME reference is set to the next closest backward reference as follows:

```
ref = find_earliest_backward()
if ( ref >= 0 ) {
  ref_frame_idx[ ALTREF2_FRAME - LAST_FRAME ] = ref
  usedFrame[ ref ] = 1
}
```

The remaining references are set to be forward references in anti-chronological order as follows:

```
for ( i = 0; i < REFS_PER_FRAME - 2; i++ ) {
  refFrame = Ref_Frame_List[ i ]
  if ( ref_frame_idx[ refFrame - LAST_FRAME ] < 0 ) {
    ref = find_latest_forward()
    if ( ref >= 0 ) {
      ref_frame_idx[ refFrame - LAST_FRAME ] = ref
      usedFrame[ ref ] = 1
    }
  }
}
```

where Ref_Frame_List is specifed as:

```
Ref_Frame_List[ REFS_PER_FRAME - 2 ] = {
  LAST2_FRAME, LAST3_FRAME, BWDREF_FRAME, ALTREF2_FRAME, ALTREF_FRAME
}
```

and find_latest_forward is defined as:

```
find_latest_forward() {
  ref = -1
  for ( i = 0; i < NUM_REF_FRAMES; i++ ) {
    hint = shiftedOrderHints[ i ]
    if ( !usedFrame[ i ] &&
         hint < curFrameHint &&
         ( ref < 0 || hint >= latestOrderHint ) ) {
      ref = i
      latestOrderHint = hint
    }
  }
  return ref
}
```

Finally, any remaining references are set to the reference frame with smallest output order as follows:

```
ref = -1
for ( i = 0; i < NUM_REF_FRAMES; i++ ) {
  hint = shiftedOrderHints[ i ]
  if ( ref < 0 || hint < earliestOrderHint ) {
    ref = i
    earliestOrderHint = hint
  }
}
for ( i = 0; i < REFS_PER_FRAME; i++ ) {
  if ( ref_frame_idx[ i ] < 0 ) {
    ref_frame_idx[ i ] = ref
  }
}
```

Note: Multiple reference frames can share the same value for OrderHint and care needs to be taken to handle this case consistently. The reference implementation uses an equivalent implementation based on sorting the reference frames based on their expected output order, with ties broken based on the reference frame index.

7.9. Motion field estimation process

7.9.1. General

This process is triggered by a call to motion_field_estimation while reading the uncompressed header.

A linear projection model is employed to create a motion field estimation that is able to capture high velocity temporal motion trajectories.

The motion field is estimated based on the saved motion vectors from the reference frames and the relative frame distances.

As the frame distances depend on the frame being referenced, a separate motion field is estimated for each reference frame used by the current frame.

A motion vector (for each reference frame type) is prepared at each location on an 8x8 luma sample grid.

The variable w8 (representing the width of the motion field in units of 8x8 luma samples) is set equal to MiCols >> 1.

The variable h8 (representing the height of the motion field in units of 8x8 luma samples) is set equal to MiRows >> 1.

As the linear projection can create a field with holes, the motion fields are initialized to an invalid motion vector of -32768, -32768 as follows:

```
for ( ref = LAST_FRAME; ref <= ALTREF_FRAME; ref++ )
    for ( y = 0; y < h8 ; y++ )
        for ( x = 0; x < w8; x++ )
            for ( j = 0; j < 2; j++ )
                MotionFieldMvs[ ref ][ y ][ x ][ j ] = -1 << 15
```

The variable lastIdx (representing which reference frame is used for LAST_FRAME) is set equal to ref_frame_idx[0].

The variable curGoldOrderHint (representing the expected output order for GOLDEN_FRAME of the current frame) is set equal to OrderHints[GOLDEN_FRAME].

The variable lastAltOrderHint (representing the expected output order for ALTREF_FRAME of LAST_FRAME) is set equal to SavedOrderHints[lastIdx][ALTREF_FRAME].

The variable useLast (representing whether to project the motion vectors from LAST_FRAME) is set equal to (lastAltOrderHint != curGoldOrderHint).

If useLast is equal to 1, the projection process in section 7.9.2 is invoked with src equal to LAST_FRAME, and dstSign equal to -1. (The output of this process is discarded.)

The variable refStamp (that limits how many reference frames have to be projected) is set equal to MFMV_STACK_SIZE - 2.

The variable useBwd is set equal to get_relative_dist(OrderHints[BWDREF_FRAME], OrderHint) > 0.

If useBwd is equal to 1, the following steps apply:

- The projection process in section 7.9.2 is invoked with src equal to BWDREF_FRAME, and dstSign equal to 1, and the output assigned to projOutput.
- If projOutput is equal to 1, refStamp is set equal to refStamp - 1.

The variable useAlt2 is set equal to get_relative_dist(OrderHints[ALTREF2_FRAME], OrderHint) > 0.

If useAlt2 is equal to 1, the following steps apply:

- The projection process in section 7.9.2 is invoked with src equal to ALTREF2_FRAME, and dstSign equal to 1, and the output assigned to projOutput.
- If projOutput is equal to 1, refStamp is set equal to refStamp - 1.

The variable useAlt is set equal to get_relative_dist(OrderHints[ALTREF_FRAME], OrderHint) > 0.

If useAlt is equal to 1 and (refStamp >= 0), the following steps apply:

- The projection process in section 7.9.2 is invoked with src equal to ALTREF_FRAME, and dstSign equal to 1, and the output assigned to projOutput.

- If projOutput is equal to 1, refStamp is set equal to refStamp - 1.

If (refStamp >= 0), the projection process in section 7.9.2 is invoked with src equal to LAST2_FRAME, and dstSign equal to -1. (The output of this process is discarded.)

7.9.2. Projection process

The inputs to this process are:

- a variable src specifying which reference frame's motion vectors should be projected,
- a variable dstSign specifying a negation multiplier for the motion vector direction.

The process projects the motion vectors from a whole reference frame and stores the results in MotionFieldMvs.

The process outputs a single boolean value representing whether the source frame was valid for this operation. If the output is zero, no modification is made to MotionFieldMvs.

The variable srcIdx (representing which reference frame is used) is set equal to ref_frame_idx[src - LAST_FRAME].

The variable w8 (representing the width of the motion field in units of 8x8 luma samples) is set equal to MiCols >> 1.

The variable h8 (representing the height of the motion field in units of 8x8 luma samples) is set equal to MiRows >> 1.

If RefMiRows[srcIdx] is not equal to MiRows, RefMiCols[srcIdx] is not equal to MiCols, or RefFrameType[srcIdx] is equal to INTRA_ONLY_FRAME or KEY_FRAME, the process exits at this point, with the output set equal to 0.

The process is specified as follows:

```
for ( y8 = 0; y8 < h8; y8++ ) {
    for ( x8 = 0; x8 < w8; x8++ ) {
        row = 2 * y8 + 1
        col = 2 * x8 + 1
        srcRef = SavedRefFrames[ srcIdx ][ row ][ col ]
        if ( srcRef > INTRA_FRAME ) {
            refToCur = get_relative_dist( OrderHints[ src ], OrderHint )
            refOffset = get_relative_dist( OrderHints[ src ], SavedOrderHints[ srcIdx ][ srcRef ] )
            posValid = Abs( refToCur ) <= MAX_FRAME_DISTANCE &&
                       Abs( refOffset ) <= MAX_FRAME_DISTANCE &&
                       refOffset > 0
            if ( posValid ) {
                mv = SavedMvs[ srcIdx ][ row ][ col ]
                projMv = get_mv_projection( mv, refToCur * dstSign, refOffset )
                posValid = get_block_position( x8, y8, dstSign, projMv )
                if ( posValid ) {
                    for ( dst = LAST_FRAME; dst <= ALTREF_FRAME; dst++ ) {
                        refToDst = get_relative_dist( OrderHint, OrderHints[ dst ] )
                        projMv = get_mv_projection( mv, refToDst, refOffset )
                        MotionFieldMvs[ dst ][ PosY8 ][ PosX8 ] = projMv
                    }
                }
            }
        }
    }
}
```

When the function get_mv_projection is called, the get mv projection process specified in section 7.9.3 is invoked and the output assigned to projMv.

When the function get_block_position is called, the get block position process specified in section 7.9.4 is invoked and the output assigned to posValid. This process also sets up the variables PosY8 and PosX8 representing the projected location in the motion field.

The process now exits with the output set equal to 1.

7.9.3. Get MV projection process

The inputs to this process are:

- a length 2 array mv specifying a motion vector,
- a variable numerator specifying the number of frames to be covered by the projected motion vector,
- a variable denominator specifying the number of frames covered by the original motion vector.

The outputs of this process are:

- a length 2 array projMv containing the projected motion vector

This process starts with a motion vector mv from a previous frame. This motion vector gives the displacement expected when moving a certain number of frames (given by the variable denominator). In order to use the motion vector for predictions using a different reference frame, the length of the motion vector must be scaled.

The variable clippedDenominator is set equal to Min(MAX_FRAME_DISTANCE, denominator).

The variable clippedNumerator is set equal to Clip3(-MAX_FRAME_DISTANCE, MAX_FRAME_DISTANCE, numerator).

The projected motion vector is specified as follows:

```
for ( i = 0; i < 2; i++ ) {
    scaled = Round2Signed( mv[ i ] * clippedNumerator * Div_Mult[ clippedDenominator ], 14 )
    projMv[ i ] = Clip3( -(1 << 14) + 1, (1 << 14) - 1, scaled )
}
```

where Div_Mult is a constant lookup table specified as:

```
Div_Mult[32] = {
  0,    16384, 8192, 5461, 4096, 3276, 2730, 2340, 2048, 1820, 1638,
  1489, 1365,  1260, 1170, 1092, 1024, 963,  910,  862,  819,  780,
  744,  712,   682,  655,  630,  606,  585,  564,  546,  528
}
```

7.9.4. Get block position process

The inputs to this process are:

- variables x8 and y8 specifying a location in units of 8x8 luma samples,
- a variable dstSign specifying a negation multiplier for the motion vector direction,
- a length 2 array projMv specifying a projected motion vector.

The process generates global variables PosX8 and PosY8 representing the projected location in units of 8x8 luma samples.

The process returns a flag posValid that indicates if the position should be used.

> **Note:** posValid is specified such that only blocks within a certain distance of the current location need to be projected.

The variable posValid is set equal to 1.

The variable PosY8 is set equal to project(y8, projMv[0], dstSign, MiRows >> 1, MAX_OFFSET_HEIGHT).

The variable PosX8 is set equal to project(x8, projMv[1], dstSign, MiCols >> 1, MAX_OFFSET_WIDTH).

where the function project is specified as follows:

```
project( v8, delta, dstSign, max8, maxOff8 ) {
    base8 = (v8 >> 3) << 3
    if ( delta >= 0 ) {
        offset8 = delta >> ( 3 + 1 + MI_SIZE_LOG2 )
    } else {
        offset8 = -( ( -delta ) >> ( 3 + 1 + MI_SIZE_LOG2 ) )
    }
    v8 += dstSign * offset8
    if ( v8 < 0 ||
         v8 >= max8 ||
         v8 < base8 - maxOff8 ||
         v8 >= base8 + 8 + maxOff8 ) {
        posValid = 0
    }
    return v8
}
```

The project function clears posValid if the resulting position is offset too far.

7.10. Motion vector prediction processes

7.10.1. General

The following sections define the processes used for predicting the motion vectors.

The entry point to these processes is triggered by the function call to find_mv_stack in the inter block mode info syntax described in section 5.11.23. This function call invokes the Find MV Stack Process specified in section 7.10.2.

7.10.2. Find MV stack process

This process is triggered by a function call to find_mv_stack.

The input to this process is a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

This process constructs an array RefStackMv containing motion vector candidates.

The process also prepares the value of the contexts used when decoding inter prediction syntax elements.

The array RefStackMv will be constructed during this process. RefStackMv[idx][list][comp] represents component comp (0 for y or 1 for x) of a motion vector for a particular list (0 or 1) at position idx (0 to MAX_REF_MV_STACK_SIZE - 1) in the stack. No initialization is needed because each entry is always written before it can be read.

The variable bw4 specifying the width of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_Wide[MiSize].

The variable bh4 specifying the height of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_High[MiSize].

The following ordered steps apply:

1. The variable NumMvFound (representing the number of motion vector candidates in RefStackMv) is set equal to 0.
2. The variable NewMvCount (representing the number of candidates found that used NEWMV encoding) is set equal to 0.
3. The setup global mv process specified in section 7.10.2.1 is invoked with the input 0 and the output is assigned to GlobalMvs[0].
4. If isCompound is equal to 1, the setup global mv process specified in section 7.10.2.1 is invoked with the input 1 and the output is assigned to GlobalMvs[1].
5. The variable FoundMatch is set equal to 0.
6. The scan row process in section 7.10.2.2 is invoked with deltaRow equal to -1 and isCompound as inputs.
7. The variable foundAboveMatch is set equal to FoundMatch, and FoundMatch is set equal to 0.
8. The scan col process in section 7.10.2.3 is invoked with deltaCol equal to -1 and isCompound as inputs.
9. The variable foundLeftMatch is set equal to FoundMatch, and FoundMatch is set equal to 0.
10. If Max(bw4, bh4) is less than or equal to 16, the scan point process in section 7.10.2.4 is invoked with deltaRow equal to -1, deltaCol equal to bw4, and isCompound as inputs.
11. If FoundMatch is equal to 1, the variable foundAboveMatch is set equal to 1.
12. The variable CloseMatches (representing candidates found in the immediate neighborhood) is set equal to foundAboveMatch + foundLeftMatch.
13. The variable numNearest (representing the number of motion vectors found in the immediate neighborhood) is set equal to NumMvFound
14. The variable numNew (representing the number of times a NEWMV candidate was found in the immediate neighborhood) is set equal to NewMvCount
15. If numNearest is greater than 0, WeightStack[idx] is incremented by REF_CAT_LEVEL for idx = 0..(numNearest-1).
16. The variable ZeroMvContext is set equal to 0.
17. If use_ref_frame_mvs is equal to 1, the temporal scan process in section 7.10.2.5 is invoked with isCompound as input (the temporal scan process affects ZeroMvContext).

18. The scan point process in section 7.10.2.4 is invoked with deltaRow equal to -1, deltaCol equal to -1, and isCompound as inputs.

19. If FoundMatch is equal to 1, the variable foundAboveMatch is set equal to 1.

20. The variable FoundMatch is set equal to 0.

21. The scan row process in section 7.10.2.2 is invoked with deltaRow equal to -3 and isCompound as inputs.

22. If FoundMatch is equal to 1, the variable foundAboveMatch is set equal to 1.

23. The variable FoundMatch is set equal to 0.

24. The scan col process in section 7.10.2.3 is invoked with deltaCol equal to -3 and isCompound as inputs.

25. If FoundMatch is equal to 1, the variable foundLeftMatch is set equal to 1.

26. The variable FoundMatch is set equal to 0.

27. If bh4 is greater than 1, the scan row process in section 7.10.2.2 is invoked with deltaRow equal to -5 and isCompound as inputs.

28. If FoundMatch is equal to 1, the variable foundAboveMatch is set equal to 1.

29. The variable FoundMatch is set equal to 0.

30. If bw4 is greater than 1, the scan col process in section 7.10.2.3 is invoked with deltaCol equal to -5 and isCompound as inputs.

31. If FoundMatch is equal to 1, the variable foundLeftMatch is set equal to 1.

32. The variable TotalMatches (representing all found candidates) is set equal to foundAboveMatch + foundLeftMatch.

33. The sorting process in section 7.10.2.11 is invoked with start equal to 0, end equal to numNearest, and isCompound as input.

34. The sorting process in section 7.10.2.11 is invoked with start equal to numNearest, end equal to NumMvFound, and isCompound as input.

35. If NumMvFound is less than 2, the extra search process in section 7.10.2.12 is invoked with isCompound as input.

36. The context and clamping process in section 7.10.2.14 is invoked with isCompound and numNew as input.

7.10.2.1. Setup global MV process

The input to this process is a variable refList specifying which set of motion vectors to predict.

The output is a motion vector mv representing global motion for this block.

The variable ref (specifying the reference frame) is set equal to RefFrame[refList].

If ref is not equal to INTRA_FRAME, the variable typ (specifying the type of global motion) is set equal to GmType[ref].

The variable bw (representing the width of the block in units of luma samples) is set equal to Block_Width[MiSize].

The variable bh (representing the height of the block in units of luma samples) is set equal to Block_Height[MiSize].

The output motion vector mv is specified by projecting the central luma sample of the block as follows:

```
if ( ref == INTRA_FRAME || typ == IDENTITY ) {
    mv[0] = 0
    mv[1] = 0
} else if ( typ == TRANSLATION ) {
    mv[0] = gm_params[ref][0] >> (WARPEDMODEL_PREC_BITS - 3)
    mv[1] = gm_params[ref][1] >> (WARPEDMODEL_PREC_BITS - 3)
} else {
    x = MiCol * MI_SIZE + bw / 2 - 1
    y = MiRow * MI_SIZE + bh / 2 - 1
    xc = (gm_params[ref][2] - (1 << WARPEDMODEL_PREC_BITS)) * x +
          gm_params[ref][3] * y +
          gm_params[ref][0]
    yc =  gm_params[ref][4] * x +
         (gm_params[ref][5] - (1 << WARPEDMODEL_PREC_BITS)) * y +
          gm_params[ref][1]
    if ( allow_high_precision_mv ) {
      mv[0] = Round2Signed(yc, WARPEDMODEL_PREC_BITS - 3)
      mv[1] = Round2Signed(xc, WARPEDMODEL_PREC_BITS - 3)
    } else {
      mv[0] = Round2Signed(yc, WARPEDMODEL_PREC_BITS - 2) * 2
      mv[1] = Round2Signed(xc, WARPEDMODEL_PREC_BITS - 2) * 2
    }
}
lower_mv_precision( mv )
```

where the call to lower_mv_precision invokes the lower precision process specified in section 7.10.2.10.

7.10.2.2. Scan row process

The inputs to this process are:

- a variable deltaRow specifying (in units of 4x4 luma samples) how far above to look for motion vectors,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

The variable bw4 specifying the width of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_Wide[MiSize].

The variable end4 specifying the last block to be scanned in horizontal 4x4 luma samples is set equal to Min(Min(bw4, MiCols - MiCol), 16).

Note: end4 limits the number of locations to be searched for large blocks. There is a similar optimization in that the scan point process for the top-right location is not invoked for large blocks. For example, for a 64 by 64 block, candidates from the row above will be examined at x offsets of -1, 0, 16, 32, 48, 64. (The 0, 16, 32, 48 locations are scanned in this process, while the -1 and 64 are scanned by the scan point process.) However, for a 128 by 64 or 64 by 128 block, candidates from the row above will only be examined at x offsets of -1, 0, 16, 32, 48 because the scan point process for the top-right location is not invoked.

The variable deltaCol is set equal to 0.

The variable useStep16 is set equal to (bw4 >= 16).

Note: useStep16 is equal to 1 when the block is 64 luma samples wide or wider. This means only 4 locations will be searched in this case. However, a 32 luma samples wide block may still search 8 locations.

If Abs(deltaRow) is greater than 1, the offset is adjusted as follows:

```
deltaRow += MiRow & 1
deltaCol = 1 - (MiCol & 1)
```

Note: These adjustments reduce the number of motion vectors that need to be kept in memory.

A series of motion vector locations is scanned as follows:

```
i = 0
while ( i < end4 ) {
    mvRow = MiRow + deltaRow
    mvCol = MiCol + deltaCol + i
    if ( !is_inside(mvRow,mvCol) )
        break
    len = Min(bw4, Num_4x4_Blocks_Wide[ MiSizes[ mvRow ][ mvCol ] ])
    if ( Abs(deltaRow) > 1 )
        len = Max(2, len)
    if ( useStep16 )
        len = Max(4, len)
    weight = len * 2
    add_ref_mv_candidate( mvRow, mvCol, isCompound, weight)
    i += len
}
```

where the call to add_ref_mv_candidate invokes the process in section 7.10.2.7.

7.10.2.3. Scan col process

The inputs to this process are:

- a variable deltaCol specifying (in units of 4x4 luma samples) how far left to look for motion vectors,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

The variable bh4 specifying the height of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_High[MiSize].

The variable end4 specifying the last block to be scanned in vertical 4x4 luma samples is set equal to Min(Min(bh4, MiRows - MiRow), 16).

The variable deltaRow is set equal to 0.

The variable useStep16 is set equal to (bh4 >= 16).

If Abs(deltaCol) is greater than 1, the offset is adjusted as follows:

```
deltaRow = 1 - (MiRow & 1)
deltaCol += MiCol & 1
```

A series of motion vector locations is scanned as follows:

```
i = 0
while ( i < end4 ) {
    mvRow = MiRow + deltaRow + i
    mvCol = MiCol + deltaCol
    if ( !is_inside(mvRow,mvCol) )
        break
    len = Min(bh4, Num_4x4_Blocks_High[ MiSizes[ mvRow ][ mvCol ] ])
    if ( Abs(deltaCol) > 1 )
        len = Max(2, len)
    if ( useStep16 )
        len = Max(4, len)
    weight = len * 2
    add_ref_mv_candidate( mvRow, mvCol, isCompound, weight )
    i += len
}
```

where the call to add_ref_mv_candidate invokes the process in section 7.10.2.7.

7.10.2.4. Scan point process

The inputs to this process are:

- a variable deltaRow specifying (in units of 4x4 luma samples) how far above to look for a motion vector,

- a variable deltaCol specifying (in units of 4x4 luma samples) how far left to look for a motion vector,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

The variable mvRow is set equal to MiRow + deltaRow.

The variable mvCol is set equal to MiCol + deltaCol.

The variable weight is set equal to 4.

If is_inside(mvRow, mvCol) is equal to 1 and RefFrames[mvRow][mvCol][0] has been written for this frame (this checks that the candidate location has been decoded), the add reference motion vector process in section 7.10.2.7 is invoked with mvRow, mvCol, isCompound, weight as inputs.

7.10.2.5. Temporal scan process

The input to this process is a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

This process scans the motion vectors in a previous frame looking for candidates which use the same reference frame.

The variable bw4 specifying the width of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_Wide[MiSize].

The variable bh4 specifying the height of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_High[MiSize].

The variable stepW4 is set equal to (bw4 >= 16) ? 4 : 2.

The variable stepH4 is set equal to (bh4 >= 16) ? 4 : 2.

The process scans the locations within the block as follows:

```
for ( deltaRow = 0; deltaRow < Min( bh4, 16 ) ; deltaRow += stepH4 ) {
    for ( deltaCol = 0; deltaCol < Min( bw4, 16 ) ; deltaCol += stepW4 ) {
        add_tpl_ref_mv( deltaRow, deltaCol, isCompound)
    }
}
```

where the call to add_tpl_ref_mv invokes the temporal sample process in section 7.10.2.6.

The process then scans positions around the block (but still within the same superblock) as follows:

```
allowExtension = ((bh4 >= Num_4x4_Blocks_High[BLOCK_8X8]) &&
                  (bh4 < Num_4x4_Blocks_High[BLOCK_64X64]) &&
                  (bw4 >= Num_4x4_Blocks_Wide[BLOCK_8X8]) &&
                  (bw4 < Num_4x4_Blocks_Wide[BLOCK_64X64]))
if ( allowExtension ) {
    for ( i = 0; i < 3; i++ ) {
        deltaRow = tplSamplePos[ i ][ 0 ]
        deltaCol = tplSamplePos[ i ][ 1 ]
        if ( check_sb_border( deltaRow, deltaCol ) ) {
            add_tpl_ref_mv( deltaRow, deltaCol, isCompound)
        }
    }
}
```

where tplSamplePos contains the offsets to search (in units of 4x4 luma samples) and is specified as:

```
tplSamplePos[3][2] = {
    { bh4, -2 }, { bh4, bw4 }, { bh4 - 2, bw4 }
}
```

and check_sb_border checks that the position is within the same 64x64 block as follows:

```
check_sb_border( deltaRow, deltaCol ) {
    row = (MiRow & 15) + deltaRow
    col = (MiCol & 15) + deltaCol

    return ( row >= 0 && row < 16 && col >= 0 && col < 16 )
}
```

7.10.2.6. Temporal sample process

The inputs to this process are:

- variables deltaRow and deltaCol specifying (in units of 4x4 luma samples) the offset to the candidate location,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

This process looks up a motion vector from the motion field and adds it into the stack.

The variable mvRow is set equal to (MiRow + deltaRow) | 1.

The variable mvCol is set equal to (MiCol + deltaCol) | 1.

If is_inside(mvRow, mvCol) is equal to 0, this process terminates immediately.

The variable x8 is set equal to mvCol >> 1.

The variable y8 is set equal to mvRow >> 1.

(x8 and y8 represent the position of the candidate in units of 8x8 luma samples.)

The process is specified as follows:

```
if ( deltaRow == 0 && deltaCol == 0 ) {
    ZeroMvContext = 1
}
if ( !isCompound ) {
    candMv = MotionFieldMvs[ RefFrame[ 0 ] ][ y8 ][ x8 ]
    if ( candMv[ 0 ] == -1 << 15 )
        return
    lower_mv_precision( candMv )
    if ( deltaRow == 0 && deltaCol == 0 ) {
        if ( Abs( candMv[ 0 ] - GlobalMvs[ 0 ][ 0 ] ) >= 16 ||
             Abs( candMv[ 1 ] - GlobalMvs[ 0 ][ 1 ] ) >= 16 )
            ZeroMvContext = 1
        else
            ZeroMvContext = 0
    }
    for ( idx = 0; idx < NumMvFound; idx++ ) {
        if ( candMv[ 0 ] == RefStackMv[ idx ][ 0 ][ 0 ] &&
             candMv[ 1 ] == RefStackMv[ idx ][ 0 ][ 1 ] )
             break
    }
    if ( idx < NumMvFound ) {
        WeightStack[ idx ] += 2
    } else if ( NumMvFound < MAX_REF_MV_STACK_SIZE ) {
        RefStackMv[ NumMvFound ][ 0 ] = candMv
        WeightStack[ NumMvFound ] = 2
        NumMvFound += 1
    }
} else {
    candMv0 = MotionFieldMvs[ RefFrame[ 0 ] ][ y8 ][ x8 ]
    if ( candMv0[ 0 ] == -1 << 15 )
        return
    candMv1 = MotionFieldMvs[ RefFrame[ 1 ] ][ y8 ][ x8 ]
    if ( candMv1[ 0 ] == -1 << 15 )
        return
    lower_mv_precision( candMv0 )
    lower_mv_precision( candMv1 )
    if ( deltaRow == 0 && deltaCol == 0 ) {
        if ( Abs( candMv0[ 0 ] - GlobalMvs[ 0 ][ 0 ] ) >= 16 ||
             Abs( candMv0[ 1 ] - GlobalMvs[ 0 ][ 1 ] ) >= 16 ||
             Abs( candMv1[ 0 ] - GlobalMvs[ 1 ][ 0 ] ) >= 16 ||
             Abs( candMv1[ 1 ] - GlobalMvs[ 1 ][ 1 ] ) >= 16 )
            ZeroMvContext = 1
        else
            ZeroMvContext = 0
    }
    for ( idx = 0; idx < NumMvFound; idx++ ) {
        if ( candMv0[ 0 ] == RefStackMv[ idx ][ 0 ][ 0 ]  &&
             candMv0[ 1 ] == RefStackMv[ idx ][ 0 ][ 1 ]  &&
             candMv1[ 0 ] == RefStackMv[ idx ][ 1 ][ 0 ]  &&
             candMv1[ 1 ] == RefStackMv[ idx ][ 1 ][ 1 ] )
```

```
            break
    }
    if ( idx < NumMvFound ) {
        WeightStack[ idx ] += 2
    } else if ( NumMvFound < MAX_REF_MV_STACK_SIZE ) {
        RefStackMv[ NumMvFound ][ 0 ] = candMv0
        RefStackMv[ NumMvFound ][ 1 ] = candMv1
        WeightStack[ NumMvFound ] = 2
        NumMvFound += 1
    }
}
```

where the call to lower_mv_precision invokes the lower precision process specified in section 7.10.2.10.

7.10.2.7. Add reference motion vector process

The inputs to this process are:

- variables mvRow and mvCol specifying (in units of 4x4 luma samples) the candidate location,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction,
- a variable weight specifying the weight attached to this motion vector.

This process examines the candidate to find matching reference frames.

If IsInters[mvRow][mvCol] is equal to 0, this process terminates immediately.

If isCompound is equal to 0, the following applies for candList = 0..1:

1. If RefFrames[mvRow][mvCol][candList] is equal to RefFrame[0], the search stack process in section 7.10.2.8 is invoked with mvRow, mvCol, weight, and candList as inputs.

Otherwise (isCompound is equal to 1), the following applies:

1. If RefFrames[mvRow][mvCol][0] is equal to RefFrame[0] and RefFrames[mvRow][mvCol][1] is equal to RefFrame[1], the compound search stack process in section 7.10.2.9 is invoked with mvRow, mvCol, and weight as inputs.

7.10.2.8. Search stack process

The inputs to this process are:

- variables mvRow and mvCol specifying (in units of 4x4 luma samples) the candidate location,
- a variable candList specifying which list in the candidate matches our reference frame,
- a variable weight proportional to the corresponding block width or height for the candidate motion vector.

This process searches the stack for an exact match with a candidate motion vector. If present, the weight of the candidate motion vector is added to the weight of its counterpart in the stack, otherwise the process adds a motion vector to the stack.

The variable candMode is set equal to YModes[mvRow][mvCol].

The variable candSize is set equal to MiSizes[mvRow][mvCol].

The variable large is set equal to (Min(Block_Width[candSize],Block_Height[candSize]) >= 8).

The candidate motion vector candMv is set as follows:

- If (candMode == GLOBALMV || candMode == GLOBAL_GLOBALMV) and (GmType[RefFrame[0]] > TRANSLATION) and (large == 1), candMv is set equal to GlobalMvs[0].
- Otherwise, candMv is set equal to Mvs[mvRow][mvCol][candList].

The lower precision process specified in section 7.10.2.10 is invoked with candMv.

If has_newmv(candMode) is equal to 1, NewMvCount is set equal to NewMvCount + 1.

The variable FoundMatch is set equal to 1.

The process depends on whether the candidate motion vector is already in the stack as follows:

- If candMv is already equal to RefStackMv[idx][0] for some idx less than NumMvFound, then WeightStack[idx] is increased by weight
- Otherwise, if NumMvFound is less than MAX_REF_MV_STACK_SIZE, the following ordered steps apply:

  a. RefStackMv[NumMvFound][0] is set equal to candMv

  b. WeightStack[NumMvFound] is set equal to weight

  c. NumMvFound is set equal to NumMvFound + 1.

- Otherwise, (NumMvFound is greater than or equal to MAX_REF_MV_STACK_SIZE), the process has no effect.

7.10.2.9. Compound search stack process

The inputs to this process are:

- variables mvRow and mvCol specifying (in units of 4x4 luma samples) the candidate location,
- a variable weight proportional to the corresponding block width or height for the candidate pair of motion vectors.

This process searches the stack for an exact match with a candidate pair of motion vectors. If present, the weight of the candidate pair of motion vectors is added to the weight of its counterpart in the stack, otherwise the process adds the motion vectors to the stack.

The array candMvs (containing two motion vectors) is set equal to Mvs[mvRow][mvCol].

The variable candMode is set equal to YModes[mvRow][mvCol].

The variable candSize is set equal to MiSizes[mvRow][mvCol].

If candMode is equal to GLOBAL_GLOBALMV, for refList = 0..1 the following applies:

- If GmType[RefFrame[refList]] > TRANSLATION, candMvs[refList] is set equal to GlobalMvs[refList].

For i = 0..1, the lower precision process specified in section 7.10.2.10 is invoked with candMvs[i].

The variable FoundMatch is set equal to 1.

The process depends on whether the candidate motion vector pair is already in the stack as follows:

- If candMvs[0] is equal to RefStackMv[idx][0] and candMvs[1] is equal to RefStackMv[idx][1] for some idx less than NumMvFound, then WeightStack[idx] is increased by weight
- Otherwise, if NumMvFound is less than MAX_REF_MV_STACK_SIZE, the following ordered steps apply:

  a. RefStackMv[NumMvFound][i] is set equal to candMvs[i] for i = 0..1

  b. WeightStack[NumMvFound] is set equal to weight

  c. NumMvFound is set equal to NumMvFound + 1.
- Otherwise, (NumMvFound is greater than or equal to MAX_REF_MV_STACK_SIZE), the process has no effect.

If has_newmv(candMode) is equal to 1, NewMvCount is set equal to NewMvCount + 1.

The function has_newmv is defined as:

```
has_newmv( mode ) {
    return (mode == NEWMV ||
            mode == NEW_NEWMV ||
            mode == NEAR_NEWMV ||
            mode == NEW_NEARMV ||
            mode == NEAREST_NEWMV ||
            mode == NEW_NEARESTMV)
}
```

Note: It is impossible for mode to equal NEWMV in this function because it is only called for compound modes.

7.10.2.10. Lower precision process

The input to this process is a reference candMv to a motion vector array.

This process modifies the contents of the input motion vector to remove the least significant bit when high precision is not allowed, and all three fractional bits when force_integer_mv is equal to 1.

If allow_high_precision_mv is equal to 1, this process terminates immediately.

For i = 0..1, the following applies:

```
if ( force_integer_mv ) {
    a = Abs( candMv[ i ] )
    aInt = (a + 3) >> 3
    if ( candMv[ i ] > 0 )
        candMv[ i ] = aInt << 3
    else
        candMv[ i ] = -( aInt << 3 )
} else {
    if ( candMv[ i ] & 1 ) {
        if ( candMv[ i ] > 0 )
            candMv[ i ]--
        else
            candMv[ i ]++
    }
}
```

7.10.2.11. Sorting process

The inputs to this process are:

- a variable start representing the first position to be sorted,
- a variable end representing the length of the array,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

This process performs a stable sort of part of the stack of motion vectors according to the corresponding weight.

Entries in RefStackMv from start (inclusive) to end (exclusive) are sorted.

The sorting process is specified as:

```
while ( end > start ) {
    newEnd = start
    for ( idx = start + 1; idx < end; idx++ ) {
        if ( WeightStack[ idx - 1 ] < WeightStack[ idx ] ) {
            swap_stack(idx - 1, idx)
            newEnd = idx
        }
    }
    end = newEnd
}
```

When the function swap_stack is invoked, the entries at locations idx and idx - 1 should be swapped in WeightStack and RefStackMv as follows:

```
swap_stack( i, j ) {
  temp = WeightStack[ i ]
  WeightStack[ i ] = WeightStack[ j ]
  WeightStack[ j ] = temp
  for ( list = 0; list < 1 + isCompound; list++ ) {
    for ( comp = 0; comp < 2; comp++ ) {
      temp = RefStackMv[ i ][ list ][ comp ]
      RefStackMv[ i ][ list ][ comp ] = RefStackMv[ j ][ list ][ comp ]
      RefStackMv[ j ][ list ][ comp ] = temp
    }
  }
}
```

7.10.2.12. Extra search process

The input to this process is a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

This process adds additional motion vectors to RefStackMv until it has 2 choices of motion vector by first searching the left and above neighbors for partially matching candidates, and second adding global motion candidates.

When doing single prediction, the motion vectors go straight on the stack.

When doing compound prediction, the motion vectors are added to arrays called RefIdMvs (counting matches from the same frame) and RefDiffMvs (counting matches from different frames).

The number of entries in these arrays are initialized to zero as follows:

```
for ( list = 0; list < 2; list++ ) {
  RefIdCount[ list ] = 0
  RefDiffCount[ list ] = 0
}
```

A two pass search for the partial matching candidates is specified as:

```
w4 = Min( 16, Num_4x4_Blocks_Wide[ MiSize ] )
h4 = Min( 16, Num_4x4_Blocks_High[ MiSize ] )
w4 = Min( w4, MiCols - MiCol )
h4 = Min( h4, MiRows - MiRow )
num4x4 = Min( w4, h4 )
for ( pass = 0; pass < 2; pass++ ) {
  idx = 0
  while ( idx < num4x4 && NumMvFound < 2 ) {
    if ( pass == 0 ) {
      mvRow = MiRow - 1
      mvCol = MiCol + idx
    } else {
      mvRow = MiRow + idx
      mvCol = MiCol - 1
    }
    if ( !is_inside( mvRow, mvCol ) )
      break
    add_extra_mv_candidate( mvRow, mvCol, isCompound )
    if ( pass == 0 ) {
      idx += Num_4x4_Blocks_Wide[ MiSizes[ mvRow ][ mvCol ] ]
    } else {
      idx += Num_4x4_Blocks_High[ MiSizes[ mvRow ][ mvCol ] ]
    }
  }
}
```

The first pass searches the row above, the second searches the column to the left.

The function call to add_extra_mv_candidate invokes the add extra mv candidate process specified in section 7.10.2.13 with mvRow, mvCol, isCompound as inputs.

If isCompound is equal to 1, the candidates in the RefIdMvs and RefDiffMvs arrays are added to the stack as follows (using the temporary array combinedMvs):

```
for ( list = 0; list < 2; list++ ) {
  compCount = 0
  for ( idx = 0; idx < RefIdCount[ list ]; idx++ ) {
    combinedMvs[ compCount ][ list ] = RefIdMvs[ list ][ idx ]
    compCount++
  }
  for ( idx = 0; idx < RefDiffCount[ list ] && compCount < 2; idx++ ) {
    combinedMvs[ compCount ][ list ] = RefDiffMvs[ list ][ idx ]
    compCount++
  }
  while ( compCount < 2 ) {
    combinedMvs[ compCount ][ list ] = GlobalMvs[ list ]
    compCount++
  }
}
if ( NumMvFound == 1 ) {
  if ( combinedMvs[ 0 ][ 0 ] == RefStackMv[ 0 ][ 0 ] &&
       combinedMvs[ 0 ][ 1 ] == RefStackMv[ 0 ][ 1 ] ) {
    RefStackMv[ NumMvFound ][ 0 ] = combinedMvs[ 1 ][ 0 ]
    RefStackMv[ NumMvFound ][ 1 ] = combinedMvs[ 1 ][ 1 ]
  } else {
    RefStackMv[ NumMvFound ][ 0 ] = combinedMvs[ 0 ][ 0 ]
    RefStackMv[ NumMvFound ][ 1 ] = combinedMvs[ 0 ][ 1 ]
  }
  WeightStack[ NumMvFound ] = 2
  NumMvFound++
} else {
  for ( idx = 0; idx < 2; idx++ ) {
    RefStackMv[ NumMvFound ][ 0 ] = combinedMvs[ idx ][ 0 ]
    RefStackMv[ NumMvFound ][ 1 ] = combinedMvs[ idx ][ 1 ]
    WeightStack[ NumMvFound ] = 2
    NumMvFound++
  }
}
```

If isCompound is equal to 0, the candidates have already been added to RefStackMv, and this process simply extends with global motion candidates as follows:

```
for ( idx = NumMvFound; idx < 2; idx++ ) {
  RefStackMv[ idx ][ 0 ] = GlobalMvs[ 0 ]
}
```

Note: For single prediction, NumMvFound is not incremented by the addition of global motion candidates, whereas for compound prediction NumMvFound will always be greater or equal to 2 by this point.

7.10.2.13. Add extra MV candidate process

The inputs to this process are:

- variables mvRow and mvCol specifying (in units of 4x4 luma samples) the candidate location,
- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction.

This process may modify the contents of the global variables RefIdMvs, RefIdCount, RefDiffMvs, RefDiffCount, RefStackMv, WeightStack, and NumMvFound.

This process examines the candidate location to find possible motion vectors as follows:

```
if ( isCompound ) {
  for ( candList = 0; candList < 2; candList++ ) {
    candRef = RefFrames[ mvRow ][ mvCol ][ candList ]
    if ( candRef > INTRA_FRAME ) {
      for ( list = 0; list < 2; list++ ) {
        candMv = Mvs[ mvRow ][ mvCol ][ candList ]
        if ( candRef == RefFrame[ list ] && RefIdCount[ list ] < 2 ) {
          RefIdMvs[ list ][ RefIdCount[ list ] ] = candMv
          RefIdCount[ list ]++
        } else if ( RefDiffCount[ list ] < 2 ) {
          if ( RefFrameSignBias[ candRef ] != RefFrameSignBias[ RefFrame[list] ] ) {
            candMv[ 0 ] *= -1
            candMv[ 1 ] *= -1
          }
          RefDiffMvs[ list ][ RefDiffCount[ list ] ] = candMv
          RefDiffCount[ list ]++
        }
      }
    }
  }
} else {
  for ( candList = 0; candList < 2; candList++ ) {
    candRef = RefFrames[ mvRow ][ mvCol ][ candList ]
    if ( candRef > INTRA_FRAME ) {
      candMv = Mvs[ mvRow ][ mvCol ][ candList ]
      if ( RefFrameSignBias[ candRef ] != RefFrameSignBias[ RefFrame[ 0 ] ] ) {
        candMv[ 0 ] *= -1
        candMv[ 1 ] *= -1
      }
      for ( idx = 0; idx < NumMvFound; idx++ ) {
        if ( candMv == RefStackMv[ idx ][ 0 ] )
          break
      }
      if ( idx == NumMvFound ) {
        RefStackMv[ idx ][ 0 ] = candMv
        WeightStack[ idx ] = 2
        NumMvFound++
      }
    }
  }
}
```

7.10.2.14. Context and clamping process

The inputs to this process are:

- a variable isCompound containing 0 for single prediction, or 1 to signal compound prediction,
- a variable numNew specifying the number of NEWMV candidates found in the immediate neighborhood.

This process computes contexts to be used when decoding syntax elements, and clamps the candidates in RefStackMv.

The variable bw (representing the width of the block in units of luma samples) is set equal to Block_Width[MiSize].

The variable bh (representing the height of the block in units of luma samples) is set equal to Block_Height[MiSize].

> **Note:** It only matters whether numNew is zero or non-zero because the value is clipped at 1 when it is used. Implementations may therefore choose to implement numNew and NewMvCount as a boolean instead of a counter.

The variable numLists specifying the number of reference frames used for this block is set equal to (isCompound ? 2 : 1).

The array DrlCtxStack is set as follows:

```
for ( idx = 0; idx < NumMvFound ; idx++ ) {
    z = 0
    if ( idx + 1 < NumMvFound ) {
        w0 = WeightStack[ idx ]
        w1 = WeightStack[ idx + 1 ]
        if ( w0 >= REF_CAT_LEVEL ) {
            if ( w1 < REF_CAT_LEVEL ) {
                z = 1
            }
        } else {
            z = 2
        }
    }
    DrlCtxStack[ idx ] = z
}
```

The motion vectors are clamped as follows:

```
for ( list = 0; list < numLists; list++ ) {
    for ( idx = 0; idx < NumMvFound ; idx++ ) {
        refMv = RefStackMv[ idx ][ list ]
        refMv[ 0 ] = clamp_mv_row( refMv[ 0 ], MV_BORDER + bh * 8)
        refMv[ 1 ] = clamp_mv_col( refMv[ 1 ], MV_BORDER + bw * 8)
        RefStackMv[ idx ][ list ] = refMv
    }
}
```

The variables RefMvContext and NewMvContext are set as follows:

```
if ( CloseMatches == 0 ) {
    NewMvContext = Min( TotalMatches, 1 )       // 0,1
    RefMvContext = TotalMatches
} else if ( CloseMatches == 1 ) {
    NewMvContext = 3 - Min( numNew, 1 )       // 2,3
    RefMvContext = 2 + TotalMatches
} else {
    NewMvContext = 5 - Min( numNew, 1 )       // 4,5
    RefMvContext = 5
}
```

7.10.3. Has overlappable candidates process

This process is triggered by a call to has_overlappable_candidates.

It returns 1 to indicate that the block has neighbors suitable for use by overlapped motion compensation, or 0 otherwise.

The process looks to see if there are any inter blocks to the left or above.

The check is only made at 8x8 granularity.

The process is specified as:

```
has_overlappable_candidates( ) {
  if ( AvailU ) {
    w4 = Num_4x4_Blocks_Wide[ MiSize ]
    for ( x4 = MiCol; x4 < Min( MiCols, MiCol + w4 ); x4 += 2 ) {
        if ( RefFrames[ MiRow - 1 ][ x4 | 1 ][ 0 ] > INTRA_FRAME )
            return 1
    }
  }
  if ( AvailL ) {
    h4 = Num_4x4_Blocks_High[ MiSize ]
    for ( y4 = MiRow; y4 < Min( MiRows, MiRow + h4 ); y4 += 2 ) {
        if ( RefFrames[ y4 | 1 ][ MiCol - 1 ][ 0 ] > INTRA_FRAME )
            return 1
    }
  }
  return 0
}
```

7.10.4. Find warp samples process

7.10.4.1. General

This process is triggered when the find_warp_samples function is invoked.

The process examines the neighboring inter predicted blocks and estimates a local warp transformation based on the motion vectors.

The process produces a variable NumSamples containing the number of valid candidates found, and an array CandList containing sorted candidates.

The variables NumSamples and NumSamplesScanned are both set equal to 0.

> **Note:** NumSamplesScanned counts the number of distinct candidates found by the add sample process - even if the motion vectors are too large. NumSamples counts the number of distinct valid candidates found by the add sample process (i.e. only counting cases where the motion vector is small enough to be considered valid). As a special case, if no small motion vectors are found, then the process returns the first large motion vector found (by setting NumSamples to 1).

The variable w4 specifying the width of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_Wide[MiSize].

The variable h4 specifying the height of the block in 4x4 luma samples is set equal to Num_4x4_Blocks_High[MiSize].

The process is specified as:

```
doTopLeft = 1
doTopRight = 1
if ( AvailU ) {
  srcSize = MiSizes[ MiRow - 1 ][ MiCol ]
  srcW = Num_4x4_Blocks_Wide[ srcSize ]
  if ( w4 <= srcW ) {
    colOffset = -(MiCol & (srcW - 1))
    if ( colOffset < 0 )
      doTopLeft = 0
    if ( colOffset + srcW > w4 )
      doTopRight = 0
    add_sample( -1, 0 )
  } else {
    for ( i = 0; i < Min( w4, MiCols - MiCol ); i += miStep ) {
      srcSize = MiSizes[ MiRow - 1 ][ MiCol + i ]
      srcW = Num_4x4_Blocks_Wide[ srcSize ]
      miStep = Min(w4, srcW)
      add_sample( -1, i )
    }
  }
}
if ( AvailL ) {
  srcSize = MiSizes[ MiRow ][ MiCol - 1 ]
  srcH = Num_4x4_Blocks_High[ srcSize ]
  if ( h4 <= srcH ) {
    rowOffset = -(MiRow & (srcH - 1))
    if ( rowOffset < 0 )
      doTopLeft = 0
    add_sample( 0, -1 )
  } else {
    for ( i = 0; i < Min( h4, MiRows - MiRow); i += miStep ) {
      srcSize = MiSizes[ MiRow + i ][ MiCol - 1 ]
      srcH = Num_4x4_Blocks_High[ srcSize ]
      miStep = Min(h4, srcH)
      add_sample( i, -1 )
    }
  }
}
if ( doTopLeft ) {
  add_sample( -1, -1 )
}
if ( doTopRight ) {
  if ( Max( w4, h4 ) <= 16 ) {
    add_sample( -1, w4 )
  }
}
if ( NumSamples == 0 && NumSamplesScanned > 0 )
   NumSamples = 1
```

where the call to add_sample specifies that the add sample process in section 7.10.4.2 should be invoked.

7.10.4.2. Add sample process

The inputs to this process are:

- a variable deltaRow specifying (in units of 4x4 luma samples) how far above to look for a motion vector,
- a variable deltaCol specifying (in units of 4x4 luma samples) how far left to look for a motion vector.

The output of this process is to add a new sample to the list of candidates if it is a valid candidate and has not been seen before.

If NumSamplesScanned is greater than or equal to LEAST_SQUARES_SAMPLES_MAX, this process immediately exits.

The variable mvRow is set equal to MiRow + deltaRow.

The variable mvCol is set equal to MiCol + deltaCol.

If is_inside(mvRow, mvCol) is equal to 0, then this process immediately returns.

If RefFrames[mvRow][mvCol][0] has not been written for this frame, then this process immediately returns.

If RefFrames[mvRow][mvCol][0] is not equal to RefFrame[0], then this process immediately returns.

If RefFrames[mvRow][mvCol][1] is not equal to NONE, then this process immediately returns.

The variable candSz is set equal to MiSizes[mvRow][mvCol].

The variable candW4 is set equal to Num_4x4_Blocks_Wide[candSz].

The variable candH4 is set equal to Num_4x4_Blocks_High[candSz].

The variable candRow is set equal to mvRow & ~(candH4 - 1).

The variable candCol is set equal to mvCol & ~(candW4 - 1).

The variable midY is set equal to candRow * 4 + candH4 * 2 - 1.

The variable midX is set equal to candCol * 4 + candW4 * 2 - 1.

The variable threshold is set equal to Clip3(16, 112, Max(Block_Width[MiSize], Block_Height[MiSize])).

The variable mvDiffRow is set equal to Abs(Mvs[candRow][candCol][0][0] - Mv[0][0]).

The variable mvDiffCol is set equal to Abs(Mvs[candRow][candCol][0][1] - Mv[0][1]).

The variable valid is set equal to ((mvDiffRow + mvDiffCol) <= threshold).

Note: candRow and candCol give the top-left position of the candidate block in units of 4x4 blocks. midX and midY give the central position of the candidate block in units of luma samples.

A candidate array (representing source and destination locations in units of 1/8 luma samples) is specified as:

```
cand[ 0 ] = midY * 8
cand[ 1 ] = midX * 8
cand[ 2 ] = midY * 8 + Mvs[ candRow ][ candCol ][ 0 ][ 0 ]
cand[ 3 ] = midX * 8 + Mvs[ candRow ][ candCol ][ 0 ][ 1 ]
```

The following ordered steps apply:

1. NumSamplesScanned is increased by 1.
2. If valid is equal to 0 and NumSamplesScanned is greater than 1, the process exits.
3. CandList[NumSamples][j] is set equal to cand[j] for j=0..3.
4. If valid is equal to 1, NumSamples is increased by 1.

7.11. Prediction processes

7.11.1. General

The following sections define the processes used for predicting the sample values.

These processes are triggered at points defined by function calls to predict_intra, predict_inter, predict_chroma_from_luma, and predict_palette in the residual syntax table described in section 5.11.34.

7.11.2. Intra prediction process

7.11.2.1. General

The intra prediction process is invoked for intra coded blocks to predict a part of the block corresponding to a transform block. When the transform size is smaller than the block size, this process can be invoked multiple times within a single block for the same plane, and the invocations are in raster order within the block.

This process is triggered by a call to predict_intra.

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables x and y specifying the location of the top left sample in the CurrFrame[plane] array of the current transform block,
- a variable haveLeft that is equal to 1 if there are valid samples to the left of this transform block,
- a variable haveAbove that is equal to 1 if there are valid samples above this transform block,

- a variable haveAboveRight that is equal to 1 if there are valid samples above the transform block to the right of this transform block,
- a variable haveBelowLeft that is equal to 1 if there are valid samples to the left of the transform block below this transform block,
- a variable mode specifying the type of intra prediction to apply,
- a variable log2W specifying the base 2 logarithm of the width of the region to be predicted,
- a variable log2H specifying the base 2 logarithm of the height of the region to be predicted.

The process makes use of the already reconstructed samples in the current frame CurrFrame to form a prediction for the current block.

The outputs of this process are intra predicted samples in the current frame CurrFrame.

The variable w is set equal to 1 << log2W.

The variable h is set equal to 1 << log2H.

The variable maxX is set equal to (MiCols * MI_SIZE) - 1.

The variable maxY is set equal to (MiRows * MI_SIZE) - 1.

If plane is greater than 0, then:

- maxX is set equal to ((MiCols * MI_SIZE) >> subsampling_x) - 1.
- maxY is set equal to ((MiRows * MI_SIZE) >> subsampling_y) - 1.

The array AboveRow[i] for i = 0..w + h - 1 is derived as follows:

- If haveAbove is equal to 0 and haveLeft is equal to 1, AboveRow[i] is set equal to CurrFrame[plane][y][x - 1].
- Otherwise, if haveAbove is equal to 0 and haveLeft is equal to 0, AboveRow[i] is set equal to (1 << (BitDepth - 1)) - 1.
- Otherwise, the following applies:
    - The variable aboveLimit is set equal to Min(maxX, x + (haveAboveRight ? 2 * w : w) - 1).
    - AboveRow[i] is set equal to CurrFrame[plane][y-1][Min(aboveLimit, x+i)].

The array LeftCol[i] for i = 0..w + h - 1 is derived as follows:

- If haveLeft is equal to 0 and haveAbove is equal to 1, LeftCol[i] is set equal to CurrFrame[plane][y - 1][x].

- Otherwise, if haveLeft is equal to 0 and haveAbove is equal to 0, LeftCol[i] is set equal to (1 << (BitDepth - 1)) + 1.
- Otherwise, the following applies:
    - The variable leftLimit is set equal to Min(maxY, y + (haveBelowLeft ? 2 * h : h) - 1).
    - LeftCol[i] is set equal to CurrFrame[plane][Min(leftLimit, y+i)][x-1].

The array AboveRow[i] for i = -1 is specified by:

- If haveAbove is equal to 1 and haveLeft is equal to 1, AboveRow[-1] is set equal to CurrFrame[plane][y-1][x-1].
- Otherwise if haveAbove is equal to 1, AboveRow[-1] is set equal to CurrFrame [plane][y - 1][x].
- Otherwise if haveLeft is equal to 1, AboveRow[-1] is set equal to CurrFrame [plane][y][x - 1].
- Otherwise, AboveRow[-1] is set equal to 1 << (BitDepth - 1).

The array LeftCol[i] for i = -1 is set equal to AboveRow[-1].

A 2D array named pred containing the intra predicted samples is constructed as follows:

- If plane is equal to 0 and use_filter_intra is true, the recursive intra prediction process specified in section 7.11.2.3 is invoked with w and h as inputs, and the output is assigned to pred.
- Otherwise, if is_directional_mode(mode) is true, the directional intra prediction process specified in section 7.11.2.4 is invoked with plane, x, y, haveLeft, haveAbove, mode, w, h, maxX, maxY as inputs and the output is assigned to pred.
- Otherwise if mode is equal to SMOOTH_PRED or SMOOTH_V_PRED or SMOOTH_H_PRED, the smooth intra prediction process specified in section 7.11.2.6 is invoked with mode, log2W, log2H, w, and h as inputs, and the output is assigned to pred.
- Otherwise if mode is equal to DC_PRED, the DC intra prediction process specified in section 7.11.2.5 is invoked with haveLeft, haveAbove, log2W, log2H, w, and h as inputs and the output is assigned to pred.
- Otherwise (mode is equal to PAETH_PRED), the basic intra prediction process specified in section 7.11.2.2 is invoked with mode, w, and h as inputs, and the output is assigned to pred.

The current frame is updated as follows:

- CurrFrame[plane][y + i][x + j] is set equal to pred[i][j] for i = 0..h-1 and j = 0..w-1.

7.11.2.2. Basic intra prediction process

The inputs to this process are:

- a variable w specifying the width of the region to be predicted,
- a variable h specifying the height of the region to be predicted.

The output of this process is a 2D array named pred containing the intra predicted samples.

The process generates filtered samples from the samples in LeftCol and AboveRow as follows:

- The following ordered steps apply for i = 0..h-1, for j = 0..w-1:
    1. The variable base is set equal to AboveRow[j] + LeftCol[i] - AboveRow[-1].
    2. The variable pLeft is set equal to Abs(base - LeftCol[i]).
    3. The variable pTop is set equal to Abs(base - AboveRow[j]).
    4. The variable pTopLeft is set equal to Abs(base - AboveRow[-1]).
    5. If pLeft <= pTop and pLeft <= pTopLeft, pred[i][j] is set equal to LeftCol[i].
    6. Otherwise, if pTop <= pTopLeft, pred[i][j] is set equal to AboveRow[j].
    7. Otherwise, pred[i][j] is set equal to AboveRow[-1].

The output of the process is the array pred.

7.11.2.3. Recursive intra prediction process

The inputs to this process are:

- a variable w specifying the width of the region to be predicted,
- a variable h specifying the height of the region to be predicted.

The output of this process is a 2D array named pred containing the intra predicted samples.

For each block of 4x2 samples, this process first prepares an array p of 7 neighboring samples, and then produces the output block by filtering this array.

The variable w4 is set equal to w >> 2.

The variable h2 is set equal to h >> 1.

The following steps apply for i2 = 0..h2-1, for j4 = 0..w4-1:

- The array p is derived as follows for i = 0..6:
    - If i is less than 5, p[i] is derived as follows:
        - If i2 is equal to 0, p[i] is set equal to AboveRow[(j4 << 2) + i - 1].

        - Otherwise, if j4 is equal to 0 and i is equal to 0, p[i] is set equal to LeftCol[(i2 << 1) - 1].
        - Otherwise, p[i] is set equal to pred[(i2 << 1) - 1][(j4 << 2) + i - 1].
    - Otherwise (i is greater than or equal to 5), p[i] is derived as follows:
        - If j4 is equal to 0, p[i] is set equal to LeftCol[(i2 << 1) + i - 5].
        - Otherwise (j4 is not equal to 0), p[i] is set equal to pred[(i2 << 1) + i - 5][(j4 << 2) - 1].
- The following steps apply for i1 = 0..1, j1 = 0..3:
    - The variable pr is set equal to 0.
    - The variable pr is incremented by Intra_Filter_Taps[filter_intra_mode][(i1 << 2) + j1][i] * p[i] for i = 0..6.
    - pred[(i2 << 1) + i1][(j4 << 2) + j1] is set equal to Clip1(Round2Signed(pr, INTRA_FILTER_SCALE_BITS)).

The output of the process is the array pred.

7.11.2.4. Directional intra prediction process

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables x and y specifying the location of the top left sample in the CurrFrame[plane] array of the current transform block,
- a variable haveLeft that is equal to 1 if there are valid samples to the left of this transform block,
- a variable haveAbove that is equal to 1 if there are valid samples above this transform block,
- a variable mode specifying the type of intra prediction to apply,
- a variable w specifying the width of the region to be predicted,
- a variable h specifying the height of the region to be predicted,
- a variable maxX specifying the largest valid x coordinate for the current plane,
- a variable maxY specifying the largest valid y coordinate for the current plane.

The output of this process is a 2D array named pred containing the intra predicted samples.

The process uses a directional filter to generate filtered samples from the samples in LeftCol and AboveRow.

The following ordered steps apply:

1. The variable angleDelta is derived as follows:
    - If plane is equal to 0, angleDelta is set equal to AngleDeltaY.
    - Otherwise (plane is not equal to 0), angleDelta is set equal to AngleDeltaUV.
2. The variable pAngle is set equal to (Mode_To_Angle[mode] + angleDelta * ANGLE_STEP).
3. The variables upsampleAbove and upsampleLeft are set equal to 0.
4. If enable_intra_edge_filter is equal to 1, the following applies:
    - If pAngle is not equal to 90 and pAngle is not equal to 180, the following applies:
        - If (pAngle > 90) and (pAngle < 180) and (w + h) >= 24), the filter corner process specified in section 7.11.2.7 is invoked and the output assigned to both LeftCol[-1] and AboveRow[-1].
        - The intra filter type process specified in section 7.11.2.8 is invoked with the input variable plane and the output assigned to filterType.
        - If haveAbove is equal to 1, the following steps apply:
            - The intra edge filter strength selection process specified in section 7.11.2.9 is invoked with w, h, filterType, and pAngle - 90 as inputs, and the output assigned to the variable strength.
            - The variable numPx is set equal to Min(w, (maxX - x + 1)) + (pAngle < 90 ? h : 0) + 1.
            - The intra edge filter process specified in section 7.11.2.12 is invoked with the parameters numPx, strength, and 0 as inputs.
        - If haveLeft is equal to 1, the following steps apply:
            - The intra edge filter strength selection process specified in section 7.11.2.9 is invoked with w, h, filterType, and pAngle - 180 as inputs, and the output assigned to the variable strength.
            - The variable numPx is set equal to Min(h, (maxY - y + 1)) + (pAngle > 180 ? w : 0) + 1.
            - The intra edge filter process specified in section 7.11.2.12 is invoked with the parameters numPx, strength, and 1 as inputs.
    - The intra edge upsample selection process specified in section 7.11.2.10 is invoked with w, h, filterType, and pAngle - 90 as inputs, and the output assigned to the variable upsampleAbove.
    - The variable numPx is set equal to (w + (pAngle < 90 ? h : 0)).

- If upsampleAbove is equal to 1, the intra edge upsample process specified in section 7.11.2.11 is invoked with the parameters numPx and 0 as inputs.
- The intra edge upsample selection process specified in section 7.11.2.10 is invoked with w, h, filterType, and pAngle - 180 as inputs, and the output assigned to the variable upsampleLeft.
- The variable numPx is set equal to (h + (pAngle > 180 ? w : 0)).
- If upsampleLeft is equal to 1, the intra edge upsample process specified in section 7.11.2.11 is invoked with the parameters numPx and 1 as inputs.

5. The variable dx is derived as follows:
   - If pAngle is less than 90, dx is set equal to Dr_Intra_Derivative[pAngle].
   - Otherwise, if pAngle is greater than 90 and less than 180, dx is set equal to Dr_Intra_Derivative[180 - pAngle].
   - Otherwise, dx is undefined.
6. The variable dy is derived as follows:
   - If pAngle is greater than 90 and less than 180, dy is set equal to Dr_Intra_Derivative[pAngle - 90].
   - Otherwise, if pAngle is greater than 180, dy is set equal to Dr_Intra_Derivative[270 - pAngle].
   - Otherwise, dy is undefined.
7. If pAngle is less than 90, the following steps apply for i = 0..h-1, for j = 0..w-1:
   - The variable idx is set equal to (i + 1) * dx.
   - The variable base is set equal to (idx >> (6 - upsampleAbove)) + (j << upsampleAbove).
   - The variable shift is set equal to ((idx << upsampleAbove) >> 1) & 0x1F.
   - The variable maxBaseX is set equal to (w + h - 1) << upsampleAbove.
   - If base is less than maxBaseX, pred[i][j] is set equal to Round2(AboveRow[base] * (32 - shift) + AboveRow[base + 1] * shift, 5).
   - Otherwise (base is greater than or equal to maxBaseX), pred[i][j] is set equal to AboveRow[maxBaseX].
8. Otherwise, if pAngle is greater than 90 and pAngle is less than 180, the following steps apply for i = 0..h-1, for j = 0..w-1:
   - The variable idx is set equal to (j << 6) - (i + 1) * dx.

- The variable base is set equal to idx >> (6 - upsampleAbove).
- If base is greater than or equal to -(1 << upsampleAbove), the following steps apply:
  - The variable shift is set equal to ((idx << upsampleAbove) >> 1) & 0x1F.
  - pred[i][j] is set equal to Round2(AboveRow[base] * (32 - shift) + AboveRow[base + 1] * shift, 5).
- Otherwise (base is less than -(1 << upsampleAbove), the following steps apply:
  - The variable idx is set equal to (i << 6) - (j + 1) * dy.
  - The variable base is set equal to idx >> (6 - upsampleLeft).
  - The variable shift is set equal to ((idx << upsampleLeft) >> 1) & 0x1F.
  - pred[i][j] is set equal to Round2(LeftCol[base] * (32 - shift) + LeftCol[base + 1] * shift, 5).

9. Otherwise, if pAngle is greater than 180, the following steps apply for i = 0..h-1, for j = 0..w-1:
   - The variable idx is set equal to (j + 1) * dy.
   - The variable base is set equal to (idx >> (6 - upsampleLeft)) + (i << upsampleLeft).
   - The variable shift is set equal to ((idx << upsampleLeft) >> 1) & 0x1F.
   - pred[i][j] is set equal to Round2(LeftCol[base] * (32 - shift) + LeftCol[base + 1] * shift, 5).
10. Otherwise, if pAngle is equal to 90, pred[i][j] is set equal to AboveRow[j] with j = 0..w-1 and i = 0..h-1 (each row of the block is filled with a copy of AboveRow).
11. Otherwise, if pAngle is equal to 180, pred[i][j] is set equal to LeftCol[i] with j = 0..w-1 and i = 0..h-1 (each column of the block is filled with a copy of LeftCol).

The output of the process is the array pred.

7.11.2.5. DC intra prediction process

The inputs to this process are:

- a variable haveLeft that is equal to 1 if there are valid samples to the left of this transform block,
- a variable haveAbove that is equal to 1 if there are valid samples above this transform block,
- a variable log2W specifying the base 2 logarithm of the width of the region to be predicted,
- a variable log2H specifying the base 2 logarithm of the height of the region to be predicted,

- a variable w specifying the width of the region to be predicted,
- a variable h specifying the height of the region to be predicted.

The output of this process is a 2D array named pred containing the intra predicted samples.

The process averages the available edge samples in LeftCol and AboveRow to generate the prediction as follows:

- If haveLeft is equal to 1 and haveAbove is equal to 1, pred[i][j] is set equal to avg with i = 0..h-1 and j = 0..w-1. The variable avg (the average of the samples in union of AboveRow and LeftCol) is specified as follows:

```
sum = 0
for ( k = 0; k < h; k++ )
    sum += LeftCol[ k ]
for ( k = 0; k < w; k++ )
    sum += AboveRow[ k ]

sum += ( w + h ) >> 1
avg = sum / ( w + h )
```

Note: The reference code shows how the division by (w+h) can be implemented with multiplication and shift operations.

- Otherwise if haveLeft is equal to 1 and haveAbove is equal to 0, pred[i][j] is set equal to leftAvg with i = 0..h-1 and j = 0..w-1. The variable leftAvg is specified as follows:

```
sum = 0
for ( k = 0; k < h; k++ ) {
    sum += LeftCol[ k ]
}
leftAvg = Clip1( ( sum + ( h >> 1 ) ) >> log2H )
```

- Otherwise if haveLeft is equal to 0 and haveAbove is equal to 1, pred[i][j] is set equal to aboveAvg with i = 0..h-1 and j = 0..w-1. The variable aboveAvg is specified as follows:

```
sum = 0
for ( k = 0; k < w; k++ ) {
    sum += AboveRow[ k ]
}
aboveAvg = Clip1( ( sum + ( w >> 1 ) ) >> log2W )
```

- Otherwise (haveLeft is equal to 0 and haveAbove is equal to 0), pred[i][j] is set equal to 1 << (BitDepth - 1) with i = 0..h-1 and j = 0..w-1.

The output of the process is the array pred.

7.11.2.6. Smooth intra prediction process

The inputs to this process are:

- a variable mode specifying the type of intra prediction to apply,
- a variable log2W specifying the base 2 logarithm of the width of the region to be predicted,
- a variable log2H specifying the base 2 logarithm of the height of the region to be predicted,
- a variable w specifying the width of the region to be predicted,
- a variable h specifying the height of the region to be predicted.

The output of this process is a 2D array named pred containing the intra predicted samples.

The process uses linear interpolation to generate filtered samples from the samples in LeftCol and AboveRow as follows:

- If mode is equal to SMOOTH_PRED, the following ordered steps apply for i = 0..h-1, for j = 0..w-1:
    1. The array smWeightsX is set dependent on the value of log2W according to the following table:

log2W	smWeightsX
2	Sm_Weights_Tx_4x4
3	Sm_Weights_Tx_8x8
4	Sm_Weights_Tx_16x16
5	Sm_Weights_Tx_32x32
6	Sm_Weights_Tx_64x64

    2. The array smWeightsY is set dependent on the value of log2H according to the following table:

log2H	smWeightsY
2	Sm_Weights_Tx_4x4
3	Sm_Weights_Tx_8x8
4	Sm_Weights_Tx_16x16
5	Sm_Weights_Tx_32x32
6	Sm_Weights_Tx_64x64

    3. The variable smoothPred is set as follows:

```
smoothPred =   smWeightsY[ i ] * AboveRow[ j ] +
             ( 256 - smWeightsY[ i ] ) * LeftCol[ h - 1 ] +
               smWeightsX[ j ] * LeftCol[ i ] +
             ( 256 - smWeightsX[ j ] ) * AboveRow[ w - 1 ]
```

4. pred[i][j] is set equal to Round2(smoothPred, 9).

- Otherwise if mode is equal to SMOOTH_V_PRED, the following ordered steps apply for i = 0..h-1, for j = 0..w-1:

1. The array smWeights is set dependent on the value of log2H according to the following table:

log2H	smWeights
2	Sm_Weights_Tx_4x4
3	Sm_Weights_Tx_8x8
4	Sm_Weights_Tx_16x16
5	Sm_Weights_Tx_32x32
6	Sm_Weights_Tx_64x64

2. The variable smoothPred is set as follows:

```
smoothPred =   smWeights[ i ] * AboveRow[ j ] +
             ( 256 - smWeights[ i ] ) * LeftCol[ h - 1 ]
```

3. pred[i][j] is set equal to Round2(smoothPred, 8).

- Otherwise (mode is equal to SMOOTH_H_PRED), the following ordered steps apply for i = 0..h-1, for j = 0..w-1:

1. The array smWeights is set dependent on the value of log2W according to the following table:

log2W	smWeights
2	Sm_Weights_Tx_4x4
3	Sm_Weights_Tx_8x8
4	Sm_Weights_Tx_16x16
5	Sm_Weights_Tx_32x32
6	Sm_Weights_Tx_64x64

2. The variable smoothPred is set as follows:

```
smoothPred =   smWeights[ j ] * LeftCol[ i ] +
             ( 256 - smWeights[ j ] ) * AboveRow[ w - 1 ]
```

3. pred[i][j] is set equal to Round2(smoothPred, 8).

The output of the process is the array pred.

7.11.2.7. Filter corner process

This process uses a three tap filter to compute the value to be used for the top-left corner.

The variable s is set equal to LeftCol[0] * 5 + AboveRow[-1] * 6 + AboveRow[0] * 5.

The output of this process is Round2(s, 4).

7.11.2.8. Intra filter type process

The input to this process is a variable plane specifying the color plane being processed.

The output of this process is a variable filterType that is set to 1 if either the block above or to the left uses a smooth prediction mode.

The process is specified as follows:

```
get_filter_type( plane ) {
  aboveSmooth = 0
  leftSmooth = 0
  if ( ( plane == 0 ) ? AvailU : AvailUChroma ) {
    r = MiRow - 1
    c = MiCol
    if ( plane > 0 ) {
        if ( subsampling_x && !( MiCol & 1 ) )
            c++
        if ( subsampling_y && ( MiRow & 1 ) )
            r--
    }
    aboveSmooth = is_smooth( r, c, plane )
  }
  if ( ( plane == 0 ) ? AvailL : AvailLChroma ) {
    r = MiRow
    c = MiCol - 1
    if ( plane > 0 ) {
        if ( subsampling_x && ( MiCol & 1 ) )
            c--
        if ( subsampling_y && !( MiRow & 1 ) )
            r++
    }
    leftSmooth = is_smooth( r, c, plane )
  }
  return aboveSmooth || leftSmooth
}
```

where the function is_smooth indicates if a prediction mode is one of the smooth intra modes and is specified as:

```
is_smooth( row, col, plane ) {
  if ( plane == 0 ) {
    mode = YModes[ row ][ col ]
  } else {
    if ( RefFrames[ row ][ col ][ 0 ] > INTRA_FRAME )
      return 0
    mode = UVModes[ row ][ col ]
  }
  return (mode == SMOOTH_PRED || mode == SMOOTH_V_PRED || mode == SMOOTH_H_PRED)
}
```

7.11.2.9. Intra edge filter strength selection process

The inputs to this process are:

- a variable w containing the width of the transform in samples,
- a variable h containing the height of the transform in samples,

- a variable filterType that is 0 or 1 that controls the strength of filtering,
- a variable delta containing an angle difference in degrees.

The output is an intra edge filter strength from 0 to 3 inclusive.

The variable d is set equal to Abs(delta).

The variable blkWh (containing the sum of the dimensions) is set equal to w + h.

The output variable strength is specified as follows:

```
strength = 0
if ( filterType == 0 ) {
    if ( blkWh <= 8 ) {
        if ( d >= 56 ) strength = 1
    } else if ( blkWh <= 12 ) {
        if ( d >= 40 ) strength = 1
    } else if ( blkWh <= 16 ) {
        if ( d >= 40 ) strength = 1
    } else if ( blkWh <= 24 ) {
        if ( d >= 8 ) strength = 1
        if ( d >= 16 ) strength = 2
        if ( d >= 32 ) strength = 3
    } else if ( blkWh <= 32 ) {
        strength = 1
        if ( d >= 4 ) strength = 2
        if ( d >= 32 ) strength = 3
    } else {
        strength = 3
    }
} else {
    if ( blkWh <= 8 ) {
        if ( d >= 40 ) strength = 1
        if ( d >= 64 ) strength = 2
    } else if ( blkWh <= 16 ) {
        if ( d >= 20 ) strength = 1
        if ( d >= 48 ) strength = 2
    } else if ( blkWh <= 24 ) {
        if ( d >= 4 ) strength = 3
    } else {
        strength = 3
    }
}
```

7.11.2.10. Intra edge upsample selection process

The inputs to this process are:

- a variable w containing the width of the transform in samples,

- a variable h containing the height of the transform in samples,
- a variable filterType that is 0 or 1 that controls the strength of filtering,
- a variable delta containing an angle difference in degrees.

The output is a flag useUpsample that is true if upsampling should be applied to the edge.

The variable d is set equal to Abs(delta).

The variable blkWh (containing the sum of the dimensions) is set equal to w + h.

The output variable useUpsample is specified as follows:

```
if ( d <= 0 || d >= 40 ) {
    useUpsample = 0
} else if ( filterType == 0 ) {
    useUpsample = (blkWh <= 16)
} else {
    useUpsample = (blkWh <= 8)
}
```

7.11.2.11. Intra edge upsample process

The inputs to this process are:

- a variable numPx specifying the number of samples to filter,
- a variable dir containing 0 when filtering the above samples, and 1 when filtering the left samples.

The output of this process are upsampled samples in the AboveRow and LeftCol arrays.

The variable buf is set depending on dir:

- If dir is equal to 0, buf is set equal to a reference to AboveRow.
- Otherwise (dir is equal to 1), buf is set equal to a reference to LeftCol.

> **Note:** buf is a reference to either AboveRow or LeftCol. “reference” indicates that modifying values in buf modifies values in the original array.

When the process starts, entries -1 to numPx-1 are valid in buf and contain the original values. When the process completes, entries -2 to 2*numPx-2 are valid in buf and contain the upsampled values.

An array dup of length numPx+3 is generated by extending buf by one sample at the start and end as follows:

```
dup[ 0 ] = buf[ -1 ]
for ( i = -1; i < numPx; i++ ) {
    dup[ i + 2 ] = buf[ i ]
}
dup[ numPx + 2 ] = buf[ numPx - 1 ]
```

The upsampling process (modifying values in buf) is specified as follows:

```
buf[-2] = dup[0]
for ( i = 0; i < numPx; i++ ) {
    s = -dup[i] + (9 * dup[i + 1]) + (9 * dup[i + 2]) - dup[i + 3]
    s = Clip1( Round2(s, 4) )
    buf[ 2 * i - 1 ] = s
    buf[ 2 * i ] = dup[i + 2]
}
```

7.11.2.12. Intra edge filter process

The inputs to this process are:

- a size sz (sz will always be less than or equal to 129),
- a filter strength strength between 0 and 3 inclusive,
- an edge direction left (when equal to 1, it specifies a vertical edge; when equal to 0, it specifies a horizontal edge.

The process filters the LeftCol (if left is equal to 1) or AboveRow (if left is equal to 0) arrays.

If strength is equal to 0, the process returns without doing anything.

The array edge is derived by setting edge[i] equal to (left ? LeftCol[i - 1] : AboveRow[i - 1]) for i = 0..sz-1.

Otherwise (strength is not equal to 0), the following ordered steps apply for i = 1..sz-1:

1. The variable s is set equal to 0.
2. The following steps now apply for j = 0..INTRA_EDGE_TAPS-1.

   a. The variable k is set equal to Clip3(0, sz - 1, i - 2 + j).

   b. The variable s is incremented by Intra_Edge_Kernel[strength - 1][j] * edge[k].
3. If left is equal to 1, LeftCol[i - 1] is set equal to (s + 8) >> 4.
4. If left is equal to 0, AboveRow[i - 1] is set equal to (s + 8) >> 4.

The array Intra_Edge_Kernel is specified as follows:

```
Intra_Edge_Kernel[INTRA_EDGE_KERNELS][INTRA_EDGE_TAPS] = {
  { 0, 4, 8, 4, 0 },
  { 0, 5, 6, 5, 0 },
  { 2, 4, 4, 4, 2 }
}
```

7.11.3. Inter prediction process

7.11.3.1. General

The inter prediction process is invoked for inter coded blocks and interintra blocks. The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables x and y specifying the location of the top left sample in the CurrFrame[plane] array of the region to be predicted,
- variables w and h specifying the width and height of the region to be predicted,
- variables candRow and candCol specifying the location (in units of 4x4 blocks) of the motion vector information to be used.

The outputs of this process are predicted samples in the current frame CurrFrame.

This process is triggered by a function call to predict_inter.

The variable isCompound is set equal to RefFrames[candRow][candCol][1] > INTRA_FRAME.

The prediction arrays are formed by the following ordered steps:

1. The rounding variables derivation process specified in section 7.11.3.2 is invoked with the variable isCompound as input.
2. If plane is equal to 0 and motion_mode is equal to LOCALWARP, the warp estimation process in section 7.11.3.8 is invoked.
3. If plane is equal to 0 and motion_mode is equal to LOCALWARP and LocalValid is equal to 1, the setup shear process specified in section 7.11.3.6 is invoked with LocalWarpParams as input, and the output warpValid is assigned to LocalValid (the other outputs are discarded).
4. The variable refList is set equal to 0.
5. The variable refFrame is set equal to RefFrames[candRow][candCol][refList].

6. If (YMode == GLOBALMV || YMode == GLOBAL_GLOBALMV) and GmType[refFrame] > TRANSLATION, the setup shear process specified in section 7.11.3.6 is invoked with gm_params[refFrame] as input, and the output warpValid is assigned to globalValid (the other outputs are discarded).

7. The variable useWarp (a value of 1 indicates local warping, 2 indicates global warping) is derived as follows:

    - If w < 8 or h < 8, useWarp is set equal to 0.
    - Otherwise, if force_integer_mv is equal to 1, useWarp is set equal to 0.
    - Otherwise, if motion_mode is equal to LOCALWARP and LocalValid is equal to 1, useWarp is set equal to 1.
    - Otherwise, if all of the following are true, useWarp is set equal to 2.
        - (YMode == GLOBALMV || YMode == GLOBAL_GLOBALMV).
        - GmType[refFrame] > TRANSLATION.
        - is_scaled(refFrame) is equal to 0.
        - globalValid is equal to 1.
    - Otherwise, useWarp is set equal to 0.

8. The motion vector array mv is set equal to Mvs[candRow][candCol][refList].

9. The variable refIdx specifying which reference frame is being used is set as follows:

    - If use_intrabc is equal to 0, refIdx is set equal to ref_frame_idx[refFrame - LAST_FRAME].
    - Otherwise (use_intrabc is equal to 1), refIdx is set equal to -1 and RefFrameWidth[-1] is set equal to FrameWidth, RefFrameHeight[-1] is set equal to FrameHeight, and RefUpscaledWidth[-1] is set equal to UpscaledWidth. (These values ensure that the motion vector scaling has no effect.)

10. The motion vector scaling process in section 7.11.3.3 is invoked with plane, refIdx, x, y, mv as inputs and the output being the initial location startX, startY, and the step sizes stepX, stepY.

11. If use_intrabc is equal to 1, RefFrameWidth[-1] is set equal to MiCols * MI_SIZE, RefFrameHeight[-1] is set equal to MiRows * MI_SIZE, and RefUpscaledWidth[-1] is set equal to MiCols * MI_SIZE. (These values are needed to avoid intrabc prediction being cropped to the frame boundaries.)

12. If useWarp is not equal to 0, the block warp process in section 7.11.3.5 is invoked with useWarp, plane, refList, x, y, i8, j8, w, h as inputs and the output is merged into the 2D array preds[refList] for i8 = 0..((h-1) >> 3) and for j8 = 0..((w-1) >> 3). (Each invocation fills in a block of output of size w by h at x offset j8 * 8 and y offset i8 * 8.)

13. If useWarp is equal to 0, the block inter prediction process in section 7.11.3.4 is invoked with plane, refIdx, startX, startY, stepX, stepY, w, h, candRow, candCol as inputs and the output is assigned to the 2D array preds[refList].

14. If isCompound is equal to 1, then the variable refList is set equal to 1 and steps 5 to 13 are repeated to form the prediction for the second reference.

An array named Mask is prepared as follows:

- If compound_type is equal to COMPOUND_WEDGE and plane is equal to 0, the wedge mask process in section 7.11.3.11 is invoked with w, h as inputs.
- Otherwise if compound_type is equal to COMPOUND_INTRA, the intra mode variant mask process in section 7.11.3.13 is invoked with w, h as inputs.
- Otherwise if compound_type is equal to COMPOUND_DIFFWTD and plane is equal to 0, the difference weight mask process in section 7.11.3.12 is invoked with preds, w, h as inputs.
- Otherwise, no mask array is needed.

If compound_type is equal to COMPOUND_DISTANCE, the distance weights process in section 7.11.3.15 is invoked with candRow and candCol as inputs.

The inter predicted samples are then derived as follows:

- If isCompound is equal to 0 and IsInterIntra is equal to 0, CurrFrame[plane][y + i][x + j] is set equal to Clip1(preds[0][i][j]) for i = 0..h-1 and j = 0..w-1.
- Otherwise if compound_type is equal to COMPOUND_AVERAGE, CurrFrame[plane][y + i][x + j] is set equal to Clip1(Round2(preds[0][i][j] + preds[1][i][j], 1 + InterPostRound)) for i = 0..h-1 and j = 0..w-1.
- Otherwise if compound_type is equal to COMPOUND_DISTANCE, CurrFrame[plane][y + i][x + j] is set equal to Clip1(Round2(FwdWeight * preds[0][i][j] + BckWeight * preds[1][i][j], 4 + InterPostRound)) for i = 0..h-1 and j = 0..w-1.
- Otherwise, the mask blend process in section 7.11.3.14 is invoked with preds, plane, x, y, w, h as inputs.

If motion_mode is equal to OBMC, the overlapped motion compensation in section 7.11.3.9 is invoked with plane, w, h as inputs.

7.11.3.2. Rounding variables derivation process

The input to this process is a variable isCompound.

The rounding variables InterRound0, InterRound1, and InterPostRound are derived as follows:

- InterRound0 (representing the amount to round by after horizontal filtering) is set equal to 3.
- InterRound1 (representing the amount to round by after vertical filtering) is set equal to (isCompound ? 7 : 11).
- If BitDepth is equal to 12, InterRound0 is set equal to InterRound0 + 2.
- If BitDepth is equal to 12 and isCompound is equal to 0, InterRound1 is set equal to InterRound1 - 2.

- InterPostRound (representing the amount to round by at the end of the prediction process) is set equal to 2 * FILTER_BITS - (InterRound0 + InterRound1).

Note: The rounding is chosen to ensure that the output of the horizontal filter always fits within 16 bits.

7.11.3.3. Motion vector scaling process

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- a variable refIdx specifying which reference frame is being used,
- variables x and y specifying the location of the top left sample in the CurrFrame[plane] array of the region to be predicted,
- a variable mv specifying the clamped motion vector (in units of 1/8 th of a luma sample, i.e. with 3 fractional bits).

The outputs of this process are the variables startX and startY giving the reference block location in units of 1/1024 th of a sample, and variables xStep and yStep giving the step size in units of 1/1024 th of a sample.

This process is responsible for computing the sampling locations in the reference frame based on the motion vector. The sampling locations are also adjusted to compensate for any difference in the size of the reference frame compared to the current frame.

Note: When intra block copy is being used, refIdx will be equal to -1 to signal prediction from the frame currently being decoded. The arrays RefFrameWidth, RefFrameHeight, and RefUpscaledWidth include values at index -1 giving the dimensions of the current frame.

It is a requirement of bitstream conformance that all the following conditions are satisfied:

- 2 * FrameWidth >= RefUpscaledWidth[refIdx]
- 2 * FrameHeight >= RefFrameHeight[refIdx]
- FrameWidth <= 16 * RefUpscaledWidth[refIdx]
- FrameHeight <= 16 * RefFrameHeight[refIdx]

A variable xScale is set equal to ((RefUpscaledWidth[refIdx] << REF_SCALE_SHIFT) + (FrameWidth / 2)) / FrameWidth.

A variable yScale is set equal to ((RefFrameHeight[refIdx] << REF_SCALE_SHIFT) + (FrameHeight / 2)) / FrameHeight.

(xScale and yScale specify the size of the reference frame relative to the current frame in units where (1 << 14) is equivalent to both frames having the same size.)

The variables subX and subY are set equal to the subsampling for the current plane as follows:

- If plane is equal to 0, subX is set equal to 0 and subY is set equal to 0.
- Otherwise, subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The variable halfSample (representing half the size of a sample in units of 1/16 th of a sample) is set equal to (1 << (SUBPEL_BITS - 1)).

The variable origX is set equal to ((x << SUBPEL_BITS) + ((2 * mv[1]) >> subX) + halfSample).

The variable origY is set equal to ((y << SUBPEL_BITS) + ((2 * mv[0]) >> subY) + halfSample).

(origX and origY specify the location of the centre of the sample at the top-left corner of the reference block in the current frame’s coordinate system in units of 1/16 th of a sample, i.e. with SUBPEL_BITS=4 fractional bits.)

The variable baseX is set equal to (origX * xScale - (halfSample << REF_SCALE_SHIFT)).

The variable baseY is set equal to (origY * yScale - (halfSample << REF_SCALE_SHIFT)).

(baseX and baseY specify the location of the top-left corner of the block in the reference frame in the reference frame’s coordinate system with 18 fractional bits.)

The variable off (containing a rounding offset for the filter tap selection) is set equal to ((1 << (SCALE_SUBPEL_BITS - SUBPEL_BITS)) / 2).

The output variable startX is set equal to (Round2Signed(baseX, REF_SCALE_SHIFT + SUBPEL_BITS - SCALE_SUBPEL_BITS) + off).

The output variable startY is set equal to (Round2Signed(baseY, REF_SCALE_SHIFT + SUBPEL_BITS - SCALE_SUBPEL_BITS) + off).

(startX and startY specify the location of the top-left corner of the block in the reference frame in the reference frame’s coordinate system with SCALE_SUBPEL_BITS=10 fractional bits.)

The output variable stepX is set equal to Round2Signed(xScale, REF_SCALE_SHIFT - SCALE_SUBPEL_BITS).

The output variable stepY is set equal to Round2Signed(yScale, REF_SCALE_SHIFT - SCALE_SUBPEL_BITS).

(stepX and stepY are the size of one current frame sample in the reference frame’s coordinate system with 10 fractional bits.)

7.11.3.4. Block inter prediction process

The inputs to this process are:

- a variable plane,
- a variable refIdx specifying which reference frame is being used (or -1 for intra block copy),
- variables x and y giving the block location with in units of 1/1024 th of a sample,
- variables xStep and yStep giving the step size in units of 1/1024 th of a sample,
- variables w and h giving the width and height of the block in units of samples,
- variables candRow and candCol specifying the location (in units of 4x4 blocks) of the motion vector information to be used.

The output from this process is the 2D array named pred containing inter predicted samples.

A variable ref specifying the reference frame contents is set as follows:

- If refIdx is equal to -1, ref is set equal to CurrFrame.
- Otherwise (refIdx is greater than or equal to 0), ref is set equal to FrameStore[refIdx].

The variables subX and subY are set equal to the subsampling for the current plane as follows:

- If plane is equal to 0, subX is set equal to 0 and subY is set equal to 0.
- Otherwise, subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The variable lastX is set equal to ((RefUpscaledWidth[refIdx] + subX) >> subX) - 1.

The variable lastY is set equal to ((RefFrameHeight[refIdx] + subY) >> subY) - 1.

(lastX and lastY specify the coordinates of the bottom right sample of the reference plane.)

The variable intermediateHeight specifying the height required for the intermediate array is set equal to (((h - 1) * yStep + (1 << SCALE_SUBPEL_BITS) - 1) >> SCALE_SUBPEL_BITS) + 8.

The sub-sample interpolation is effected via two one-dimensional convolutions. First a horizontal filter is used to build up a temporary array, and then this array is vertically filtered to obtain the final prediction. The fractional parts of the motion vectors determine the filtering process. If the fractional part is zero, then the filtering is equivalent to a straight sample copy.

The filtering is applied as follows:

- The array intermediate is specified as follows:

```
interpFilter = InterpFilters[ candRow ][ candCol ][ 1 ]
if ( w <= 4 ) {
    if ( interpFilter == EIGHTTAP || interpFilter == EIGHTTAP_SHARP ) {
        interpFilter = 4
    } else if ( interpFilter == EIGHTTAP_SMOOTH ) {
        interpFilter = 5
    }
}
for ( r = 0; r < intermediateHeight; r++ ) {
    for ( c = 0; c < w; c++ ) {
        s = 0
        p = x + xStep * c
        for ( t = 0; t < 8; t++ )
            s += Subpel_Filters[ interpFilter ][ (p >> 6) & SUBPEL_MASK ][ t ] *
              ref[ plane ] [ Clip3( 0, lastY, (y >> 10) + r - 3 ) ]
                           [ Clip3( 0, lastX, (p >> 10) + t - 3 ) ]
        intermediate[ r ][ c ] = Round2(s, InterRound0)
    }
}
```

- The array pred is specified as follows:

```
interpFilter = InterpFilters[ candRow ][ candCol ][ 0 ]
if ( h <= 4 ) {
    if ( interpFilter == EIGHTTAP || interpFilter == EIGHTTAP_SHARP ) {
        interpFilter = 4
    } else if ( interpFilter == EIGHTTAP_SMOOTH ) {
        interpFilter = 5
    }
}
for ( r = 0; r < h; r++ ) {
    for ( c = 0; c < w; c++ ) {
        s = 0
        p = (y & 1023) + yStep * r
        for ( t = 0; t < 8; t++ )
            s += Subpel_Filters[ interpFilter ][ (p >> 6) & SUBPEL_MASK ][ t ] *
              intermediate[ (p >> 10) + t ][ c ]
        pred[ r ][ c ] = Round2(s, InterRound1)
    }
}
```

where the constant array Subpel_Filters is specified as:

```
Subpel_Filters[ 6 ][ 16 ][ 8 ] = {
  {
    { 0, 0, 0, 128, 0, 0, 0, 0 },
    { 0, 2, -6, 126, 8, -2, 0, 0 },
    { 0, 2, -10, 122, 18, -4, 0, 0 },
    { 0, 2, -12, 116, 28, -8, 2, 0 },
    { 0, 2, -14, 110, 38, -10, 2, 0 },
    { 0, 2, -14, 102, 48, -12, 2, 0 },
    { 0, 2, -16, 94, 58, -12, 2, 0 },
    { 0, 2, -14, 84, 66, -12, 2, 0 },
    { 0, 2, -14, 76, 76, -14, 2, 0 },
    { 0, 2, -12, 66, 84, -14, 2, 0 },
    { 0, 2, -12, 58, 94, -16, 2, 0 },
    { 0, 2, -12, 48, 102, -14, 2, 0 },
    { 0, 2, -10, 38, 110, -14, 2, 0 },
    { 0, 2, -8, 28, 116, -12, 2, 0 },
    { 0, 0, -4, 18, 122, -10, 2, 0 },
    { 0, 0, -2, 8, 126, -6, 2, 0 }
  },
  {
    { 0, 0, 0, 128, 0, 0, 0, 0 },
    { 0, 2, 28, 62, 34, 2, 0, 0 },
    { 0, 0, 26, 62, 36, 4, 0, 0 },
    { 0, 0, 22, 62, 40, 4, 0, 0 },
    { 0, 0, 20, 60, 42, 6, 0, 0 },
    { 0, 0, 18, 58, 44, 8, 0, 0 },
    { 0, 0, 16, 56, 46, 10, 0, 0 },
    { 0, -2, 16, 54, 48, 12, 0, 0 },
    { 0, -2, 14, 52, 52, 14, -2, 0 },
    { 0, 0, 12, 48, 54, 16, -2, 0 },
    { 0, 0, 10, 46, 56, 16, 0, 0 },
    { 0, 0, 8, 44, 58, 18, 0, 0 },
    { 0, 0, 6, 42, 60, 20, 0, 0 },
    { 0, 0, 4, 40, 62, 22, 0, 0 },
    { 0, 0, 4, 36, 62, 26, 0, 0 },
    { 0, 0, 2, 34, 62, 28, 2, 0 }
  },
  {
    { 0, 0, 0, 128, 0, 0, 0, 0 },
    { -2, 2, -6, 126, 8, -2, 2, 0 },
    { -2, 6, -12, 124, 16, -6, 4, -2 },
    { -2, 8, -18, 120, 26, -10, 6, -2 },
    { -4, 10, -22, 116, 38, -14, 6, -2 },
    { -4, 10, -22, 108, 48, -18, 8, -2 },
    { -4, 10, -24, 100, 60, -20, 8, -2 },
    { -4, 10, -24, 90, 70, -22, 10, -2 },
    { -4, 12, -24, 80, 80, -24, 12, -4 },
    { -2, 10, -22, 70, 90, -24, 10, -4 },
    { -2, 8, -20, 60, 100, -24, 10, -4 },
    { -2, 8, -18, 48, 108, -22, 10, -4 },
```

```
    { -2, 6, -14, 38, 116, -22, 10, -4 },
    { -2, 6, -10, 26, 120, -18, 8, -2 },
    { -2, 4, -6, 16, 124, -12, 6, -2 },
    { 0, 2, -2, 8, 126, -6, 2, -2 }
  },
  {
    { 0, 0, 0, 128, 0, 0, 0, 0 },
    { 0, 0, 0, 120, 8, 0, 0, 0 },
    { 0, 0, 0, 112, 16, 0, 0, 0 },
    { 0, 0, 0, 104, 24, 0, 0, 0 },
    { 0, 0, 0, 96, 32, 0, 0, 0 },
    { 0, 0, 0, 88, 40, 0, 0, 0 },
    { 0, 0, 0, 80, 48, 0, 0, 0 },
    { 0, 0, 0, 72, 56, 0, 0, 0 },
    { 0, 0, 0, 64, 64, 0, 0, 0 },
    { 0, 0, 0, 56, 72, 0, 0, 0 },
    { 0, 0, 0, 48, 80, 0, 0, 0 },
    { 0, 0, 0, 40, 88, 0, 0, 0 },
    { 0, 0, 0, 32, 96, 0, 0, 0 },
    { 0, 0, 0, 24, 104, 0, 0, 0 },
    { 0, 0, 0, 16, 112, 0, 0, 0 },
    { 0, 0, 0, 8, 120, 0, 0, 0 }
  },
  {
    { 0, 0, 0, 128, 0, 0, 0, 0 },
    { 0, 0, -4, 126, 8, -2, 0, 0 },
    { 0, 0, -8, 122, 18, -4, 0, 0 },
    { 0, 0, -10, 116, 28, -6, 0, 0 },
    { 0, 0, -12, 110, 38, -8, 0, 0 },
    { 0, 0, -12, 102, 48, -10, 0, 0 },
    { 0, 0, -14, 94, 58, -10, 0, 0 },
    { 0, 0, -12, 84, 66, -10, 0, 0 },
    { 0, 0, -12, 76, 76, -12, 0, 0 },
    { 0, 0, -10, 66, 84, -12, 0, 0 },
    { 0, 0, -10, 58, 94, -14, 0, 0 },
    { 0, 0, -10, 48, 102, -12, 0, 0 },
    { 0, 0, -8, 38, 110, -12, 0, 0 },
    { 0, 0, -6, 28, 116, -10, 0, 0 },
    { 0, 0, -4, 18, 122, -8, 0, 0 },
    { 0, 0, -2, 8, 126, -4, 0, 0 }
  },
  {
    { 0, 0, 0, 128, 0, 0, 0, 0 },
    { 0, 0, 30, 62, 34, 2, 0, 0 },
    { 0, 0, 26, 62, 36, 4, 0, 0 },
    { 0, 0, 22, 62, 40, 4, 0, 0 },
    { 0, 0, 20, 60, 42, 6, 0, 0 },
    { 0, 0, 18, 58, 44, 8, 0, 0 },
    { 0, 0, 16, 56, 46, 10, 0, 0 },
    { 0, 0, 14, 54, 48, 12, 0, 0 },
```

```
    { 0, 0, 12, 52, 52, 12, 0, 0 },
    { 0, 0, 12, 48, 54, 14, 0, 0 },
    { 0, 0, 10, 46, 56, 16, 0, 0 },
    { 0, 0, 8, 44, 58, 18, 0, 0 },
    { 0, 0, 6, 42, 60, 20, 0, 0 },
    { 0, 0, 4, 40, 62, 22, 0, 0 },
    { 0, 0, 4, 36, 62, 26, 0, 0 },
    { 0, 0, 2, 34, 62, 30, 0, 0 }
  }
}
```

Note: All the values in Subpel_Filters are even. The last two filter types are used for small blocks and only have four filter taps. The filter at index 4 has a four tap version of the EIGHTTAP filter. The filter at index 5 has a four tap version of the EIGHTAP_SMOOTH filter.

7.11.3.5. Block warp process

The inputs to this process are:

- a variable useWarp (equal to 1 for local warp, or 2 for global warp),
- a variable plane,
- a variable refList specifying that the process should predict from RefFrame[refList],
- variables x and y specifying the location of the top left sample in the CurrFrame[plane] array of the region to be predicted,
- variables i8 and j8 specifying the offset (in units of 8 samples) relative to the top left sample,
- variables w and h giving the width and height of the block in units of samples.

The output from this process is the 2D array named pred containing warped inter predicted samples.

The process only updates a section of the pred array. The size of the updated section is 8x8 samples, clipped to the size of the block. Variables i8 and j8 give the location of the section to update.

A variable refIdx specifying which reference frame is being used is set equal to ref_frame_idx[RefFrame[refList] - LAST_FRAME].

A variable ref specifying the reference frame contents is set equal to FrameStore[refIdx].

The variables subX and subY are set equal to the subsampling for the current plane as follows:

- If plane is equal to 0, subX is set equal to 0 and subY is set equal to 0.
- Otherwise, subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The variable lastX is set equal to ((RefUpscaledWidth[refIdx] + subX) >> subX) - 1.

The variable lastY is set equal to ((RefFrameHeight[refIdx] + subY) >> subY) - 1.

(lastX and lastY specify the coordinates of the bottom right sample of the reference plane.)

The variable srcX is set equal to (x + j8 * 8 + 4) << subX.

The variable srcY is set equal to (y + i8 * 8 + 4) << subY.

(srcX and srcY specify a location in the luma plane that will be projected using the warp parameters.)

The array warpParams is specified as follows:

- If useWarp is equal to 1, warpParams is set equal to LocalWarpParams.
- Otherwise (useWarp is equal to 2), warpParams is set equal to gm_params[RefFrame[refList]].

The variable dstX is set equal to warpParams[2] * srcX + warpParams[3] * srcY + warpParams[0].

The variable dstY is set equal to warpParams[4] * srcX + warpParams[5] * srcY + warpParams[1].

(dstX and dstY specify the destination location in the luma plane using WARPEDMODEL_PREC_BITS bits of precision).

The setup shear process specified in section 7.11.3.6 is invoked with warpParams as input, and the outputs are assigned to warpValid, alpha, beta, gamma, and delta. (warpValid will always be equal to 1 at this point.)

The sub-sample interpolation is effected via two one-dimensional convolutions. First a horizontal filter is used to build up an intermediate array, and then this array is vertically filtered to obtain the final prediction.

The filtering is applied as follows:

- The array intermediate is specified as follows:

```
x4 = dstX >> subX
y4 = dstY >> subY
ix4 = x4 >> WARPEDMODEL_PREC_BITS
sx4 = x4 & ((1 << WARPEDMODEL_PREC_BITS) - 1)
iy4 = y4 >> WARPEDMODEL_PREC_BITS
sy4 = y4 & ((1 << WARPEDMODEL_PREC_BITS) - 1)

for ( i1 = -7; i1 < 8; i1++ ) {
    for ( i2 = -4; i2 < 4; i2++ ) {
        sx = sx4 + alpha * i2 + beta * i1
        offs = Round2(sx, WARPEDDIFF_PREC_BITS) + WARPEDPIXEL_PREC_SHIFTS
        s = 0
        for ( i3 = 0; i3 < 8; i3++ ) {
            s += Warped_Filters[ offs ][ i3 ] *
              ref[ plane ][ Clip3( 0, lastY, iy4 + i1 ) ]
                          [ Clip3( 0, lastX, ix4 + i2 - 3 + i3 ) ]
        }
        intermediate[(i1 + 7)][(i2 + 4)] = Round2(s, InterRound0)
    }
}
```

- The array pred is specified as follows:

```
for ( i1 = -4; i1 < Min(4, h - i8 * 8 - 4); i1++ ) {
    for ( i2 = -4; i2 < Min(4, w - j8 * 8 - 4); i2++ ) {
        sy = sy4 + gamma * i2 + delta * i1
        offs = Round2(sy, WARPEDDIFF_PREC_BITS) + WARPEDPIXEL_PREC_SHIFTS
        s = 0
        for ( i3 = 0; i3 < 8; i3++ ) {
            s += Warped_Filters[offs][i3] *
                 intermediate[(i1 + i3 + 4)][(i2 + 4)]
        }
        pred[ i8 * 8 + i1 + 4 ][ j8 * 8 + i2 + 4 ] = Round2(s, InterRound1)
    }
}
```

where the constant array Warped_Filters is specified as:

```
Warped_Filters[WARPEDPIXEL_PREC_SHIFTS * 3 + 1][8] = {
    { 0,   0, 127,   1,   0, 0, 0, 0 }, { 0, - 1, 127,   2,   0, 0, 0, 0 },
    { 1, - 3, 127,   4, - 1, 0, 0, 0 }, { 1, - 4, 126,   6, - 2, 1, 0, 0 },
    { 1, - 5, 126,   8, - 3, 1, 0, 0 }, { 1, - 6, 125,  11, - 4, 1, 0, 0 },
    { 1, - 7, 124,  13, - 4, 1, 0, 0 }, { 2, - 8, 123,  15, - 5, 1, 0, 0 },
    { 2, - 9, 122,  18, - 6, 1, 0, 0 }, { 2, -10, 121,  20, - 6, 1, 0, 0 },
    { 2, -11, 120,  22, - 7, 2, 0, 0 }, { 2, -12, 119,  25, - 8, 2, 0, 0 },
    { 3, -13, 117,  27, - 8, 2, 0, 0 }, { 3, -13, 116,  29, - 9, 2, 0, 0 },
    { 3, -14, 114,  32, -10, 3, 0, 0 }, { 3, -15, 113,  35, -10, 2, 0, 0 },
    { 3, -15, 111,  37, -11, 3, 0, 0 }, { 3, -16, 109,  40, -11, 3, 0, 0 },
    { 3, -16, 108,  42, -12, 3, 0, 0 }, { 4, -17, 106,  45, -13, 3, 0, 0 },
    { 4, -17, 104,  47, -13, 3, 0, 0 }, { 4, -17, 102,  50, -14, 3, 0, 0 },
    { 4, -17, 100,  52, -14, 3, 0, 0 }, { 4, -18,  98,  55, -15, 4, 0, 0 },
    { 4, -18,  96,  58, -15, 3, 0, 0 }, { 4, -18,  94,  60, -16, 4, 0, 0 },
    { 4, -18,  91,  63, -16, 4, 0, 0 }, { 4, -18,  89,  65, -16, 4, 0, 0 },
    { 4, -18,  87,  68, -17, 4, 0, 0 }, { 4, -18,  85,  70, -17, 4, 0, 0 },
    { 4, -18,  82,  73, -17, 4, 0, 0 }, { 4, -18,  80,  75, -17, 4, 0, 0 },
    { 4, -18,  78,  78, -18, 4, 0, 0 }, { 4, -17,  75,  80, -18, 4, 0, 0 },
    { 4, -17,  73,  82, -18, 4, 0, 0 }, { 4, -17,  70,  85, -18, 4, 0, 0 },
    { 4, -17,  68,  87, -18, 4, 0, 0 }, { 4, -16,  65,  89, -18, 4, 0, 0 },
    { 4, -16,  63,  91, -18, 4, 0, 0 }, { 4, -16,  60,  94, -18, 4, 0, 0 },
    { 3, -15,  58,  96, -18, 4, 0, 0 }, { 4, -15,  55,  98, -18, 4, 0, 0 },
    { 3, -14,  52, 100, -17, 4, 0, 0 }, { 3, -14,  50, 102, -17, 4, 0, 0 },
    { 3, -13,  47, 104, -17, 4, 0, 0 }, { 3, -13,  45, 106, -17, 4, 0, 0 },
    { 3, -12,  42, 108, -16, 3, 0, 0 }, { 3, -11,  40, 109, -16, 3, 0, 0 },
    { 3, -11,  37, 111, -15, 3, 0, 0 }, { 2, -10,  35, 113, -15, 3, 0, 0 },
    { 3, -10,  32, 114, -14, 3, 0, 0 }, { 2, - 9,  29, 116, -13, 3, 0, 0 },
    { 2, - 8,  27, 117, -13, 3, 0, 0 }, { 2, - 8,  25, 119, -12, 2, 0, 0 },
    { 2, - 7,  22, 120, -11, 2, 0, 0 }, { 1, - 6,  20, 121, -10, 2, 0, 0 },
    { 1, - 6,  18, 122, - 9, 2, 0, 0 }, { 1, - 5,  15, 123, - 8, 2, 0, 0 },
    { 1, - 4,  13, 124, - 7, 1, 0, 0 }, { 1, - 4,  11, 125, - 6, 1, 0, 0 },
    { 1, - 3,   8, 126, - 5, 1, 0, 0 }, { 1, - 2,   6, 126, - 4, 1, 0, 0 },
    { 0, - 1,   4, 127, - 3, 1, 0, 0 }, { 0,   0,   2, 127, - 1, 0, 0, 0 },

    { 0,  0,   0, 127,   1,   0,  0,  0}, { 0,  0,  -1, 127,   2,   0,  0,  0},
    { 0,  1,  -3, 127,   4,  -2,  1,  0}, { 0,  1,  -5, 127,   6,  -2,  1,  0},
    { 0,  2,  -6, 126,   8,  -3,  1,  0}, {-1,  2,  -7, 126,  11,  -4,  2, -1},
    {-1,  3,  -8, 125,  13,  -5,  2, -1}, {-1,  3, -10, 124,  16,  -6,  3, -1},
    {-1,  4, -11, 123,  18,  -7,  3, -1}, {-1,  4, -12, 122,  20,  -7,  3, -1},
    {-1,  4, -13, 121,  23,  -8,  3, -1}, {-2,  5, -14, 120,  25,  -9,  4, -1},
    {-1,  5, -15, 119,  27, -10,  4, -1}, {-1,  5, -16, 118,  30, -11,  4, -1},
    {-2,  6, -17, 116,  33, -12,  5, -1}, {-2,  6, -17, 114,  35, -12,  5, -1},
    {-2,  6, -18, 113,  38, -13,  5, -1}, {-2,  7, -19, 111,  41, -14,  6, -2},
    {-2,  7, -19, 110,  43, -15,  6, -2}, {-2,  7, -20, 108,  46, -15,  6, -2},
    {-2,  7, -20, 106,  49, -16,  6, -2}, {-2,  7, -21, 104,  51, -16,  7, -2},
    {-2,  7, -21, 102,  54, -17,  7, -2}, {-2,  8, -21, 100,  56, -18,  7, -2},
    {-2,  8, -22,  98,  59, -18,  7, -2}, {-2,  8, -22,  96,  62, -19,  7, -2},
    {-2,  8, -22,  94,  64, -19,  7, -2}, {-2,  8, -22,  91,  67, -20,  8, -2},
    {-2,  8, -22,  89,  69, -20,  8, -2}, {-2,  8, -22,  87,  72, -21,  8, -2},
    {-2,  8, -21,  84,  74, -21,  8, -2}, {-2,  8, -22,  82,  77, -21,  8, -2},
```

```
{-2,  8, -21,  79,  79, -21,  8, -2}, {-2,  8, -21,  77,  82, -22,  8, -2},
{-2,  8, -21,  74,  84, -21,  8, -2}, {-2,  8, -21,  72,  87, -22,  8, -2},
{-2,  8, -20,  69,  89, -22,  8, -2}, {-2,  8, -20,  67,  91, -22,  8, -2},
{-2,  7, -19,  64,  94, -22,  8, -2}, {-2,  7, -19,  62,  96, -22,  8, -2},
{-2,  7, -18,  59,  98, -22,  8, -2}, {-2,  7, -18,  56, 100, -21,  8, -2},
{-2,  7, -17,  54, 102, -21,  7, -2}, {-2,  7, -16,  51, 104, -21,  7, -2},
{-2,  6, -16,  49, 106, -20,  7, -2}, {-2,  6, -15,  46, 108, -20,  7, -2},
{-2,  6, -15,  43, 110, -19,  7, -2}, {-2,  6, -14,  41, 111, -19,  7, -2},
{-1,  5, -13,  38, 113, -18,  6, -2}, {-1,  5, -12,  35, 114, -17,  6, -2},
{-1,  5, -12,  33, 116, -17,  6, -2}, {-1,  4, -11,  30, 118, -16,  5, -1},
{-1,  4, -10,  27, 119, -15,  5, -1}, {-1,  4,  -9,  25, 120, -14,  5, -2},
{-1,  3,  -8,  23, 121, -13,  4, -1}, {-1,  3,  -7,  20, 122, -12,  4, -1},
{-1,  3,  -7,  18, 123, -11,  4, -1}, {-1,  3,  -6,  16, 124, -10,  3, -1},
{-1,  2,  -5,  13, 125,  -8,  3, -1}, {-1,  2,  -4,  11, 126,  -7,  2, -1},
{ 0,  1,  -3,   8, 126,  -6,  2,  0}, { 0,  1,  -2,   6, 127,  -5,  1,  0},
{ 0,  1,  -2,   4, 127,  -3,  1,  0}, { 0,  0,   0,   2, 127,  -1,  0,  0},

{ 0, 0, 0,   1, 127,   0,   0, 0 }, { 0, 0, 0, - 1, 127,   2,   0, 0 },
{ 0, 0, 1, - 3, 127,   4, - 1, 0 }, { 0, 0, 1, - 4, 126,   6, - 2, 1 },
{ 0, 0, 1, - 5, 126,   8, - 3, 1 }, { 0, 0, 1, - 6, 125,  11, - 4, 1 },
{ 0, 0, 1, - 7, 124,  13, - 4, 1 }, { 0, 0, 2, - 8, 123,  15, - 5, 1 },
{ 0, 0, 2, - 9, 122,  18, - 6, 1 }, { 0, 0, 2, -10, 121,  20, - 6, 1 },
{ 0, 0, 2, -11, 120,  22, - 7, 2 }, { 0, 0, 2, -12, 119,  25, - 8, 2 },
{ 0, 0, 3, -13, 117,  27, - 8, 2 }, { 0, 0, 3, -13, 116,  29, - 9, 2 },
{ 0, 0, 3, -14, 114,  32, -10, 3 }, { 0, 0, 3, -15, 113,  35, -10, 2 },
{ 0, 0, 3, -15, 111,  37, -11, 3 }, { 0, 0, 3, -16, 109,  40, -11, 3 },
{ 0, 0, 3, -16, 108,  42, -12, 3 }, { 0, 0, 4, -17, 106,  45, -13, 3 },
{ 0, 0, 4, -17, 104,  47, -13, 3 }, { 0, 0, 4, -17, 102,  50, -14, 3 },
{ 0, 0, 4, -17, 100,  52, -14, 3 }, { 0, 0, 4, -18,  98,  55, -15, 4 },
{ 0, 0, 4, -18,  96,  58, -15, 3 }, { 0, 0, 4, -18,  94,  60, -16, 4 },
{ 0, 0, 4, -18,  91,  63, -16, 4 }, { 0, 0, 4, -18,  89,  65, -16, 4 },
{ 0, 0, 4, -18,  87,  68, -17, 4 }, { 0, 0, 4, -18,  85,  70, -17, 4 },
{ 0, 0, 4, -18,  82,  73, -17, 4 }, { 0, 0, 4, -18,  80,  75, -17, 4 },
{ 0, 0, 4, -18,  78,  78, -18, 4 }, { 0, 0, 4, -17,  75,  80, -18, 4 },
{ 0, 0, 4, -17,  73,  82, -18, 4 }, { 0, 0, 4, -17,  70,  85, -18, 4 },
{ 0, 0, 4, -17,  68,  87, -18, 4 }, { 0, 0, 4, -16,  65,  89, -18, 4 },
{ 0, 0, 4, -16,  63,  91, -18, 4 }, { 0, 0, 4, -16,  60,  94, -18, 4 },
{ 0, 0, 3, -15,  58,  96, -18, 4 }, { 0, 0, 4, -15,  55,  98, -18, 4 },
{ 0, 0, 3, -14,  52, 100, -17, 4 }, { 0, 0, 3, -14,  50, 102, -17, 4 },
{ 0, 0, 3, -13,  47, 104, -17, 4 }, { 0, 0, 3, -13,  45, 106, -17, 4 },
{ 0, 0, 3, -12,  42, 108, -16, 3 }, { 0, 0, 3, -11,  40, 109, -16, 3 },
{ 0, 0, 3, -11,  37, 111, -15, 3 }, { 0, 0, 2, -10,  35, 113, -15, 3 },
{ 0, 0, 3, -10,  32, 114, -14, 3 }, { 0, 0, 2, - 9,  29, 116, -13, 3 },
{ 0, 0, 2, - 8,  27, 117, -13, 3 }, { 0, 0, 2, - 8,  25, 119, -12, 2 },
{ 0, 0, 2, - 7,  22, 120, -11, 2 }, { 0, 0, 1, - 6,  20, 121, -10, 2 },
{ 0, 0, 1, - 6,  18, 122, - 9, 2 }, { 0, 0, 1, - 5,  15, 123, - 8, 2 },
{ 0, 0, 1, - 4,  13, 124, - 7, 1 }, { 0, 0, 1, - 4,  11, 125, - 6, 1 },
{ 0, 0, 1, - 3,   8, 126, - 5, 1 }, { 0, 0, 1, - 2,   6, 126, - 4, 1 },
{ 0, 0, 0, - 1,   4, 127, - 3, 1 }, { 0, 0, 0,   0,   2, 127, - 1, 0 },
```

```
    { 0, 0, 0,   0,   2, 127, -1, 0 }
}
```

7.11.3.6. Setup shear process

The input for this process is an array warpParams representing an affine transformation.

The outputs from this process are the variable warpValid and variables alpha, beta, gamma, delta representing two shearing operations that combine to make the full affine transformation.

The variable alpha0 is set equal to Clip3(-32768, 32767, warpParams[2] - (1 << WARPEDMODEL_PREC_BITS)).

The variable beta0 is set equal to Clip3(-32768, 32767, warpParams[3]).

The resolve divisor process specified in section 7.11.3.7 is invoked with warpParams[2] as input, and the outputs assigned to divShift and divFactor.

The variable v is set equal to (warpParams[4] << WARPEDMODEL_PREC_BITS).

The variable gamma0 is set equal to Clip3(-32768, 32767, Round2Signed(v * divFactor, divShift)).

The variable w is set equal to (warpParams[3] * warpParams[4]).

The variable delta0 is set equal to Clip3(-32768, 32767, warpParams[5] - Round2Signed(w * divFactor, divShift) - (1 << WARPEDMODEL_PREC_BITS)).

The output variables alpha, beta, gamma, delta are set as follows:

```
alpha = Round2Signed( alpha0, WARP_PARAM_REDUCE_BITS ) << WARP_PARAM_REDUCE_BITS
beta = Round2Signed( beta0, WARP_PARAM_REDUCE_BITS ) << WARP_PARAM_REDUCE_BITS
gamma = Round2Signed( gamma0, WARP_PARAM_REDUCE_BITS ) << WARP_PARAM_REDUCE_BITS
delta = Round2Signed( delta0, WARP_PARAM_REDUCE_BITS ) << WARP_PARAM_REDUCE_BITS
```

The output warpValid is set as follows:

- If 4 * Abs(alpha) + 7 * Abs(beta) is greater than or equal to (1 << WARPEDMODEL_PREC_BITS), warpValid is set equal to 0.
- If 4 * Abs(gamma) + 4 * Abs(delta) is greater than or equal to (1 << WARPEDMODEL_PREC_BITS), warpValid is set equal to 0.
- Otherwise, warpValid is set equal to 1.

7.11.3.7. Resolve divisor process

The input for this process is a variable d.

The outputs for this process are variables divShift and divFactor that can be used to perform an approximate division by d via multiplying by divFactor and shifting right by divShift.

The variable n (representing the location of the most signficant bit in Abs(d)) is set equal to FloorLog2(Abs(d)).

The variable e is set equal to Abs(d) - (1 << n).

The variable f is set as follows:

- If n > DIV_LUT_BITS, f is set equal to Round2(e, n - DIV_LUT_BITS).
- Otherwise, f is set equal to e << (DIV_LUT_BITS - n).

The output variable divShift is set equal to (n + DIV_LUT_PREC_BITS).

The output variable divFactor is set as follows:

- If d is less than 0, divFactor is set equal to -Div_Lut[f].
- Otherwise, divFactor is set equal to Div_Lut[f].

The lookup table Div_Lut is specified as:

```
Div_Lut[DIV_LUT_NUM] = {
  16384, 16320, 16257, 16194, 16132, 16070, 16009, 15948, 15888, 15828, 15768,
  15709, 15650, 15592, 15534, 15477, 15420, 15364, 15308, 15252, 15197, 15142,
  15087, 15033, 14980, 14926, 14873, 14821, 14769, 14717, 14665, 14614, 14564,
  14513, 14463, 14413, 14364, 14315, 14266, 14218, 14170, 14122, 14075, 14028,
  13981, 13935, 13888, 13843, 13797, 13752, 13707, 13662, 13618, 13574, 13530,
  13487, 13443, 13400, 13358, 13315, 13273, 13231, 13190, 13148, 13107, 13066,
  13026, 12985, 12945, 12906, 12866, 12827, 12788, 12749, 12710, 12672, 12633,
  12596, 12558, 12520, 12483, 12446, 12409, 12373, 12336, 12300, 12264, 12228,
  12193, 12157, 12122, 12087, 12053, 12018, 11984, 11950, 11916, 11882, 11848,
  11815, 11782, 11749, 11716, 11683, 11651, 11619, 11586, 11555, 11523, 11491,
  11460, 11429, 11398, 11367, 11336, 11305, 11275, 11245, 11215, 11185, 11155,
  11125, 11096, 11067, 11038, 11009, 10980, 10951, 10923, 10894, 10866, 10838,
  10810, 10782, 10755, 10727, 10700, 10673, 10645, 10618, 10592, 10565, 10538,
  10512, 10486, 10460, 10434, 10408, 10382, 10356, 10331, 10305, 10280, 10255,
  10230, 10205, 10180, 10156, 10131, 10107, 10082, 10058, 10034, 10010, 9986,
  9963,  9939,  9916,  9892,  9869,  9846,  9823,  9800,  9777,  9754,  9732,
  9709,  9687,  9664,  9642,  9620,  9598,  9576,  9554,  9533,  9511,  9489,
  9468,  9447,  9425,  9404,  9383,  9362,  9341,  9321,  9300,  9279,  9259,
  9239,  9218,  9198,  9178,  9158,  9138,  9118,  9098,  9079,  9059,  9039,
  9020,  9001,  8981,  8962,  8943,  8924,  8905,  8886,  8867,  8849,  8830,
  8812,  8793,  8775,  8756,  8738,  8720,  8702,  8684,  8666,  8648,  8630,
  8613,  8595,  8577,  8560,  8542,  8525,  8508,  8490,  8473,  8456,  8439,
  8422,  8405,  8389,  8372,  8355,  8339,  8322,  8306,  8289,  8273,  8257,
  8240,  8224,  8208,  8192
}
```

7.11.3.8. Warp estimation process

This process produces the array LocalWarpParams based on NumSamples candidates in CandList by performing a least squares fit.

It also produces a variable LocalValid indicating whether the process was successful.

A 2x2 matrix A, and two length 2 arrays Bx and By are constructed as follows:

```
for ( i = 0; i < 2; i++ ) {
    for ( j = 0; j < 2; j++ ) {
        A[i][j] = 0
    }
    Bx[i] = 0
    By[i] = 0
}
w4 = Num_4x4_Blocks_Wide[MiSize]
h4 = Num_4x4_Blocks_High[MiSize]
midY = MiRow * 4 + h4 * 2 - 1
midX = MiCol * 4 + w4 * 2 - 1
suy = midY * 8
sux = midX * 8
duy = suy + Mv[0][0]
dux = sux + Mv[0][1]
for ( i = 0; i < NumSamples; i++ ) {
    sy = CandList[i][0] - suy
    sx = CandList[i][1] - sux
    dy = CandList[i][2] - duy
    dx = CandList[i][3] - dux
    if ( Abs(sx - dx) < LS_MV_MAX && Abs(sy - dy) < LS_MV_MAX ) {
        A[0][0] += ls_product(sx, sx) + 8
        A[0][1] += ls_product(sx, sy) + 4
        A[1][1] += ls_product(sy, sy) + 8
        Bx[0] += ls_product(sx, dx) + 8
        Bx[1] += ls_product(sy, dx) + 4
        By[0] += ls_product(sx, dy) + 4
        By[1] += ls_product(sy, dy) + 8
    }
}
```

where ls_product is specified as:

```
ls_product(a, b) {
    return ( (a * b) >> 2) + (a + b)
}
```

Note: The matrix A is symmetric so entry A[1][0] is omitted.

The variable det (containing the determinant of the matrix A) is set equal to A[0][0] * A[1][1] - A[0][1] * A[0][1].

The variable LocalValid is set as follows:

- If det is equal to 0, LocalValid is set equal to 0.
- Otherwise, LocalValid is set equal to 1.

If det is equal to 0, this process terminates at this point.

The resolve divisor process specified in section 7.11.3.7 is invoked with det as input, and the outputs assigned to divShift and divFactor.

The local warp parameters in LocalWarpParams are derived as follows:

```
divShift -= WARPEDMODEL_PREC_BITS
if ( divShift < 0 ) {
    divFactor = divFactor << (-divShift)
    divShift = 0
}
LocalWarpParams[2] = diag(     A[1][1] * Bx[0] - A[0][1] * Bx[1])
LocalWarpParams[3] = nondiag( -A[0][1] * Bx[0] + A[0][0] * Bx[1])
LocalWarpParams[4] = nondiag(  A[1][1] * By[0] - A[0][1] * By[1])
LocalWarpParams[5] = diag(    -A[0][1] * By[0] + A[0][0] * By[1])

mvx = Mv[ 0 ][ 1 ]
mvy = Mv[ 0 ][ 0 ]
vx = mvx * (1 << (WARPEDMODEL_PREC_BITS - 3)) -
     (midX * (LocalWarpParams[2] - (1 << WARPEDMODEL_PREC_BITS)) + midY * LocalWarpParams[3])
vy = mvy * (1 << (WARPEDMODEL_PREC_BITS - 3)) -
     (midX * LocalWarpParams[4] + midY * (LocalWarpParams[5] - (1 << WARPEDMODEL_PREC_BITS)))
LocalWarpParams[0] = Clip3(-WARPEDMODEL_TRANS_CLAMP, WARPEDMODEL_TRANS_CLAMP - 1, vx)
LocalWarpParams[1] = Clip3(-WARPEDMODEL_TRANS_CLAMP, WARPEDMODEL_TRANS_CLAMP - 1, vy)
```

where diag and nondiag are specified to divide and clamp using divFactor and divShift as follows:

```
nondiag(v) {
    return Clip3(-WARPEDMODEL_NONDIAGAFFINE_CLAMP + 1,
                  WARPEDMODEL_NONDIAGAFFINE_CLAMP - 1,
                  Round2Signed(v * divFactor, divShift))
}

diag(v) {
    return Clip3((1 << WARPEDMODEL_PREC_BITS) - WARPEDMODEL_NONDIAGAFFINE_CLAMP + 1,
                 (1 << WARPEDMODEL_PREC_BITS) + WARPEDMODEL_NONDIAGAFFINE_CLAMP - 1,
                 Round2Signed(v * divFactor, divShift))
}
```

7.11.3.9. Overlapped motion compensation process

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables w and h specifying the width and height of the region to be predicted.

The outputs of this process are modified inter predicted samples in the current frame CurrFrame.

This process blends the inter predicted samples for the current block with inter predicted samples based on motion vectors from the above and left blocks.

The maximum number of overlapped predictions is limited based on the size of the block.

For small blocks, only the left neighbor will be used to form the prediction.

The variables subX and subY describing the subsampling of the current plane are derived as follows:

- If plane is equal to 0, subX and subY are set equal to 0.
- Otherwise (plane is not equal to 0), subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The process is specified as:

```
if ( AvailU ) {
    if ( get_plane_residual_size( MiSize, plane ) >= BLOCK_8X8 ) {
        pass = 0
        w4 = Num_4x4_Blocks_Wide[ MiSize ]
        x4 = MiCol
        y4 = MiRow
        nCount = 0
        nLimit = Min(4, Mi_Width_Log2[ MiSize ])
        while ( nCount < nLimit && x4 < Min( MiCols, MiCol + w4 ) ) {
            candRow = MiRow - 1
            candCol = x4 | 1
            candSz = MiSizes[ candRow ][ candCol ]
            step4 = Clip3( 2, 16, Num_4x4_Blocks_Wide[ candSz ] )
            if ( RefFrames[ candRow ][ candCol ][ 0 ] > INTRA_FRAME ) {
                nCount += 1
                predW = Min( w, ( step4 * MI_SIZE ) >> subX )
                predH = Min( h >> 1, 32 >> subY )
                mask = get_obmc_mask( predH )
                predict_overlap( )
            }
            x4 += step4
        }
    }
}
if ( AvailL ) {
    pass = 1
    h4 = Num_4x4_Blocks_High[ MiSize ]
    x4 = MiCol
    y4 = MiRow
    nCount = 0
    nLimit = Min(4, Mi_Height_Log2[ MiSize ])
    while ( nCount < nLimit && y4 < Min( MiRows, MiRow + h4 ) ) {
        candCol = MiCol - 1
        candRow = y4 | 1
        candSz = MiSizes[ candRow ][ candCol ]
        step4 = Clip3( 2, 16, Num_4x4_Blocks_High[ candSz ] )
        if ( RefFrames[ candRow ][ candCol ][ 0 ] > INTRA_FRAME ) {
            nCount += 1
            predW = Min( w >> 1, 32 >> subX )
            predH = Min( h, ( step4 * MI_SIZE ) >> subY )
            mask = get_obmc_mask( predW )
            predict_overlap( )
        }
        y4 += step4
    }
}
```

When the function predict_overlap is invoked, the following ordered steps apply to form the overlap prediction for a region of size predW by predH based on the candidate motion vector:

1. The motion vector mv is set equal to Mvs[candRow][candCol][0].
2. The variable refIdx is set equal to ref_frame_idx[RefFrames[candRow][candCol][0] - LAST_FRAME].
3. The variable predX is set equal to (x4 * 4) >> subX.
4. The variable predY is set equal to (y4 * 4) >> subY.
5. The motion vector scaling process in section 7.11.3.3 is invoked with plane, refIdx, predX, predY, mv as inputs and the output being the initial location startX, startY, and the step sizes stepX, stepY.
6. The block inter prediction process in section 7.11.3.4 is invoked with plane, refIdx, startX, startY, stepX, stepY, predW, predH, candRow, candCol as inputs and the output is assigned to the 2D array obmcPred.
7. obmcPred[i][j] is set equal to Clip1(obmcPred[i][j]) for i = 0..predH-1 and j = 0..predW-1.
8. The blending process in section 7.11.3.10 is invoked with plane, predX, predY, predW, predH, pass, obmcPred, and mask as inputs.

The function get_obmc_mask returns a blending mask as follows:

```
get_obmc_mask( length ) {
    if ( length == 2 ) {
        return Obmc_Mask_2
    } else if ( length == 4 ) {
        return Obmc_Mask_4
    } else if ( length == 8 ) {
        return Obmc_Mask_8
    } else if ( length == 16 ) {
        return Obmc_Mask_16
    } else {
        return Obmc_Mask_32
    }
}
```

The blending masks are defined as follows:

```
Obmc_Mask_2[2] = { 45, 64 }

Obmc_Mask_4[4] = { 39, 50, 59, 64 }

Obmc_Mask_8[8] = { 36, 42, 48, 53, 57, 61, 64, 64 }

Obmc_Mask_16[16] = { 34, 37, 40, 43, 46, 49, 52, 54,
                     56, 58, 60, 61, 64, 64, 64, 64 }

Obmc_Mask_32[32] = { 33, 35, 36, 38, 40, 41, 43, 44,
                     45, 47, 48, 50, 51, 52, 53, 55,
                     56, 57, 58, 59, 60, 60, 61, 62,
                     64, 64, 64, 64, 64, 64, 64, 64 }
```

7.11.3.10. Overlap blending process

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables predX and predY specifying the location of the top left sample in the CurrFrame[plane] array of the region to be predicted,
- variables predW and predH specifying the width and height of the region to be predicted,
- a variable pass equal to 0 if blending above samples, or equal to 1 if blending left samples,
- a 2d array obmcPred containing the samples predicted from a neighboring motion vector,
- an array mask containing the blending weights.

The outputs of this process are modified inter predicted samples in the current frame CurrFrame.

For i = 0..(predH - 1) and j = 0..(predW - 1), the following ordered steps apply:

1. The variable m specifying the blending factor is specifed as follows:
    - If pass is equal to 0 (blend from above), m is set equal to mask[i].
    - Otherwise (pass is equal to 1 meaning blend from left), m is set equal to mask[j].
2. CurrFrame[plane][predY + i][predX + j] is set equal to Round2(m * CurrFrame[plane][predY + i][predX + j] + (64 - m) * obmcPred[i][j], 6)

7.11.3.11. Wedge mask process

The input to this process is:

- variables w and h specifying the width and height of the region to be predicted.

This process sets up a mask array for the luma samples.

The mask is specified as:

```
for ( i = 0; i < h; i++ ) {
    for ( j = 0; j < w; j++ ) {
        Mask[ i ][ j ] = WedgeMasks[ MiSize ][ wedge_sign ][ wedge_index ][ i ][ j ]
    }
}
```

where WedgeMasks is a fixed lookup table that is generated by the following function:

```
initialise_wedge_mask_table( ) {
    w = MASK_MASTER_SIZE
    h = MASK_MASTER_SIZE
    for ( j = 0; j < w; j++ ) {
        shift = MASK_MASTER_SIZE / 4
        for ( i = 0; i < h; i += 2 ) {
            MasterMask[ WEDGE_OBLIQUE63 ][ i ][ j ] = Wedge_Master_Oblique_Even[ Clip3( 0,
MASK_MASTER_SIZE - 1, j - shift ) ]
            shift -= 1
            MasterMask[ WEDGE_OBLIQUE63 ][ i + 1][ j ] = Wedge_Master_Oblique_Odd[ Clip3( 0,
MASK_MASTER_SIZE - 1, j - shift ) ]
            MasterMask[ WEDGE_VERTICAL ][ i ][ j ] = Wedge_Master_Vertical[ j ]
            MasterMask[ WEDGE_VERTICAL ][ i + 1 ][ j ] = Wedge_Master_Vertical[ j ]
        }
    }
    for ( i = 0; i < h; i++ ) {
        for ( j = 0; j < w; j++ ) {
          msk = MasterMask[ WEDGE_OBLIQUE63 ][ i ][ j ]
          MasterMask[ WEDGE_OBLIQUE27 ][ j  ][ i ] = msk
          MasterMask[ WEDGE_OBLIQUE117 ][ i ][ w - 1 - j ] = 64 - msk
          MasterMask[ WEDGE_OBLIQUE153 ][ w - 1 - j ][ i ] = 64 - msk
          MasterMask[ WEDGE_HORIZONTAL ][ j ][ i ] = MasterMask[ WEDGE_VERTICAL ][ i ][ j ]
        }
    }
    for ( bsize = BLOCK_8X8; bsize < BLOCK_SIZES; bsize++ ) {
        if ( Wedge_Bits[ bsize ] > 0 ) {
            w = Block_Width[ bsize ]
            h = Block_Height[ bsize ]
            for ( wedge = 0; wedge < WEDGE_TYPES; wedge++ ) {
                dir = get_wedge_direction(bsize, wedge)
                xoff = MASK_MASTER_SIZE / 2 - ((get_wedge_xoff(bsize, wedge) * w) >> 3)
                yoff = MASK_MASTER_SIZE / 2 - ((get_wedge_yoff(bsize, wedge) * h) >> 3)
                sum = 0
                for ( i = 0; i < w; i++ )
                  sum += MasterMask[ dir ][ yoff ][ xoff+i ]
                for ( i = 1; i < h; i++ )
                  sum += MasterMask[ dir ][ yoff+i ][ xoff ]
                avg = (sum + (w + h - 1) / 2) / (w + h - 1)
                flipSign = (avg < 32)
                for ( i = 0; i < h; i++ ) {
                    for ( j = 0; j < w; j++ ) {
                      WedgeMasks[ bsize ][ flipSign ][ wedge ][ i ][ j ] = MasterMask[ dir ][ yoff+i
][ xoff+j ]
                      WedgeMasks[ bsize ][ !flipSign ][ wedge ][ i ][ j ] = 64 - MasterMask[ dir ][
yoff+i ][ xoff+j ]
                    }
                }
            }
        }
    }
```

```
}
```

The 1d lookup tables are defined as:

```
Wedge_Master_Oblique_Odd[MASK_MASTER_SIZE] = {
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  1,  2,  6,  18,
  37, 53, 60, 63, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64,
  64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64
}

Wedge_Master_Oblique_Even[MASK_MASTER_SIZE] = {
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  1,  4,  11, 27,
  46, 58, 62, 63, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64,
  64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64
}

Wedge_Master_Vertical[MASK_MASTER_SIZE] = {
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  2,  7,  21,
  43, 57, 62, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64,
  64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64, 64
}
```

The get_wedge functions are defined as:

```
block_shape(bsize) {
  w4 = Num_4x4_Blocks_Wide[bsize]
  h4 = Num_4x4_Blocks_High[bsize]
  if ( h4 > w4 )
      return 0
  else if ( h4 < w4 )
      return 1
  else
      return 2
}

get_wedge_direction(bsize, index) {
  return Wedge_Codebook[block_shape(bsize)][index][0]
}

get_wedge_xoff(bsize, index) {
  return Wedge_Codebook[block_shape(bsize)][index][1]
}

get_wedge_yoff(bsize, index) {
  return Wedge_Codebook[block_shape(bsize)][index][2]
}

Wedge_Codebook[3][16][3] = {
    {
        { WEDGE_OBLIQUE27, 4, 4 },  { WEDGE_OBLIQUE63, 4, 4 },
        { WEDGE_OBLIQUE117, 4, 4 }, { WEDGE_OBLIQUE153, 4, 4 },
        { WEDGE_HORIZONTAL, 4, 2 }, { WEDGE_HORIZONTAL, 4, 4 },
        { WEDGE_HORIZONTAL, 4, 6 }, { WEDGE_VERTICAL, 4, 4 },
        { WEDGE_OBLIQUE27, 4, 2 },  { WEDGE_OBLIQUE27, 4, 6 },
        { WEDGE_OBLIQUE153, 4, 2 }, { WEDGE_OBLIQUE153, 4, 6 },
        { WEDGE_OBLIQUE63, 2, 4 },  { WEDGE_OBLIQUE63, 6, 4 },
        { WEDGE_OBLIQUE117, 2, 4 }, { WEDGE_OBLIQUE117, 6, 4 },
    },
    {
        { WEDGE_OBLIQUE27, 4, 4 },  { WEDGE_OBLIQUE63, 4, 4 },
        { WEDGE_OBLIQUE117, 4, 4 }, { WEDGE_OBLIQUE153, 4, 4 },
        { WEDGE_VERTICAL, 2, 4 },   { WEDGE_VERTICAL, 4, 4 },
        { WEDGE_VERTICAL, 6, 4 },   { WEDGE_HORIZONTAL, 4, 4 },
        { WEDGE_OBLIQUE27, 4, 2 },  { WEDGE_OBLIQUE27, 4, 6 },
        { WEDGE_OBLIQUE153, 4, 2 }, { WEDGE_OBLIQUE153, 4, 6 },
        { WEDGE_OBLIQUE63, 2, 4 },  { WEDGE_OBLIQUE63, 6, 4 },
        { WEDGE_OBLIQUE117, 2, 4 }, { WEDGE_OBLIQUE117, 6, 4 },
    },
    {
        { WEDGE_OBLIQUE27, 4, 4 },  { WEDGE_OBLIQUE63, 4, 4 },
        { WEDGE_OBLIQUE117, 4, 4 }, { WEDGE_OBLIQUE153, 4, 4 },
        { WEDGE_HORIZONTAL, 4, 2 }, { WEDGE_HORIZONTAL, 4, 6 },
        { WEDGE_VERTICAL, 2, 4 },   { WEDGE_VERTICAL, 6, 4 },
        { WEDGE_OBLIQUE27, 4, 2 },  { WEDGE_OBLIQUE27, 4, 6 },
```

```
        { WEDGE_OBLIQUE153, 4, 2 }, { WEDGE_OBLIQUE153, 4, 6 },
        { WEDGE_OBLIQUE63, 2, 4 },  { WEDGE_OBLIQUE63, 6, 4 },
        { WEDGE_OBLIQUE117, 2, 4 }, { WEDGE_OBLIQUE117, 6, 4 },
    }
}
```

The wedge direction constants used above are defined as follows:

Constant	Value
WEDGE_HORIZONTAL	0
WEDGE_VERTICAL	1
WEDGE_OBLIQUE27	2
WEDGE_OBLIQUE63	3
WEDGE_OBLIQUE117	4
WEDGE_OBLIQUE153	5

7.11.3.12. Difference weight mask process

The input to this process is:

- an array preds containing the predicted samples,
- variables w and h specifying the width and height of the region to be predicted.

This process prepares an array Mask containing the blending weights for the luma samples.

The process sets the array based on the difference between the two predictions as follows:

```
for ( i = 0; i < h; i++ ) {
    for ( j = 0; j < w; j++ ) {
        diff = Abs(preds[ 0 ][ i ][ j ] - preds[ 1 ][ i ][ j ])
        diff = Round2(diff, (BitDepth - 8) + InterPostRound)
        m = Clip3(0, 64, 38 + diff / 16)
        if ( mask_type )
            Mask[ i ][ j ] = 64 - m
        else
            Mask[ i ][ j ] = m

    }
}
```

7.11.3.13. Intra mode variant mask process

The input to this process is:

- variables w and h specifying the width and height of the region to be predicted.

This process prepares an array Mask containing the blending weights for the luma samples.

The process sets the array based on the mode used for intra prediction as follows:

```
sizeScale = MAX_SB_SIZE / Max( h, w )
for ( i = 0; i < h; i++ ) {
    for ( j = 0; j < w; j++ ) {
        if ( interintra_mode == II_V_PRED ) {
            Mask[ i ][ j ] = Ii_Weights_1d[ i * sizeScale ]
        } else if ( interintra_mode == II_H_PRED ) {
            Mask[ i ][ j ] = Ii_Weights_1d[ j * sizeScale ]
        } else if ( interintra_mode == II_SMOOTH_PRED ) {
            Mask[ i ][ j ] = Ii_Weights_1d[ Min(i, j) * sizeScale ]
        } else {
            Mask[ i ][ j ] = 32
        }
    }
}
```

where the table Ii_Weights_1d is defined as:

```
Ii_Weights_1d[MAX_SB_SIZE] = {
  60, 58, 56, 54, 52, 50, 48, 47, 45, 44, 42, 41, 39, 38, 37, 35, 34, 33, 32,
  31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 22, 21, 20, 19, 19, 18, 18, 17, 16,
  16, 15, 15, 14, 14, 13, 13, 12, 12, 12, 11, 11, 10, 10, 10,  9,  9,  9,  8,
  8,  8,  8,  7,  7,  7,  7,  6,  6,  6,  6,  6,  5,  5,  5,  5,  5,  4,  4,
  4,  4,  4,  4,  4,  4,  3,  3,  3,  3,  3,  3,  3,  3,  3,  2,  2,  2,  2,
  2,  2,  2,  2,  2,  2,  2,  2,  2,  2,  2,  1,  1,  1,  1,  1,  1,  1,  1,
  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1,  1
}
```

7.11.3.14. Mask blend process

The inputs to this process are

- an array preds containing the predicted samples,
- a variable plane specifying which plane is being predicted,
- variables dstX and dstY specifying the location of the top left sample in the CurrFrame[plane] array of the region to be predicted,

- variables w and h specifying the width and height of the region to be predicted.

The process combines two predictions according to the mask. It makes use of an array Mask containing the blending weights to apply (the weights are defined for the current plane samples if compound_type is equal to COMPOUND_INTRA, or the luma plane otherwise).

The variables subX and subY describing the subsampling of the current plane are derived as follows:

- If plane is equal to 0, subX and subY are set equal to 0.
- Otherwise (plane is not equal to 0), subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The process is specified as follows:

```
for ( y = 0; y < h; y++ ) {
    for ( x = 0; x < w; x++ ) {
        if ( (!subX && !subY) ||
             (interintra && !wedge_interintra) ) {
            m = Mask[ y ][ x ]
        } else if ( subX && !subY ) {
            m = Round2( Mask[ y ][ 2*x ] + Mask[ y ][ 2*x+1 ], 1 )
        } else if ( !subX && subY ) {
            m = Round2( Mask[ 2*y ][ x ] + Mask[ 2*y+1 ][ x ], 1 )
        } else {
            m = Round2( Mask[ 2*y ][ 2*x ] + Mask[ 2*y ][ 2*x+1 ] +
                Mask[ 2*y+1 ][ 2*x ] + Mask[ 2*y+1 ][ 2*x+1 ], 2 )
        }
        if ( interintra ) {
            pred0 = Clip1( Round2( preds[ 0 ][ y ][ x ], InterPostRound ) )
            pred1 = CurrFrame[plane][y+dstY][x+dstX]
            CurrFrame[plane][y+dstY][x+dstX] = Round2( m * pred1 + (64 - m) * pred0, 6 )
        } else {
            pred0 = preds[ 0 ][ y ][ x ]
            pred1 = preds[ 1 ][ y ][ x ]
            CurrFrame[plane][y+dstY][x+dstX] = Clip1( Round2( m * pred0 + (64 - m) * pred1, 6 +
InterPostRound ) )
        }
    }
}
```

7.11.3.15. Distance weights process

The inputs to this process are variables candRow and candCol specifying the location (in units of 4x4 blocks) of the motion vector information to be used.

This process computes weights to be used for blending predictions together based on the expected output times of the reference frames.

The weights are computed as follows:

```
for ( refList = 0; refList < 2; refList++ ) {
  h = OrderHints[ RefFrames[ candRow ][ candCol ][ refList ] ]
  dist[ refList ] = Clip3( 0, MAX_FRAME_DISTANCE, Abs( get_relative_dist( h, OrderHint ) ) )
}
d0 = dist[ 1 ]
d1 = dist[ 0 ]
order = d0 <= d1
if ( d0 == 0 || d1 == 0 ) {
    FwdWeight = Quant_Dist_Lookup[ 3 ][ order ]
    BckWeight = Quant_Dist_Lookup[ 3 ][ 1 - order ]
} else {
  for ( i = 0; i < 3; i++ ) {
    c0 = Quant_Dist_Weight[ i ][ order ]
    c1 = Quant_Dist_Weight[ i ][ 1 - order ]
    if ( order ) {
      if ( d0 * c0 > d1 * c1 )
        break
    } else {
      if ( d0 * c0 < d1 * c1 )
        break
    }
  }
  FwdWeight = Quant_Dist_Lookup[ i ][ order ]
  BckWeight = Quant_Dist_Lookup[ i ][ 1 - order ]
}
```

where the tables Quant_Dist_Lookup and Quant_Dist_Weight are specified as:

```
Quant_Dist_Weight[ 4 ][ 2 ] = {
  { 2, 3 }, { 2, 5 }, { 2, 7 }, { 1, MAX_FRAME_DISTANCE }
}

Quant_Dist_Lookup[ 4 ][ 2 ] = {
  { 9, 7 }, { 11, 5 }, { 12, 4 }, { 13, 3 }
}
```

7.11.4. Palette prediction process

The palette prediction process is invoked for palette coded intra blocks to predict a part of the block using the limited palette.

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables startX and startY specifying the location of the top left sample in the CurrFrame[plane] array of the current transform block,
- variables x and y specifying the location in 4x4 units relative to the top left sample of the current transform block,

- a variable txSz, specifying the size of the current transform block.

The outputs of this process are palette predicted samples in the current frame CurrFrame.

The variable w specifying the width of the transform block is set equal to Tx_Width[txSz].

The variable h specifying the height of the transform block is set equal to Tx_Height[txSz].

The variable palette is specified as follows:

- If plane is 0, palette is set to palette_colors_y.
- Otherwise, if plane is 1, palette is set to palette_colors_u.
- Otherwise (plane is 2), palette is set to palette_colors_v.

The variable map is specified as follows:

- If plane is 0, map is set to ColorMapY.
- Otherwise (plane is not 0), map is set to ColorMapUV.

The current frame is updated as follows:

- CurrFrame[plane][startY + i][startX + j] is set equal to palette[map[y * 4 + i][x * 4 + j]] for i = 0..h-1 and j = 0..w-1.

7.11.5. Predict chroma from luma process

The chroma from luma process uses reconstructed luma samples to form a prediction for the chroma samples. The high frequencies are taken from the reconstructed luma samples and combined with DC predicted chroma samples.

The inputs to this process are:

- a variable plane (greater than zero) specifying which plane is being predicted,
- variables startX and startY specifying the location of the top left sample in the CurrFrame[plane] array of the current transform block,
- a variable txSz, specifying the size of the current transform block.

The outputs of this process are modified chroma predicted samples in the current frame CurrFrame.

The variable w specifying the width of the transform block is set equal to Tx_Width[txSz].

The variable h specifying the height of the transform block is set equal to Tx_Height[txSz].

The variable subX is set equal to subsampling_x.

The variable subY is set equal to subsampling_y.

The variable alpha depends on the plane as follows:

- If plane is equal to 1, alpha is set equal to CflAlphaU.
- Otherwise (plane is equal to 2), alpha is set equal to CflAlphaV.

An array L (containing subsampled reconstructed luma samples with 3 fractional bits of precision) and lumaAvg (representing the average reconstructed luma intensity with 3 fractional bits of precision) is specified as:

```
lumaAvg = 0
for ( i = 0; i < h; i++ ) {
    lumaY = (startY + i) << subY
    lumaY = Min( lumaY, MaxLumaH - (1 << subY) )
    for ( j = 0; j < w; j++ ) {
        lumaX = (startX + j) << subX
        lumaX = Min( lumaX, MaxLumaW - (1 << subX) )
        t = 0
        for ( dy = 0; dy <= subY; dy += 1 )
            for ( dx = 0; dx <= subX; dx += 1 )
                t += CurrFrame[ 0 ][ lumaY + dy ]
                                   [ lumaX + dx ]
        v = t << ( 3 - subX - subY )
        L[ i ][ j ] = v
        lumaAvg += v
    }
}
lumaAvg = Round2( lumaAvg, Tx_Width_Log2[ txSz ] + Tx_Height_Log2[ txSz ] )
```

The predicted chroma samples are specified as:

```
for ( i = 0; i < h; i++ ) {
    for ( j = 0; j < w; j++ ) {
        dc = CurrFrame[ plane ][ startY + i ][ startX + j ]
        scaledLuma = Round2Signed( alpha * ( L[ i ][ j ] - lumaAvg ), 6 )
        CurrFrame[ plane ][ startY + i ][ startX + j ] = Clip1( dc + scaledLuma )
    }
}
```

7.12. Reconstruction and dequantization

7.12.1. General

This section details the process of reconstructing a block of coefficients using dequantization and inverse transforms.

7.12.2. Dequantization functions

This section defines the functions get_dc_quant and get_ac_quant that are needed by the dequantization process.

The quantization parameters are derived from lookup tables.

The function dc_q(b) is specified as Dc_Qlookup[(BitDepth-8) >> 1][Clip3(0, 255, b)] where Dc_Qlookup is defined as follows:

```
Dc_Qlookup[ 3 ][ 256 ] = {
  {
    4, 8, 8, 9, 10, 11, 12, 12, 13, 14, 15, 16,
    17, 18, 19, 19, 20, 21, 22, 23, 24, 25, 26, 26,
    27, 28, 29, 30, 31, 32, 32, 33, 34, 35, 36, 37,
    38, 38, 39, 40, 41, 42, 43, 43, 44, 45, 46, 47,
    48, 48, 49, 50, 51, 52, 53, 53, 54, 55, 56, 57,
    57, 58, 59, 60, 61, 62, 62, 63, 64, 65, 66, 66,
    67, 68, 69, 70, 70, 71, 72, 73, 74, 74, 75, 76,
    77, 78, 78, 79, 80, 81, 81, 82, 83, 84, 85, 85,
    87, 88, 90, 92, 93, 95, 96, 98, 99, 101, 102, 104,
    105, 107, 108, 110, 111, 113, 114, 116, 117, 118, 120, 121,
    123, 125, 127, 129, 131, 134, 136, 138, 140, 142, 144, 146,
    148, 150, 152, 154, 156, 158, 161, 164, 166, 169, 172, 174,
    177, 180, 182, 185, 187, 190, 192, 195, 199, 202, 205, 208,
    211, 214, 217, 220, 223, 226, 230, 233, 237, 240, 243, 247,
    250, 253, 257, 261, 265, 269, 272, 276, 280, 284, 288, 292,
    296, 300, 304, 309, 313, 317, 322, 326, 330, 335, 340, 344,
    349, 354, 359, 364, 369, 374, 379, 384, 389, 395, 400, 406,
    411, 417, 423, 429, 435, 441, 447, 454, 461, 467, 475, 482,
    489, 497, 505, 513, 522, 530, 539, 549, 559, 569, 579, 590,
    602, 614, 626, 640, 654, 668, 684, 700, 717, 736, 755, 775,
    796, 819, 843, 869, 896, 925, 955, 988, 1022, 1058, 1098, 1139,
    1184, 1232, 1282, 1336
  },
  {
    4, 9, 10, 13, 15, 17, 20, 22, 25, 28, 31, 34,
    37, 40, 43, 47, 50, 53, 57, 60, 64, 68, 71, 75,
    78, 82, 86, 90, 93, 97, 101, 105, 109, 113, 116, 120,
    124, 128, 132, 136, 140, 143, 147, 151, 155, 159, 163, 166,
    170, 174, 178, 182, 185, 189, 193, 197, 200, 204, 208, 212,
    215, 219, 223, 226, 230, 233, 237, 241, 244, 248, 251, 255,
    259, 262, 266, 269, 273, 276, 280, 283, 287, 290, 293, 297,
    300, 304, 307, 310, 314, 317, 321, 324, 327, 331, 334, 337,
    343, 350, 356, 362, 369, 375, 381, 387, 394, 400, 406, 412,
    418, 424, 430, 436, 442, 448, 454, 460, 466, 472, 478, 484,
    490, 499, 507, 516, 525, 533, 542, 550, 559, 567, 576, 584,
    592, 601, 609, 617, 625, 634, 644, 655, 666, 676, 687, 698,
    708, 718, 729, 739, 749, 759, 770, 782, 795, 807, 819, 831,
    844, 856, 868, 880, 891, 906, 920, 933, 947, 961, 975, 988,
    1001, 1015, 1030, 1045, 1061, 1076, 1090, 1105, 1120, 1137, 1153, 1170,
    1186, 1202, 1218, 1236, 1253, 1271, 1288, 1306, 1323, 1342, 1361, 1379,
    1398, 1416, 1436, 1456, 1476, 1496, 1516, 1537, 1559, 1580, 1601, 1624,
    1647, 1670, 1692, 1717, 1741, 1766, 1791, 1817, 1844, 1871, 1900, 1929,
    1958, 1990, 2021, 2054, 2088, 2123, 2159, 2197, 2236, 2276, 2319, 2363,
    2410, 2458, 2508, 2561, 2616, 2675, 2737, 2802, 2871, 2944, 3020, 3102,
    3188, 3280, 3375, 3478, 3586, 3702, 3823, 3953, 4089, 4236, 4394, 4559,
    4737, 4929, 5130, 5347
  },
  {
```

```
    4, 12, 18, 25, 33, 41, 50, 60,
    70, 80, 91, 103, 115, 127, 140, 153,
    166, 180, 194, 208, 222, 237, 251, 266,
    281, 296, 312, 327, 343, 358, 374, 390,
    405, 421, 437, 453, 469, 484, 500, 516,
    532, 548, 564, 580, 596, 611, 627, 643,
    659, 674, 690, 706, 721, 737, 752, 768,
    783, 798, 814, 829, 844, 859, 874, 889,
    904, 919, 934, 949, 964, 978, 993, 1008,
    1022, 1037, 1051, 1065, 1080, 1094, 1108, 1122,
    1136, 1151, 1165, 1179, 1192, 1206, 1220, 1234,
    1248, 1261, 1275, 1288, 1302, 1315, 1329, 1342,
    1368, 1393, 1419, 1444, 1469, 1494, 1519, 1544,
    1569, 1594, 1618, 1643, 1668, 1692, 1717, 1741,
    1765, 1789, 1814, 1838, 1862, 1885, 1909, 1933,
    1957, 1992, 2027, 2061, 2096, 2130, 2165, 2199,
    2233, 2267, 2300, 2334, 2367, 2400, 2434, 2467,
    2499, 2532, 2575, 2618, 2661, 2704, 2746, 2788,
    2830, 2872, 2913, 2954, 2995, 3036, 3076, 3127,
    3177, 3226, 3275, 3324, 3373, 3421, 3469, 3517,
    3565, 3621, 3677, 3733, 3788, 3843, 3897, 3951,
    4005, 4058, 4119, 4181, 4241, 4301, 4361, 4420,
    4479, 4546, 4612, 4677, 4742, 4807, 4871, 4942,
    5013, 5083, 5153, 5222, 5291, 5367, 5442, 5517,
    5591, 5665, 5745, 5825, 5905, 5984, 6063, 6149,
    6234, 6319, 6404, 6495, 6587, 6678, 6769, 6867,
    6966, 7064, 7163, 7269, 7376, 7483, 7599, 7715,
    7832, 7958, 8085, 8214, 8352, 8492, 8635, 8788,
    8945, 9104, 9275, 9450, 9639, 9832, 10031, 10245,
    10465, 10702, 10946, 11210, 11482, 11776, 12081, 12409,
    12750, 13118, 13501, 13913, 14343, 14807, 15290, 15812,
    16356, 16943, 17575, 18237, 18949, 19718, 20521, 21387
  }
}
```

The function ac_q(b) is specified as Ac_Qlookup[(BitDepth-8) >> 1][Clip3(0, 255, b)] where Ac_Qlookup is defined as follows:

```
Ac_Qlookup[ 3 ][ 256 ] = {
  {
    4, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18,
    19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30,
    31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42,
    43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54,
    55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66,
    67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78,
    79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90,
    91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102,
    104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126,
    128, 130, 132, 134, 136, 138, 140, 142, 144, 146, 148, 150,
    152, 155, 158, 161, 164, 167, 170, 173, 176, 179, 182, 185,
    188, 191, 194, 197, 200, 203, 207, 211, 215, 219, 223, 227,
    231, 235, 239, 243, 247, 251, 255, 260, 265, 270, 275, 280,
    285, 290, 295, 300, 305, 311, 317, 323, 329, 335, 341, 347,
    353, 359, 366, 373, 380, 387, 394, 401, 408, 416, 424, 432,
    440, 448, 456, 465, 474, 483, 492, 501, 510, 520, 530, 540,
    550, 560, 571, 582, 593, 604, 615, 627, 639, 651, 663, 676,
    689, 702, 715, 729, 743, 757, 771, 786, 801, 816, 832, 848,
    864, 881, 898, 915, 933, 951, 969, 988, 1007, 1026, 1046, 1066,
    1087, 1108, 1129, 1151, 1173, 1196, 1219, 1243, 1267, 1292, 1317, 1343,
    1369, 1396, 1423, 1451, 1479, 1508, 1537, 1567, 1597, 1628, 1660, 1692,
    1725, 1759, 1793, 1828
  },
  {
    4, 9, 11, 13, 16, 18, 21, 24, 27, 30, 33, 37,
    40, 44, 48, 51, 55, 59, 63, 67, 71, 75, 79, 83,
    88, 92, 96, 100, 105, 109, 114, 118, 122, 127, 131, 136,
    140, 145, 149, 154, 158, 163, 168, 172, 177, 181, 186, 190,
    195, 199, 204, 208, 213, 217, 222, 226, 231, 235, 240, 244,
    249, 253, 258, 262, 267, 271, 275, 280, 284, 289, 293, 297,
    302, 306, 311, 315, 319, 324, 328, 332, 337, 341, 345, 349,
    354, 358, 362, 367, 371, 375, 379, 384, 388, 392, 396, 401,
    409, 417, 425, 433, 441, 449, 458, 466, 474, 482, 490, 498,
    506, 514, 523, 531, 539, 547, 555, 563, 571, 579, 588, 596,
    604, 616, 628, 640, 652, 664, 676, 688, 700, 713, 725, 737,
    749, 761, 773, 785, 797, 809, 825, 841, 857, 873, 889, 905,
    922, 938, 954, 970, 986, 1002, 1018, 1038, 1058, 1078, 1098, 1118,
    1138, 1158, 1178, 1198, 1218, 1242, 1266, 1290, 1314, 1338, 1362, 1386,
    1411, 1435, 1463, 1491, 1519, 1547, 1575, 1603, 1631, 1663, 1695, 1727,
    1759, 1791, 1823, 1859, 1895, 1931, 1967, 2003, 2039, 2079, 2119, 2159,
    2199, 2239, 2283, 2327, 2371, 2415, 2459, 2507, 2555, 2603, 2651, 2703,
    2755, 2807, 2859, 2915, 2971, 3027, 3083, 3143, 3203, 3263, 3327, 3391,
    3455, 3523, 3591, 3659, 3731, 3803, 3876, 3952, 4028, 4104, 4184, 4264,
    4348, 4432, 4516, 4604, 4692, 4784, 4876, 4972, 5068, 5168, 5268, 5372,
    5476, 5584, 5692, 5804, 5916, 6032, 6148, 6268, 6388, 6512, 6640, 6768,
    6900, 7036, 7172, 7312
  },
  {
```

```
    4, 13, 19, 27, 35, 44, 54, 64,
    75, 87, 99, 112, 126, 139, 154, 168,
    183, 199, 214, 230, 247, 263, 280, 297,
    314, 331, 349, 366, 384, 402, 420, 438,
    456, 475, 493, 511, 530, 548, 567, 586,
    604, 623, 642, 660, 679, 698, 716, 735,
    753, 772, 791, 809, 828, 846, 865, 884,
    902, 920, 939, 957, 976, 994, 1012, 1030,
    1049, 1067, 1085, 1103, 1121, 1139, 1157, 1175,
    1193, 1211, 1229, 1246, 1264, 1282, 1299, 1317,
    1335, 1352, 1370, 1387, 1405, 1422, 1440, 1457,
    1474, 1491, 1509, 1526, 1543, 1560, 1577, 1595,
    1627, 1660, 1693, 1725, 1758, 1791, 1824, 1856,
    1889, 1922, 1954, 1987, 2020, 2052, 2085, 2118,
    2150, 2183, 2216, 2248, 2281, 2313, 2346, 2378,
    2411, 2459, 2508, 2556, 2605, 2653, 2701, 2750,
    2798, 2847, 2895, 2943, 2992, 3040, 3088, 3137,
    3185, 3234, 3298, 3362, 3426, 3491, 3555, 3619,
    3684, 3748, 3812, 3876, 3941, 4005, 4069, 4149,
    4230, 4310, 4390, 4470, 4550, 4631, 4711, 4791,
    4871, 4967, 5064, 5160, 5256, 5352, 5448, 5544,
    5641, 5737, 5849, 5961, 6073, 6185, 6297, 6410,
    6522, 6650, 6778, 6906, 7034, 7162, 7290, 7435,
    7579, 7723, 7867, 8011, 8155, 8315, 8475, 8635,
    8795, 8956, 9132, 9308, 9484, 9660, 9836, 10028,
    10220, 10412, 10604, 10812, 11020, 11228, 11437, 11661,
    11885, 12109, 12333, 12573, 12813, 13053, 13309, 13565,
    13821, 14093, 14365, 14637, 14925, 15213, 15502, 15806,
    16110, 16414, 16734, 17054, 17390, 17726, 18062, 18414,
    18766, 19134, 19502, 19886, 20270, 20670, 21070, 21486,
    21902, 22334, 22766, 23214, 23662, 24126, 24590, 25070,
    25551, 26047, 26559, 27071, 27599, 28143, 28687, 29247
  }
}
```

The function get_qindex(ignoreDeltaQ, segmentId) returns the quantizer index for the current block and is specified by the following:

- If seg_feature_active_idx(segmentId, SEG_LVL_ALT_Q) is equal to 1 the following ordered steps apply:
    1. Set the variable data equal to FeatureData[segmentId][SEG_LVL_ALT_Q].
    2. Set qindex equal to base_q_idx + data.
    3. If ignoreDeltaQ is equal to 0 and delta_q_present is equal to 1, set qindex equal to CurrentQIndex + data.
    4. Return Clip3(0, 255, qindex).

- Otherwise, if ignoreDeltaQ is equal to 0 and delta_q_present is equal to 1, return CurrentQIndex.
- Otherwise, return base_q_idx.

Note: When using both delta quantization and lossless segments, care should be taken that get_qindex returns 0 for the lossless segments. One approach is to set FeatureData[segmentId][SEG_LVL_ALT_Q] to -255 for the lossless segments.

The function get_dc_quant(plane) returns the quantizer value for the dc coefficient for a particular plane and is derived as follows:

- If plane is equal to 0, return dc_q(get_qindex(0, segment_id) + DeltaQYDc).
- Otherwise if plane is equal to 1, return dc_q(get_qindex(0, segment_id) + DeltaQUDc).
- Otherwise (plane is equal to 2), return dc_q(get_qindex(0, segment_id) + DeltaQVDc).

The function get_ac_quant(plane) returns the quantizer value for the ac coefficient for a particular plane and is derived as follows:

- If plane is equal to 0, return ac_q(get_qindex(0, segment_id)).
- Otherwise if plane is equal to 1, return ac_q(get_qindex(0, segment_id) + DeltaQUAc).
- Otherwise (plane is equal to 2), return ac_q(get_qindex(0, segment_id) + DeltaQVAc).

7.12.3. Reconstruct process

The reconstruct process is invoked to perform dequantization, inverse transform and reconstruction. This process is triggered at a point defined by a function call to reconstruct in the transform block syntax table described in section 5.11.35.

The inputs to this process are:

- a variable plane specifying which plane is being reconstructed,
- variables x and y specifying the location of the top left sample in the CurrFrame[plane] array of the current transform block,
- a variable txSz, specifying the size of the transform block.

The outputs of this process are reconstructed samples in the current frame CurrFrame.

The reconstruction and dequantization process is defined as follows:

The variable dqDenom is derived as follows:

- If txSz is equal to TX_32X32, TX_16X32, TX_32X16, TX_16X64, or TX_64X16, dqDenom is set equal to 2.

- Otherwise, if txSz is equal to TX_64X64, TX_32X64, or TX_64X32, dqDenom is set equal to 4.
- Otherwise, dqDenom is set equal to 1.

The variable log2W (specifying the base 2 logarithm of the width of the transform block) is set equal to Tx_Width_Log2[txSz].

The variable log2H (specifying the base 2 logarithm of the height of the transform block) is set equal to Tx_Height_Log2[txSz].

The variable w (specifying the width of the transform block) is set equal to 1 << log2W.

The variable h (specifying the height of the transform block) is set equal to 1 << log2H.

The variable tw is set equal to Min(32, w).

The variable th is set equal to Min(32, h).

The variable flipUD is derived as follows. If PlaneTxType is equal to one of FLIPADST_DCT, FLIPADST_ADST, V_FLIPADST, or FLIPADST_FLIPADST, flipUD is set equal to 1. Otherwise, flipUD is set equal to 0.

The variable flipLR is derived as follows. If PlaneTxType is equal to one of DCT_FLIPADST, ADST_FLIPADST, H_FLIPADST, or FLIPADST_FLIPADST, flipLR is set equal to 1. Otherwise, flipLR is set equal to 0.

The following ordered steps apply:

1. For i = 0..(th-1), for j = 0..(tw-1), the following ordered steps apply:

   a. The variable q is derived as follows:

      - If i is equal to 0 and j is equal to 0, the variable q is set equal to get_dc_quant(plane).
      - Otherwise (i, j or both are not equal to 0), the variable q is set equal to get_ac_quant(plane).

   b. The variable q2 is derived as follows:

      - If using_qmatrix is equal to 1, PlaneTxType is less than IDTX, and SegQMLevel[plane][segment_id] is less than 15, q2 is set equal to Round2(q * Quantizer_Matrix[SegQMLevel[plane][segment_id]][plane > 0][Qm_Offset[txSz] + i * tw + j], 5).
      - Otherwise, q2 is set equal to q.

   c. The variable dq is set equal to Quant[i * tw + j] * q2.

   d. The variable sign is set equal to (dq < 0) ? -1 : 1.

   e. The variable dq2 is set equal to sign * (Abs(dq) & 0xFFFFFF) / dqDenom.

   f. Dequant[i][j] is set equal to Clip3(- (1 << (7 + BitDepth)), (1 << (7 + BitDepth)) - 1, dq2).

2. Invoke the 2D inverse transform block process defined in section 7.13.3 with the variable txSz as input. The inverse transform outputs are stored in the Residual buffer.

3. For i = 0..(h-1), for j = 0..(w-1), the following applies:

    - The variable xx is set equal to flipLR ? (w - j - 1) : j.
    - The variable yy is set equal to flipUD ? (h - i - 1) : i.
    - CurrFrame[plane][y + yy][x + xx] is set equal to Clip1(CurrFrame[plane][y + yy][x + xx] + Residual[i][j]).

If Lossless is equal to 1, it is a requirement of bitstream conformance that the values written into the Residual array in step 2 are representable by a signed integer with 1 + BitDepth bits.

Note: When Lossless is equal to 0, values written into Residual may not be representable by 1 + BitDepth bits (for example, due to quantization noise). The constraints in other parts of the specification ensure that the values will always be representable by a signed integer with Max(BitDepth + 5, 15) bits.

7.13. Inverse transform process

7.13.1. General

This section details the inverse transforms used during the reconstruction processes detailed in section 7.12.

7.13.2. 1D transforms

7.13.2.1. Butterfly functions

This section defines the butterfly functions B and H used by the 1D transform processes.

The inverse transform process works by writing values into an array T.

The function brev(numBits, x) returns the bit-reversal of numBits of x and is specified as follows:

```
brev( numBits, x ) {
    t = 0
    for ( i = 0; i < numBits; i++ ) {
        bit = (x >> i) & 1
        t += bit << (numBits - 1 - i)
    }
    return t
}
```

The function B(a, b, angle, 0, r) performs a butterfly rotation specified by the following ordered steps:

1. The variable x is set equal to T[a] * cos128(angle) - T[b] * sin128(angle).
2. The variable y is set equal to T[a] * sin128(angle) + T[b] * cos128(angle).
3. T[a] is set equal to Round2(x, 12).
4. T[b] is set equal to Round2(y, 12).

It is a requirement of bitstream conformance that the values saved into the array T by this function are representable by a signed integer using r bits of precision.

The function cos128(angle) is specified for integer values of the input angle by the following ordered steps:

1. Set a variable angle2 equal to angle & 255.
2. If angle2 is greater than or equal to 0 and less than or equal to 64, return Cos128_Lookup[angle2].
3. If angle2 is greater than 64 and less than or equal to 128, return Cos128_Lookup[128 - angle2] * -1.
4. If angle2 is greater than 128 and less than or equal to 192, return Cos128_Lookup[angle2 - 128] * -1.
5. Otherwise (if angle2 is greater than 192 and less than 256), return Cos128_Lookup[256 - angle2].

Where Cos128_Lookup is a constant lookup table defined as:

```
Cos128_Lookup[ 65 ] = {
    4096, 4095, 4091, 4085, 4076, 4065, 4052, 4036,
    4017, 3996, 3973, 3948, 3920, 3889, 3857, 3822,
    3784, 3745, 3703, 3659, 3612, 3564, 3513, 3461,
    3406, 3349, 3290, 3229, 3166, 3102, 3035, 2967,
    2896, 2824, 2751, 2675, 2598, 2520, 2440, 2359,
    2276, 2191, 2106, 2019, 1931, 1842, 1751, 1660,
    1567, 1474, 1380, 1285, 1189, 1092, 995, 897,
    799, 700, 601, 501, 401, 301, 201, 101, 0
}
```

The function sin128(angle) is defined to be cos128(angle - 64).

> **Note:** The cos128 function implements the expression 4096 * cos(angle * pi / 128) rounded to the nearest integer. The sin128 function implements the expression 4096 * sin(angle * pi / 128) rounded to the nearest integer.

When the angle is equal to 32 + 64 * k for integer k the butterfly rotation can be equivalently performed with two fewer multiplications (because the magnitude of cos128(32 + 64 * k) is always equal to that of sin128(32 + 64 * k)) by the following process:

1. The variable v is set equal to (angle & 64) ? T[a] + T[b] : T[a] - T[b].

2. The variable w is set equal to (angle & 64) ? -T[a] + T[b] : T[a] + T[b].
3. The variable x is set equal to v * cos128(angle).
4. The variable y is set equal to w * cos128(angle).
5. T[a] is set equal to Round2(x, 12).
6. T[b] is set equal to Round2(y, 12).

It is a requirement of bitstream conformance that the values saved into the array T by this function are representable by a signed integer using r bits of precision.

The function B(a ,b, angle, 1, r) performs a butterfly rotation and flip specified by the following ordered steps:

1. The function B(a, b, angle, 0, r) is invoked.
2. The contents of T[a] and T[b] are exchanged.

The function H(a, b, 0, r) performs a Hadamard rotation specified by the following ordered steps:

1. The variable x is set equal to T[a].
2. The variable y is set equal to T[b].
3. T[a] is set equal to Clip3(- (1 << (r - 1)), (1 << (r - 1)) - 1, x + y).
4. T[b] is set equal to Clip3(- (1 << (r - 1)), (1 << (r - 1)) - 1, x - y).

The function H(a, b, 1, r) performs a Hadamard rotation with flipped indices and is specified as follows:

1. The function H(b, a, 0, r) is invoked.

7.13.2.2. Inverse DCT array permutation process

This process performs an in-place permutation of the array T of length 2^n for $2 \le n \le 6$ which is required before execution of the inverse DCT process.

The input to this process is a variable n that specifies the base 2 logarithm of the length of the input array.

A temporary array named copyT is set equal to T.

T[i] is set equal to copyT[brev(n, i)] for i = 0..((1 << n) - 1).

7.13.2.3. Inverse DCT process

This process performs an in-place inverse discrete cosine transform of the permuted array T which is of length 2^n for $2 \le n \le 6$.

The inputs to this process are:

- a variable n that specifies the base 2 logarithm of the length of the input array,
- a variable r that specifies the intermediate clamping range.

The following ordered steps apply:

1. Invoke the inverse DCT permutation process as specified in section 7.13.2.2 with the input variable n.
2. If n is equal to 6, invoke B(32 + i, 63 - i, 63 - 4 * brev(4, i), 0, r) for i = 0..15.
3. If n is greater than or equal to 5, invoke B(16 + i, 31 - i, 6 + (brev(3, 7 - i) << 3), 0, r) for i = 0..7.
4. If n is equal to 6, invoke H(32 + i * 2, 33 + i * 2, i & 1, r) for i = 0..15.
5. If n is greater than or equal to 4, invoke B(8 + i, 15 - i, 12 + (brev(2, 3 - i) << 4), 0, r) for i = 0..3.
6. If n is greater than or equal to 5, invoke H(16 + 2 * i, 17 + 2 * i, i & 1, r) for i = 0..7.
7. If n is equal to 6, invoke B(62 - i * 4 - j, 33 + i * 4 + j, 60 - 16 * brev(2, i) + 64 * j, 1, r) for i = 0..3, for j = 0..1.
8. If n is greater than or equal to 3, invoke B(4 + i, 7 - i, 56 - 32 * i, 0, r) for i = 0..1.
9. If n is greater than or equal to 4, invoke H(8 + 2 * i, 9 + 2 * i, i & 1, r) for i = 0..3.
10. If n is greater than or equal to 5, invoke B(30 - 4 * i - j, 17 + 4 * i + j, 24 + (j << 6) + ((1 - i) << 5), 1, r) for i = 0..1, for j=0..1.
11. If n is equal to 6, invoke H(32 + i * 4 + j, 35 + i * 4 - j, i & 1, r) for i = 0..7, for j = 0..1.
12. Invoke B(2 * i, 2 * i + 1, 32 + 16 * i, 1 - i, r) for i = 0..1.
13. If n is greater than or equal to 3, invoke H(4 + 2 * i, 5 + 2 * i, i, r) for i = 0..1.
14. If n is greater than or equal to 4, invoke B(14 - i, 9 + i, 48 + 64 * i, 1, r) for i = 0..1.
15. If n is greater than or equal to 5, invoke H(16 + 4 * i + j, 19 + 4 * i - j, i & 1, r) for i = 0..3, for j = 0..1.
16. If n is equal to 6, invoke B(61 - i * 8 - j, 34 + i * 8 + j, 56 - i * 32 + (j >> 1) * 64, 1, r) for i = 0..1, for j = 0..3.
17. Invoke H(i, 3 - i, 0, r) for i = 0..1.
18. If n is greater than or equal to 3, invoke B(6, 5, 32, 1, r).
19. If n is greater than or equal to 4, invoke H(8 + 4 * i + j, 11 + 4 * i - j, i, r) for i = 0..1, for j = 0..1.
20. If n is greater than or equal to 5, invoke B(29 - i, 18 + i, 48 + (i >> 1) * 64, 1, r) for i = 0..3.
21. If n is equal to 6, invoke H(32 + 8 * i + j, 39 + 8 * i - j, i & 1, r) for i = 0..3, for j = 0..3.
22. If n is greater than or equal to 3, invoke H(i, 7 - i, 0, r) for i = 0..3.

23. If n is greater than or equal to 4, invoke B(13 - i, 10 + i, 32, 1, r) for i = 0..1.
24. If n is greater than or equal to 5, invoke H(16 + i * 8 + j, 23 + i * 8 - j, i, r) for i = 0..1, for j = 0..3.
25. If n is equal to 6, invoke B(59 - i, 36 + i, i < 4 ? 48 : 112, 1, r) for i = 0..7.
26. If n is greater than or equal to 4, invoke H(i, 15 - i, 0, r) for i = 0..7.
27. If n is greater than or equal to 5, invoke B(27 - i, 20 + i, 32, 1, r) for i = 0..3.
28. If n is equal to 6, the following steps apply for i = 0..7:
    - Invoke H(32 + i, 47 - i, 0, r).
    - Invoke H(48 + i, 63 - i, 1, r).
29. If n is greater than or equal to 5, invoke H(i, 31 - i, 0, r) for i = 0..15.
30. If n is equal to 6, invoke B(55 - i, 40 + i, 32, 1, r) for i = 0..7.
31. If n is equal to 6, invoke H(i, 63 - i, 0, r) for i = 0..31.

7.13.2.4. Inverse ADST input array permutation process

This process performs the in-place permutation of the array T of length 2^n which is required as the first step of the inverse ADST, where $3 \le n \le 4$.

The input to this process is a variable n that specifies the base 2 logarithm of the length of the input array.

The variable n0 is set equal to 1 << n.

A temporary array named copyT is set equal to T.

The following steps apply for i = 0..(n0-1):

- The variable idx is set equal to (i & 1) ? (i - 1) : (n0 - i - 1).
- T[i] is set equal to copyT[idx].

7.13.2.5. Inverse ADST output array permutation process

This process performs the in-place permutation of the array T of length 2^n which is required before the final step of the inverse ADST, where $3 \le n \le 4$.

The input to this process is a variable n that specifies the base 2 logarithm of the length of the input array.

The variable n0 is set equal to 1 << n.

A temporary array named copyT is set equal to T.

The following steps apply for i = 0..(n0-1):

- The variable a is set equal to ((i >> 3) & 1).
- The variable b is set equal to ((i >> 2) & 1) ^ ((i >> 3) & 1).
- The variable c is set equal to ((i >> 1) & 1) ^ ((i >> 2) & 1).
- The variable d is set equal to (i & 1) ^ ((i >> 1) & 1).
- The variable idx is set equal to ((d << 3) | (c << 2) | (b << 1) | a) >> (4 - n).
- T[i] is set equal to (i & 1) ? (- copyT[idx]) : copyT[idx].

7.13.2.6. Inverse ADST4 process

This process performs an in-place inverse ADST process on the array T of size 4.

The input to this process is a variable r, specifying the intermediate clamping range.

The following applies:

```
s[ 0 ] = SINPI_1_9 * T[ 0 ]
s[ 1 ] = SINPI_2_9 * T[ 0 ]
s[ 2 ] = SINPI_3_9 * T[ 1 ]
s[ 3 ] = SINPI_4_9 * T[ 2 ]
s[ 4 ] = SINPI_1_9 * T[ 2 ]
s[ 5 ] = SINPI_2_9 * T[ 3 ]
s[ 6 ] = SINPI_4_9 * T[ 3 ]
a7 = T[ 0 ] - T[ 2 ]
b7 = a7 + T[ 3 ]

s[ 0 ] = s[ 0 ] + s[ 3 ]
s[ 1 ] = s[ 1 ] - s[ 4 ]
s[ 3 ] = s[ 2 ]
s[ 2 ] = SINPI_3_9 * b7

s[ 0 ] = s[ 0 ] + s[ 5 ]
s[ 1 ] = s[ 1 ] - s[ 6 ]

x[ 0 ] = s[ 0 ] + s[ 3 ]
x[ 1 ] = s[ 1 ] + s[ 3 ]
x[ 2 ] = s[ 2 ]
x[ 3 ] = s[ 0 ] + s[ 1 ]

x[ 3 ] = x[ 3 ] - s[ 3 ]

T[ 0 ] = Round2( x[ 0 ], 12 )
T[ 1 ] = Round2( x[ 1 ], 12 )
T[ 2 ] = Round2( x[ 2 ], 12 )
T[ 3 ] = Round2( x[ 3 ], 12 )
```

where the constants used are defined as follows:

Symbol	Value
SINPI_1_9	1321
SINPI_2_9	2482
SINPI_3_9	3344
SINPI_4_9	3803

It is a requirement of bitstream conformance that all values stored in the s and x arrays by this process are representable by a signed integer using r + 12 bits of precision.

It is a requirement of bitstream conformance that values stored in the variable a7 by this process are representable by a signed integer using r + 1 bits of precision.

It is a requirement of bitstream conformance that values stored in the variable b7 by this process are representable by a signed integer using r bits of precision.

7.13.2.7. Inverse ADST8 process

This process performs an in-place inverse ADST process on the array T of size 8.

The input to this process is a variable r, specifying the intermediate clamping range.

The following ordered steps apply:

1. Invoke the ADST input array permutation process specified in section 7.13.2.4 with the input variable n set to 3.
2. Invoke B(2 * i, 2 * i + 1, 60 - 16 * i, 1, r) for i = 0..3.
3. Invoke H(i, 4 + i, 0, r) for i = 0..3.
4. Invoke B(4 + 3 * i, 5 + i, 48 - 32 * i, 1, r) for i = 0..1.
5. Invoke H(4 * j + i, 2 + 4 * j + i, 0, r) for i = 0..1, for j = 0..1.
6. Invoke B(2 + 4 * i, 3 + 4 * i, 32, 1, r) for i = 0..1.
7. Invoke the ADST output array permutation process specified in section 7.13.2.5 with the input variable n set to 3.

7.13.2.8. Inverse ADST16 process

This process performs an in-place inverse ADST process on the array T of size 16.

The input to this process is a variable r, specifying the intermediate clamping range.

The following ordered steps apply:

1. Invoke the ADST input array permutation process specified in section 7.13.2.4 with the input variable n set to 4.
2. Invoke B(2 * i, 2 * i + 1, 62 - 8 * i, 1, r) for i = 0..7.
3. Invoke H(i, 8 + i, 0, r) for i = 0..7.
4. Invoke B(8 + 2 * i, 9 + 2 * i, 56 - 32 * i, 1, r) and B(13 + 2 * i, 12 + 2 * i, 8 + 32 * i, 1, r) for i = 0..1.
5. Invoke H(8 * j + i, 4 + 8 * j + i, 0, r) for i = 0..3, for j = 0..1.
6. Invoke B(4 + 8 * j + 3 * i, 5 + 8 * j + i, 48 - 32 * i, 1, r) for i = 0..1, for j = 0..1.
7. Invoke H(4 * j + i, 2 + 4 * j + i, 0, r) for i = 0..1, for j = 0..3.
8. Invoke B(2 + 4 * i, 3 + 4 * i, 32, 1, r) for i = 0..3.
9. Invoke the ADST output array permutation process specified in section 7.13.2.5 with the input variable n set to 4.

7.13.2.9. Inverse ADST process

This process performs an in-place inverse ADST process on the array T of size 2^n for $2 \le n \le 4$.

The inputs to this process are:

- a variable n that specifies the base 2 logarithm of the length of the input array.
- a variable r that specifies the intermediate clamping range.

The following steps apply:

- If n is equal to 2, invoke the inverse ADST4 process in section 7.13.2.6, with the input variable r.
- Otherwise, if n is equal to 3, invoke the inverse ADST8 process in section 7.13.2.7, with the input variable r.
- Otherwise (n is equal to 4), invoke the inverse ADST16 process in section 7.13.2.8, with the input variable r.

7.13.2.10. Inverse Walsh-Hadamard transform process

The input to this process is a variable shift that specifies the amount of pre-scaling.

This process does an in-place transform of the array T (of length 4) by the following ordered steps:

```
a = T[ 0 ] >> shift
c = T[ 1 ] >> shift
d = T[ 2 ] >> shift
b = T[ 3 ] >> shift
a += c
d -= b
e = (a - d) >> 1
b = e - b
c = e - c
a -= b
d += c
T[ 0 ] = a
T[ 1 ] = b
T[ 2 ] = c
T[ 3 ] = d
```

7.13.2.11. Inverse identity transform 4 process

The process does an in-place transform of the array T (of length 4) by the following calculation for i = 0..3:

```
T[ i ] = Round2( T[ i ] * 5793, 12 )
```

7.13.2.12. Inverse identity transform 8 process

The process does an in-place transform of the array T (of length 8) by the following calculation for i = 0..7:

```
T[ i ] = T[ i ] * 2
```

7.13.2.13. Inverse identity transform 16 process

The process does an in-place transform of the array T (of length 16) by the following calculation for i = 0..15:

```
T[ i ] = Round2( T[ i ] * 11586, 12 )
```

7.13.2.14. Inverse identity transform 32 process

The process does an in-place transform of the array T (of length 32) by the following calculation for i = 0..31:

```
T[ i ] = T[ i ] * 4
```

7.13.2.15. Inverse identity transform process

This process performs an in-place identity transform process (with a size-dependent scaling factor) on the array T of size 2^n for $2 \le n \le 5$.

The input to this process is a variable n that specifies the base 2 logarithm of the length of the input array.

The process to invoke depends on n as follows:

- If n is equal to 2, invoke the inverse identity transform 4 process in section 7.13.2.11.
- Otherwise, if n is equal to 3, invoke the inverse identity transform 8 process in section 7.13.2.12.
- Otherwise, if n is equal to 4, invoke the inverse identity transform 16 process in section 7.13.2.13.
- Otherwise (n is equal to 5), invoke the inverse identity transform 32 process in section 7.13.2.14.

7.13.3. 2D inverse transform process

This process performs a 2D inverse transform for an array of coefficients stored in the 2D array Dequant. The output is placed in the 2D array Residual.

The input to this process is a variable txSz that specifies the transform size.

Set the variable log2W equal to Tx_Width_Log2[txSz].

Set the variable log2H equal to Tx_Height_Log2[txSz].

Set the variable w equal to 1 << log2W.

Set the variable h equal to 1 << log2H.

Set the variable rowShift equal to Lossless ? 0 : Transform_Row_Shift[txSz].

Set the variable colShift equal to Lossless ? 0 : 4.

Set the variable rowClampRange equal to BitDepth + 8.

Set the variable colClampRange equal to Max(BitDepth + 6, 16).

The row transforms with i = 0..(h-1) are applied as follows:

- T[j] is derived as follows for j = 0..(w-1):
    - If i and j are both less than 32, T[j] is set equal to Dequant[i][j].
    - Otherwise, T[j] is set equal to 0.
- If Abs(log2W - log2H) is equal to 1, T[j] is set equal to Round2(T[j] * 2896, 12) for j = 0..(w-1).
- If Lossless is equal to 1, invoke the Inverse WHT process as specified in section 7.13.2.10 with shift equal to 2.
- Otherwise, if PlaneTxType is equal to one of DCT_DCT, ADST_DCT, FLIPADST_DCT or H_DCT, invoke the inverse DCT process as specified in section 7.13.2.3 with the input variable n equal to log2W and the input variable r equal to rowClampRange.
- Otherwise, if PlaneTxType is equal to one of DCT_ADST, ADST_ADST, DCT_FLIPADST, FLIPADST_FLIPADST, ADST_FLIPADST, FLIPADST_ADST, H_ADST, or H_FLIPADST, invoke the inverse ADST process as specified in section 7.13.2.9 with input variable n equal to log2W and the input variable r equal to rowClampRange.
- Otherwise, invoke the inverse identity transform process specified in section 7.13.2.15 with the input variable n equal to log2W.
- Set Residual[i][j] equal to Round2(T[j], rowShift) for j = 0..(w-1).

Between the row and column transforms, Residual[i][j] is set equal to Clip3(- (1 << (colClampRange - 1)), (1 << (colClampRange - 1)) - 1, Residual[i][j]) for i = 0..(h-1), for j = 0..(w-1).

The column transforms with j = 0..(w-1) are applied as follows:

- Set T[i] equal to Residual[i][j] for i = 0..(h-1).
- If Lossless is equal to 1, invoke the Inverse WHT process as specified in section 7.13.2.10 with shift equal to 0.
- Otherwise, if PlaneTxType is equal to one of DCT_DCT, DCT_ADST, DCT_FLIPADST or V_DCT, invoke the inverse DCT process as specified in section 7.13.2.3 with the input variable n equal to log2H and the input variable r equal to colClampRange.

- Otherwise, if PlaneTxType is equal to one of ADST_DCT, ADST_ADST, FLIPADST_DCT, FLIPADST_FLIPADST, ADST_FLIPADST, FLIPADST_ADST, V_ADST, or V_FLIPADST, invoke the inverse ADST process as specified in section 7.13.2.9 with input variable n equal to log2H and the input variable r equal to colClampRange.
- Otherwise, invoke the inverse identity transform process specified in section 7.13.2.15 with the input variable n equal to log2H.
- Residual[i][j] is set equal to Round2(T[i], colShift) for i = 0..(h-1).

where Transform_Row_Shift is defined as:

```
Transform_Row_Shift[ TX_SIZES_ALL ] = {
  0, 1, 2, 2, 2, 0, 0, 1, 1,
  1, 1, 1, 1, 1, 1, 2, 2, 2, 2
}
```

7.14. Loop filter process

7.14.1. General

Input to this process is the array CurrFrame of reconstructed samples.

Output from this process is a modified array CurrFrame containing deblocked samples.

The purpose of the loop filter is to eliminate (or at least reduce) visually objectionable artifacts associated with the semi-independence of the coding of super blocks and their constituent sub-blocks.

The loop filter is applied on all vertical boundaries followed by all horizontal boundaries as follows:

```
for ( plane = 0; plane < NumPlanes; plane++ ) {
    if ( plane == 0 ||
         loop_filter_level[ 1 + plane ] ) {
        for ( pass = 0; pass < 2; pass++ ) {
            rowStep = ( plane == 0 ) ? 1 : ( 1 << subsampling_y )
            colStep = ( plane == 0 ) ? 1 : ( 1 << subsampling_x )
            for ( row = 0; row < MiRows; row += rowStep )
                for ( col = 0; col < MiCols; col += colStep )
                    loop_filter_edge( plane, pass, row, col )
        }
    }
}
```

When the function loop_filter_edge is called, the edge loop filter process specified in section 7.14.2 is invoked with the variables plane, pass, row, and col as inputs.

Note: The loop filter is an integral part of the decoding process, in that the results of loop filtering are used in the prediction of subsequent frames.

Note: The loop filtering is designed so that any order of filtering for the edges will give identical results, provided that the vertical boundaries are filtered before the horizontal boundaries.

7.14.2. Edge loop filter process

The inputs to this process are:

- a variable plane specifying whether the process is filtering Y, U, or V samples,
- a variable pass specifying the direction of the edges. pass equal to 0 means the process is filtering vertical block boundaries, and pass equal to 1 means the process is filtering horizontal block boundaries,
- variables row and col specifying the location of the edge in units of 4x4 blocks in the luma plane.

The outputs of this process are modified values in the array CurrFrame.

The variables subX and subY describing the subsampling of the current plane are derived as follows:

- If plane is equal to 0, subX and subY are set equal to 0.
- Otherwise (plane is not equal to 0), subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The variables dx and dy are derived as follows:

- If pass is equal to 0, then dx is set equal to 1, dy is set equal to 0.
- Otherwise (pass is equal to 1), dy is set equal to 1, dx is set equal to 0.

dx and dy specify the offset between the samples to be filtered.

The variable x is set equal to col * MI_SIZE.

The variable y is set equal to row * MI_SIZE.

x and y contain the location in luma coordinates.

The variables row and col are adjusted as follows:

- row is set equal to (row | subY)
- col is set equal to (col | subX)

The variable onScreen (equal to 1 if the samples on both sides of the boundary lie in the visible area) is derived as follows:

- If x is greater than or equal to FrameWidth, onScreen is set equal to 0.
- Otherwise, if y is greater than or equal to FrameHeight, onScreen is set equal to 0.
- Otherwise, if pass is equal to 0 and x is equal to 0, onScreen is set equal to 0.
- Otherwise, if pass is equal to 1 and y is equal to 0, onScreen is set equal to 0.
- Otherwise, onScreen is set equal to 1.

If onScreen is equal to 0, then this process immediately returns and no filtering is applied to this edge.

The variables xP and yP (containing the location in the current plane) are derived as follows:

- Set xP equal to x >> subX
- Set yP equal to y >> subY

The variables prevRow and prevCol (containing the location of the mode info block on the other side of the boundary) are derived as follows:

- Set prevRow equal to row - (dy << subY)
- Set prevCol equal to col - (dx << subX)

Set the variable MiSize equal to MiSizes[row][col].

Set the variable txSz equal to LoopfilterTxSizes[plane][row >> subY][col >> subX].

Set the variable planeSize equal to get_plane_residual_size(MiSize, plane)

Set the variable skip equal to Skips[row][col].

Set the variable isIntra equal to RefFrames[row][col][0] <= INTRA_FRAME.

Set the variable prevTxSz equal to LoopfilterTxSizes[plane][prevRow >> subY][prevCol >> subX].

The variable isBlockEdge (equal to 1 if the samples cross a prediction block edge) is derived as follows:

- If pass is equal to 0 and xP is an exact multiple of Block_Width[planeSize], isBlockEdge is set equal to 1.
- Otherwise, if pass is equal to 1 and yP is an exact multiple of Block_Height[planeSize], isBlockEdge is set equal to 1.
- Otherwise, isBlockEdge is set equal to 0.

The variable isTxEdge (equal to 1 if the samples cross a transform block edge) is derived as follows:

- If pass is equal to 0 and xP is an exact multiple of Tx_Width[txSz], isTxEdge is set equal to 1.

- Otherwise, if pass is equal to 1 and yP is an exact multiple of Tx_Height[txSz], isTxEdge is set equal to 1.
- Otherwise, isTxEdge is set equal to 0.

The variable applyFilter (equal to 1 if the samples are filtered) is derived as follows:

- If isTxEdge is equal to 0, applyFilter is set equal to 0.
- Otherwise, if isBlockEdge is equal to 1 or skip is equal to 0 or isIntra is equal to 1, applyFilter is set equal to 1.
- Otherwise applyFilter is set equal to 0.

The filter size process specified in section 7.14.3 is invoked with the inputs txSz, prevTxSz, pass, and plane, and the output assigned to the variable filterSize (containing the maximum filter size that can be used).

The adaptive filter strength process specified in section 7.14.4 is invoked with the inputs row, col, plane, and pass, and the output assigned to the variables lvl, limit, blimit, and thresh.

If lvl is equal to 0, the adaptive filter strength process specified in section 7.14.4 is invoked with the inputs prevRow, prevCol, plane, and pass, and the output assigned to the variables lvl, limit, blimit, and thresh.

For the variable i taking values from 0 to MI_SIZE - 1, the following applies:

- If applyFilter is equal to 1 and lvl is greater than zero, the sample filtering process specified in section 7.14.6 is invoked with the input variable x set equal to xP + dy * i, the input variable y set equal to yP + dx * i, and the variables plane, limit, blimit, thresh, dx, dy, and filterSize supplied as inputs.

Note: the vector (dx,dy) represents the direction of the filter, while (dy,dx) represents the direction of the boundary.

7.14.3. Filter size process

The inputs to this process are:

- a variable txSz specifying the size of the transform block,
- a variable prevTxSz specifying the size of the transform block on the other side of the boundary,
- a variable pass specifying the direction of the edges,
- a variable plane specifying whether the process is filtering Y, U, or V samples.

The output of this process is the variable filterSize containing the maximum filter size that can be used in samples.

The purpose of this process is to reduce the width of the chroma filters and to ensure that different boundaries can be filtered in parallel.

The variable baseSize is derived as follows:

- If pass is equal to 0, baseSize is set equal to Min(Tx_Width[prevTxSz], Tx_Width[txSz]),
- Otherwise (pass is equal to 1), baseSize is set equal to Min(Tx_Height[prevTxSz], Tx_Height[txSz]).

The output variable filterSize is derived as follows:

- If plane is equal to 0, filterSize is set equal to Min(16, baseSize),
- Otherwise, (plane is greater than 0), filterSize is set equal to Min(8, baseSize).

7.14.4. Adaptive filter strength process

The inputs to this process are:

- the variables row and col specifying the luma location in units of 4x4 blocks,
- the variable plane specifying whether the process is filtering Y, U or V samples,
- the variable pass specifying the direction of the edge being filtered. pass equal to 0 means the process is filtering vertical block boundaries, and pass equal to 1 means the process is filtering horizontal block boundaries.

The outputs of this process are the variables lvl, limit, blimit, and thresh.

The output variable lvl is derived as follows:

- The variable segment is set equal to SegmentIds[row][col].
- The variable ref is set equal to RefFrames[row][col][0].
- The variable mode is set equal to YModes[row][col].
- The variable modeType is derived as follows:
    1. If mode is greater than or equal to NEARESTMV, and not equal to GLOBALMV, and not equal to GLOBAL_GLOBALMV, modeType is set equal to 1.
    2. Otherwise (if mode is an intra type or GLOBALMV or GLOBAL_GLOBALMV), modeType is set equal to 0.
- The variable deltaLF is derived as follows:
    1. If delta_lf_multi is equal to 0, deltaLF is set equal to DeltaLFs[row][col][0].
    2. Otherwise (delta_lf_multi is equal to 1), deltaLF is set equal to DeltaLFs[row][col][(plane == 0) ? pass : (plane + 1)].
- The adaptive filter strength selection process specified in section 7.14.5 is invoked, with segment, ref, modeType, deltaLF, plane, and pass as inputs, and the output being the output variable lvl.

The variable shift is derived as follows:

- If loop_filter_sharpness is greater than 4, shift is set equal to 2.
- Otherwise, if loop_filter_sharpness is greater than 0, shift is set equal to 1.
- Otherwise, shift is set equal to 0.

The output variable limit is derived as follows:

- If loop_filter_sharpness is greater than 0, limit is set equal to Clip3(1, 9 - loop_filter_sharpness, lvl >> shift).
- Otherwise, limit is set equal to Max(1, lvl >> shift).

The output variable blimit is set equal to 2 * (lvl + 2) + limit.

The output variable thresh is set equal to lvl >> 4.

7.14.5. Adaptive filter strength selection process

The inputs to this process are:

- The variable segment, specifying the current segment id,
- The variable ref, specifying the reference frame type (INTRA_FRAME, LAST_FRAME, etc.),
- The variable modeType, specifying the loop filter mode type,
- The variable deltaLF, specifying the loop filter delta value,
- The variable plane, specifying whether the process is filtering Y, U or V samples,
- The variable pass, specifying the direction of the edge being filtered. pass equal to 0 means the process is filtering vertical block boundaries, and pass equal to 1 means the process is filtering horizontal block boundaries.

The output of this process is a filter strength level.

This process is invoked to select a loop filter strength level.

The variable i is set equal to (plane == 0) ? pass : (plane + 1).

The variable baseFilterLevel is set equal to Clip3(0, MAX_LOOP_FILTER, deltaLF + loop_filter_level[i]).

The following ordered steps apply:

1. The variable lvlSeg is set equal to baseFilterLevel.
2. The variable feature is set equal to SEG_LVL_ALT_LF_Y_V + i.
3. If seg_feature_active_idx(segment, feature) is equal to 1 the following ordered steps apply:

a. lvlSeg is set equal to FeatureData[segment][feature] + lvlSeg.

b. lvlSeg is set equal to Clip3(0, MAX_LOOP_FILTER, lvlSeg).

4. If loop_filter_delta_enabled is equal to 1, then the following ordered steps apply:

   a. The variable nShift is set equal to lvlSeg >> 5.

   b. If ref is equal to INTRA_FRAME, then lvlSeg is set equal to lvlSeg + (loop_filter_ref_deltas[INTRA_FRAME] << nShift).

   c. Otherwise, if ref is not equal to INTRA_FRAME, then lvlSeg is set equal to lvlSeg + (loop_filter_ref_deltas[ref] << nShift) + (loop_filter_mode_deltas[modeType] << nShift).

   d. lvlSeg is set equal to Clip3(0, MAX_LOOP_FILTER, lvlSeg).

5. Return lvlSeg.

7.14.6. Sample filtering process

7.14.6.1. General

The inputs to this process are:

- variables x and y specifying the location within CurrFrame[plane],
- a variable plane specifying whether the block is the Y, U or V plane,
- variables limit, blimit, thresh that specify the strength of the filtering operation,
- variables dx and dy specifying the direction perpendicular to the edge being filtered,
- a variable filterSize of specifying the maximum size of filter allowed.

The outputs of this process are modified values in the array CurrFrame.

First the filter mask process specified in section 7.14.6.2 is invoked with the inputs x, y, plane, limit, blimit, thresh, dx, dy, and filterSize, and the output is assigned to the variables hevMask, filterMask, flatMask, and flatMask2.

Then the appropriate filter process is invoked with the inputs x, y, plane, dx, dy as follows:

- If filterMask is equal to 0, no filter is invoked.
- Otherwise, if filterSize is equal to 4 or flatMask is equal to 0, the narrow filter process specified in section 7.14.6.3 is invoked with the additional input variable hevMask.
- Otherwise, if filterSize is equal to 8 or flatMask2 is equal to 0, the wide filter process specified in section 7.14.6.4 is invoked with the additional input variable log2Size set to 3.

- Otherwise, the wide filter process specified in section 7.14.6.4 is invoked with the additional input variable log2Size set to 4.

7.14.6.2. Filter mask process

The inputs to this process are:

- variables x and y specifying the location within CurrFrame[plane],
- a variable plane specifying whether the block is the Y, U or V plane,
- variables limit, blimit, thresh that specify the strength of the filtering operation,
- variables dx and dy specifying the direction perpendicular to the edge being filtered,
- a variable filterSize of specifying the maximum size of filter allowed.

The outputs from this process are the variables:

- hevMask,
- filterMask,
- flatMask, (only used if filterSize >= 8),
- flatMask2 (only used if filterSize >= 16).

The values output for these masks depend on the differences between samples on either side of the specified boundary. These samples are specified as follows:

```
q0 = CurrFrame[ plane ][ y ][ x ]
q1 = CurrFrame[ plane ][ y + dy     ][ x + dx     ]
q2 = CurrFrame[ plane ][ y + dy * 2 ][ x + dx * 2 ]
q3 = CurrFrame[ plane ][ y + dy * 3 ][ x + dx * 3 ]
q4 = CurrFrame[ plane ][ y + dy * 4 ][ x + dx * 4 ]
q5 = CurrFrame[ plane ][ y + dy * 5 ][ x + dx * 5 ]
q6 = CurrFrame[ plane ][ y + dy * 6 ][ x + dx * 6 ]
p0 = CurrFrame[ plane ][ y - dy     ][ x - dx     ]
p1 = CurrFrame[ plane ][ y - dy * 2 ][ x - dx * 2 ]
p2 = CurrFrame[ plane ][ y - dy * 3 ][ x - dx * 3 ]
p3 = CurrFrame[ plane ][ y - dy * 4 ][ x - dx * 4 ]
p4 = CurrFrame[ plane ][ y - dy * 5 ][ x - dx * 5 ]
p5 = CurrFrame[ plane ][ y - dy * 6 ][ x - dx * 6 ]
p6 = CurrFrame[ plane ][ y - dy * 7 ][ x - dx * 7 ]
```

Note: Samples q4, q5, q6, p4, p5, and p6 are only used if filterSize is equal to 16.

The value of hevMask indicates whether the sample has high edge variance. It is calculated as follows:

```
hevMask = 0
threshBd = thresh << (BitDepth - 8)
hevMask |= (Abs( p1 - p0 ) > threshBd)
hevMask |= (Abs( q1 - q0 ) > threshBd)
```

The variable filterLen, representing the number of taps each side of the central sample in the filter, is derived as follows:

- If filterSize is equal to 4, filterLen is set equal to 4.
- Otherwise, if plane is not equal to 0, filterLen is set equal to 6.
- Otherwise, if filterSize is equal to 8, filterLen is set equal to 8.
- Otherwise, filterLen is set equal to 16.

The value of filterMask indicates whether adjacent samples close to the edge (within four samples either side of the specified boundary) vary by less than the limits given by limit and blimit. It is used to determine if any filtering should occur and is calculated as follows:

```
limitBd = limit << (BitDepth - 8)
blimitBd = blimit << (BitDepth - 8)
mask = 0
mask |= (Abs( p1 - p0 ) > limitBd)
mask |= (Abs( q1 - q0 ) > limitBd)
mask |= (Abs( p0 - q0 ) * 2 + Abs( p1 - q1 ) / 2 > blimitBd)
if ( filterLen >= 6 ) {
    mask |= (Abs( p2 - p1 ) > limitBd)
    mask |= (Abs( q2 - q1 ) > limitBd)
}
if ( filterLen >= 8 ) {
    mask |= (Abs( p3 - p2 ) > limitBd)
    mask |= (Abs( q3 - q2 ) > limitBd)
}
filterMask = (mask == 0)
```

The value of flatMask is only required when filterSize >= 8. It measures whether samples from each side of the specified boundary are in a flat region. That is whether those samples are at most (1 << (BitDepth - 8)) different from the sample on the boundary. It is calculated as follows:

```
thresholdBd = 1 << (BitDepth - 8)
if ( filterSize >= 8 ) {
    mask = 0
    mask |= (Abs( p1 - p0 ) > thresholdBd)
    mask |= (Abs( q1 - q0 ) > thresholdBd)
    mask |= (Abs( p2 - p0 ) > thresholdBd)
    mask |= (Abs( q2 - q0 ) > thresholdBd)
    if ( filterLen >= 8 ) {
        mask |= (Abs( p3 - p0 ) > thresholdBd)
        mask |= (Abs( q3 - q0 ) > thresholdBd)
    }
    flatMask = (mask == 0)
}
```

The value of flatMask2 is only required when filterSize >= 16. It measures whether at least seven samples from each side of the specified boundary are in a flat region assuming the first four on each side are (so the full region is flat if flatMask & flatMask2 == 0). The value of flatMask2 is calculated as follows:

```
thresholdBd = 1 << (BitDepth - 8)
if ( filterSize >= 16 ) {
    mask = 0
    mask |= (Abs( p6 - p0 ) > thresholdBd)
    mask |= (Abs( q6 - q0 ) > thresholdBd)
    mask |= (Abs( p5 - p0 ) > thresholdBd)
    mask |= (Abs( q5 - q0 ) > thresholdBd)
    mask |= (Abs( p4 - p0 ) > thresholdBd)
    mask |= (Abs( q4 - q0 ) > thresholdBd)
    flatMask2 = (mask == 0)
}
```

7.14.6.3. Narrow filter process

The inputs to this filter are:

- a variable hevMask specifying whether this is a high edge variance case,
- variables x, y specifying the location within CurrFrame[plane],
- a variable plane specifying whether the block is the Y, U or V plane,
- variables dx and dy specifying the direction perpendicular to the edge being filtered.

This process modifies up to two samples on each side of the specified boundary depending on the value of hevMask as follows:

- If hevMask is equal to 0 (i.e. the samples do not have high edge variance), this process modifies two samples on each side of the specified boundary, using a filter constructed from just the inner two (one from each side of the specified boundary).
- Otherwise (the samples do have high edge variance), this process only modifies the one value on each side of the specified boundary, using a filter constructed from four input samples (two from each side of the specified boundary).

The process subtracts 0x80 << (BitDepth - 8) from the input sample values so that they are in the range -(1 << (BitDepth - 1)) to (1 << (BitDepth - 1)) - 1 inclusive. Intermediate values are made to be in this range by the following function:

```
filter4_clamp( value ) {
    return Clip3( -(1 << (BitDepth - 1)), (1 << (BitDepth - 1)) - 1, value )
}
```

The process is specified as follows:

```
q0 = CurrFrame[ plane ][ y ][ x ]
q1 = CurrFrame[ plane ][ y + dy ][ x + dx ]
p0 = CurrFrame[ plane ][ y - dy ][ x - dx ]
p1 = CurrFrame[ plane ][ y - dy * 2 ][ x - dx * 2 ]
ps1 = p1 - (0x80 << (BitDepth - 8))
ps0 = p0 - (0x80 << (BitDepth - 8))
qs0 = q0 - (0x80 << (BitDepth - 8))
qs1 = q1 - (0x80 << (BitDepth - 8))
filter = hevMask ? filter4_clamp( ps1 - qs1 ) : 0
filter = filter4_clamp( filter + 3 * (qs0 - ps0) )
filter1 = filter4_clamp( filter + 4 ) >> 3
filter2 = filter4_clamp( filter + 3 ) >> 3
oq0 = filter4_clamp( qs0 - filter1 ) + (0x80 << (BitDepth - 8))
op0 = filter4_clamp( ps0 + filter2 ) + (0x80 << (BitDepth - 8))
CurrFrame[ plane ][ y ][ x ] = oq0
CurrFrame[ plane ][ y - dy ][ x - dx ] = op0
if ( !hevMask ) {
    filter = Round2( filter1, 1 )
    oq1 = filter4_clamp( qs1 - filter ) + (0x80 << (BitDepth - 8))
    op1 = filter4_clamp( ps1 + filter ) + (0x80 << (BitDepth - 8))
    CurrFrame[ plane ][ y + dy ][ x + dx ] = oq1
    CurrFrame[ plane ][ y - dy * 2 ][ x - dx * 2 ] = op1
}
```

7.14.6.4. Wide filter process

The inputs to this filter are:

- variables x, y specifying the the location within CurrFrame[plane],

- a variable plane specifying whether the block is the Y, U or V plane,
- variables dx and dy specifying the direction perpendicular to the edge being filtered,
- a variable log2Size specifying the base 2 logarithm of the number of taps.

This filter is only applied when samples from each side of the boundary are detected to be in a flat region.

The variable n (specifying the number of filter taps on each side of the central sample) is set as follows:

- If log2Size is equal to 4, n is set equal to 6.
- Otherwise if plane is equal to 0, n is set equal to 3.
- Otherwise (log2Size is equal to 3 and plane is greater than 0), n is set equal to 2.

The variable n2 (specifying the number of filter taps equal to 2 on each side of the central sample needed to give a unity DC gain) is set as follows:

- If log2Size is equal to 3 and plane is equal to 0, n2 is set equal to 0.
- Otherwise (log2Size is equal to 4 or plane is greater than 0), n2 is set equal to 1.

This process modifies the samples on each side of the specified boundary by applying a low pass filter as follows:

```
for ( i = -n; i < n; i++ ) {
    t = 0
    for ( j = -n; j <= n; j++ ) {
        p = Clip3( -( n + 1 ), n, i + j )
        tap = ( Abs( j ) <= n2 ) ? 2 : 1
        t += CurrFrame[ plane ][ y + p * dy ][ x + p * dx ] * tap
    }
    F[ i ] = Round2( t, log2Size )
}
for ( i = -n; i < n; i++ )
    CurrFrame[ plane ][ y+i * dy ][ x+i * dx ] = F[ i ]
```

where F is an array with indices from -n to n - 1 used to store the filtered results.

7.15. CDEF process

Input to this process is the array CurrFrame of reconstructed samples.

Output from this process is the array CdefFrame containing deringed samples.

The purpose of CDEF is to perform deringing based on the detected direction of blocks.

CDEF parameters are stored for each 64 by 64 block of luma samples.

The CDEF filter is applied on each 8 by 8 block as follows:

```
step4 = Num_4x4_Blocks_Wide[ BLOCK_8X8 ]
cdefSize4 = Num_4x4_Blocks_Wide[ BLOCK_64X64 ]
cdefMask4 = ~(cdefSize4 - 1)
for ( r = 0; r < MiRows; r += step4 ) {
    for ( c = 0; c < MiCols; c += step4 ) {
          baseR = r & cdefMask4
          baseC = c & cdefMask4
          idx = cdef_idx[ baseR ][ baseC ]
          cdef_block(r, c, idx)
    }
}
```

When the cdef_block function is called, the CDEF block process specified in section 7.15.1 is invoked with r, c, and idx as inputs.

7.15.1. CDEF block process

The inputs to this process are:

- variables r and c specifying the location of an 8x8 block in units of 4x4 blocks in the luma plane,
- a variable idx specifying which set of CDEF parameters to use, or -1 to signal that no filtering should be applied.

The block is first copied to the CdefFrame as follows:

```
startY = r * MI_SIZE
endY = startY + MI_SIZE * 2
startX = c * MI_SIZE
endX = startX + MI_SIZE * 2
for ( y = startY; y < endY; y++ ) {
    for ( x = startX; x < endX; x++ ) {
        CdefFrame[ 0 ][ y ][ x ] = CurrFrame[ 0 ][ y ][ x ]
    }
}
if ( NumPlanes > 1 ) {
    startY >>= subsampling_y
    endY >>= subsampling_y
    startX >>= subsampling_x
    endX >>= subsampling_x
    for ( y = startY; y < endY; y++ ) {
        for ( x = startX; x < endX; x++ ) {
            CdefFrame[ 1 ][ y ][ x ] = CurrFrame[ 1 ][ y ][ x ]
            CdefFrame[ 2 ][ y ][ x ] = CurrFrame[ 2 ][ y ][ x ]
        }
    }
}
```

Note If CDEF filtering turns out to be needed, then the contents of CdefFrame will be overwritten later in this process.

If idx is equal to -1, then the process returns immediately after performing this copy.

The variable coeffShift is set equal to BitDepth - 8.

The variable skip is set equal to (Skips[r][c] && Skips[r + 1][c] && Skips[r][c + 1] && Skips[r + 1][c + 1]).

If skip is equal to 0, the CDEF direction process specified in section 7.15.2 is invoked with r and c as inputs, and the outputs assigned to variables yDir and var.

If skip is equal to 0, the following ordered steps apply:

1. The variable priStr is set equal to cdef_y_pri_strength[idx] << coeffShift.
2. The variable secStr is set equal to cdef_y_sec_strength[idx] << coeffShift.
3. The variable dir is set equal to (priStr == 0) ? 0 : yDir.
4. The variable varStr is set equal to (var >> 6) ? Min(FloorLog2(var >> 6), 12) : 0.
5. The variable priStr is set equal to (var ? (priStr * (4 + varStr) + 8) >> 4 : 0).
6. The variable damping is set equal to CdefDamping + coeffShift.
7. The CDEF filter process specified in section 7.15.3 is invoked with plane equal to 0, r, c, priStr, secStr, damping, and dir as input.
8. If NumPlanes is equal to 1, the process terminates at this point (i.e. filtering is not done for the U and V planes).
9. The variable priStr is set equal to cdef_uv_pri_strength[idx] << coeffShift.
10. The variable secStr is set equal to cdef_uv_sec_strength[idx] << coeffShift.
11. The variable dir is set equal to (priStr == 0) ? 0 : Cdef_Uv_Dir[subsampling_x][subsampling_y][yDir].
12. The variable damping is set equal to CdefDamping + coeffShift - 1.
13. The CDEF filter process specified in section 7.15.3 is invoked with plane equal to 1, r, c, priStr, secStr, damping, and dir as input.
14. The CDEF filter process specified in section 7.15.3 is invoked with plane equal to 2, r, c, priStr, secStr, damping, and dir as input.

Cdef_Uv_Dir is a constant lookup table defined as:

```
Cdef_Uv_Dir[ 2 ][ 2 ][ 8 ] = {
  { {0, 1, 2, 3, 4, 5, 6, 7},
    {1, 2, 2, 2, 3, 4, 6, 0} },
  { {7, 0, 2, 4, 5, 6, 6, 6},
    {0, 1, 2, 3, 4, 5, 6, 7} }
}
```

7.15.2. CDEF direction process

The inputs to this process are variables r and c specifying the location of an 8x8 block in units of 4x4 blocks in the luma plane.

The outputs of this process are:

- a variable yDir containing the direction of this block,
- a variable var containing the variance for this block.

This block uses luma samples to measure the direction and variance of a block.

The process is specified as:

```
for ( i = 0; i < 8; i++ ) {
    cost[i] = 0
    for ( j = 0; j < 15; j++ )
        partial[i][j] = 0
}
bestCost = 0
yDir = 0
x0 = c << MI_SIZE_LOG2
y0 = r << MI_SIZE_LOG2
for ( i = 0; i < 8; i++ ) {
    for ( j = 0; j < 8; j++ ) {
        x = (CurrFrame[ 0 ][y0 + i][x0 + j] >> (BitDepth - 8)) - 128
        partial[0][i + j] += x
        partial[1][i + j / 2] += x
        partial[2][i] += x
        partial[3][3 + i - j / 2] += x
        partial[4][7 + i - j] += x
        partial[5][3 - i / 2 + j] += x
        partial[6][j] += x
        partial[7][i / 2 + j] += x
    }
}
for ( i = 0; i < 8; i++ ) {
    cost[2] += partial[2][i] * partial[2][i]
    cost[6] += partial[6][i] * partial[6][i]
}
cost[2] *= Div_Table[8]
cost[6] *= Div_Table[8]
for ( i = 0; i < 7; i++ ) {
    cost[0] += (partial[0][i] * partial[0][i] +
                partial[0][14 - i] * partial[0][14 - i]) *
               Div_Table[i + 1]
    cost[4] += (partial[4][i] * partial[4][i] +
                partial[4][14 - i] * partial[4][14 - i]) *
               Div_Table[i + 1]
}
cost[0] += partial[0][7] * partial[0][7] * Div_Table[8]
cost[4] += partial[4][7] * partial[4][7] * Div_Table[8]
for ( i = 1; i < 8; i += 2 ) {
    for ( j = 0; j < 4 + 1; j++ ) {
      cost[i] += partial[i][3 + j] * partial[i][3 + j]
    }
    cost[i] *= Div_Table[8]
    for ( j = 0; j < 4 - 1; j++ ) {
        cost[i] += (partial[i][j] * partial[i][j] +
                    partial[i][10 - j] * partial[i][10 - j]) *
                   Div_Table[2 * j + 2]
    }
}
for ( i = 0; i < 8; i++ ) {
```

```
    if ( cost[i] > bestCost ) {
      bestCost = cost[i]
      yDir = i
    }
}
var = (bestCost - cost[(yDir + 4) & 7]) >> 10
```

where the Div_Table is a constant lookup table specified as:

```
Div_Table[9] = {
    0, 840, 420, 280, 210, 168, 140, 120, 105
}
```

7.15.3. CDEF filter process

The inputs to this process are:

- a variable plane specifying which plane is being predicted,
- variables r and c specifying the location of an 8x8 block in units of 4x4 blocks in the luma plane,
- a variable priStr specifying the primary filter strength,
- a variable secStr specifying the secondary filter strength,
- a variable damping specifying a shift used for damping,
- a variable dir specifying the detected direction of the block.

The process modifies samples in CdefFrame based on filtering samples from CurrFrame.

MiColStart, MiRowStart, MiColEnd, MiRowEnd are set equal to the values they had when the syntax element MiSizes[r][c] was written.

> **Note:** These variables are used by the is_inside_filter_region function to determine which samples are available for use in filtering.

The variable coeffShift is set equal to BitDepth - 8.

The filtering is applied as follows:

```
subX = (plane > 0) ? subsampling_x : 0
subY = (plane > 0) ? subsampling_y : 0
x0 = (c * MI_SIZE ) >> subX
y0 = (r * MI_SIZE ) >> subY
w = 8 >> subX
h = 8 >> subY
for ( i = 0; i < h; i++ ) {
    for ( j = 0; j < w; j++ ) {
        sum = 0
        x = CurrFrame[plane][y0 + i][x0 + j]
        max = x
        min = x
        for ( k = 0; k < 2; k++ ) {
            for ( sign = -1; sign <= 1; sign += 2 ) {
                p = cdef_get_at(plane, x0, y0, i, j, dir, k, sign, subX, subY)
                if ( CdefAvailable ) {
                    sum += Cdef_Pri_Taps[(priStr >> coeffShift) & 1][k] * constrain(p - x, priStr,
damping)
                    max = Max(p, max)
                    min = Min(p, min)
                }
                for ( dirOff = -2; dirOff <= 2; dirOff += 4) {
                    s = cdef_get_at(plane, x0, y0, i, j, (dir + dirOff) & 7, k, sign, subX, subY)
                    if ( CdefAvailable ) {
                        sum += Cdef_Sec_Taps[(priStr >> coeffShift) & 1][k] * constrain(s - x,
secStr, damping)
                        max = Max(s, max)
                        min = Min(s, min)
                    }
                }
            }
        }
        CdefFrame[plane][y0 + i][x0 + j] = Clip3(min, max, x + ((8 + sum - (sum < 0)) >> 4) )
    }
}
```

where Cdef_Pri_Taps and Cdef_Sec_Taps are constant lookup tables specified as:

```
Cdef_Pri_Taps[2][2] = {
    { 4, 2 }, { 3, 3 }
}

Cdef_Sec_Taps[2][2] = {
    { 2, 1 }, { 2, 1 }
}
```

constrain is specified as:

```
constrain(diff, threshold, damping) {
    if ( !threshold )
      return 0
    dampingAdj = Max(0, damping - FloorLog2( threshold ) )
    sign = (diff < 0) ? -1 : 1
    return sign * Clip3(0, Abs(diff), threshold - (Abs(diff) >> dampingAdj) )
}
```

cdef_get_at fetches a sample from CurrFrame and sets CdefAvailable according to whether the sample is available. cdef_get_at is specified as:

```
cdef_get_at(plane, x0, y0, i, j, dir, k, sign, subX, subY) {
    y = y0 + i + sign * Cdef_Directions[dir][k][0]
    x = x0 + j + sign * Cdef_Directions[dir][k][1]
    candidateR = (y << subY) >> MI_SIZE_LOG2
    candidateC = (x << subX) >> MI_SIZE_LOG2
    if ( is_inside_filter_region( candidateR, candidateC ) ) {
        CdefAvailable = 1
        return CurrFrame[ plane ][ y ][ x ]
    } else {
        CdefAvailable = 0
        return 0
    }
}
```

where Cdef_Directions is a constant lookup table defined as:

```
Cdef_Directions[8][2][2] = {
  { { -1, 1 }, { -2,  2 } },
  { {  0, 1 }, { -1,  2 } },
  { {  0, 1 }, {  0,  2 } },
  { {  0, 1 }, {  1,  2 } },
  { {  1, 1 }, {  2,  2 } },
  { {  1, 0 }, {  2,  1 } },
  { {  1, 0 }, {  2,  0 } },
  { {  1, 0 }, {  2, -1 } }
}
```

7.16. Upscaling process

Input to this process is an array inputFrame of width FrameWidth and height FrameHeight.

The output of this process is a horizontally upscaled frame of width UpscaledWidth and height FrameHeight.

If use_superres is equal to 0, no upscaling is required and this process returns inputFrame.

This process is specified as:

```
for ( plane = 0; plane < NumPlanes; plane++ ) {
    if ( plane > 0 ) {
        subX = subsampling_x
        subY = subsampling_y
    } else {
        subX = 0
        subY = 0
    }
    downscaledPlaneW = Round2(FrameWidth, subX)
    upscaledPlaneW = Round2(UpscaledWidth, subX)
    planeH = Round2(FrameHeight, subY)
    stepX = ((downscaledPlaneW << SUPERRES_SCALE_BITS) + (upscaledPlaneW / 2)) / upscaledPlaneW
    err = (upscaledPlaneW * stepX) - (downscaledPlaneW << SUPERRES_SCALE_BITS)
    initialSubpelX =
      (-((upscaledPlaneW - downscaledPlaneW) << (SUPERRES_SCALE_BITS - 1)) + upscaledPlaneW / 2) /
upscaledPlaneW +
      (1 << (SUPERRES_EXTRA_BITS - 1)) - err / 2
    initialSubpelX &= SUPERRES_SCALE_MASK
    miW = MiCols >> subX
    minX = 0
    maxX = miW * MI_SIZE - 1
    for ( y = 0; y < planeH; y++ ) {
        for ( x = 0; x < upscaledPlaneW; x++ ) {
            srcX = -(1 << SUPERRES_SCALE_BITS) + initialSubpelX + x*stepX
            srcXPx = (srcX >> SUPERRES_SCALE_BITS)
            srcXSubpel = (srcX & SUPERRES_SCALE_MASK) >> SUPERRES_EXTRA_BITS
            sum = 0
            for ( k = 0; k < SUPERRES_FILTER_TAPS; k++ ) {
                sampleX = Clip3(minX, maxX, srcXPx + (k - SUPERRES_FILTER_OFFSET))
                px = frame[plane][y][sampleX]
                sum += px * Upscale_Filter[srcXSubpel][k]
            }
            outputFrame[plane][y][x] = Clip1(Round2(sum, FILTER_BITS))
        }
    }
}
```

where Upscale_Filter is specified as:

```
Upscale_Filter[SUPERRES_FILTER_SHIFTS][SUPERRES_FILTER_TAPS] = {
  { 0, 0, 0, 128, 0, 0, 0, 0 },        { 0, 0, -1, 128, 2, -1, 0, 0 },
  { 0, 1, -3, 127, 4, -2, 1, 0 },      { 0, 1, -4, 127, 6, -3, 1, 0 },
  { 0, 2, -6, 126, 8, -3, 1, 0 },      { 0, 2, -7, 125, 11, -4, 1, 0 },
  { -1, 2, -8, 125, 13, -5, 2, 0 },    { -1, 3, -9, 124, 15, -6, 2, 0 },
  { -1, 3, -10, 123, 18, -6, 2, -1 },  { -1, 3, -11, 122, 20, -7, 3, -1 },
  { -1, 4, -12, 121, 22, -8, 3, -1 },  { -1, 4, -13, 120, 25, -9, 3, -1 },
  { -1, 4, -14, 118, 28, -9, 3, -1 },  { -1, 4, -15, 117, 30, -10, 4, -1 },
  { -1, 5, -16, 116, 32, -11, 4, -1 }, { -1, 5, -16, 114, 35, -12, 4, -1 },
  { -1, 5, -17, 112, 38, -12, 4, -1 }, { -1, 5, -18, 111, 40, -13, 5, -1 },
  { -1, 5, -18, 109, 43, -14, 5, -1 }, { -1, 6, -19, 107, 45, -14, 5, -1 },
  { -1, 6, -19, 105, 48, -15, 5, -1 }, { -1, 6, -19, 103, 51, -16, 5, -1 },
  { -1, 6, -20, 101, 53, -16, 6, -1 }, { -1, 6, -20, 99, 56, -17, 6, -1 },
  { -1, 6, -20, 97, 58, -17, 6, -1 },  { -1, 6, -20, 95, 61, -18, 6, -1 },
  { -2, 7, -20, 93, 64, -18, 6, -2 },  { -2, 7, -20, 91, 66, -19, 6, -1 },
  { -2, 7, -20, 88, 69, -19, 6, -1 },  { -2, 7, -20, 86, 71, -19, 6, -1 },
  { -2, 7, -20, 84, 74, -20, 7, -2 },  { -2, 7, -20, 81, 76, -20, 7, -1 },
  { -2, 7, -20, 79, 79, -20, 7, -2 },  { -1, 7, -20, 76, 81, -20, 7, -2 },
  { -2, 7, -20, 74, 84, -20, 7, -2 },  { -1, 6, -19, 71, 86, -20, 7, -2 },
  { -1, 6, -19, 69, 88, -20, 7, -2 },  { -1, 6, -19, 66, 91, -20, 7, -2 },
  { -2, 6, -18, 64, 93, -20, 7, -2 },  { -1, 6, -18, 61, 95, -20, 6, -1 },
  { -1, 6, -17, 58, 97, -20, 6, -1 },  { -1, 6, -17, 56, 99, -20, 6, -1 },
  { -1, 6, -16, 53, 101, -20, 6, -1 }, { -1, 5, -16, 51, 103, -19, 6, -1 },
  { -1, 5, -15, 48, 105, -19, 6, -1 }, { -1, 5, -14, 45, 107, -19, 6, -1 },
  { -1, 5, -14, 43, 109, -18, 5, -1 }, { -1, 5, -13, 40, 111, -18, 5, -1 },
  { -1, 4, -12, 38, 112, -17, 5, -1 }, { -1, 4, -12, 35, 114, -16, 5, -1 },
  { -1, 4, -11, 32, 116, -16, 5, -1 }, { -1, 4, -10, 30, 117, -15, 4, -1 },
  { -1, 3, -9, 28, 118, -14, 4, -1 },  { -1, 3, -9, 25, 120, -13, 4, -1 },
  { -1, 3, -8, 22, 121, -12, 4, -1 },  { -1, 3, -7, 20, 122, -11, 3, -1 },
  { -1, 2, -6, 18, 123, -10, 3, -1 },  { 0, 2, -6, 15, 124, -9, 3, -1 },
  { 0, 2, -5, 13, 125, -8, 2, -1 },    { 0, 1, -4, 11, 125, -7, 2, 0 },
  { 0, 1, -3, 8, 126, -6, 2, 0 },      { 0, 1, -3, 6, 127, -4, 1, 0 },
  { 0, 1, -2, 4, 127, -3, 1, 0 },      { 0, 0, -1, 2, 128, -1, 0, 0 },
}
```

It is a requirement of bitstream conformance that upscaledPlaneW is strictly greater than downscaledPlaneW.

The output of this process is equal to outputFrame.

7.17. Loop restoration process

Input to this process are the arrays UpscaledCurrFrame (of reconstructed samples) and UpscaledCdefFrame (of deringed samples).

Output from this process is the array LrFrame of loop restored samples.

> **Note:** Although this process loops over 4x4 blocks, loop restoration is designed to work in stripes 64 luma samples high without needing additional line buffers. Samples within the current stripe are fetched from UpscaledCdefFrame. Samples outside the current stripe are fetched from UpscaledCurrFrame (these samples will be deblocked, but will not have CDEF filtering applied).

The array LrFrame is set equal to a copy of UpscaledCdefFrame. (The contents of LrFrame will later be overwritten for blocks that require restoration filtering.)

If UsesLr is equal to 0, then the process returns immediately after performing this copy.

Otherwise, loop restoration is applied as follows:

```
for ( y = 0; y < FrameHeight; y += MI_SIZE ) {
  for ( x = 0; x < UpscaledWidth; x += MI_SIZE ) {
    for ( plane = 0; plane < NumPlanes; plane++ ) {
      if ( FrameRestorationType[ plane ] != RESTORE_NONE ) {
        row = y >> MI_SIZE_LOG2
        col = x >> MI_SIZE_LOG2
        loop_restore_block( plane, row, col )
      }
    }
  }
}
```

When loop_restore_block is called, the loop restore block process in section 7.17.1 is invoked with plane, row, and col as inputs.

7.17.1. Loop restore block process

The inputs to this process are:

- a variable plane specifying whether the process is filtering Y, U, or V samples,
- variables row and col specifying the location of the block in units of 4x4 blocks in the upscaled luma plane.

The output of this process are samples in LrFrame[plane].

The variable lumaY is set equal to row * MI_SIZE.

The variable stripeNum (specifying the zero-based index of the current stripe) is set equal to (lumaY + 8) / 64.

> **Note:** The stripes are offset upwards by 8 luma samples to make pipelined implementations more efficient. When a row of superblocks has been received, enough rows of deblocked output can be produced to allow loop restoration of the corresponding stripes.

The variables subX and subY are set equal to the subsampling for the current plane as follows:

- If plane is equal to 0, subX is set equal to 0 and subY is set equal to 0.
- Otherwise, subX is set equal to subsampling_x and subY is set equal to subsampling_y.

The variable StripeStartY (specifying the start of the stripe in units of samples in the current plane) is set equal to ((-8 + stripeNum * 64) >> subY).

The variable StripeEndY (specifying the end of the stripe in units of samples in the current plane) is set equal to StripeStartY + (64 >> subY) - 1.

Note: StripeStartY and StripeEndY are used by the get source sample process to decide whether to fetch from UpscaledCurrFrame or UpscaledCdefFrame.

The variable unitSize (specifying the size of restoration units in units of samples in the current plane) is set equal to LoopRestorationSize[plane].

The variable unitRows (specifying the number of restoration units down the frame) is set equal to count_units_in_frame(unitSize, Round2(FrameHeight, subY)).

The variable unitCols (specifying the number of restoration units across the frame) is set equal to count_units_in_frame(unitSize, Round2(UpscaledWidth, subX)).

Note: The number of restoration units in a frame can be different for chroma and luma.

The variable unitRow (specifying the vertical index of the current loop restoration unit) is set equal to Min(unitRows - 1, ((row * MI_SIZE + 8) >> subY) / unitSize).

The variable unitCol (specifying the horizontal index of the current loop restoration unit) is set equal to Min(unitCols - 1, (col * MI_SIZE >> subX) / unitSize).

The horizontal extent of the space allowed for filtering is specified as follows:

The variable PlaneEndX (specifying the horizontal extent of the space allowed for filtering) is set equal to Round2(UpscaledWidth, subX) - 1.

The variable PlaneEndY (specifying the vertical extent of the space allowed for filtering) is set equal to Round2(FrameHeight, subY) - 1.

The variable x is set equal to (col * MI_SIZE >> subX).

The variable y is set equal to (row * MI_SIZE >> subY).

The variable w is set equal to Min(MI_SIZE >> subX, PlaneEndX - x + 1).

The variable h is set equal to Min(MI_SIZE >> subY, PlaneEndY - y + 1).

(Variables x and y represent the position of the block in samples relative to the top-left corner of the current plane. Variables w and h represent the size of the block in samples.)

> **Note:** Although the filter is described as operating on small blocks, the output will be the same if larger blocks are used - provided all contained samples belong to the same loop restoration unit.

The variable rType (specifying the loop restoration type) is set equal to LrType[plane][unitRow][unitCol].

The filter to used depends on rType as follows:

- If rType is equal to RESTORE_WIENER, the Wiener filter process specified in section 7.17.4 is invoked with plane, unitRow, unitCol, x, y, w, and h as inputs.
- Otherwise, if rType is equal to RESTORE_SGRPROJ, the self guided filter process specified in section 7.17.2 is invoked with plane, unitRow, unitCol, x, y, w, and h as inputs.
- Otherwise (rType is equal to RESTORE_NONE), no filtering is applied.

7.17.2. Self guided filter process

The inputs to this block are:

- a variable plane specifying whether the process is filtering Y, U, or V samples,
- variables unitRow and unitCol specifying the position of the loop restoration unit,
- variables x and y specifying the position of the block in samples relative to the top-left corner of the current plane,
- variables w and h specifying the size of the block in samples.

The arrays flt0 and flt1 are prepared by the following ordered steps:

1. The variable set is set equal to LrSgrSet[plane][unitRow][unitCol].
2. The variable pass is set equal to 0.
3. The box filter process specified in section 7.17.3 is invoked with plane, x, y, w, h, set, and pass as inputs, and the output assigned to flt0.
4. The variable pass is set equal to 1.
5. The box filter process specified in section 7.17.3 is invoked with plane, x, y, w, h, set, and pass as inputs, and the output assigned to flt1.

The restoration process is then applied for each sample as follows:

```
w0 = LrSgrXqd[ plane ][ unitRow ][ unitCol ][ 0 ]
w1 = LrSgrXqd[ plane ][ unitRow ][ unitCol ][ 1 ]
w2 = (1 << SGRPROJ_PRJ_BITS) - w0 - w1
r0 = Sgr_Params[ set ][ 0 ]
r1 = Sgr_Params[ set ][ 2 ]
for ( i = 0; i < h; i++ ) {
    for ( j = 0; j < w; j++ ) {
        u = UpscaledCdefFrame[ plane ][ y + i ][ x + j ] << SGRPROJ_RST_BITS
        v = w1 * u
        if ( r0 )
          v += w0 * flt0[ i ][ j ]
        else
          v += w0 * u
        if ( r1 )
          v += w2 * flt1[ i ][ j ]
        else
          v += w2 * u
        s = Round2( v, SGRPROJ_RST_BITS + SGRPROJ_PRJ_BITS )
        LrFrame[ plane ][ y + i ][ x + j ] = Clip1( s )
    }
}
```

7.17.3. Box filter process

The inputs to this process are:

- a variable plane specifying whether the process is filtering Y, U, or V samples,
- variables x and y specifying the position of the block in samples relative to the top-left corner of the current plane,
- variables w and h specifying the size of the block in samples,
- a variable set specifying the strength of the filtering,
- a variable pass (equal to 0 or 1), specifying if the process is generating the first or second filtered output.

The output of this process is a 2d array F.

The variable r (specifying that the box filters have side length 2*r+1) is set equal to Sgr_Params[set][pass * 2 + 0].

If r is equal to 0, then this process immediately terminates.

The variable eps (specifying a scaling for the output) is set equal to Sgr_Params[set][pass * 2 + 1].

The 2d arrays A and B (note these arrays are valid for coordinates including an extra sample around the boundary) are prepared as follows:

```
n = ( 2 * r + 1 ) * ( 2 * r + 1 )
n2e = n * n * eps
s = (((1 << SGRPROJ_MTABLE_BITS) + n2e / 2) / n2e)
for ( i = -1; i < h + 1; i++ ) {
    for ( j = -1; j < w + 1; j++ ) {
        a = 0
        b = 0
        for ( dy = -r ; dy <= r; dy++ ) {
            for ( dx = -r; dx <= r; dx++ ) {
                c = get_source_sample( plane, x + j + dx, y + i + dy )
                a += c * c
                b += c
            }
        }
        a = Round2( a, 2 * (BitDepth - 8) )
        d = Round2( b, BitDepth - 8 )
        p = Max( 0, a * n - d * d )
        z = Round2( p * s, SGRPROJ_MTABLE_BITS )
        if ( z >= 255 )
            a2 = 256
        else if ( z == 0 )
            a2 = 1
        else
            a2 = ((z << SGRPROJ_SGR_BITS) + (z/2)) / (z + 1)
        oneOverN = ((1 << SGRPROJ_RECIP_BITS) + (n/2)) / n
        b2 = ( (1 << SGRPROJ_SGR_BITS) - a2 ) * b * oneOverN
        A[ i ][ j ] = a2
        B[ i ][ j ] = Round2( b2, SGRPROJ_RECIP_BITS )
    }
}
```

Note: When pass is equal to 0, only odd rows (i.e. entries A[i][j] and B[i][j] with i odd) will be used to generate the output.

where the call to get_source_sample specifies that the get source sample process specified in section 7.17.6 should be invoked and the output assigned to variable c.

After A and B are prepared, the output array F is generated as follows:

```
for ( i = 0; i < h; i++ ) {
    shift = 5
    if ( pass == 0 && ( i & 1 ) ) {
        shift = 4
    }
    for ( j = 0; j < w; j++ ) {
        a = 0
        b = 0
        for ( dy = -1 ; dy <= 1; dy++ ) {
            for ( dx = -1; dx <= 1; dx++ ) {
                if ( pass == 0 ) {
                    if ( (i + dy) & 1 ) {
                        weight = (dx == 0) ? 6 : 5
                    } else {
                        weight = 0
                    }
                } else {
                    weight = (dx == 0 || dy == 0) ? 4 : 3
                }
                a += weight * A[ i + dy ][ j + dx ]
                b += weight * B[ i + dy ][ j + dx ]
            }
        }
        v = a * UpscaledCdefFrame[ plane ][ y + i ][ x + j ] + b
        F[ i ][ j ] = Round2( v, SGRPROJ_SGR_BITS + shift - SGRPROJ_RST_BITS)
    }
}
```

Note: When pass is equal to 0, the weights for even rows of A and B are always equal to 0.

The constant lookup table Sgr_Params is specified as:

```
Sgr_Params[ (1 << SGRPROJ_PARAMS_BITS) ][ 4 ] = {
  { 2, 12, 1, 4 },  { 2, 15, 1, 6 },  { 2, 18, 1, 8 },  { 2, 21, 1, 9 },
  { 2, 24, 1, 10 }, { 2, 29, 1, 11 }, { 2, 36, 1, 12 }, { 2, 45, 1, 13 },
  { 2, 56, 1, 14 }, { 2, 68, 1, 15 }, { 0, 0, 1, 5 },   { 0, 0, 1, 8 },
  { 0, 0, 1, 11 },  { 0, 0, 1, 14 },  { 2, 30, 0, 0 },  { 2, 75, 0, 0 }
}
```

7.17.4. Wiener filter process

The inputs to this block are:

- a variable plane specifying whether the process is filtering Y, U, or V samples,
- variables unitRow and unitCol specifying the position of the loop restoration unit,

- variables x and y specifying the position of the block in samples relative to the top-left corner of the current plane,
- variables w and h specifying the size of the block in samples.

The output from this process are modified samples in LrFrame.

The sub-sample interpolation is effected via two one-dimensional convolutions. First a horizontal filter is used to build up a temporary array, and then this array is vertically filtered to obtain the final prediction.

The rounding variables derivation process specified in section 7.11.3.2 is invoked with the input variable isCompound set equal to 0.

The Wiener coefficient process specified in section 7.17.5 is invoked with an input of LrWiener[plane][unitRow][unitCol][0] and the output assigned to vfilter.

The Wiener coefficient process specified in section 7.17.5 is invoked with an input of LrWiener[plane][unitRow][unitCol][1] and the output assigned to hfilter.

> **Note:** The horizontal filter needs to be applied before the vertical filter, but the horizontal coefficients are sent after the vertical coefficients.

The filtering is applied as follows:

- The array intermediate is specified as follows:

```
offset = (1 << (BitDepth + FILTER_BITS - InterRound0 - 1))
limit = (1 << (BitDepth + 1 + FILTER_BITS - InterRound0)) - 1
for ( r = 0; r < h + 6; r++ ) {
    for ( c = 0; c < w; c++ ) {
        s = 0
        for ( t = 0; t < 7; t++ )
            s += hfilter[ t ] * get_source_sample( plane, x + c + t - 3, y + r - 3 )
        v = Round2(s, InterRound0)
        intermediate[ r ][ c ] = Clip3( -offset, limit - offset, v )
    }
}
```

  Where the call to get_source_sample specifies that the get source sample process specified in section 7.17.6 should be invoked.

  > **Note:** The intermediate result is clipped so that (intermediate[r][c] + offset) fits in an unsigned variable with Min(15,BitDepth + 5) bits.

- The output samples are written as follows:

```
for ( r = 0; r < h; r++ ) {
    for ( c = 0; c < w; c++ ) {
        s = 0
        for ( t = 0; t < 7; t++ )
            s += vfilter[ t ] * intermediate[ r + t ][ c ]
        v = Round2( s, InterRound1 )
        LrFrame[ plane ][ y + r ][ x + c ] = Clip1( v )
    }
}
```

7.17.5. Wiener coefficient process

The input to this process is an array coeff containing 3 coefficients.

The output from this process is an an array containing 7 coefficients.

The Wiener filter is always symmetrical and has a unit DC gain, so there are only three coefficients that need to be explicitly coded.

This process computes the full set of coefficients as follows:

```
filter[ 3 ] = 128
for ( i = 0; i < 3; i++ ) {
    c = coeff[ i ]
    filter[ i ] = c
    filter[ 6 - i ] = c
    filter[ 3 ] -= 2 * c
}
```

The output of the process is the array filter.

Note: When chroma is being filtered, coeff[0] will always be equal to 0, therefore filter[0] and filter[6] will always be equal to 0. In other words, luma uses a 7-tap filter, while chroma uses a 5-tap filter.

7.17.6. Get source sample process

The inputs to this process are:

- a variable plane specifying whether the process is filtering Y, U, or V samples,
- variables x and y specifying the location in the current plane in units of samples.

This process makes sure samples are taken from within the allowed extent for loop restoration filtering.

Samples within the current stripe are taken after Cdef filtering has been applied, samples outside the current stripe are taken before Cdef filtering.

The sample to return is specified as follows:

```
x = Min(PlaneEndX, x)
x = Max(0, x)
y = Min(PlaneEndY, y)
y = Max(0, y)
if ( y < StripeStartY ) {
    y = Max(StripeStartY - 2,y)
    return UpscaledCurrFrame[ plane ][ y ][ x ]
} else if ( y > StripeEndY ) {
    y = Min(StripeEndY + 2,y)
    return UpscaledCurrFrame[ plane ][ y ][ x ]
} else {
    return UpscaledCdefFrame[ plane ][ y ][ x ]
}
```

Note: This process can be called for samples on the three lines above and three lines below the current stripe. However, the coordinates are cropped such that only two lines above and below the stripe need to be fetched. In other words, requests for the third line (above or below) are given a copy of the second line.

7.18. Output process

7.18.1. General

This process is invoked to prepare output frames.

If scalability is being used (OperatingPointIdc not equal to 0), an application-specific function is called to decide whether this frame will be output. If this function returns a value equal to 0, then this process terminates immediately.

Note: Applications that are displaying the decoded video are expected to only display one frame from each temporal unit within the selected operating point. This frame should be the highest spatial layer that is both within the operating point and present within the temporal unit. Other applications may set their own policy about which frames are output.

The intermediate output preparation process specified in section 7.18.2 is invoked to prepare arrays OutY, OutU, and OutV, and the outputs are assigned to w, h, subX, and subY.

If film_grain_params_present is equal to 1 and apply_grain is equal to 1, then the film grain synthesis process specified in section 7.18.3 is invoked with inputs of w, h, subX, and subY. (This process modifies the output arrays OutY, OutU, OutV).

Finally, the frame to be output is defined to be the arrays OutY, OutU, OutV where the bit depth for each sample is BitDepth.

This frame to be output is the overall output of the decoding process and further processing (such as color conversion) is outside the scope of this specification.

For example, a real implementation might use these arrays to display the frame to the user, or a test system might save the arrays so the output can be verified.

> **Note:** If NumPlanes is equal to 1, then the U and V planes should be ignored.

7.18.2. Intermediate output preparation process

The output of this process are the variables w, h, subX, and subY describing the format of the data in arrays OutY, OutU, and OutV.

If show_existing_frame is equal to 1, then the decoder should copy OutY, OutU, and OutV from a previously decoded frame as follows:

- The variable w is set equal to RefUpscaledWidth[frame_to_show_map_idx].
- The variable h is set equal to RefFrameHeight[frame_to_show_map_idx].
- The variable subX is set equal to RefSubsamplingX[frame_to_show_map_idx].
- The variable subY is set equal to RefSubsamplingY[frame_to_show_map_idx].
- The array OutY is w samples across by h samples down and the sample at location x samples across and y samples down is given by OutY[y][x] = FrameStore[frame_to_show_map_idx][0][y][x] with x = 0..w - 1 and y = 0..h - 1.
- The array OutU is (w + subX) >> subX samples across by (h + subY) >> subY samples down and the sample at location x samples across and y samples down is given by OutU[y][x] = FrameStore[frame_to_show_map_idx][1][y][x] with x = 0..((w + subX) >> subX) - 1 and y = 0..((h + subY) >> subY) - 1.
- The array OutV is (w + subX) >> subX samples across by (h + subY) >> subY samples down and the sample at location x samples across and y samples down is given by OutV[y][x] = FrameStore[frame_to_show_map_idx][2][x][y] with x = 0..((w + subX) >> subX) - 1 and y = 0..((h + subY) >> subY) - 1.
- The variable BitDepth is set equal to RefBitDepth[frame_to_show_map_idx].
- The bit depth for each sample is BitDepth.

Otherwise (show_existing_frame is equal to 0), then the decoder should copy the current frame as follows:

- The variable w is set equal to UpscaledWidth.

- The variable h is set equal to FrameHeight.
- The variable subX is set equal to subsampling_x.
- The variable subY is set equal to subsampling_y.
- The array OutY is w samples across by h samples down and the sample at location x samples across and y samples down is given by OutY[y][x] = LrFrame[0][y][x] with x = 0..w - 1 and y = 0..h - 1.
- The array OutU is (w + subX) >> subX samples across by (h + subY) >> subY samples down and the sample at location x samples across and y samples down is given by OutU[y][x] = LrFrame[1][y][x] with x = 0..((w + subX) >> subX) - 1 and y = 0..((h + subY) >> subY) - 1.
- The array OutV is (w + subX) >> subX samples across by (h + subY) >> subY samples down and the sample at location x samples across and y samples down is given by OutV[y][x] = LrFrame[2][y][x] with x = 0..((w + subX) >> subX) - 1 and y = 0..((h + subY) >> subY) - 1.
- The bit depth for each sample is BitDepth.

The output of this process are the variables w, h, subX, and subY.

7.18.3. Film grain synthesis process

7.18.3.1. General

The inputs to this process are:

- variables w and h specifying the width and height of the frame,
- variables subX and subY specifying the subsampling parameters of the frame.

The process modifies the arrays OutY, OutU, OutV to add film grain noise as follows:

1. The variable RandomRegister (used for generating pseudo-random numbers) is set equal to grain_seed.
2. The variable GrainCenter is set equal to 128 << (BitDepth - 8).
3. The variable GrainMin is set equal to = -GrainCenter.
4. The variable GrainMax is set equal to (256 << (BitDepth - 8)) - 1 - GrainCenter.
5. The generate grain process specified in section 7.18.3.3 is invoked.
6. The scaling lookup initialization process specified in section 7.18.3.4 is invoked.
7. The add noise process specified in section 7.18.3.5 is invoked with w, h, subX, and subY as inputs.

7.18.3.2. Random number process

The input to this process is a variable bits specifying the number of random bits to return.

The output of this process is a pseudo-random number based on the state in RandomRegister.

The process is specified as follows:

```
get_random_number( bits ) {
  r = RandomRegister
  bit = ((r >> 0) ^ (r >> 1) ^ (r >> 3) ^ (r >> 12)) & 1
  r = (r >> 1) | (bit << 15)
  result = (r >> (16 - bits)) & ((1 << bits) - 1)
  RandomRegister = r
  return result
}
```

The output of this process is the variable result.

7.18.3.3. Generate grain process

This process generates noise via an auto-regressive filter.

First an array LumaGrain 82 samples wide and 73 samples high of white noise is generated for luma as follows:

```
shift = 12 - BitDepth + grain_scale_shift
for ( y = 0; y < 73; y++ ) {
  for ( x = 0; x < 82; x++ ) {
    if ( num_y_points > 0 ) {
      g = Gaussian_Sequence[ get_random_number( 11 ) ]
    } else {
      g = 0
    }
    LumaGrain[ y ][ x ] = Round2( g, shift )
  }
}
```

where the function call get_random_number invokes the random number process specified in section 7.18.3.2.

Then an auto-regressive filter is applied to the white noise as follows:

```
shift = ar_coeff_shift_minus_6 + 6
for ( y = 3; y < 73; y++ ) {
  for ( x = 3; x < 82 - 3; x++ ) {
    s = 0
    pos = 0
    for ( deltaRow = -ar_coeff_lag; deltaRow <= 0; deltaRow++ ) {
      for ( deltaCol = -ar_coeff_lag; deltaCol <= ar_coeff_lag; deltaCol++ ) {
        if ( deltaRow == 0 && deltaCol == 0 )
          break
        c = ar_coeffs_y_plus_128[ pos ] - 128
        s += LumaGrain[ y + deltaRow ][ x + deltaCol ] * c
        pos++
      }
    }
    LumaGrain[ y ][ x ] = Clip3( GrainMin, GrainMax, LumaGrain[ y ][ x ] + Round2( s, shift ) )
  }
}
```

If mono_chrome is equal to 0, the chroma grain is generated in a similar way, except the filtering includes a coefficient that introduces a correlation with the luma grain.

The variable chromaW (representing the width of the chroma noise array) is set equal to (subsampling_x ? 44 : 82).

The variable chromaH (representing the height of the chroma noise array) is set equal to (subsampling_y ? 38 : 73).

White noise arrays CbGrain and CrGrain chromaW samples wide and chromaH samples high are generated as follows:

```
shift = 12 - BitDepth + grain_scale_shift
RandomRegister = grain_seed ^ 0xb524
for ( y = 0; y < chromaH; y++ ) {
  for ( x = 0; x < chromaW; x++ ) {
    if ( num_cb_points > 0 || chroma_scaling_from_luma) {
      g = Gaussian_Sequence[ get_random_number( 11 ) ]
    } else {
      g = 0
    }
    CbGrain[ y ][ x ] = Round2( g, shift )
  }
}
RandomRegister = grain_seed ^ 0x49d8
for ( y = 0; y < chromaH; y++ ) {
  for ( x = 0; x < chromaW; x++ ) {
    if ( num_cr_points > 0 || chroma_scaling_from_luma) {
      g = Gaussian_Sequence[ get_random_number( 11 ) ]
    } else {
      g = 0
    }
    CrGrain[ y ][ x ] = Round2( g, shift )
  }
}
```

Then the auto-regressive filter is applied as follows:

```
shift = ar_coeff_shift_minus_6 + 6
for ( y = 3; y < chromaH; y++ ) {
  for ( x = 3; x < chromaW - 3; x++ ) {
    s0 = 0
    s1 = 0
    pos = 0
    for ( deltaRow = -ar_coeff_lag; deltaRow <= 0; deltaRow++ ) {
      for ( deltaCol = -ar_coeff_lag; deltaCol <= ar_coeff_lag; deltaCol++ ) {
        c0 = ar_coeffs_cb_plus_128[ pos ] - 128
        c1 = ar_coeffs_cr_plus_128[ pos ] - 128
        if ( deltaRow == 0 && deltaCol == 0 ) {
          if ( num_y_points > 0 ) {
            luma = 0
            lumaX = ( (x - 3) << subsampling_x ) + 3
            lumaY = ( (y - 3) << subsampling_y ) + 3
            for ( i = 0; i <= subsampling_y; i++ )
              for ( j = 0; j <= subsampling_x; j++ )
                luma += LumaGrain[ lumaY + i ][ lumaX + j ]
            luma = Round2( luma, subsampling_x + subsampling_y )
            s0 += luma * c0
            s1 += luma * c1
          }
          break
        }
        s0 += CbGrain[ y + deltaRow ][ x + deltaCol ] * c0
        s1 += CrGrain[ y + deltaRow ][ x + deltaCol ] * c1
        pos++
      }
    }
    CbGrain[ y ][ x ] = Clip3( GrainMin, GrainMax, CbGrain[ y ][ x ] + Round2( s0, shift ) )
    CrGrain[ y ][ x ] = Clip3( GrainMin, GrainMax, CrGrain[ y ][ x ] + Round2( s1, shift ) )
  }
}
```

Note: When num_y_points is equal to 0, this process may use uninitialized values within ar_coeffs_y_plus_128 to compute LumaGrain. However, LumaGrain will never be read in this case so it does not matter what values are constucted. Similarly, when num_cr_points/num_cb_points are equal to 0 and chroma_scaling_from_luma is equal to 0, the CbGrain/CrGrain arrays will never be read.

7.18.3.4. Scaling lookup initialization process

This process computes 3 lookup tables for the different color components.

Each lookup table ScalingLut[plane] contains 256 entries constructed by a piecewise linear interpolation of the given points as follows:

```
for ( plane = 0; plane < NumPlanes; plane++ ) {
    if ( plane == 0 || chroma_scaling_from_luma )
        numPoints = num_y_points
    else if ( plane == 1 )
        numPoints = num_cb_points
    else
        numPoints = num_cr_points
    if ( numPoints == 0 ) {
        for ( x = 0; x < 256; x++ ) {
            ScalingLut[ plane ][ x ] = 0
        }
    } else {
        for ( x = 0; x < get_x( plane, 0 ); x++ ) {
            ScalingLut[ plane ][ x ] = get_y( plane, 0 )
        }
        for ( i = 0; i < numPoints - 1; i++ ) {
            deltaY = get_y( plane, i + 1 ) - get_y( plane, i )
            deltaX = get_x( plane, i + 1 ) - get_x( plane, i )
            delta = deltaY * ( ( 65536 + (deltaX >> 1) ) / deltaX )
            for ( x = 0; x < deltaX; x++ ) {
                v = get_y( plane, i ) + ( ( x * delta + 32768 ) >> 16 )
                ScalingLut[ plane ][ get_x( plane, i )  + x ] = v
            }
        }
        for ( x = get_x( plane, numPoints - 1 ); x < 256; x++ ) {
            ScalingLut[ plane ][ x ] = get_y( plane, numPoints - 1 )
        }
    }
}
```

where the functions get_x and get_y return the coordinates for a specific point and are specified as:

```
get_x( plane, i ) {
    if ( plane == 0 || chroma_scaling_from_luma )
        return point_y_value[ i ]
    else if ( plane == 1 )
        return point_cb_value[ i ]
    else
        return point_cr_value[ i ]
}

get_y( plane, i ) {
    if ( plane == 0 || chroma_scaling_from_luma )
        return point_y_scaling[ i ]
    else if ( plane == 1 )
        return point_cb_scaling[ i ]
    else
        return point_cr_scaling[ i ]
}
```

7.18.3.5. Add noise synthesis process

The inputs to this process are:

- variables w and h specifying the width and height of the frame,
- variables subX and subY specifying the subsampling parameters of the frame.

This process combines the film grain with the image data.

First an array of noise data noiseStripe is generated for each 32 luma sample high stripe of the image.

noiseStripe[lumaNum][0] is 34 samples high and w samples wide (a few additional samples across are actually written to the array, but these are never read) and contains noise for the luma component.

noiseStripe[lumaNum][1] and noiseStripe[lumaNum][2] are (34 >> subY) samples high and Round2(w, subX) samples wide and contain noise for the chroma components.

noiseStripe represents the result of constructing square grain blocks and blending horizontally adjacent blocks together (although blending is only applied if overlap_flag is equal to 1) and is constructed as follows:

```
lumaNum = 0
for ( y = 0; y < (h + 1)/2 ; y += 16 ) {
  RandomRegister = grain_seed
  RandomRegister ^= ((lumaNum * 37 + 178) & 255) << 8
  RandomRegister ^= ((lumaNum * 173 + 105) & 255)
  for ( x = 0; x < (w + 1)/2 ; x += 16 ) {
    rand = get_random_number( 8 )
    offsetX = rand >> 4
    offsetY = rand & 15
    for ( plane = 0 ; plane < NumPlanes; plane++ ) {
      planeSubX = ( plane > 0) ? subX : 0
      planeSubY = ( plane > 0) ? subY : 0
      planeOffsetX = planeSubX ? 6 + offsetX : 9 + offsetX * 2
      planeOffsetY = planeSubY ? 6 + offsetY : 9 + offsetY * 2
      for ( i = 0; i < 34 >> planeSubY ; i++ ) {
        for ( j = 0; j < 34 >> planeSubX ; j++ ) {
          if ( plane == 0 )
            g = LumaGrain[ planeOffsetY + i ][ planeOffsetX + j ]
          else if ( plane == 1 )
            g = CbGrain[ planeOffsetY + i ][ planeOffsetX + j ]
          else
            g = CrGrain[ planeOffsetY + i ][ planeOffsetX + j ]
          if ( planeSubX == 0 ) {
            if ( j < 2 && overlap_flag && x > 0 ) {
              old = noiseStripe[ lumaNum ][ plane ][ i ][ x * 2 + j ]
              if ( j == 0 ) {
                g = old * 27 + g * 17
              } else {
                g = old * 17 + g * 27
              }
              g = Clip3( GrainMin, GrainMax, Round2(g, 5) )
            }
            noiseStripe[ lumaNum ][ plane ][ i ][ x * 2 + j ] = g
          } else {
            if ( j == 0 && overlap_flag && x > 0 ) {
              old = noiseStripe[ lumaNum ][ plane ][ i ][ x + j ]
              g = old * 23 + g * 22
              g = Clip3( GrainMin, GrainMax, Round2(g, 5) )
            }
            noiseStripe[ lumaNum ][ plane ][ i ][ x + j ] = g
          }
        }
      }
    }
  }
  lumaNum++
}
```

Then the noise stripes are blended together to form a noise image noiseImage as follows:

```
for ( plane = 0; plane < NumPlanes; plane++ ) {
  planeSubX = ( plane > 0) ? subX : 0
  planeSubY = ( plane > 0) ? subY : 0
  for ( y = 0; y < ( (h + planeSubY) >> planeSubY ) ; y++ ) {
    lumaNum = y >> ( 5 - planeSubY )
    i = y - (lumaNum << ( 5 - planeSubY ) )
    for ( x = 0; x < ( (w + planeSubX) >> planeSubX) ; x++ ) {
      g = noiseStripe[ lumaNum ][ plane ][ i ][ x ]
      if ( planeSubY == 0 ) {
        if ( i < 2 && lumaNum > 0 && overlap_flag ) {
          old = noiseStripe[ lumaNum - 1 ][ plane ][ i + 32 ][ x ]
          if ( i == 0 ) {
            g = old * 27 + g * 17
          } else {
            g = old * 17 + g * 27
          }
          g = Clip3( GrainMin, GrainMax, Round2(g, 5) )
        }
      } else {
        if ( i < 1 && lumaNum > 0 && overlap_flag ) {
          old = noiseStripe[ lumaNum - 1 ][ plane ][ i + 16 ][ x ]
          g = old * 23 + g * 22
          g = Clip3( GrainMin, GrainMax, Round2(g, 5) )
        }
      }
      noiseImage[ plane ][ y ][ x ] = g
    }
  }
}
```

Note: Although this process is specified in terms of full size noiseStripe and noiseImage arrays, the reference code shows how it is possible to implement the grain synthesis with just 2 line buffers for luma, and 1 line buffer for each chroma component.

Finally, the noise is blended with the original image data as follows:

```
if ( clip_to_restricted_range ) {
  minValue = 16 << (BitDepth - 8)
  maxLuma = 235 << (BitDepth - 8)
  if ( matrix_coefficients == MC_IDENTITY )
    maxChroma = maxLuma
  else
    maxChroma = 240 << (BitDepth - 8)
} else {
  minValue = 0
  maxLuma = (256 << (BitDepth - 8)) - 1
  maxChroma = maxLuma
}
ScalingShift = grain_scaling_minus_8 + 8
for ( y = 0; y < ( (h + subY) >> subY) ; y++ ) {
  for ( x = 0; x < ( (w + subX) >> subX) ; x++ ) {
    lumaX = x << subX
    lumaY = y << subY
    lumaNextX = Min( lumaX + 1, w - 1 )
    if ( subX )
      averageLuma = Round2( OutY[ lumaY ][ lumaX ] + OutY[ lumaY ][ lumaNextX ], 1 )
    else
      averageLuma = OutY[ lumaY ][ lumaX ]
    if ( num_cb_points > 0 || chroma_scaling_from_luma ) {
      orig = OutU[ y ][ x ]
      if ( chroma_scaling_from_luma ) {
        merged = averageLuma
      } else {
        combined = averageLuma * ( cb_luma_mult - 128 ) + orig * ( cb_mult - 128 )
        merged = Clip1( ( combined >> 6 ) + ( (cb_offset - 256 ) << (BitDepth - 8) ) )
      }
      noise = noiseImage[ 1 ][ y ][ x ]
      noise = Round2( scale_lut( 1, merged ) * noise, ScalingShift )
      OutU[ y ][ x ] = Clip3( minValue, maxChroma, orig + noise )
    }

    if ( num_cr_points > 0 || chroma_scaling_from_luma) {
      orig = OutV[ y ][ x ]
      if ( chroma_scaling_from_luma ) {
        merged = averageLuma
      } else {
        combined = averageLuma * ( cr_luma_mult - 128 ) + orig * ( cr_mult - 128 )
        merged = Clip1( ( combined >> 6 ) + ( (cr_offset - 256 ) << (BitDepth - 8) ) )
      }
      noise = noiseImage[ 2 ][ y ][ x ]
      noise = Round2( scale_lut( 2, merged ) * noise, ScalingShift )
      OutV[ y ][ x ] = Clip3( minValue, maxChroma, orig + noise )
    }
  }
}
for ( y = 0; y < h ; y++ ) {
```

```
  for ( x = 0; x < w ; x++ ) {
    orig = OutY[ y ][ x ]
    noise = noiseImage[ 0 ][ y ][ x ]
    noise = Round2( scale_lut( 0, orig ) * noise, ScalingShift )
    if ( num_y_points > 0 ) {
      OutY[ y ][ x ] = Clip3( minValue, maxLuma, orig + noise )
    }
  }
}
```

where scale_lut is a function that performs a piecewise linear interpolation into the appropriate scaling table. The scale_lut function is specified as follows:

```
scale_lut( plane, index ) {
  shift = BitDepth - 8
  x = index >> shift
  rem = index - ( x << shift )
  if ( BitDepth == 8 || x == 255) {
    return ScalingLut[ plane ][ x ]
  } else {
    start = ScalingLut[ plane ][ x ]
    end = ScalingLut[ plane ][ x + 1 ]
    return start + Round2( (end - start) * rem, shift )
  }
}
```

7.19. Motion field motion vector storage process

This process applies some filtering and reordering to the motion vectors to prepare them for storage as part of the reference frame update process.

The following applies for row = 0..MiRows-1, for col = 0..MiCols-1:

```
MfRefFrames[ row ][ col ] = NONE
MfMvs[ row ][ col ][ 0 ] = 0
MfMvs[ row ][ col ][ 1 ] = 0
for ( list = 0; list < 2; list++ ) {
    r = RefFrames[ row ][ col ][ list ]
    if ( r > INTRA_FRAME ) {
        refIdx = ref_frame_idx[ r - LAST_FRAME ]
        dist = get_relative_dist( RefOrderHint[ refIdx ], OrderHint )
        if ( dist < 0 ) {
            mvRow = Mvs[ row ][ col ][ list ][ 0 ]
            mvCol = Mvs[ row ][ col ][ list ][ 1 ]
            if ( Abs( mvRow ) <= REFMVS_LIMIT && Abs( mvCol ) <= REFMVS_LIMIT ) {
                MfRefFrames[ row ][ col ] = r
                MfMvs[ row ][ col ][ 0 ] = mvRow
                MfMvs[ row ][ col ][ 1 ] = mvCol
            }
        }
    }
}
```

Note: Although this process stores all the motion vectors into MfMvs, only the values where row and col are both odd will affect the decoding process.

7.20. Reference frame update process

This process is invoked as the final step in decoding a frame.

The inputs to this process are the decoded samples for the current frame LrFrame[plane][x][y].

The output from this process is an updated set of reference frames and previous motion vectors.

For each value of i from 0 to NUM_REF_FRAMES - 1, the following applies if bit i of refresh_frame_flags is equal to 1 (i.e. if (refresh_frame_flags >> i) & 1 is equal to 1):

- RefValid[i] is set equal to 1.
- RefFrameId[i] is set equal to current_frame_id.
- RefUpscaledWidth[i] is set equal to UpscaledWidth.
- RefFrameWidth[i] is set equal to FrameWidth.
- RefFrameHeight[i] is set equal to FrameHeight.
- RefRenderWidth[i] is set equal to RenderWidth.
- RefRenderHeight[i] is set equal to RenderHeight.

- RefMiCols[i] is set equal to MiCols.
- RefMiRows[i] is set equal to MiRows.
- RefFrameType[i] is set equal to frame_type.
- RefSubsamplingX[i] is set equal to subsampling_x.
- RefSubsamplingY[i] is set equal to subsampling_y.
- RefBitDepth[i] is set equal to BitDepth.
- SavedOrderHints[i][j + LAST_FRAME] is set equal to OrderHints[j + LAST_FRAME] for j = 0..REFS_PER_FRAME-1.
- FrameStore[i][0][y][x] is set equal to LrFrame[0][y][x] for x = 0..UpscaledWidth-1, for y = 0..FrameHeight-1.
- FrameStore[i][plane][y][x] is set equal to LrFrame[plane][y][x] for plane = 1..2, for x = 0..((UpscaledWidth + subsampling_x) >> subsampling_x) - 1, for y = 0..((FrameHeight + subsampling_y) >> subsampling_y) - 1.
- SavedRefFrames[i][row][col] is set equal to MfRefFrames[row][col] for row = 0..MiRows-1, for col = 0..MiCols-1.
- SavedMvs[i][row][col][comp] is set equal to MfMvs[row][col][comp] for comp = 0..1, for row = 0..MiRows-1, for col = 0..MiCols-1.
- SavedGmParams[i][ref][j] is set equal to gm_params[ref][j] for ref = LAST_FRAME..ALTREF_FRAME, for j = 0..5.
- SavedSegmentIds[i][row][col] is set equal to SegmentIds[row][col] for row = 0..MiRows-1, for col = 0..MiCols-1.
- The function save_cdfs(i) is invoked (see below).
- If film_grain_params_present is equal to 1, the function save_grain_params(i) is invoked (see below).
- The function save_loop_filter_params(i) is invoked (see below).
- The function save_segmentation_params(i) is invoked (see below).

For each value of i from 0 to NUM_REF_FRAMES - 1, the following applies if bit i of refresh_frame_flags is equal to 1 (i.e. if (refresh_frame_flags >> i) & 1 is equal to 1):

- RefOrderHint[i] is set equal to OrderHint.

save_cdfs(ctx) is a function call that indicates that all the CDF arrays are saved into frame context number ctx in the range 0 to (NUM_REF_FRAMES - 1). When this function is invoked the following takes place:

- A copy of each CDF array mentioned in the semantics for init_coeff_cdfs and init_non_coeff_cdfs is saved in an area of memory indexed by ctx.

save_grain_params(i) is a function call that indicates that all the syntax elements that can be read in film_grain_params should be saved into an area of memory indexed by i.

save_loop_filter_params(i) is a function call that indicates that the values of loop_filter_ref_deltas[j] for j = 0 .. TOTAL_REFS_PER_FRAME-1, and the values of loop_filter_mode_deltas[j] for j = 0 .. 1 should be saved into an area of memory indexed by i.

save_segmentation_params(i) is a function call that indicates that the values of FeatureEnabled[j][k] and FeatureData[j][k] for j = 0 .. MAX_SEGMENTS-1, for k = 0 .. SEG_LVL_MAX-1 should be saved into an area of memory indexed by i.

Note: Although this process stores all the motion vectors into SavedMvs, only the values where row and col are both odd will affect the decoding process.

7.21. Reference frame loading process

This process is the reverse of the reference frame update process specified in section 7.20. It loads saved values for a previous reference frame back into the current frame variables. The index of the saved reference frame to load is given by the syntax element frame_to_show_map_idx.

- current_frame_id is set equal to RefFrameId[i].
- UpscaledWidth is set equal to RefUpscaledWidth[frame_to_show_map_idx].
- FrameWidth is set equal to RefFrameWidth[frame_to_show_map_idx].
- FrameHeight is set equal to RefFrameHeight[frame_to_show_map_idx].
- RenderWidth is set equal to RefRenderWidth[frame_to_show_map_idx].
- RenderHeight is set equal to RefRenderHeight[frame_to_show_map_idx].
- MiCols is set equal to RefMiCols[frame_to_show_map_idx].
- MiRows is set equal to RefMiRows[frame_to_show_map_idx].
- subsampling_x is set equal to RefSubsamplingX[frame_to_show_map_idx].
- subsampling_y is set equal to RefSubsamplingY[frame_to_show_map_idx].
- BitDepth is set equal to RefBitDepth[frame_to_show_map_idx].
- OrderHint is set equal to RefOrderHint[frame_to_show_map_idx].

- OrderHints[j + LAST_FRAME] is set equal to SavedOrderHints[frame_to_show_map_idx][j + LAST_FRAME] for j = 0..REFS_PER_FRAME-1.
- LrFrame[0][y][x] is set equal to FrameStore[frame_to_show_map_idx][0][y][x] for x = 0..UpscaledWidth-1, for y = 0..FrameHeight-1.
- LrFrame[plane][y][x] is set equal to FrameStore[frame_to_show_map_idx][plane][y][x] for plane = 1..2, for x = 0..((UpscaledWidth + subsampling_x) >> subsampling_x) - 1, for y = 0..((FrameHeight + subsampling_y) >> subsampling_y) - 1.
- MfRefFrames[row][col] is set equal to SavedRefFrames[frame_to_show_map_idx][row][col] for row = 0..MiRows-1, for col = 0..MiCols-1.
- MfMvs[row][col][comp] is set equal to SavedMvs[frame_to_show_map_idx][row][col][comp] for comp = 0..1, for row = 0..MiRows-1, for col = 0..MiCols-1.
- gm_params[ref][j] is set equal to SavedGmParams[frame_to_show_map_idx][ref][j] for ref = LAST_FRAME..ALTREF_FRAME, for j = 0..5.
- SegmentIds[row][col] is set equal to SavedSegmentIds[frame_to_show_map_idx][row][col] for row = 0..MiRows-1, for col = 0..MiCols-1.
- The function load_cdfs(frame_to_show_map_idx) is invoked.
- If film_grain_params_present is equal to 1, the function load_grain_params(frame_to_show_map_idx) is invoked (see section 6.8.20).
- The function load_loop_filter_params(frame_to_show_map_idx) is invoked (see below).
- The function load_segmentation_params(frame_to_show_map_idx) is invoked (see below).

load_loop_filter_params(i) is a function call that indicates that the values of loop_filter_ref_deltas[j] for j = 0 .. TOTAL_REFS_PER_FRAME-1, and the values of loop_filter_mode_deltas[j] for j = 0 .. 1 should be loaded from an area of memory indexed by i.

load_segmentation_params(i) is a function call that indicates that the values of FeatureEnabled[j][k] and FeatureData[j][k] for j = 0 .. MAX_SEGMENTS-1, for k = 0 .. SEG_LVL_MAX-1 should be loaded from an area of memory indexed by i.

8. Parsing process

8.1. Parsing process for f(n)

This process is invoked when the descriptor of a syntax element in the syntax tables is equal to f(n).

The next n bits are read from the bit stream.

This process is specified as follows:

```
x = 0
for ( i = 0; i < n; i++ ) {
    x = 2 * x + read_bit( )
}
```

read_bit( ) reads the next bit from the bitstream and advances the bitstream position indicator by 1. If the bitstream is provided as a series of bytes, then the first bit is given by the most significant bit of the first byte.

The value for the syntax element is given by x.

8.2. Parsing process for symbol decoder

8.2.1. General

The entropy decoder is referred to as the “Symbol decoder” and the functions init_symbol(sz), exit_symbol( ), read_symbol(cdf), and read_bool( ) are used in this Specification to indicate the entropy decoding operation.

8.2.2. Initialization process for symbol decoder

The input to this process is a variable sz specifying the number of bytes to be read by the Symbol decoder.

This process is invoked when the function init_symbol(sz) is called from the syntax structure.

> **Note:** The bit position will always be byte aligned when init_symbol is invoked because the uncompressed header and the data partitions are always a whole number of bytes long.

The variable numBits is set equal to Min(sz * 8, 15).

The variable buf is read using the f(numBits) parsing process.

The variable paddedBuf is set equal to (buf << (15 - numBits)).

The variable SymbolValue is set to ((1 << 15) - 1) ^ paddedBuf.

The variable SymbolRange is set to 1 << 15.

The variable SymbolMaxBits is set to 8 * sz - 15.

SymbolMaxBits (when non-negative) represents the number of bits still available to be read. It is allowed for this number to go negative (either here or during read_symbol). SymbolMaxBits (when negative) signifies that all available bits have been read, and that -SymbolMaxBits of padding zero bits have been used in the symbol decoding process. These padding zero bits are not present in the bitstream.

The array TileIntraFrameYModeCdf is set equal to a copy of Default_Intra_Frame_Y_Mode_Cdf.

A copy is made of each of the CDF arrays mentioned in the semantics for init_coeff_cdfs and init_non_coeff_cdfs. The name of the copy is the name of the CDF array prefixed with “Tile”. This copying produces the following arrays:

- TileYModeCdf
- TileUVModeCflNotAllowedCdf
- TileUVModeCflAllowedCdf
- TileAngleDeltaCdf
- TileIntrabcCdf
- TilePartitionW8Cdf
- TilePartitionW16Cdf
- TilePartitionW32Cdf
- TilePartitionW64Cdf
- TilePartitionW128Cdf
- TileSegmentIdCdf
- TileSegmentIdPredictedCdf
- TileTx8x8Cdf
- TileTx16x16Cdf
- TileTx32x32Cdf
- TileTx64x64Cdf
- TileTxfmSplitCdf
- TileFilterIntraModeCdf
- TileFilterIntraCdf

- TileInterpFilterCdf
- TileMotionModeCdf
- TileNewMvCdf
- TileZeroMvCdf
- TileRefMvCdf
- TileCompoundModeCdf
- TileDrlModeCdf
- TileIsInterCdf
- TileCompModeCdf
- TileSkipModeCdf
- TileSkipCdf
- TileCompRefCdf
- TileCompBwdRefCdf
- TileSingleRefCdf
- TileMvJointCdf
- TileMvSignCdf
- TileMvClassCdf
- TileMvClass0BitCdf
- TileMvFrCdf
- TileMvClass0FrCdf
- TileMvClass0HpCdf
- TileMvBitCdf
- TileMvHpCdf
- TilePaletteYModeCdf
- TilePaletteUVModeCdf

- TilePaletteYSizeCdf
- TilePaletteUVSizeCdf
- TilePaletteSize2YColorCdf
- TilePaletteSize2UVColorCdf
- TilePaletteSize3YColorCdf
- TilePaletteSize3UVColorCdf
- TilePaletteSize4YColorCdf
- TilePaletteSize4UVColorCdf
- TilePaletteSize5YColorCdf
- TilePaletteSize5UVColorCdf
- TilePaletteSize6YColorCdf
- TilePaletteSize6UVColorCdf
- TilePaletteSize7YColorCdf
- TilePaletteSize7UVColorCdf
- TilePaletteSize8YColorCdf
- TilePaletteSize8UVColorCdf
- TileDeltaQCdf
- TileDeltaLFCdf
- TileDeltaLFMultiCdf[i] for i = 0..FRAME_LF_COUNT-1
- TileIntraTxTypeSet1Cdf
- TileIntraTxTypeSet2Cdf
- TileInterTxTypeSet1Cdf
- TileInterTxTypeSet2Cdf
- TileInterTxTypeSet3Cdf
- TileUseObmcCdf

- TileInterIntraCdf
- TileCompRefTypeCdf
- TileCflSignCdf
- TileUniCompRefCdf
- TileWedgeInterIntraCdf
- TileCompGroupIdxCdf
- TileCompoundIdxCdf
- TileCompoundTypeCdf
- TileInterIntraModeCdf
- TileWedgeIndexCdf
- TileCflAlphaCdf
- TileUseWienerCdf
- TileUseSgrprojCdf
- TileRestorationTypeCdf
- TileTxbSkipCdf
- TileEobPt16Cdf
- TileEobPt32Cdf
- TileEobPt64Cdf
- TileEobPt128Cdf
- TileEobPt256Cdf
- TileEobPt512Cdf
- TileEobPt1024Cdf
- TileEobExtraCdf
- TileDcSignCdf
- TileCoeffBaseEobCdf

- TileCoeffBaseCdf
- TileCoeffBrCdf

8.2.3. Boolean decoding process

This process decodes a pseudo-raw bit assuming equal probability for decoding a 0 or a 1.

This process is invoked when the function read_bool( ) is called from the read_literal function in section 8.2.5.

An array cdf of length 3 is constructed as follows:

```
cdf[ 0 ] = 1 << 14
cdf[ 1 ] = 1 << 15
cdf[ 2 ] = 0
```

The output of this process is given by read_symbol(cdf).

Note: This cdf array is constructed each time read_bool is invoked. This means that implementations can omit the cdf update performed by read_symbol when invoked from read_bool because the modified values are never used.

8.2.4. Exit process for symbol decoder

This process is invoked when the function exit_symbol( ) is called from the syntax structure.

It is a requirement of bitstream conformance that SymbolMaxBits is greater than or equal to -14 whenever this process is invoked.

The variable trailingBitPosition is set equal to get_position() - Min(15, SymbolMaxBits+15).

The bitstream position indicator is advanced by Max(0,SymbolMaxBits). (This skips over any trailing bits that have not already been read during symbol decode.)

The variable paddingEndPosition is set equal to get_position().

Note: paddingEndPosition will always be a multiple of 8 indicating that the bit position is byte aligned.

It is a requirement of bitstream conformance that the bit at position trailingBitPosition is equal to 1.

It is a requirement of bitstream conformance that the bit at position x is equal to 0 for values of x strictly between trailingBitPosition and paddingEndPosition.

Note: This exit process consumes the OBU trailing bits for a tile group.

If disable_frame_end_update_cdf is equal to 0 and TileNum is equal to context_update_tile_id, a copy is made of the final CDF values for each of the CDF arrays mentioned in the semantics for init_coeff_cdfs and init_non_coeff_cdfs. The name of the destination for the copy is the name of the CDF array prefixed with “Saved”. The name of the source for the copy is the name of the CDF array prefixed with “Tile”. For example, an array SavedYModeCdf will be created with values equal to TileYModeCdf.

8.2.5. Parsing process for read_literal

This process is invoked when the function read_literal(n) is invoked.

This process is specified as follows:

```
x = 0
for ( i = 0 ; i < n; i++ ) {
    x = 2 * x + read_bool( )
}
```

The return value for the function is given by x.

8.2.6. Symbol decoding process

The input to this process is an array cdf of length N + 1 which specifies the cumulative distribution for a symbol with N possible values.

The output of this process is the variable symbol, containing a decoded syntax element. The process also modifies the input array cdf to adapt the probabilities to the content of the stream.

This process is invoked when the function read_symbol(cdf) is called.

Note: When this process is invoked, N will be greater than 1 and cdf[N-1] will be equal to 1 << 15.

The variables cur, prev, and symbol are calculated as follows:

```
cur = SymbolRange
symbol = -1
do {
  symbol++
  prev = cur
  f = ( 1 << 15 ) - cdf[ symbol ]
  cur = ((SymbolRange >> 8) * (f >> EC_PROB_SHIFT)) >> (7 - EC_PROB_SHIFT)
  cur += EC_MIN_PROB * (N - symbol - 1)
} while ( SymbolValue < cur )
```

Note: Implementations may prefer to store the inverse cdf to move the subtraction out of this loop.

The variable SymbolRange is set to prev - cur.

The variable SymbolValue is set equal to SymbolValue - cur.

The range and value are renormalized by the following ordered steps:

1. The variable bits is set to 15 – FloorLog2(SymbolRange). This represents the number of new bits to be added to SymbolValue.
2. The variable SymbolRange is set to SymbolRange << bits.
3. The variable numBits is set equal to Min(bits, Max(0, SymbolMaxBits)). This represents the number of new bits to read from the bitstream.
4. The variable newData is read using the f(numBits) parsing process.
5. The variable paddedData is set equal to newData << (bits - numBits).
6. The variable SymbolValue is set to paddedData ^ (((SymbolValue + 1) << bits) - 1).
7. The variable SymbolMaxBits is set to SymbolMaxBits - bits.

Note: bits may be equal to 0, in which case these ordered steps have no effect.

If disable_cdf_update is equal to 0, the cumulative distribution is updated as follows:

```
rate = 3 + ( cdf[ N ] > 15 ) + ( cdf[ N ] > 31 ) + Min( FloorLog2( N ), 2 )
tmp = 0
for ( i = 0; i < N - 1; i++ ) {
  tmp = ( i == symbol ) ? ( 1 << 15 ) : tmp
  if ( tmp < cdf[ i ] ) {
    cdf[ i ] -= ( ( cdf[ i ] - tmp ) >> rate )
  } else {
    cdf[ i ] += ( ( tmp - cdf[ i ] ) >> rate )
  }
}
cdf[ N ] += ( cdf[ N ] < 32 )
```

Note: The last entry of the cdf array is used to keep a count of the number of times the symbol has been decoded (up to a maximum of 32). This allows the cdf adaption rate to depend on the number of times the symbol has been decoded.

The return value from the function is given by symbol.

8.3. Parsing process for CDF encoded syntax elements

8.3.1. General

This process is invoked when the descriptor of a syntax element in the syntax tables is equal to S.

The input to this process is the name of a syntax element.

Section 8.3.2 specifies how a CDF array is chosen for the syntax element. The variable cdf is set equal to a reference to this CDF array.

> **Note:** The array must be passed by reference because read_symbol will adjust the array contents.

The output of this process is the result of calling the function read_symbol(cdf).

8.3.2. Cdf selection process

The input to this process is the name of a syntax element.

The output of this process is a reference to a CDF array.

When the description in this section uses variables, these variables are taken to have the values defined by the syntax tables at the point that the syntax element is being decoded.

The probabilities depend on the syntax element as follows:

use_intrabc: The cdf for use_intrabc is given by TileIntrabcCdf.

intra_frame_y_mode: The cdf for intra_frame_y_mode is given by TileIntraFrameYModeCdf[abovemode][leftmode] where abovemode and leftmode are the intra modes used for the blocks immediately above and to the left of this block and are computed as:

```
abovemode = Intra_Mode_Context[ AvailU ? YModes[ MiRow - 1 ][ MiCol ] : DC_PRED ]
leftmode = Intra_Mode_Context[ AvailL ? YModes[ MiRow ][ MiCol - 1] : DC_PRED ]
```

where Intra_Mode_Context is defined as follows:

```
Intra_Mode_Context[ INTRA_MODES ] = {
  0, 1, 2, 3, 4, 4, 4, 4, 3, 0, 1, 2, 0
}
```

> **Note:** We are using a 2D array to store the YModes and UVModes for clarity. It is possible to reduce memory consumption by only storing one intra mode for each 4x4 horizontal and vertical position, i.e. to use two 1D arrays instead.

y_mode: The cdf for y_mode is given by TileYModeCdf[ctx] where the variable ctx is computed as Size_Group[MiSize].

uv_mode: The cdf for uv_mode is derived as follows:

- If Lossless is equal to 1 and get_plane_residual_size(MiSize, 1) is equal to BLOCK_4X4, the cdf is given by TileUVModeCflAllowedCdf[YMode].
- Otherwise, if Lossless is equal to 0 and Max(Block_Width[MiSize], Block_Height[MiSize]) <= 32, the cdf is given by TileUVModeCflAllowedCdf[YMode].
- Otherwise, the cdf is given by TileUVModeCflNotAllowedCdf[YMode].

angle_delta_y: The cdf for angle_delta_y is given by TileAngleDeltaCdf[YMode - V_PRED].

angle_delta_uv: The cdf for angle_delta_uv is given by TileAngleDeltaCdf[UVMode - V_PRED].

partition: The variable ctx is computed as follows:

```
bsl = Mi_Width_Log2[ bSize ]
above = AvailU && ( Mi_Width_Log2[ MiSizes[ r - 1 ][ c ] ] < bsl )
left = AvailL && ( Mi_Height_Log2[ MiSizes[ r ][ c - 1 ] ] < bsl )
ctx = left * 2 + above
```

The cdf is derived as follows:

- If bsl is equal to 1, the cdf is given by TilePartitionW8Cdf[ctx].
- Otherwise, if bsl is equal to 2, the cdf is given by TilePartitionW16Cdf[ctx].
- Otherwise, if bsl is equal to 3, the cdf is given by TilePartitionW32Cdf[ctx].
- Otherwise, if bsl is equal to 4, the cdf is given by TilePartitionW64Cdf[ctx].
- Otherwise (bsl is equal to 5), the cdf is given by TilePartitionW128Cdf[ctx].

split_or_horz: split_or_horz uses the same derivation for the variable ctx as for the syntax element partition.

The array partitionCdf is derived according to the cdf derivation procedure for the syntax element partition (note that bsl is never equal to 1 when decoding split_or_horz).

The cdf to return is given by an array of length 3 which is constructed as follows:

```
psum = ( partitionCdf[ PARTITION_VERT ] - partitionCdf[ PARTITION_VERT - 1 ] +
         partitionCdf[ PARTITION_SPLIT ] - partitionCdf[ PARTITION_SPLIT - 1 ] +
         partitionCdf[ PARTITION_HORZ_A ] - partitionCdf[ PARTITION_HORZ_A - 1 ] +
         partitionCdf[ PARTITION_VERT_A ] - partitionCdf[ PARTITION_VERT_A - 1 ] +
         partitionCdf[ PARTITION_VERT_B ] - partitionCdf[ PARTITION_VERT_B - 1 ] )
if ( bSize != BLOCK_128X128 )
    psum += partitionCdf[ PARTITION_VERT_4 ] - partitionCdf[ PARTITION_VERT_4 - 1 ] )
cdf[0] = ( 1 << 15 ) - psum
cdf[1] = 1 << 15
cdf[2] = 0
```

Note: The syntax element split_or_horz is not allowed to return a PARTITION_VERT, so the probability for a vertical partition is assigned to the probability for the split partition.

split_or_vert: split_or_vert uses the same derivation for the variable ctx as for the syntax element partition.

The array partitionCdf is derived according to the cdf derivation procedure for the syntax element partition (note that bsl is never equal to 1 when decoding split_or_vert).

The cdf to return is given by an array of length 3 which is constructed as follows:

```
psum = ( partitionCdf[ PARTITION_HORZ ] - partitionCdf[ PARTITION_HORZ - 1 ] +
         partitionCdf[ PARTITION_SPLIT ] - partitionCdf[ PARTITION_SPLIT - 1 ] +
         partitionCdf[ PARTITION_HORZ_A ] - partitionCdf[ PARTITION_HORZ_A - 1 ] +
         partitionCdf[ PARTITION_HORZ_B ] - partitionCdf[ PARTITION_HORZ_B - 1 ] +
         partitionCdf[ PARTITION_VERT_A ] - partitionCdf[ PARTITION_VERT_A - 1 ] )
if ( bSize != BLOCK_128X128 )
    psum += partitionCdf[ PARTITION_HORZ_4 ] - partitionCdf[ PARTITION_HORZ_4 - 1 ]
cdf[0] = ( 1 << 15 ) - psum
cdf[1] = 1 << 15
cdf[2] = 0
```

tx_depth: the cdf depends on the value of maxRectTxSize and ctx, where ctx is computed by:

```
maxTxWidth = Tx_Width[ maxRectTxSize ]
maxTxHeight = Tx_Height[ maxRectTxSize ]

if ( AvailU && IsInters[ MiRow - 1 ][ MiCol ] ) {
    aboveW = Block_Width[ MiSizes[ MiRow - 1 ][ MiCol ] ]
} else if ( AvailU ) {
    aboveW = get_above_tx_width( MiRow, MiCol )
} else {
    aboveW = 0
}

if ( AvailL && IsInters[ MiRow ][ MiCol - 1 ] ) {
    leftH = Block_Height[ MiSizes[ MiRow ][ MiCol - 1 ] ]
} else if ( AvailL ) {
    leftH = get_left_tx_height( MiRow, MiCol )
} else {
    leftH = 0
}

ctx = ( aboveW >= maxTxWidth ) + ( leftH >= maxTxHeight )
```

where get_above_tx_width and get_left_tx_height are functions defined as specified in the CDF selection process for txfm_split.

The cdf to return is given by:

- TileTx64x64Cdf[ctx] if maxTxDepth is equal to 4.
- TileTx32x32Cdf[ctx] if maxTxDepth is equal to 3.
- TileTx16x16Cdf[ctx] if maxTxDepth is equal to 2.
- TileTx8x8Cdf[ctx] otherwise.

txfm_split: the cdf is given by TileTxfmSplitCdf[ctx], where ctx is computed by:

```
above = get_above_tx_width( row, col ) < Tx_Width[ txSz ]
left = get_left_tx_height( row, col ) < Tx_Height[ txSz ]
size = Min( 64, Max( Block_Width[ MiSize ], Block_Height[ MiSize ] ) )
maxTxSz = find_tx_size( size, size )
txSzSqrUp = Tx_Size_Sqr_Up[ txSz ]
ctx = (txSzSqrUp != maxTxSz) * 3 +
      (TX_SIZES - 1 - maxTxSz) * 6 + above + left
```

where get_above_tx_width and get_left_tx_height are functions defined as follows:

```
get_above_tx_width( row, col ) {
    if ( row == MiRow ) {
        if ( !AvailU ) {
            return 64
        } else if ( Skips[ row - 1 ][ col ] && IsInters[ row - 1 ][ col ] ) {
            return Block_Width[ MiSizes[ row - 1 ][ col ] ]
        }
    }
    return Tx_Width[ InterTxSizes[ row - 1 ][ col ] ]
}

get_left_tx_height( row, col ) {
    if ( col == MiCol ) {
        if ( !AvailL ) {
            return 64
        } else if ( Skips[ row ][ col - 1 ] && IsInters[ row ][ col - 1 ] ) {
            return Block_Height[ MiSizes[ row ][ col - 1 ] ]
        }
    }
    return Tx_Height[ InterTxSizes[ row ][ col - 1 ] ]
}
```

segment_id: The cdf is given by TileSegmentIdCdf[ctx] where ctx is computed by:

```
if ( prevUL < 0 )
    ctx = 0
else if ( (prevUL == prevU) && (prevUL == prevL) )
    ctx = 2
else if ( (prevUL == prevU) || (prevUL == prevL) || (prevU == prevL) )
    ctx = 1
else
    ctx = 0
```

seg_id_predicted: the cdf is given by TileSegmentIdPredictedCdf[ctx], where ctx is computed by:

```
ctx = LeftSegPredContext[ MiRow ] + AboveSegPredContext[ MiCol ]
```

new_mv: the cdf is given by TileNewMvCdf[NewMvContext].

zero_mv: the cdf is given by TileZeroMvCdf[ZeroMvContext].

ref_mv: the cdf is given by TileRefMvCdf[RefMvContext].

drl_mode: the cdf is given by TileDrlModeCdf[DrlCtxStack[idx]].

is_inter: the cdf is given by TileIsInterCdf[ctx] where ctx is computed by:

```
if ( AvailU && AvailL )
    ctx = (LeftIntra && AboveIntra) ? 3 : LeftIntra || AboveIntra
else if ( AvailU || AvailL )
    ctx = 2 * (AvailU ? AboveIntra : LeftIntra)
else
    ctx = 0
```

use_filter_intra: the cdf is given by TileFilterIntraCdf[MiSize].

filter_intra_mode: the cdf is given by TileFilterIntraModeCdf.

comp_mode: the cdf is given by TileCompModeCdf[ctx] where ctx is computed by:

```
if ( AvailU && AvailL ) {
    if ( AboveSingle && LeftSingle )
    ctx = check_backward( AboveRefFrame[ 0 ] )
        ^ check_backward( LeftRefFrame[ 0 ] )
    else if ( AboveSingle )
        ctx = 2 + ( check_backward( AboveRefFrame[ 0 ] ) || AboveIntra)
    else if ( LeftSingle )
        ctx = 2 + ( check_backward( LeftRefFrame[ 0 ] ) || LeftIntra)
    else
        ctx = 4
} else if ( AvailU ) {
    if ( AboveSingle )
        ctx = check_backward( AboveRefFrame[ 0 ] )
    else
        ctx = 3
} else if ( AvailL ) {
    if ( LeftSingle )
        ctx= check_backward( LeftRefFrame[ 0 ] )
    else
        ctx = 3
} else {
    ctx = 1
}
```

where check_backward is a function specified as follows:

```
check_backward(refFrame) {
  return ( ( refFrame >= BWDREF_FRAME ) && ( refFrame <= ALTREF_FRAME ) )
}
```

skip_mode: the cdf is given by TileSkipModeCdf[ctx] where ctx is computed by:

```
    ctx = 0
    if ( AvailU )
        ctx += SkipModes[ MiRow - 1 ][ MiCol ]
    if ( AvailL )
        ctx += SkipModes[ MiRow ][ MiCol - 1 ]
```

skip: the cdf is given by TileSkipCdf[ctx] where ctx is computed by:

```
    ctx = 0
    if ( AvailU )
        ctx += Skips[ MiRow - 1 ][ MiCol ]
    if ( AvailL )
        ctx += Skips[ MiRow ][ MiCol - 1 ]
```

comp_ref: the cdf is given by TileCompRefCdf[ctx][0] where ctx is computed by:

```
last12Count = count_refs( LAST_FRAME ) + count_refs( LAST2_FRAME )
last3GoldCount = count_refs( LAST3_FRAME ) + count_refs( GOLDEN_FRAME )
ctx = ref_count_ctx( last12Count, last3GoldCount )
```

where count_refs is defined as:

```
count_refs(frameType) {
    c = 0
    if ( AvailU ) {
        if ( AboveRefFrame[ 0 ] == frameType ) c++
        if ( AboveRefFrame[ 1 ] == frameType ) c++
    }
    if ( AvailL ) {
        if ( LeftRefFrame[ 0 ] == frameType ) c++
        if ( LeftRefFrame[ 1 ] == frameType ) c++
    }
    return c
}
```

and ref_count_ctx is defined as:

```
ref_count_ctx(counts0, counts1) {
  if ( counts0 < counts1 )
    return 0
  else if ( counts0 == counts1 )
    return 1
  else
    return 2
}
```

comp_ref_p1: the cdf is given by TileCompRefCdf[ctx][1] where ctx is computed by:

```
lastCount = count_refs( LAST_FRAME )
last2Count = count_refs( LAST2_FRAME )
ctx = ref_count_ctx( lastCount, last2Count )
```

where count_refs and ref_count_ctx are the same as given in the CDF selection process for comp_ref.

comp_ref_p2: the cdf is given by TileCompRefCdf[ctx][2] where ctx is computed by:

```
last3Count = count_refs( LAST3_FRAME )
goldCount = count_refs( GOLDEN_FRAME )
ctx = ref_count_ctx( last3Count, goldCount )
```

where count_refs and ref_count_ctx are the same as given in the CDF selection process for comp_ref.

comp_bwdref: the cdf is given by TileCompBwdRefCdf[ctx][0] where ctx is computed by:

```
brfarf2Count = count_refs( BWDREF_FRAME ) + count_refs( ALTREF2_FRAME )
arfCount = count_refs( ALTREF_FRAME )
ctx = ref_count_ctx( brfarf2Count, arfCount )
```

where count_refs and ref_count_ctx are the same as given in the CDF selection process for comp_ref.

comp_bwdref_p1: the cdf is given by TileCompBwdRefCdf[ctx][1] where ctx is computed by:

```
brfCount = count_refs( BWDREF_FRAME )
arf2Count = count_refs( ALTREF2_FRAME )
ctx = ref_count_ctx( brfCount, arf2Count )
```

where count_refs and ref_count_ctx are the same as given in the CDF selection process for comp_ref.

single_ref_p1: the cdf is given by TileSingleRefCdf[ctx][0] where ctx is computed by:

```
fwdCount = count_refs( LAST_FRAME )
fwdCount += count_refs( LAST2_FRAME )
fwdCount += count_refs( LAST3_FRAME )
fwdCount += count_refs( GOLDEN_FRAME )
bwdCount = count_refs( BWDREF_FRAME )
bwdCount += count_refs( ALTREF2_FRAME )
bwdCount += count_refs( ALTREF_FRAME )
ctx = ref_count_ctx( fwdCount, bwdCount )
```

where count_refs and ref_count_ctx are the same as given in the CDF selection process for comp_ref.

single_ref_p2: the cdf is given by TileSingleRefCdf[ctx][1] where ctx is computed as in the CDF selection process for comp_bwdref.

single_ref_p3: the cdf is given by TileSingleRefCdf[ctx][2] where ctx is computed as in the CDF selection process for comp_ref.

single_ref_p4: the cdf is given by TileSingleRefCdf[ctx][3] where ctx is computed as in the CDF selection process for comp_ref_p1.

single_ref_p5: the cdf is given by TileSingleRefCdf[ctx][4] where ctx is computed as in the CDF selection process for comp_ref_p2.

single_ref_p6: the cdf is given by TileSingleRefCdf[ctx][5] where ctx is computed as in the CDF selection process for comp_bwdref_p1.

compound_mode: the cdf is given by TileCompoundModeCdf[ctx] where ctx is computed by:

```
ctx = Compound_Mode_Ctx_Map[ RefMvContext >> 1 ][ Min(NewMvContext, COMP_NEWMV_CTXS - 1) ]
```

where Compound_Mode_Ctx_Map is defined as follows:

```
Compound_Mode_Ctx_Map[ 3 ][ COMP_NEWMV_CTXS ] = {
    { 0, 1, 1, 1, 1 },
    { 1, 2, 3, 4, 4 },
    { 4, 4, 5, 6, 7 }
}
```

interp_filter: the cdf is given by TileInterpFilterCdf[ctx] where ctx is computed by:

```
ctx = ( ( dir & 1 ) * 2 + ( RefFrame[ 1 ] > INTRA_FRAME ) ) * 4
leftType = 3
aboveType = 3

if ( AvailL ) {
    if ( RefFrames[ MiRow ][ MiCol - 1 ][ 0 ] == RefFrame[ 0 ] ||
         RefFrames[ MiRow ][ MiCol - 1 ][ 1 ] == RefFrame[ 0 ] )
        leftType = InterpFilters[ MiRow ] [ MiCol - 1 ][ dir ]
}

if ( AvailU ) {
    if ( RefFrames[ MiRow - 1 ][ MiCol ][ 0 ] == RefFrame[ 0 ] ||
         RefFrames[ MiRow - 1 ][ MiCol ][ 1 ] == RefFrame[ 0 ] )
        aboveType = InterpFilters[ MiRow - 1 ] [ MiCol ][ dir ]
}

if ( leftType == aboveType )
    ctx += leftType
else if ( leftType == 3 )
    ctx += aboveType
else if ( aboveType == 3 )
    ctx += leftType
else
    ctx += 3
```

motion_mode: the cdf is given by TileMotionModeCdf[MiSize].

mv_joint: the cdf is given by TileMvJointCdf[MvCtx].

mv_sign: the cdf is given by TileMvSignCdf[MvCtx][comp].

mv_class: the cdf is given by TileMvClassCdf[MvCtx][comp].

mv_class0_bit: the cdf is given by TileMvClass0BitCdf[MvCtx][comp].

mv_class0_fr: the cdf is given by TileMvClass0FrCdf[MvCtx][comp][mv_class0_bit].

mv_class0_hp: the cdf is given by TileMvClass0HpCdf[MvCtx][comp].

mv_fr: the cdf is given by TileMvFrCdf[MvCtx][comp].

mv_hp: the cdf is given by TileMvHpCdf[MvCtx][comp].

mv_bit: the cdf is given by TileMvBitCdf[MvCtx][comp][i].

all_zero: the cdf is given by TileTxbSkipCdf[txSzCtx][ctx], where ctx is computed as follows:

```
maxX4 = MiCols
maxY4 = MiRows
if ( plane > 0 ) {
    maxX4 = maxX4 >> subsampling_x
    maxY4 = maxY4 >> subsampling_y
}

w = Tx_Width[txSz]
h = Tx_Height[txSz]

bsize = get_plane_residual_size( MiSize, plane )
bw = Block_Width[ bsize ]
bh = Block_Height[ bsize ]

if ( plane == 0 ) {
    top = 0
    left = 0
    for ( k = 0; k < w4; k++ ) {
        if ( x4 + k < maxX4 )
            top = Max( top, AboveLevelContext[ plane ][ x4 + k ] )
    }
    for ( k = 0; k < h4; k++ ) {
        if ( y4 + k < maxY4 )
            left = Max( left, LeftLevelContext[ plane ][ y4 + k ] )
    }
    top = Min( top, 255 )
    left = Min( left, 255 )
    if ( bw == w && bh == h ) {
        ctx = 0
    } else if ( top == 0 && left == 0 ) {
        ctx = 1
    } else if ( top == 0 || left == 0 ) {
        ctx = 2 + ( Max( top, left ) > 3 )
    } else if ( Max( top, left ) <= 3 ) {
        ctx = 4
    } else if ( Min( top, left ) <= 3 ) {
        ctx = 5
    } else {
        ctx = 6
    }
} else {
    above = 0
    left = 0
    for ( i = 0; i < w4; i++ ) {
        if ( x4 + i < maxX4 ) {
            above |= AboveLevelContext[ plane ][ x4 + i ]
            above |= AboveDcContext[ plane ][ x4 + i ]
        }
    }
    for ( i = 0; i < h4; i++ ) {
```

```
        if ( y4 + i < maxY4 ) {
            left |= LeftLevelContext[ plane ][ y4 + i ]
            left |= LeftDcContext[ plane ][ y4 + i ]
        }
    }
    ctx = ( above != 0 ) + ( left != 0 )
    ctx += 7
    if ( bw * bh > w * h )
        ctx += 3
}
```

eob_pt_16: the cdf is given by TileEobPt16Cdf[ptype][ctx], where ctx is computed as follows:

```
txType = compute_tx_type( plane, txSz, x4, y4 )
ctx = ( get_tx_class( txType ) == TX_CLASS_2D ) ? 0 : 1
```

where get_tx_class() is defined as in the CDF selection for coeff_base.

eob_pt_32: the cdf is given by TileEobPt32Cdf[ptype][ctx], where ctx is computed as for eob_pt_16.

eob_pt_64: the cdf is given by TileEobPt64Cdf[ptype][ctx], where ctx is computed as for eob_pt_16.

eob_pt_128: the cdf is given by TileEobPt128Cdf[ptype][ctx], where ctx is computed as for eob_pt_16.

eob_pt_256: the cdf is given by TileEobPt256Cdf[ptype][ctx], where ctx is computed as for eob_pt_16.

eob_pt_512: the cdf is given by TileEobPt512Cdf[ptype].

eob_pt_1024: the cdf is given by TileEobPt1024Cdf[ptype].

eob_extra: the cdf is given by TileEobExtraCdf[txSzCtx][ptype][eobPt - 3].

coeff_base: the cdf is given by TileCoeffBaseCdf[txSzCtx][ptype][ctx], where ctx is computed as follows:

```
ctx = get_coeff_base_ctx(txSz, plane, x4, y4, scan[c], c, 0)
```

where get_coeff_base_ctx is defined as:

```
get_coeff_base_ctx( txSz, plane, blockX, blockY, pos, c, isEob ) {
    adjTxSz = Adjusted_Tx_Size[ txSz ]
    bwl = Tx_Width_Log2[ adjTxSz ]
    width = 1 << bwl
    height = Tx_Height[ adjTxSz ]
    txType = compute_tx_type( plane, txSz, blockX, blockY )
    if ( isEob ) {
        if ( c == 0 ) {
            return SIG_COEF_CONTEXTS - 4
        }
        if ( c <= (height << bwl) / 8 ) {
            return SIG_COEF_CONTEXTS - 3
        }
        if ( c <= (height << bwl) / 4 ) {
            return SIG_COEF_CONTEXTS - 2
        }
        return SIG_COEF_CONTEXTS - 1
    }
    txClass = get_tx_class( txType )
    row = pos >> bwl
    col = pos - (row << bwl)
    mag = 0

    for ( idx = 0; idx < SIG_REF_DIFF_OFFSET_NUM; idx++ ) {
        refRow = row + Sig_Ref_Diff_Offset[ txClass ][ idx ][ 0 ]
        refCol = col + Sig_Ref_Diff_Offset[ txClass ][ idx ][ 1 ]
        if ( refRow >= 0 &&
             refCol >= 0 &&
             refRow < height &&
             refCol < width ) {
            mag += Min( Abs( Quant[ (refRow << bwl) + refCol ] ), 3 )
        }
    }

    ctx = Min( ( mag + 1 ) >> 1, 4 )
    if ( txClass == TX_CLASS_2D ) {
        if ( row == 0 && col == 0 ) {
            return 0
        }
        return ctx + Coeff_Base_Ctx_Offset[ txSz ][ Min( row, 4 ) ][ Min( col, 4 ) ]
    }
    idx = ( txClass == TX_CLASS_VERT ) ? row : col
    return ctx + Coeff_Base_Pos_Ctx_Offset[ Min( idx, 2 ) ]
}
```

where get_tx_class is defined as:

```
get_tx_class( txType ) {
    if ( ( txType == V_DCT ) ||
         ( txType == V_ADST ) ||
         ( txType == V_FLIPADST ) ) {
        return TX_CLASS_VERT
    } else if ( ( txType == H_DCT ) ||
                ( txType == H_ADST ) ||
                ( txType == H_FLIPADST ) ) {
        return TX_CLASS_HORIZ
    } else
        return TX_CLASS_2D
}
```

Coeff_Base_Ctx_Offset is defined as:

```
Coeff_Base_Ctx_Offset[ TX_SIZES_ALL ][ 5 ][ 5 ] = {
  {
    { 0, 1, 6, 6, 0 },
    { 1, 6, 6, 21, 0 },
    { 6, 6, 21, 21, 0 },
    { 6, 21, 21, 21, 0 },
    { 0, 0, 0, 0, 0 }
  },
  {
    { 0, 1, 6, 6, 21 },
    { 1, 6, 6, 21, 21 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 1, 6, 6, 21 },
    { 1, 6, 6, 21, 21 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 1, 6, 6, 21 },
    { 1, 6, 6, 21, 21 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 1, 6, 6, 21 },
    { 1, 6, 6, 21, 21 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 11, 11, 11, 0 },
    { 11, 11, 11, 11, 0 },
    { 6, 6, 21, 21, 0 },
    { 6, 21, 21, 21, 0 },
    { 21, 21, 21, 21, 0 }
  },
  {
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 0, 0, 0, 0, 0 }
  },
```

```
  {
    { 0, 11, 11, 11, 11 },
    { 11, 11, 11, 11, 11 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 }
  },
  {
    { 0, 11, 11, 11, 11 },
    { 11, 11, 11, 11, 11 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 }
  },
  {
    { 0, 11, 11, 11, 11 },
    { 11, 11, 11, 11, 11 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 }
  },
  {
    { 0, 11, 11, 11, 0 },
    { 11, 11, 11, 11, 0 },
    { 6, 6, 21, 21, 0 },
    { 6, 21, 21, 21, 0 },
    { 21, 21, 21, 21, 0 }
  },
  {
```

```
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 0, 0, 0, 0, 0 }
  },
  {
    { 0, 11, 11, 11, 11 },
    { 11, 11, 11, 11, 11 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 }
  },
  {
    { 0, 11, 11, 11, 11 },
    { 11, 11, 11, 11, 11 },
    { 6, 6, 21, 21, 21 },
    { 6, 21, 21, 21, 21 },
    { 21, 21, 21, 21, 21 }
  },
  {
    { 0, 16, 6, 6, 21 },
    { 16, 16, 6, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 },
    { 16, 16, 21, 21, 21 }
  }
}
```

and Coeff_Base_Pos_Ctx_Offset is defined as:

```
Coeff_Base_Pos_Ctx_Offset[ 3 ] = {
  SIG_COEF_CONTEXTS_2D,
  SIG_COEF_CONTEXTS_2D + 5,
  SIG_COEF_CONTEXTS_2D + 10
}
```

coeff_base_eob: the cdf is given by TileCoeffBaseEobCdf[txSzCtx][ptype][ctx], where ctx is computed as follows:

```
ctx = get_coeff_base_ctx(txSz, plane, x4, y4, scan[c], c, 1) - SIG_COEF_CONTEXTS +
SIG_COEF_CONTEXTS_EOB
```

where get_coeff_base_ctx() is as defined in the CDF selection for coeff_base.

dc_sign: the cdf is given by TileDcSignCdf[ptype][ctx], where ctx is computed as follows:

```
maxX4 = MiCols
maxY4 = MiRows
if ( plane > 0 ) {
    maxX4 = maxX4 >> subsampling_x
    maxY4 = maxY4 >> subsampling_y
}

dcSign = 0
for ( k = 0; k < w4; k++ ) {
    if ( x4 + k < maxX4 ) {
        sign = AboveDcContext[ plane ][ x4 + k ]
        if ( sign == 1 ) {
            dcSign--
        } else if ( sign == 2 ) {
            dcSign++
        }
    }
}
for ( k = 0; k < h4; k++ ) {
    if ( y4 + k < maxY4 ) {
        sign = LeftDcContext[ plane ][ y4 + k ]
        if ( sign == 1 ) {
            dcSign--
        } else if ( sign == 2 ) {
            dcSign++
        }
    }
}
if ( dcSign < 0 ) {
    ctx = 1
} else if ( dcSign > 0 ) {
    ctx = 2
} else {
    ctx = 0
}
```

coeff_br: the cdf is given by TileCoeffBrCdf[Min(txSzCtx, TX_32X32)][ptype][ctx], where ctx is computed as follows:

```
adjTxSz = Adjusted_Tx_Size[ txSz ]
bwl = Tx_Width_Log2[ adjTxSz ]
txw = Tx_Width[ adjTxSz ]
txh = Tx_Height[ adjTxSz ]
row = pos >> bwl
col = pos - (row << bwl)

mag = 0

txType = compute_tx_type( plane, txSz, x4, y4 )
txClass = get_tx_class( txType )

for ( idx = 0; idx < 3; idx++ ) {
    refRow = row + Mag_Ref_Offset_With_Tx_Class[ txClass ][ idx ][ 0 ]
    refCol = col + Mag_Ref_Offset_With_Tx_Class[ txClass ][ idx ][ 1 ]
    if ( refRow >= 0 &&
         refCol >= 0 &&
         refRow < txh &&
         refCol < (1 << bwl) ) {
        mag += Min( Quant[ refRow * txw + refCol ], COEFF_BASE_RANGE + NUM_BASE_LEVELS + 1 )
    }
}

mag = Min( ( mag + 1 ) >> 1, 6 )
if ( pos == 0 ) {
    ctx = mag
} else if ( txClass == 0 ) {
    if ( ( row < 2 ) && ( col < 2 ) ) {
        ctx = mag + 7
    } else {
        ctx = mag + 14
    }
} else {
    if ( txClass == 1 ) {
        if ( col == 0 ) {
            ctx = mag + 7
        } else {
            ctx = mag + 14
        }
    } else {
        if ( row == 0 ) {
            ctx = mag + 7
        } else {
            ctx = mag + 14
        }
    }
}
```

where get_tx_class() is defined as in the CDF selection for coeff_base, and Mag_Ref_Offset_With_Tx_Class is defined as:

```
Mag_Ref_Offset_With_Tx_Class[ 3 ][ 3 ][ 2 ] = {
  { { 0, 1 }, { 1, 0 }, { 1, 1 } },
  { { 0, 1 }, { 1, 0 }, { 0, 2 } },
  { { 0, 1 }, { 1, 0 }, { 2, 0 } }
}
```

has_palette_y: the cdf is given by TilePaletteYModeCdf[bsizeCtx][ctx] where ctx is computed as follows:

```
ctx = 0
if ( AvailU && PaletteSizes[ 0 ][ MiRow - 1 ][ MiCol ] > 0 )
    ctx += 1
if ( AvailL && PaletteSizes[ 0 ][ MiRow ][ MiCol - 1 ] > 0 )
    ctx += 1
```

has_palette_uv: the cdf is given by TilePaletteUVModeCdf[ctx] where ctx is computed as follows:

```
ctx = ( PaletteSizeY > 0 ) ? 1 : 0
```

palette_size_y_minus_2: the cdf is given by TilePaletteYSizeCdf[bsizeCtx].

palette_size_uv_minus_2: the cdf is given by TilePaletteUVSizeCdf[bsizeCtx].

palette_color_idx_y: the cdf depends on PaletteSizeY, as follows:

PaletteSizeY	cdf
2	TilePaletteSize2YColorCdf[ctx]
3	TilePaletteSize3YColorCdf[ctx]
4	TilePaletteSize4YColorCdf[ctx]
5	TilePaletteSize5YColorCdf[ctx]
6	TilePaletteSize6YColorCdf[ctx]
7	TilePaletteSize7YColorCdf[ctx]
8	TilePaletteSize8YColorCdf[ctx]

where ctx is computed as follows:

```
ctx = Palette_Color_Context[ ColorContextHash ]
```

palette_color_idx_uv: the cdf depends on PaletteSizeUV, as follows:

PaletteSizeUV	cdf
2	TilePaletteSize2UVColorCdf[ctx]
3	TilePaletteSize3UVColorCdf[ctx]
4	TilePaletteSize4UVColorCdf[ctx]
5	TilePaletteSize5UVColorCdf[ctx]
6	TilePaletteSize6UVColorCdf[ctx]
7	TilePaletteSize7UVColorCdf[ctx]
8	TilePaletteSize8UVColorCdf[ctx]

where ctx is computed as follows:

```
ctx = Palette_Color_Context[ ColorContextHash ]
```

delta_q_abs: the cdf is given by TileDeltaQCdf.

delta_lf_abs: the cdf is derived as follows:

- If delta_lf_multi is equal to 0, the cdf is given by TileDeltaLFCdf.
- Otherwise (delta_lf_multi is equal to 1), the cdf is given by TileDeltaLFMultiCdf[i].

intra_tx_type: the cdf depends on the variable set, as follows:

set	cdf
TX_SET_INTRA_1	TileIntraTxTypeSet1Cdf[Tx_Size_Sqr[txSz]][intraDir]
TX_SET_INTRA_2	TileIntraTxTypeSet2Cdf[Tx_Size_Sqr[txSz]][intraDir]

where the variable intraDir is derived as follows:

- If use_filter_intra is equal to 1, intraDir is set equal to Filter_Intra_Mode_To_Intra_Dir[filter_intra_mode],
- Otherwise (use_filter_intra is equal to 0), intraDir is set equal to YMode.

The table Filter_Intra_Mode_To_Intra_Dir is defined as:

```
Filter_Intra_Mode_To_Intra_Dir[ INTRA_FILTER_MODES ] = {
  DC_PRED, V_PRED, H_PRED, D157_PRED, DC_PRED
}
```

inter_tx_type: the cdf depends on the variable set, as follows:

set	cdf
TX_SET_INTER_1	TileInterTxTypeSet1Cdf[Tx_Size_Sqr[txSz]]
TX_SET_INTER_2	TileInterTxTypeSet2Cdf
TX_SET_INTER_3	TileInterTxTypeSet3Cdf[Tx_Size_Sqr[txSz]]

comp_ref_type: The cdf is given by TileCompRefTypeCdf[ctx], where ctx is computed as follows:

```
above0 = AboveRefFrame[ 0 ]
above1 = AboveRefFrame[ 1 ]
left0 = LeftRefFrame[ 0 ]
left1 = LeftRefFrame[ 1 ]
aboveCompInter = AvailU && !AboveIntra && !AboveSingle
leftCompInter = AvailL && !LeftIntra && !LeftSingle
aboveUniComp = aboveCompInter && is_samedir_ref_pair(above0, above1)
leftUniComp = leftCompInter && is_samedir_ref_pair(left0, left1)

if ( AvailU && !AboveIntra && AvailL && !LeftIntra ) {
    samedir = is_samedir_ref_pair(above0, left0)

    if ( !aboveCompInter && !leftCompInter ) {
        ctx = 1 + 2 * samedir
    } else if ( !aboveCompInter ) {
        if ( !leftUniComp )
            ctx = 1
        else
            ctx = 3 + samedir
    } else if ( !leftCompInter ) {
        if ( !aboveUniComp )
            ctx = 1
        else
            ctx = 3 + samedir
    } else {
        if ( !aboveUniComp && !leftUniComp )
            ctx = 0
        else if ( !aboveUniComp || !leftUniComp )
            ctx = 2
        else
            ctx = 3 + ((above0 == BWDREF_FRAME) == (left0 == BWDREF_FRAME))
    }
} else if ( AvailU && AvailL ) {
    if ( aboveCompInter )
        ctx = 1 + 2 * aboveUniComp
    else if ( leftCompInter )
        ctx = 1 + 2 * leftUniComp
    else
        ctx = 2
} else if ( aboveCompInter ) {
    ctx = 4 * aboveUniComp
} else if ( leftCompInter ) {
    ctx = 4 * leftUniComp
} else {
    ctx = 2
}
```

where is_samedir_ref_pair is defined as:

```
is_samedir_ref_pair(ref0, ref1) {
  return (ref0 >= BWDREF_FRAME) == (ref1 >= BWDREF_FRAME)
}
```

uni_comp_ref: The cdf is given by TileUniCompRefCdf[ctx][0], where ctx is computed as in the CDF selection process for single_ref_p1.

uni_comp_ref_p1: The cdf is given by TileUniCompRefCdf[ctx][1], where ctx is computed as follows:

```
last2Count = count_refs( LAST2_FRAME )
last3GoldCount = count_refs( LAST3_FRAME ) + count_refs( GOLDEN_FRAME )
ctx = ref_count_ctx( last2Count, last3GoldCount )
```

where count_refs and ref_count_ctx are the same as given in the CDF selection process for comp_ref.

uni_comp_ref_p2: The cdf is given by TileUniCompRefCdf[ctx][2], where ctx is computed as in the CDF selection process for comp_ref_p2.

comp_group_idx: The cdf is given by TileCompGroupIdxCdf[ctx], where ctx is computed as follows:

```
ctx = 0
if ( AvailU ) {
  if ( !AboveSingle )
    ctx += CompGroupIdxs[ MiRow - 1 ][ MiCol ]
  else if ( AboveRefFrame[ 0 ] == ALTREF_FRAME )
    ctx += 3
}
if ( AvailL ) {
  if ( !LeftSingle )
    ctx += CompGroupIdxs[ MiRow ][ MiCol - 1 ]
  else if ( LeftRefFrame[ 0 ] == ALTREF_FRAME )
    ctx += 3
}
ctx = Min( 5, ctx )
```

compound_idx: The cdf is given by TileCompoundIdxCdf[ctx], where ctx is computed as follows:

```
fwd = Abs( get_relative_dist( OrderHints[ RefFrame[ 0 ] ], OrderHint ) )
bck = Abs( get_relative_dist( OrderHints[ RefFrame[ 1 ] ], OrderHint ) )
ctx = ( fwd == bck ) ? 3 : 0
if ( AvailU ) {
  if ( !AboveSingle )
    ctx += CompoundIdxs[ MiRow - 1 ][ MiCol ]
  else if ( AboveRefFrame[ 0 ] == ALTREF_FRAME )
    ctx++
}
if ( AvailL ) {
  if ( !LeftSingle )
    ctx += CompoundIdxs[ MiRow ][ MiCol - 1 ]
  else if ( LeftRefFrame[ 0 ] == ALTREF_FRAME )
    ctx++
}
```

compound_type: The cdf is given by TileCompoundTypeCdf[MiSize].

interintra: The cdf is given by TileInterIntraCdf[ctx], where ctx is computed as follows:

```
ctx = Size_Group[ MiSize ] - 1
```

interintra_mode: The cdf is given by TileInterIntraModeCdf[ctx], where ctx is computed as follows:

```
ctx = Size_Group[ MiSize ] - 1
```

wedge_index: The cdf is given by TileWedgeIndexCdf[MiSize].

wedge_interintra: The cdf is given by TileWedgeInterIntraCdf[MiSize].

use_obmc: The cdf is given by TileUseObmcCdf[MiSize].

cfl_alpha_signs: The cdf is given by TileCflSignCdf.

cfl_alpha_u: The cdf is given by TileCflAlphaCdf[ctx], where ctx is obtained from the following table:

cfl_alpha_signs	ctx
0	N/A
1	N/A
2	0
3	1

cfl_alpha_signs	ctx
4	2
5	3
6	4
7	5

Note: N/A is used to indicate that no context is needed as the sign is zero and no value is decoded.

or computed as follows:

```
ctx = (signU - 1) * 3 + signV
```

Note: As shown in the previous table, the variable ctx produced by this calculation will be equal to cfl_alpha_signs - 2.

cfl_alpha_v: The cdf is given by TileCflAlphaCdf[ctx], where ctx is obtained from the following table:

cfl_alpha_signs	ctx
0	0
1	3
2	N/A
3	1
4	4
5	N/A
6	2
7	5

Note: N/A is used to indicate that no context is needed as the sign is zero and no value is decoded.

or computed as follows:

```
ctx = (signV - 1) * 3 + signU
```

use_wiener: The cdf is given by TileUseWienerCdf.

use_sgrproj: The cdf is given by TileUseSgrprojCdf.

restoration_type: The cdf is given by TileRestorationTypeCdf.

9. Additional tables

9.1. General

This section contains tables that do not naturally fit in the main sections of the Specification.

9.2. Scan tables

This section defines the scan order for different types of transform. Each table is named in the form <type>_Scan_<w>x<h>, and contains an ordered list of positions within a rectangle of width w and height h. Each position is calculated as w * y + x.

The following table lists pairs of scan tables which are transposes of each other. A table T_wxh is a transpose of another table T_hxw if the following function returns 1:

```
is_transpose( ) {
    for ( pos = 0; pos < w * h; pos++ ) {
        x1 = T_wxh[ pos ] % w
        y1 = T_wxh[ pos ] / w
        x2 = T_hxw[ pos ] % h
        y2 = T_hxw[ pos ] / h
        if ( x1 != y2 || y1 != x2 )
            return 0
    }
    return 1
}
```

Table	Transpose
Default_Scan_4x8	Default_Scan_8x4
Default_Scan_16x32	Default_Scan_32x16
Default_Scan_16x4	Default_Scan_4x16
Default_Scan_16x8	Default_Scan_8x16
Default_Scan_32x8	Default_Scan_8x32
Mcol_Scan_4x4	Mrow_Scan_4x4
Mcol_Scan_4x8	Mrow_Scan_8x4
Mcol_Scan_8x8	Mrow_Scan_8x8
Mcol_Scan_16x8	Mrow_Scan_8x16
Mcol_Scan_16x16	Mrow_Scan_16x16
Mcol_Scan_16x4	Mrow_Scan_4x16

Table	Transpose
Mrow_Scan_4x4	Mcol_Scan_4x4
Mrow_Scan_4x8	Mcol_Scan_8x4
Mrow_Scan_8x8	Mcol_Scan_8x8
Mrow_Scan_16x8	Mcol_Scan_8x16
Mrow_Scan_16x16	Mcol_Scan_16x16
Mrow_Scan_16x4	Mcol_Scan_4x16

```
Default_Scan_4x4[ 16 ] = {
    0, 1, 4, 8,
    5, 2, 3, 6,
    9, 12, 13, 10,
    7, 11, 14, 15
}
```

```
Mcol_Scan_4x4[ 16 ] = {
    0, 4, 8, 12,
    1, 5, 9, 13,
    2, 6, 10, 14,
    3, 7, 11, 15
}
```

```
Mrow_Scan_4x4[ 16 ] = {
    0, 1, 2, 3,
    4, 5, 6, 7,
    8, 9, 10, 11,
    12, 13, 14, 15
}
```

```
Default_Scan_4x8[ 32 ] = {
  0,  1,  4,  2,  5,  8,  3,  6,  9,  12, 7,  10, 13, 16, 11, 14,
  17, 20, 15, 18, 21, 24, 19, 22, 25, 28, 23, 26, 29, 27, 30, 31
}
```

```
Mcol_Scan_4x8[ 32 ] = {
  0, 4, 8,  12, 16, 20, 24, 28, 1, 5, 9,  13, 17, 21, 25, 29,
  2, 6, 10, 14, 18, 22, 26, 30, 3, 7, 11, 15, 19, 23, 27, 31
}
```

```
Mrow_Scan_4x8[ 32 ] = {
  0,  1,  2,  3,  4,  5,  6,  7,  8,  9,  10, 11, 12, 13, 14, 15,
  16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31
}
```

```
Default_Scan_8x4[ 32 ] = {
  0,  8, 1,  16, 9,  2, 24, 17, 10, 3, 25, 18, 11, 4,  26, 19,
  12, 5, 27, 20, 13, 6, 28, 21, 14, 7, 29, 22, 15, 30, 23, 31
}
```

```
Mcol_Scan_8x4[ 32 ] = {
  0, 8,  16, 24, 1, 9,  17, 25, 2, 10, 18, 26, 3, 11, 19, 27,
  4, 12, 20, 28, 5, 13, 21, 29, 6, 14, 22, 30, 7, 15, 23, 31
}
```

```
Mrow_Scan_8x4[ 32 ] = {
  0,  1,  2,  3,  4,  5,  6,  7,  8,  9,  10, 11, 12, 13, 14, 15,
  16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31
}
```

```
Default_Scan_8x8[ 64 ] = {
    0,  1,  8,  16, 9,  2,  3,  10,
    17, 24, 32, 25, 18, 11, 4,  5,
    12, 19, 26, 33, 40, 48, 41, 34,
    27, 20, 13, 6,  7,  14, 21, 28,
    35, 42, 49, 56, 57, 50, 43, 36,
    29, 22, 15, 23, 30, 37, 44, 51,
    58, 59, 52, 45, 38, 31, 39, 46,
    53, 60, 61, 54, 47, 55, 62, 63
}
```

```
Mcol_Scan_8x8[ 64 ] = {
  0, 8,  16, 24, 32, 40, 48, 56,
  1, 9,  17, 25, 33, 41, 49, 57,
  2, 10, 18, 26, 34, 42, 50, 58,
  3, 11, 19, 27, 35, 43, 51, 59,
  4, 12, 20, 28, 36, 44, 52, 60,
  5, 13, 21, 29, 37, 45, 53, 61,
  6, 14, 22, 30, 38, 46, 54, 62,
  7, 15, 23, 31, 39, 47, 55, 63
}
```

```
Mrow_Scan_8x8[ 64 ] = {
  0,  1,  2,  3,  4,  5,  6,  7,
  8,  9,  10, 11, 12, 13, 14, 15,
  16, 17, 18, 19, 20, 21, 22, 23,
  24, 25, 26, 27, 28, 29, 30, 31,
  32, 33, 34, 35, 36, 37, 38, 39,
  40, 41, 42, 43, 44, 45, 46, 47,
  48, 49, 50, 51, 52, 53, 54, 55,
  56, 57, 58, 59, 60, 61, 62, 63
}
```

```
Default_Scan_8x16[ 128 ] = {
  0,   1,   8,   2,   9,   16,  3,   10,  17,  24,  4,   11,  18,  25,  32,
  5,   12,  19,  26,  33,  40,  6,   13,  20,  27,  34,  41,  48,  7,   14,
  21,  28,  35,  42,  49,  56,  15,  22,  29,  36,  43,  50,  57,  64,  23,
  30,  37,  44,  51,  58,  65,  72,  31,  38,  45,  52,  59,  66,  73,  80,
  39,  46,  53,  60,  67,  74,  81,  88,  47,  54,  61,  68,  75,  82,  89,
  96,  55,  62,  69,  76,  83,  90,  97,  104, 63,  70,  77,  84,  91,  98,
  105, 112, 71,  78,  85,  92,  99,  106, 113, 120, 79,  86,  93,  100, 107,
  114, 121, 87,  94,  101, 108, 115, 122, 95,  102, 109, 116, 123, 103, 110,
  117, 124, 111, 118, 125, 119, 126, 127
}
```

```
Mcol_Scan_8x16[ 128 ] = {
  0, 8,  16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96,  104, 112, 120,
  1, 9,  17, 25, 33, 41, 49, 57, 65, 73, 81, 89, 97,  105, 113, 121,
  2, 10, 18, 26, 34, 42, 50, 58, 66, 74, 82, 90, 98,  106, 114, 122,
  3, 11, 19, 27, 35, 43, 51, 59, 67, 75, 83, 91, 99,  107, 115, 123,
  4, 12, 20, 28, 36, 44, 52, 60, 68, 76, 84, 92, 100, 108, 116, 124,
  5, 13, 21, 29, 37, 45, 53, 61, 69, 77, 85, 93, 101, 109, 117, 125,
  6, 14, 22, 30, 38, 46, 54, 62, 70, 78, 86, 94, 102, 110, 118, 126,
  7, 15, 23, 31, 39, 47, 55, 63, 71, 79, 87, 95, 103, 111, 119, 127
}
```

```
Mrow_Scan_8x16[ 128 ] = {
  0,   1,   2,   3,   4,   5,   6,   7,   8,   9,   10,  11,  12,  13,  14,
  15,  16,  17,  18,  19,  20,  21,  22,  23,  24,  25,  26,  27,  28,  29,
  30,  31,  32,  33,  34,  35,  36,  37,  38,  39,  40,  41,  42,  43,  44,
  45,  46,  47,  48,  49,  50,  51,  52,  53,  54,  55,  56,  57,  58,  59,
  60,  61,  62,  63,  64,  65,  66,  67,  68,  69,  70,  71,  72,  73,  74,
  75,  76,  77,  78,  79,  80,  81,  82,  83,  84,  85,  86,  87,  88,  89,
  90,  91,  92,  93,  94,  95,  96,  97,  98,  99,  100, 101, 102, 103, 104,
  105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119,
  120, 121, 122, 123, 124, 125, 126, 127
}
```

```
Default_Scan_16x8[ 128 ] = {
  0,  16,  1,   32, 17,  2,   48,  33,  18, 3,  64,  49,  34,  19,  4,   80,
  65, 50,  35,  20, 5,   96,  81,  66,  51, 36, 21,  6,   112, 97,  82,  67,
  52, 37,  22,  7,  113, 98,  83,  68,  53, 38, 23,  8,   114, 99,  84,  69,
  54, 39,  24,  9,  115, 100, 85,  70,  55, 40, 25,  10,  116, 101, 86,  71,
  56, 41,  26,  11, 117, 102, 87,  72,  57, 42, 27,  12,  118, 103, 88,  73,
  58, 43,  28,  13, 119, 104, 89,  74,  59, 44, 29,  14,  120, 105, 90,  75,
  60, 45,  30,  15, 121, 106, 91,  76,  61, 46, 31,  122, 107, 92,  77,  62,
  47, 123, 108, 93, 78,  63,  124, 109, 94, 79, 125, 110, 95,  126, 111, 127
}
```

```
Mcol_Scan_16x8[ 128 ] = {
  0,  16, 32, 48, 64, 80, 96,  112, 1,  17, 33, 49, 65, 81, 97,  113,
  2,  18, 34, 50, 66, 82, 98,  114, 3,  19, 35, 51, 67, 83, 99,  115,
  4,  20, 36, 52, 68, 84, 100, 116, 5,  21, 37, 53, 69, 85, 101, 117,
  6,  22, 38, 54, 70, 86, 102, 118, 7,  23, 39, 55, 71, 87, 103, 119,
  8,  24, 40, 56, 72, 88, 104, 120, 9,  25, 41, 57, 73, 89, 105, 121,
  10, 26, 42, 58, 74, 90, 106, 122, 11, 27, 43, 59, 75, 91, 107, 123,
  12, 28, 44, 60, 76, 92, 108, 124, 13, 29, 45, 61, 77, 93, 109, 125,
  14, 30, 46, 62, 78, 94, 110, 126, 15, 31, 47, 63, 79, 95, 111, 127
}
```

```
Mrow_Scan_16x8[ 128 ] = {
  0,   1,   2,   3,   4,   5,   6,   7,   8,   9,   10,  11,  12,  13,  14,
  15,  16,  17,  18,  19,  20,  21,  22,  23,  24,  25,  26,  27,  28,  29,
  30,  31,  32,  33,  34,  35,  36,  37,  38,  39,  40,  41,  42,  43,  44,
  45,  46,  47,  48,  49,  50,  51,  52,  53,  54,  55,  56,  57,  58,  59,
  60,  61,  62,  63,  64,  65,  66,  67,  68,  69,  70,  71,  72,  73,  74,
  75,  76,  77,  78,  79,  80,  81,  82,  83,  84,  85,  86,  87,  88,  89,
  90,  91,  92,  93,  94,  95,  96,  97,  98,  99,  100, 101, 102, 103, 104,
  105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119,
  120, 121, 122, 123, 124, 125, 126, 127
}
```

```
Default_Scan_16x16[ 256 ] = {
    0,   1,   16,  32,  17,  2,   3,   18,  33,  48,  64,  49,  34,  19,   4,   5,
    20,  35,  50,  65,  80,  96,  81,  66,  51,  36,  21,  6,   7,   22,  37,  52,
    67,  82,  97,  112, 128, 113, 98,  83,  68,  53,  38,  23,  8,   9,   24,  39,
    54,  69,  84,  99,  114, 129, 144, 160, 145, 130, 115, 100, 85,  70,  55,  40,
    25,  10,  11,  26,  41,  56,  71,  86,  101, 116, 131, 146, 161, 176, 192, 177,
    162, 147, 132, 117, 102, 87,  72,  57,  42,  27,  12,  13,  28,  43,  58,  73,
    88,  103, 118, 133, 148, 163, 178, 193, 208, 224, 209, 194, 179, 164, 149, 134,
    119, 104, 89,  74,  59,  44,  29,  14,  15,  30,  45,  60,  75,  90,  105, 120,
    135, 150, 165, 180, 195, 210, 225, 240, 241, 226, 211, 196, 181, 166, 151, 136,
    121, 106, 91,  76,  61,  46,  31,  47,  62,  77,  92,  107, 122, 137, 152, 167,
    182, 197, 212, 227, 242, 243, 228, 213, 198, 183, 168, 153, 138, 123, 108, 93,
    78,  63,  79,  94,  109, 124, 139, 154, 169, 184, 199, 214, 229, 244, 245, 230,
    215, 200, 185, 170, 155, 140, 125, 110, 95,  111, 126, 141, 156, 171, 186, 201,
    216, 231, 246, 247, 232, 217, 202, 187, 172, 157, 142, 127, 143, 158, 173, 188,
    203, 218, 233, 248, 249, 234, 219, 204, 189, 174, 159, 175, 190, 205, 220, 235,
    250, 251, 236, 221, 206, 191, 207, 222, 237, 252, 253, 238, 223, 239, 254, 255
}
```

```
Mcol_Scan_16x16[ 256 ] = {
  0,  16, 32, 48, 64, 80, 96,  112, 128, 144, 160, 176, 192, 208, 224, 240,
  1,  17, 33, 49, 65, 81, 97,  113, 129, 145, 161, 177, 193, 209, 225, 241,
  2,  18, 34, 50, 66, 82, 98,  114, 130, 146, 162, 178, 194, 210, 226, 242,
  3,  19, 35, 51, 67, 83, 99,  115, 131, 147, 163, 179, 195, 211, 227, 243,
  4,  20, 36, 52, 68, 84, 100, 116, 132, 148, 164, 180, 196, 212, 228, 244,
  5,  21, 37, 53, 69, 85, 101, 117, 133, 149, 165, 181, 197, 213, 229, 245,
  6,  22, 38, 54, 70, 86, 102, 118, 134, 150, 166, 182, 198, 214, 230, 246,
  7,  23, 39, 55, 71, 87, 103, 119, 135, 151, 167, 183, 199, 215, 231, 247,
  8,  24, 40, 56, 72, 88, 104, 120, 136, 152, 168, 184, 200, 216, 232, 248,
  9,  25, 41, 57, 73, 89, 105, 121, 137, 153, 169, 185, 201, 217, 233, 249,
  10, 26, 42, 58, 74, 90, 106, 122, 138, 154, 170, 186, 202, 218, 234, 250,
  11, 27, 43, 59, 75, 91, 107, 123, 139, 155, 171, 187, 203, 219, 235, 251,
  12, 28, 44, 60, 76, 92, 108, 124, 140, 156, 172, 188, 204, 220, 236, 252,
  13, 29, 45, 61, 77, 93, 109, 125, 141, 157, 173, 189, 205, 221, 237, 253,
  14, 30, 46, 62, 78, 94, 110, 126, 142, 158, 174, 190, 206, 222, 238, 254,
  15, 31, 47, 63, 79, 95, 111, 127, 143, 159, 175, 191, 207, 223, 239, 255
}
```

```
Mrow_Scan_16x16[ 256 ] = {
  0,   1,   2,   3,   4,   5,   6,   7,   8,   9,   10,  11,  12,  13,  14,
  15,  16,  17,  18,  19,  20,  21,  22,  23,  24,  25,  26,  27,  28,  29,
  30,  31,  32,  33,  34,  35,  36,  37,  38,  39,  40,  41,  42,  43,  44,
  45,  46,  47,  48,  49,  50,  51,  52,  53,  54,  55,  56,  57,  58,  59,
  60,  61,  62,  63,  64,  65,  66,  67,  68,  69,  70,  71,  72,  73,  74,
  75,  76,  77,  78,  79,  80,  81,  82,  83,  84,  85,  86,  87,  88,  89,
  90,  91,  92,  93,  94,  95,  96,  97,  98,  99,  100, 101, 102, 103, 104,
  105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119,
  120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134,
  135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149,
  150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164,
  165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179,
  180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194,
  195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209,
  210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224,
  225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239,
  240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254,
  255
}
```

```
Default_Scan_16x32[ 512 ] = {
  0,   1,   16,  2,   17,  32,  3,   18,  33,  48,  4,   19,  34,  49,  64,
  5,   20,  35,  50,  65,  80,  6,   21,  36,  51,  66,  81,  96,  7,   22,
  37,  52,  67,  82,  97,  112, 8,   23,  38,  53,  68,  83,  98,  113, 128,
  9,   24,  39,  54,  69,  84,  99,  114, 129, 144, 10,  25,  40,  55,  70,
  85,  100, 115, 130, 145, 160, 11,  26,  41,  56,  71,  86,  101, 116, 131,
  146, 161, 176, 12,  27,  42,  57,  72,  87,  102, 117, 132, 147, 162, 177,
  192, 13,  28,  43,  58,  73,  88,  103, 118, 133, 148, 163, 178, 193, 208,
  14,  29,  44,  59,  74,  89,  104, 119, 134, 149, 164, 179, 194, 209, 224,
  15,  30,  45,  60,  75,  90,  105, 120, 135, 150, 165, 180, 195, 210, 225,
  240, 31,  46,  61,  76,  91,  106, 121, 136, 151, 166, 181, 196, 211, 226,
  241, 256, 47,  62,  77,  92,  107, 122, 137, 152, 167, 182, 197, 212, 227,
  242, 257, 272, 63,  78,  93,  108, 123, 138, 153, 168, 183, 198, 213, 228,
  243, 258, 273, 288, 79,  94,  109, 124, 139, 154, 169, 184, 199, 214, 229,
  244, 259, 274, 289, 304, 95,  110, 125, 140, 155, 170, 185, 200, 215, 230,
  245, 260, 275, 290, 305, 320, 111, 126, 141, 156, 171, 186, 201, 216, 231,
  246, 261, 276, 291, 306, 321, 336, 127, 142, 157, 172, 187, 202, 217, 232,
  247, 262, 277, 292, 307, 322, 337, 352, 143, 158, 173, 188, 203, 218, 233,
  248, 263, 278, 293, 308, 323, 338, 353, 368, 159, 174, 189, 204, 219, 234,
  249, 264, 279, 294, 309, 324, 339, 354, 369, 384, 175, 190, 205, 220, 235,
  250, 265, 280, 295, 310, 325, 340, 355, 370, 385, 400, 191, 206, 221, 236,
  251, 266, 281, 296, 311, 326, 341, 356, 371, 386, 401, 416, 207, 222, 237,
  252, 267, 282, 297, 312, 327, 342, 357, 372, 387, 402, 417, 432, 223, 238,
  253, 268, 283, 298, 313, 328, 343, 358, 373, 388, 403, 418, 433, 448, 239,
  254, 269, 284, 299, 314, 329, 344, 359, 374, 389, 404, 419, 434, 449, 464,
  255, 270, 285, 300, 315, 330, 345, 360, 375, 390, 405, 420, 435, 450, 465,
  480, 271, 286, 301, 316, 331, 346, 361, 376, 391, 406, 421, 436, 451, 466,
  481, 496, 287, 302, 317, 332, 347, 362, 377, 392, 407, 422, 437, 452, 467,
  482, 497, 303, 318, 333, 348, 363, 378, 393, 408, 423, 438, 453, 468, 483,
  498, 319, 334, 349, 364, 379, 394, 409, 424, 439, 454, 469, 484, 499, 335,
  350, 365, 380, 395, 410, 425, 440, 455, 470, 485, 500, 351, 366, 381, 396,
  411, 426, 441, 456, 471, 486, 501, 367, 382, 397, 412, 427, 442, 457, 472,
  487, 502, 383, 398, 413, 428, 443, 458, 473, 488, 503, 399, 414, 429, 444,
  459, 474, 489, 504, 415, 430, 445, 460, 475, 490, 505, 431, 446, 461, 476,
  491, 506, 447, 462, 477, 492, 507, 463, 478, 493, 508, 479, 494, 509, 495,
  510, 511
}
```

```
Default_Scan_32x16[ 512 ] = {
  0,   32,  1,   64,  33,  2,   96,  65,  34,  3,   128, 97,  66,  35,  4,
  160, 129, 98,  67,  36,  5,   192, 161, 130, 99,  68,  37,  6,   224, 193,
  162, 131, 100, 69,  38,  7,   256, 225, 194, 163, 132, 101, 70,  39,  8,
  288, 257, 226, 195, 164, 133, 102, 71,  40,  9,   320, 289, 258, 227, 196,
  165, 134, 103, 72,  41,  10,  352, 321, 290, 259, 228, 197, 166, 135, 104,
  73,  42,  11,  384, 353, 322, 291, 260, 229, 198, 167, 136, 105, 74,  43,
  12,  416, 385, 354, 323, 292, 261, 230, 199, 168, 137, 106, 75,  44,  13,
  448, 417, 386, 355, 324, 293, 262, 231, 200, 169, 138, 107, 76,  45,  14,
  480, 449, 418, 387, 356, 325, 294, 263, 232, 201, 170, 139, 108, 77,  46,
  15,  481, 450, 419, 388, 357, 326, 295, 264, 233, 202, 171, 140, 109, 78,
  47,  16,  482, 451, 420, 389, 358, 327, 296, 265, 234, 203, 172, 141, 110,
  79,  48,  17,  483, 452, 421, 390, 359, 328, 297, 266, 235, 204, 173, 142,
  111, 80,  49,  18,  484, 453, 422, 391, 360, 329, 298, 267, 236, 205, 174,
  143, 112, 81,  50,  19,  485, 454, 423, 392, 361, 330, 299, 268, 237, 206,
  175, 144, 113, 82,  51,  20,  486, 455, 424, 393, 362, 331, 300, 269, 238,
  207, 176, 145, 114, 83,  52,  21,  487, 456, 425, 394, 363, 332, 301, 270,
  239, 208, 177, 146, 115, 84,  53,  22,  488, 457, 426, 395, 364, 333, 302,
  271, 240, 209, 178, 147, 116, 85,  54,  23,  489, 458, 427, 396, 365, 334,
  303, 272, 241, 210, 179, 148, 117, 86,  55,  24,  490, 459, 428, 397, 366,
  335, 304, 273, 242, 211, 180, 149, 118, 87,  56,  25,  491, 460, 429, 398,
  367, 336, 305, 274, 243, 212, 181, 150, 119, 88,  57,  26,  492, 461, 430,
  399, 368, 337, 306, 275, 244, 213, 182, 151, 120, 89,  58,  27,  493, 462,
  431, 400, 369, 338, 307, 276, 245, 214, 183, 152, 121, 90,  59,  28,  494,
  463, 432, 401, 370, 339, 308, 277, 246, 215, 184, 153, 122, 91,  60,  29,
  495, 464, 433, 402, 371, 340, 309, 278, 247, 216, 185, 154, 123, 92,  61,
  30,  496, 465, 434, 403, 372, 341, 310, 279, 248, 217, 186, 155, 124, 93,
  62,  31,  497, 466, 435, 404, 373, 342, 311, 280, 249, 218, 187, 156, 125,
  94,  63,  498, 467, 436, 405, 374, 343, 312, 281, 250, 219, 188, 157, 126,
  95,  499, 468, 437, 406, 375, 344, 313, 282, 251, 220, 189, 158, 127, 500,
  469, 438, 407, 376, 345, 314, 283, 252, 221, 190, 159, 501, 470, 439, 408,
  377, 346, 315, 284, 253, 222, 191, 502, 471, 440, 409, 378, 347, 316, 285,
  254, 223, 503, 472, 441, 410, 379, 348, 317, 286, 255, 504, 473, 442, 411,
  380, 349, 318, 287, 505, 474, 443, 412, 381, 350, 319, 506, 475, 444, 413,
  382, 351, 507, 476, 445, 414, 383, 508, 477, 446, 415, 509, 478, 447, 510,
  479, 511
}
```

```
Default_Scan_32x32[ 1024 ] = {
    0,    1,    32,   64,   33,   2,   3,    34,   65,   96,   128,  97,  66,
    35,   4,    5,    36,   67,   98,  129,  160,  192,  161,  130,  99,  68,
    37,   6,    7,    38,   69,   100, 131,  162,  193,  224,  256,  225, 194,
    163,  132,  101,  70,   39,   8,   9,    40,   71,   102,  133,  164, 195,
    226,  257,  288,  320,  289,  258, 227,  196,  165,  134,  103,  72,  41,
    10,   11,   42,   73,   104,  135, 166,  197,  228,  259,  290,  321, 352,
    384,  353,  322,  291,  260,  229, 198,  167,  136,  105,  74,   43,  12,
    13,   44,   75,   106,  137,  168, 199,  230,  261,  292,  323,  354, 385,
    416,  448,  417,  386,  355,  324, 293,  262,  231,  200,  169,  138, 107,
    76,   45,   14,   15,   46,   77,  108,  139,  170,  201,  232,  263, 294,
    325,  356,  387,  418,  449,  480, 512,  481,  450,  419,  388,  357, 326,
    295,  264,  233,  202,  171,  140, 109,  78,   47,   16,   17,   48,  79,
    110,  141,  172,  203,  234,  265, 296,  327,  358,  389,  420,  451, 482,
    513,  544,  576,  545,  514,  483, 452,  421,  390,  359,  328,  297, 266,
    235,  204,  173,  142,  111,  80,  49,   18,   19,   50,   81,   112, 143,
    174,  205,  236,  267,  298,  329, 360,  391,  422,  453,  484,  515, 546,
    577,  608,  640,  609,  578,  547, 516,  485,  454,  423,  392,  361, 330,
    299,  268,  237,  206,  175,  144, 113,  82,   51,   20,   21,   52,  83,
    114,  145,  176,  207,  238,  269, 300,  331,  362,  393,  424,  455, 486,
    517,  548,  579,  610,  641,  672, 704,  673,  642,  611,  580,  549, 518,
    487,  456,  425,  394,  363,  332, 301,  270,  239,  208,  177,  146, 115,
    84,   53,   22,   23,   54,   85,  116,  147,  178,  209,  240,  271, 302,
    333,  364,  395,  426,  457,  488, 519,  550,  581,  612,  643,  674, 705,
    736,  768,  737,  706,  675,  644, 613,  582,  551,  520,  489,  458, 427,
    396,  365,  334,  303,  272,  241, 210,  179,  148,  117,  86,   55,  24,
    25,   56,   87,   118,  149,  180, 211,  242,  273,  304,  335,  366, 397,
    428,  459,  490,  521,  552,  583, 614,  645,  676,  707,  738,  769, 800,
    832,  801,  770,  739,  708,  677, 646,  615,  584,  553,  522,  491, 460,
    429,  398,  367,  336,  305,  274, 243,  212,  181,  150,  119,  88,  57,
    26,   27,   58,   89,   120,  151, 182,  213,  244,  275,  306,  337, 368,
    399,  430,  461,  492,  523,  554, 585,  616,  647,  678,  709,  740, 771,
    802,  833,  864,  896,  865,  834, 803,  772,  741,  710,  679,  648, 617,
    586,  555,  524,  493,  462,  431, 400,  369,  338,  307,  276,  245, 214,
    183,  152,  121,  90,   59,   28,  29,   60,   91,   122,  153,  184, 215,
    246,  277,  308,  339,  370,  401, 432,  463,  494,  525,  556,  587, 618,
    649,  680,  711,  742,  773,  804, 835,  866,  897,  928,  960,  929, 898,
    867,  836,  805,  774,  743,  712, 681,  650,  619,  588,  557,  526, 495,
    464,  433,  402,  371,  340,  309, 278,  247,  216,  185,  154,  123, 92,
    61,   30,   31,   62,   93,   124, 155,  186,  217,  248,  279,  310, 341,
    372,  403,  434,  465,  496,  527, 558,  589,  620,  651,  682,  713, 744,
    775,  806,  837,  868,  899,  930, 961,  992,  993,  962,  931,  900, 869,
    838,  807,  776,  745,  714,  683, 652,  621,  590,  559,  528,  497, 466,
    435,  404,  373,  342,  311,  280, 249,  218,  187,  156,  125,  94,  63,
    95,   126,  157,  188,  219,  250, 281,  312,  343,  374,  405,  436, 467,
    498,  529,  560,  591,  622,  653, 684,  715,  746,  777,  808,  839, 870,
    901,  932,  963,  994,  995,  964, 933,  902,  871,  840,  809,  778, 747,
    716,  685,  654,  623,  592,  561, 530,  499,  468,  437,  406,  375, 344,
    313,  282,  251,  220,  189,  158, 127,  159,  190,  221,  252,  283, 314,
    345,  376,  407,  438,  469,  500, 531,  562,  593,  624,  655,  686, 717,
```

```
    748,  779,  810,  841,  872,  903, 934,  965,  996,  997,  966,  935, 904,
    873,  842,  811,  780,  749,  718, 687,  656,  625,  594,  563,  532, 501,
    470,  439,  408,  377,  346,  315, 284,  253,  222,  191,  223,  254, 285,
    316,  347,  378,  409,  440,  471, 502,  533,  564,  595,  626,  657, 688,
    719,  750,  781,  812,  843,  874, 905,  936,  967,  998,  999,  968, 937,
    906,  875,  844,  813,  782,  751, 720,  689,  658,  627,  596,  565, 534,
    503,  472,  441,  410,  379,  348, 317,  286,  255,  287,  318,  349, 380,
    411,  442,  473,  504,  535,  566, 597,  628,  659,  690,  721,  752, 783,
    814,  845,  876,  907,  938,  969, 1000, 1001, 970,  939,  908,  877, 846,
    815,  784,  753,  722,  691,  660, 629,  598,  567,  536,  505,  474, 443,
    412,  381,  350,  319,  351,  382, 413,  444,  475,  506,  537,  568, 599,
    630,  661,  692,  723,  754,  785, 816,  847,  878,  909,  940,  971, 1002,
    1003, 972,  941,  910,  879,  848, 817,  786,  755,  724,  693,  662, 631,
    600,  569,  538,  507,  476,  445, 414,  383,  415,  446,  477,  508, 539,
    570,  601,  632,  663,  694,  725, 756,  787,  818,  849,  880,  911, 942,
    973,  1004, 1005, 974,  943,  912, 881,  850,  819,  788,  757,  726, 695,
    664,  633,  602,  571,  540,  509, 478,  447,  479,  510,  541,  572, 603,
    634,  665,  696,  727,  758,  789, 820,  851,  882,  913,  944,  975, 1006,
    1007, 976,  945,  914,  883,  852, 821,  790,  759,  728,  697,  666, 635,
    604,  573,  542,  511,  543,  574, 605,  636,  667,  698,  729,  760, 791,
    822,  853,  884,  915,  946,  977, 1008, 1009, 978,  947,  916,  885, 854,
    823,  792,  761,  730,  699,  668, 637,  606,  575,  607,  638,  669, 700,
    731,  762,  793,  824,  855,  886, 917,  948,  979,  1010, 1011, 980, 949,
    918,  887,  856,  825,  794,  763, 732,  701,  670,  639,  671,  702, 733,
    764,  795,  826,  857,  888,  919, 950,  981,  1012, 1013, 982,  951, 920,
    889,  858,  827,  796,  765,  734, 703,  735,  766,  797,  828,  859, 890,
    921,  952,  983,  1014, 1015, 984, 953,  922,  891,  860,  829,  798, 767,
    799,  830,  861,  892,  923,  954, 985,  1016, 1017, 986,  955,  924, 893,
    862,  831,  863,  894,  925,  956, 987,  1018, 1019, 988,  957,  926, 895,
    927,  958,  989,  1020, 1021, 990, 959,  991,  1022, 1023
}
```

```
Default_Scan_4x16[ 64 ] = {
  0,  1,  4,  2,  5,  8,  3,  6,  9,  12, 7,  10, 13, 16, 11, 14,
  17, 20, 15, 18, 21, 24, 19, 22, 25, 28, 23, 26, 29, 32, 27, 30,
  33, 36, 31, 34, 37, 40, 35, 38, 41, 44, 39, 42, 45, 48, 43, 46,
  49, 52, 47, 50, 53, 56, 51, 54, 57, 60, 55, 58, 61, 59, 62, 63
}
```

```
Mcol_Scan_4x16[ 64 ] = {
  0, 4, 8,  12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60,
  1, 5, 9,  13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61,
  2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, 50, 54, 58, 62,
  3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, 51, 55, 59, 63
}
```

```
Mrow_Scan_4x16[ 64 ] = {
  0,  1,  2,  3,  4,  5,  6,  7,  8,  9,  10, 11, 12, 13, 14, 15,
  16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31,
  32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47,
  48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63
}
```

```
Default_Scan_16x4[ 64 ] = {
  0,  16, 1,  32, 17, 2,  48, 33, 18, 3,  49, 34, 19, 4,  50, 35,
  20, 5,  51, 36, 21, 6,  52, 37, 22, 7,  53, 38, 23, 8,  54, 39,
  24, 9,  55, 40, 25, 10, 56, 41, 26, 11, 57, 42, 27, 12, 58, 43,
  28, 13, 59, 44, 29, 14, 60, 45, 30, 15, 61, 46, 31, 62, 47, 63
}
```

```
Mcol_Scan_16x4[ 64 ] = {
  0,  16, 32, 48, 1,  17, 33, 49, 2,  18, 34, 50, 3,  19, 35, 51,
  4,  20, 36, 52, 5,  21, 37, 53, 6,  22, 38, 54, 7,  23, 39, 55,
  8,  24, 40, 56, 9,  25, 41, 57, 10, 26, 42, 58, 11, 27, 43, 59,
  12, 28, 44, 60, 13, 29, 45, 61, 14, 30, 46, 62, 15, 31, 47, 63
}
```

```
Mrow_Scan_16x4[ 64 ] = {
  0,  1,  2,  3,  4,  5,  6,  7,  8,  9,  10, 11, 12, 13, 14, 15,
  16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31,
  32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47,
  48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63
}
```

```
Default_Scan_8x32[ 256 ] = {
  0,   1,   8,   2,   9,   16,  3,   10,  17,  24,  4,   11,  18,  25,  32,
  5,   12,  19,  26,  33,  40,  6,   13,  20,  27,  34,  41,  48,  7,   14,
  21,  28,  35,  42,  49,  56,  15,  22,  29,  36,  43,  50,  57,  64,  23,
  30,  37,  44,  51,  58,  65,  72,  31,  38,  45,  52,  59,  66,  73,  80,
  39,  46,  53,  60,  67,  74,  81,  88,  47,  54,  61,  68,  75,  82,  89,
  96,  55,  62,  69,  76,  83,  90,  97,  104, 63,  70,  77,  84,  91,  98,
  105, 112, 71,  78,  85,  92,  99,  106, 113, 120, 79,  86,  93,  100, 107,
  114, 121, 128, 87,  94,  101, 108, 115, 122, 129, 136, 95,  102, 109, 116,
  123, 130, 137, 144, 103, 110, 117, 124, 131, 138, 145, 152, 111, 118, 125,
  132, 139, 146, 153, 160, 119, 126, 133, 140, 147, 154, 161, 168, 127, 134,
  141, 148, 155, 162, 169, 176, 135, 142, 149, 156, 163, 170, 177, 184, 143,
  150, 157, 164, 171, 178, 185, 192, 151, 158, 165, 172, 179, 186, 193, 200,
  159, 166, 173, 180, 187, 194, 201, 208, 167, 174, 181, 188, 195, 202, 209,
  216, 175, 182, 189, 196, 203, 210, 217, 224, 183, 190, 197, 204, 211, 218,
  225, 232, 191, 198, 205, 212, 219, 226, 233, 240, 199, 206, 213, 220, 227,
  234, 241, 248, 207, 214, 221, 228, 235, 242, 249, 215, 222, 229, 236, 243,
  250, 223, 230, 237, 244, 251, 231, 238, 245, 252, 239, 246, 253, 247, 254,
  255
}
```

```
Default_Scan_32x8[ 256 ] = {
  0,   32,  1,   64,  33,  2,   96,  65,  34,  3,   128, 97,  66,  35,  4,
  160, 129, 98,  67,  36,  5,   192, 161, 130, 99,  68,  37,  6,   224, 193,
  162, 131, 100, 69,  38,  7,   225, 194, 163, 132, 101, 70,  39,  8,   226,
  195, 164, 133, 102, 71,  40,  9,   227, 196, 165, 134, 103, 72,  41,  10,
  228, 197, 166, 135, 104, 73,  42,  11,  229, 198, 167, 136, 105, 74,  43,
  12,  230, 199, 168, 137, 106, 75,  44,  13,  231, 200, 169, 138, 107, 76,
  45,  14,  232, 201, 170, 139, 108, 77,  46,  15,  233, 202, 171, 140, 109,
  78,  47,  16,  234, 203, 172, 141, 110, 79,  48,  17,  235, 204, 173, 142,
  111, 80,  49,  18,  236, 205, 174, 143, 112, 81,  50,  19,  237, 206, 175,
  144, 113, 82,  51,  20,  238, 207, 176, 145, 114, 83,  52,  21,  239, 208,
  177, 146, 115, 84,  53,  22,  240, 209, 178, 147, 116, 85,  54,  23,  241,
  210, 179, 148, 117, 86,  55,  24,  242, 211, 180, 149, 118, 87,  56,  25,
  243, 212, 181, 150, 119, 88,  57,  26,  244, 213, 182, 151, 120, 89,  58,
  27,  245, 214, 183, 152, 121, 90,  59,  28,  246, 215, 184, 153, 122, 91,
  60,  29,  247, 216, 185, 154, 123, 92,  61,  30,  248, 217, 186, 155, 124,
  93,  62,  31,  249, 218, 187, 156, 125, 94,  63,  250, 219, 188, 157, 126,
  95,  251, 220, 189, 158, 127, 252, 221, 190, 159, 253, 222, 191, 254, 223,
  255
}
```

9.3. Conversion tables

This section defines the constant lookup tables used to convert between different representations.

For a block size x (with values having the same interpretation as for the variable subSize), Mi_Width_Log2[x] gives the base 2 logarithm of the width of the block in units of 4 samples.

```
Mi_Width_Log2[ BLOCK_SIZES ] = {
    0, 0, 1, 1, 1, 2, 2, 2, 3, 3, 3,
    4, 4, 4, 5, 5, 0, 2, 1, 3, 2, 4
}
```

For a block size x, Mi_Height_Log2[x] gives the base 2 logarithm of the height of the block in units of 4 samples.

```
Mi_Height_Log2[ BLOCK_SIZES ] = {
    0, 1, 0, 1, 2, 1, 2, 3, 2, 3, 4,
    3, 4, 5, 4, 5, 2, 0, 3, 1, 4, 2
}
```

For a block size x, Num_4x4_Blocks_Wide[x] gives the width of the block in units of 4 samples.

```
Num_4x4_Blocks_Wide[ BLOCK_SIZES ] = {
    1, 1, 2, 2, 2, 4, 4, 4, 8, 8, 8,
    16, 16, 16, 32, 32, 1, 4, 2, 8, 4, 16
}
```

For a block size x, Block_Width[x] gives the width of the block in units of samples. Block_Width[x] is defined to be equal to 4 * Num_4x4_Blocks_Wide[x].

For a block size x, Num_4x4_Blocks_High[x] gives the the height of the block in units of 4 samples.

```
Num_4x4_Blocks_High[ BLOCK_SIZES ] = {
    1, 2, 1, 2, 4, 2, 4, 8, 4, 8, 16,
    8, 16, 32, 16, 32, 4, 1, 8, 2, 16, 4
}
```

For a block size x, Block_Height[x] gives the height of the block in units of samples. Block_Height[x] is defined to be equal to 4 * Num_4x4_Blocks_High[x].

Size_Group is used to map a block size into a context for intra syntax elements.

```
Size_Group[ BLOCK_SIZES ] = {
  0, 0, 0, 1, 1, 1, 2, 2, 2, 3, 3,
  3, 3, 3, 3, 3, 0, 0, 1, 1, 2, 2
}
```

For a luma block size x, Max_Tx_Size_Rect[x] returns the largest transform size that can be used for blocks of size x (this can be either square or rectangular).

```
Max_Tx_Size_Rect[ BLOCK_SIZES ] = {
  TX_4X4, TX_4X8, TX_8X4, TX_8X8,
  TX_8X16, TX_16X8, TX_16X16, TX_16X32,
  TX_32X16, TX_32X32, TX_32X64, TX_64X32,
  TX_64X64, TX_64X64, TX_64X64, TX_64X64,
  TX_4X16, TX_16X4, TX_8X32, TX_32X8,
  TX_16X64, TX_64X16
}
```

For a square block size x, and a partition type p, Partition_Subsize[p][x] returns the size of the sub-blocks used by this partition. (If the partition produces blocks of different sizes, then the table contains the largest sub-block size.)

The table will never get accessed for rectangular block sizes.

```
Partition_Subsize[ 10 ][ BLOCK_SIZES ] = {
  {
                                BLOCK_4X4,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_128X128,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X4,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_128X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_4X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X128,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_4X4,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X4,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_128X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X4,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X8,
```

```
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_128X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                  BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_4X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X128,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                  BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_4X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X128,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                  BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X4,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_32X8,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_64X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }, {
                                  BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_4X16,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_8X32,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_16X64,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID,
    BLOCK_INVALID, BLOCK_INVALID, BLOCK_INVALID
  }
}
```

```
Split_Tx_Size[ TX_SIZES_ALL ] = {
  TX_4X4,
  TX_4X4,
  TX_8X8,
  TX_16X16,
  TX_32X32,
  TX_4X4,
  TX_4X4,
  TX_8X8,
  TX_8X8,
  TX_16X16,
  TX_16X16,
  TX_32X32,
  TX_32X32
  TX_4X8,
  TX_8X4,
  TX_8X16,
  TX_16X8,
  TX_16X32,
  TX_32X16
}
```

```
Mode_To_Txfm[ UV_INTRA_MODES_CFL_ALLOWED ] = {
    DCT_DCT,   // DC_PRED
    ADST_DCT,  // V_PRED
    DCT_ADST,  // H_PRED
    DCT_DCT,   // D45_PRED
    ADST_ADST, // D135_PRED
    ADST_DCT,  // D113_PRED
    DCT_ADST,  // D157_PRED
    DCT_ADST,  // D203_PRED
    ADST_DCT,  // D67_PRED
    ADST_ADST, // SMOOTH_PRED
    ADST_DCT,  // SMOOTH_V_PRED
    DCT_ADST,  // SMOOTH_H_PRED
    ADST_ADST, // PAETH_PRED
    DCT_DCT,   // UV_CFL_PRED
}
```

```
Palette_Color_Context[ PALETTE_MAX_COLOR_CONTEXT_HASH + 1 ] =
  { -1, -1, 0, -1, -1, 4,  3,  2, 1 }
```

Note: The negative numbers in the array Palette_Color_Context indicate values that will never be accessed.

```
Palette_Color_Hash_Multipliers[ PALETTE_NUM_NEIGHBORS ] = { 1, 2, 2 }
```

```
Sm_Weights_Tx_4x4  [  4 ] = { 255, 149,  85,  64 }
Sm_Weights_Tx_8x8  [  8 ] = { 255, 197, 146, 105,  73,  50,  37,  32 }
Sm_Weights_Tx_16x16[ 16 ] = { 255, 225, 196, 170, 145, 123, 102,  84,  68,  54,  43,  33,  26, 20,
17, 16 }
Sm_Weights_Tx_32x32[ 32 ] = { 255, 240, 225, 210, 196, 182, 169, 157, 145, 133, 122, 111, 101, 92,
83, 74,
                              66,  59,  52,  45,  39,  34,  29,  25,  21,  17,  14,  12,  10,  9,
8,  8 }
Sm_Weights_Tx_64x64[ 64 ] = { 255, 248, 240, 233, 225, 218, 210, 203, 196, 189, 182, 176, 169, 163,
156,
                              150, 144, 138, 133, 127, 121, 116, 111, 106, 101, 96, 91, 86, 82, 77,
73, 69,
                              65, 61, 57, 54, 50, 47, 44, 41, 38, 35, 32, 29, 27, 25, 22, 20, 18, 16,
15,
                              13, 12, 10, 9, 8, 7, 6, 6, 5, 5, 4, 4, 4 }
```

```
Mode_To_Angle[ INTRA_MODES ] = { 0, 90, 180, 45, 135, 113, 157, 203, 67, 0, 0, 0, 0 }
```

```
Dr_Intra_Derivative[ 90 ] = {
  0, 0, 0, 1023, 0, 0, 547, 0, 0, 372, 0, 0, 0, 0,
  273, 0, 0, 215, 0, 0, 178, 0, 0, 151, 0, 0, 132, 0, 0,
  116, 0, 0, 102, 0, 0, 0, 90, 0, 0, 80, 0, 0, 71, 0, 0,
  64, 0, 0, 57, 0, 0, 51, 0, 0, 45, 0, 0, 0, 40, 0, 0,
  35, 0, 0, 31, 0, 0, 27, 0, 0, 23, 0, 0, 19, 0, 0,
  15, 0, 0, 0, 0, 11, 0, 0, 7, 0, 0, 3, 0, 0
}
```

```
Intra_Filter_Taps[ INTRA_FILTER_MODES ][ 8 ][ 7 ] = {
  {
      { -6, 10, 0, 0, 0, 12, 0 },
      { -5, 2, 10, 0, 0, 9, 0 },
      { -3, 1, 1, 10, 0, 7, 0 },
      { -3, 1, 1, 2, 10, 5, 0 },
      { -4, 6, 0, 0, 0, 2, 12 },
      { -3, 2, 6, 0, 0, 2, 9 },
      { -3, 2, 2, 6, 0, 2, 7 },
      { -3, 1, 2, 2, 6, 3, 5 },
  },
  {
      { -10, 16, 0, 0, 0, 10, 0 },
      { -6, 0, 16, 0, 0, 6, 0 },
      { -4, 0, 0, 16, 0, 4, 0 },
      { -2, 0, 0, 0, 16, 2, 0 },
      { -10, 16, 0, 0, 0, 0, 10 },
      { -6, 0, 16, 0, 0, 0, 6 },
      { -4, 0, 0, 16, 0, 0, 4 },
      { -2, 0, 0, 0, 16, 0, 2 },
  },
  {
      { -8, 8, 0, 0, 0, 16, 0 },
      { -8, 0, 8, 0, 0, 16, 0 },
      { -8, 0, 0, 8, 0, 16, 0 },
      { -8, 0, 0, 0, 8, 16, 0 },
      { -4, 4, 0, 0, 0, 0, 16 },
      { -4, 0, 4, 0, 0, 0, 16 },
      { -4, 0, 0, 4, 0, 0, 16 },
      { -4, 0, 0, 0, 4, 0, 16 },
  },
  {
      { -2, 8, 0, 0, 0, 10, 0 },
      { -1, 3, 8, 0, 0, 6, 0 },
      { -1, 2, 3, 8, 0, 4, 0 },
      { 0, 1, 2, 3, 8, 2, 0 },
      { -1, 4, 0, 0, 0, 3, 10 },
      { -1, 3, 4, 0, 0, 4, 6 },
      { -1, 2, 3, 4, 0, 4, 4 },
      { -1, 2, 2, 3, 4, 3, 3 },
  },
  {
      { -12, 14, 0, 0, 0, 14, 0 },
      { -10, 0, 14, 0, 0, 12, 0 },
      { -9, 0, 0, 14, 0, 11, 0 },
      { -8, 0, 0, 0, 14, 10, 0 },
      { -10, 12, 0, 0, 0, 0, 14 },
      { -9, 1, 12, 0, 0, 0, 12 },
      { -8, 0, 0, 12, 0, 1, 11 },
      { -7, 0, 0, 1, 12, 1, 9 },
```

```
  }
}
```

For a transform size t (of width w and height h) (with the same interpretation as for the TxSize variable), Tx_Size_Sqr[t] returns a square tx size with side length Min(w, h).

```
Tx_Size_Sqr[ TX_SIZES_ALL ] = {
    TX_4X4,
    TX_8X8,
    TX_16X16,
    TX_32X32,
    TX_64X64,
    TX_4X4,
    TX_4X4,
    TX_8X8,
    TX_8X8,
    TX_16X16,
    TX_16X16,
    TX_32X32,
    TX_32X32,
    TX_4X4,
    TX_4X4,
    TX_8X8,
    TX_8X8,
    TX_16X16,
    TX_16X16
}
```

For a transform size t (of width w and height h), Tx_Size_Sqr_Up[t] returns a square tx size with side length Max(w, h).

```
Tx_Size_Sqr_Up[ TX_SIZES_ALL ] = {
    TX_4X4,
    TX_8X8,
    TX_16X16,
    TX_32X32,
    TX_64X64,
    TX_8X8,
    TX_8X8,
    TX_16X16,
    TX_16X16,
    TX_32X32,
    TX_32X32,
    TX_64X64,
    TX_64X64,
    TX_16X16,
    TX_16X16,
    TX_32X32,
    TX_32X32,
    TX_64X64,
    TX_64X64
}
```

For a transform size t (of width w and height h), Tx_Width[t] returns w.

```
Tx_Width[ TX_SIZES_ALL ] = {
    4,  8, 16, 32, 64, 4,  8, 8,  16, 16, 32, 32, 64, 4, 16, 8, 32, 16, 64
}
```

For a transform size t (of width w and height h), Tx_Height[t] returns h.

```
Tx_Height[ TX_SIZES_ALL ] = {
    4,  8, 16, 32, 64, 8,  4, 16, 8,  32, 16, 64, 32, 16, 4, 32, 8, 64, 16
}
```

For a transform size t (of width w and height h), Tx_Width_Log2[t] returns the base 2 logarithm of w.

```
Tx_Width_Log2[ TX_SIZES_ALL ] = {
    2, 3, 4, 5, 6, 2, 3, 3, 4, 4, 5, 5, 6, 2, 4, 3, 5, 4, 6
}
```

For a transform size t (of width w and height h), Tx_Height_Log2[t] returns the base 2 logarithm of h.

```
Tx_Height_Log2[ TX_SIZES_ALL ] = {
    2, 3, 4, 5, 6, 3, 2, 4, 3, 5, 4, 6, 5, 4, 2, 5, 3, 6, 4
}
```

```
Wedge_Bits[ BLOCK_SIZES ] = {
  0, 0, 0, 4, 4, 4, 4, 4, 4, 4, 0,
  0, 0, 0, 0, 0, 0, 0, 4, 4, 0, 0
 }
```

```
Sig_Ref_Diff_Offset[ 3 ][ SIG_REF_DIFF_OFFSET_NUM ][ 2 ] = {
  {
    { 0, 1 }, { 1, 0 }, { 1, 1 }, { 0, 2 }, { 2, 0 }
  },
  {
    { 0, 1 }, { 1, 0 }, { 0, 2 }, { 0, 3 }, { 0, 4 }
  },
  {
    { 0, 1 }, { 1, 0 }, { 2, 0 }, { 3, 0 }, { 4, 0 }
  }
}
```

```
Adjusted_Tx_Size[ TX_SIZES_ALL ] = {
    TX_4X4,
    TX_8X8,
    TX_16X16,
    TX_32X32,
    TX_32X32,
    TX_4X8,
    TX_8X4,
    TX_8X16,
    TX_16X8,
    TX_16X32,
    TX_32X16,
    TX_32X32,
    TX_32X32,
    TX_4X16,
    TX_16X4,
    TX_8X32,
    TX_32X8,
    TX_16X32,
    TX_32X16
}
```

The array Gaussian_Sequence contains random samples from a Gaussian distribution with zero mean and standard deviation of about 512 clipped to the range of [-2048, 2047] and rounded to the nearest multiple of 4.

```
Gaussian_Sequence[ 2048 ] = {
    56,    568,   -180,  172,   124,   -84,   172,   -64,   -900,  24,   820,
  224,   1248,  996,   272,   -8,    -916,  -388,  -732,  -104,  -188, 800,
  112,   -652,  -320,  -376,  140,   -252,  492,   -168,  44,    -788, 588,
  -584,  500,   -228,  12,    680,   272,   -476,  972,   -100,  652,  368,
  432,   -196,  -720,  -192,  1000,  -332,  652,   -136,  -552,  -604, -4,
  192,   -220,  -136,  1000,  -52,   372,   -96,   -624,  124,   -24,  396,
  540,   -12,   -104,  640,   464,   244,   -208,  -84,   368,   -528, -740,
  248,   -968,  -848,  608,   376,   -60,   -292,  -40,   -156,  252,  -292,
  248,   224,   -280,  400,   -244,  244,   -60,   76,    -80,   212,  532,
  340,   128,   -36,   824,   -352,  -60,   -264,  -96,   -612,  416,  -704,
  220,   -204,  640,   -160,  1220,  -408,  900,   336,   20,    -336, -96,
  -792,  304,   48,    -28,   -1232, -1172, -448,  104,   -292,  -520, 244,
  60,    -948,  0,     -708,  268,   108,   356,   -548,  488,   -344, -136,
  488,   -196,  -224,  656,   -236,  -1128, 60,    4,     140,   276,  -676,
  -376,  168,   -108,  464,   8,     564,   64,    240,   308,   -300, -400,
  -456,  -136,  56,    120,   -408,  -116,  436,   504,   -232,  328,  844,
  -164,  -84,   784,   -168,  232,   -224,  348,   -376,  128,   568,  96,
  -1244, -288,  276,   848,   832,   -360,  656,   464,   -384,  -332, -356,
  728,   -388,  160,   -192,  468,   296,   224,   140,   -776,  -100, 280,
  4,     196,   44,    -36,   -648,  932,   16,    1428,  28,    528,  808,
  772,   20,    268,   88,    -332,  -284,  124,   -384,  -448,  208,  -228,
  -1044, -328,  660,   380,   -148,  -300,  588,   240,   540,   28,   136,
  -88,   -436,  256,   296,   -1000, 1400,  0,     -48,   1056,  -136, 264,
  -528,  -1108, 632,   -484,  -592,  -344,  796,   124,   -668,  -768, 388,
  1296,  -232,  -188,  -200,  -288,  -4,    308,   100,   -168,  256,  -500,
  204,   -508,  648,   -136,  372,   -272,  -120,  -1004, -552,  -548, -384,
  548,   -296,  428,   -108,  -8,    -912,  -324,  -224,  -88,   -112, -220,
  -100,  996,   -796,  548,   360,   -216,  180,   428,   -200,  -212, 148,
  96,    148,   284,   216,   -412,  -320,  120,   -300,  -384,  -604, -572,
  -332,  -8,    -180,  -176,  696,   116,   -88,   628,   76,    44,   -516,
  240,   -208,  -40,   100,   -592,  344,   -308,  -452,  -228,  20,   916,
  -1752, -136,  -340,  -804,  140,   40,    512,   340,   248,   184,  -492,
  896,   -156,  932,   -628,  328,   -688,  -448,  -616,  -752,  -100, 560,
  -1020, 180,   -800,  -64,   76,    576,   1068,  396,   660,   552,  -108,
  -28,   320,   -628,  312,   -92,   -92,   -472,  268,   16,    560,  516,
  -672,  -52,   492,   -100,  260,   384,   284,   292,   304,   -148, 88,
  -152,  1012,  1064,  -228,  164,   -376,  -684,  592,   -392,  156,  196,
  -524,  -64,   -884,  160,   -176,  636,   648,   404,   -396,  -436, 864,
  424,   -728,  988,   -604,  904,   -592,  296,   -224,  536,   -176, -920,
  436,   -48,   1176,  -884,  416,   -776,  -824,  -884,  524,   -548, -564,
  -68,   -164,  -96,   692,   364,   -692,  -1012, -68,   260,   -480, 876,
  -1116, 452,   -332,  -352,  892,   -1088, 1220,  -676,  12,    -292, 244,
  496,   372,   -32,   280,   200,   112,   -440,  -96,   24,    -644, -184,
  56,    -432,  224,   -980,  272,   -260,  144,   -436,  420,   356,  364,
  -528,  76,    172,   -744,  -368,  404,   -752,  -416,  684,   -688, 72,
  540,   416,   92,    444,   480,   -72,   -1416, 164,   -1172, -68,  24,
  424,   264,   1040,  128,   -912,  -524,  -356,  64,    876,   -12,  4,
  -88,   532,   272,   -524,  320,   276,   -508,  940,   24,    -400, -120,
  756,   60,    236,   -412,  100,   376,   -484,  400,   -100,  -740, -108,
```

```
-260,  328,   -268,  224,   -200,  -416,  184,   -604,  -564,  -20,  296,
60,    892,   -888,  60,    164,   68,    -760,  216,   -296,  904,  -336,
-28,   404,   -356,  -568,  -208,  -1480, -512,  296,   328,   -360, -164,
-1560, -776,  1156,  -428,  164,   -504,  -112,  120,   -216,  -148, -264,
308,   32,    64,    -72,   72,    116,   176,   -64,   -272,  460,  -536,
-784,  -280,  348,   108,   -752,  -132,  524,   -540,  -776,  116,  -296,
-1196, -288,  -560,  1040,  -472,  116,   -848,  -1116, 116,   636,  696,
284,   -176,  1016,  204,   -864,  -648,  -248,  356,   972,   -584, -204,
264,   880,   528,   -24,   -184,  116,   448,   -144,  828,   524,  212,
-212,  52,    12,    200,   268,   -488,  -404,  -880,  824,   -672, -40,
908,   -248,  500,   716,   -576,  492,   -576,  16,    720,   -108, 384,
124,   344,   280,   576,   -500,  252,   104,   -308,  196,   -188, -8,
1268,  296,   1032,  -1196, 436,   316,   372,   -432,  -200,  -660, 704,
-224,  596,   -132,  268,   32,    -452,  884,   104,   -1008, 424,  -1348,
-280,  4,     -1168, 368,   476,   696,   300,   -8,    24,    180,  -592,
-196,  388,   304,   500,   724,   -160,  244,   -84,   272,   -256, -420,
320,   208,   -144,  -156,  156,   364,   452,   28,    540,   316,  220,
-644,  -248,  464,   72,    360,   32,    -388,  496,   -680,  -48,  208,
-116,  -408,  60,    -604,  -392,  548,   -840,  784,   -460,  656,  -544,
-388,  -264,  908,   -800,  -628,  -612,  -568,  572,   -220,  164,  288,
-16,   -308,  308,   -112,  -636,  -760,  280,   -668,  432,   364,  240,
-196,  604,   340,   384,   196,   592,   -44,   -500,  432,   -580, -132,
636,   -76,   392,   4,     -412,  540,   508,   328,   -356,  -36,  16,
-220,  -64,   -248,  -60,   24,    -192,  368,   1040,  92,    -24,  -1044,
-32,   40,    104,   148,   192,   -136,  -520,  56,    -816,  -224, 732,
392,   356,   212,   -80,   -424,  -1008, -324,  588,   -1496, 576,  460,
-816,  -848,  56,    -580,  -92,   -1372, -112,  -496,  200,   364,  52,
-140,  48,    -48,   -60,   84,    72,    40,    132,   -356,  -268, -104,
-284,  -404,  732,   -520,  164,   -304,  -540,  120,   328,   -76,  -460,
756,   388,   588,   236,   -436,  -72,   -176,  -404,  -316,  -148, 716,
-604,  404,   -72,   -88,   -888,  -68,   944,   88,    -220,  -344, 960,
472,   460,   -232,  704,   120,   832,   -228,  692,   -508,  132,  -476,
844,   -748,  -364,  -44,   1116,  -1104, -1056, 76,    428,   552,  -692,
60,    356,   96,    -384,  -188,  -612,  -576,  736,   508,   892,  352,
-1132, 504,   -24,   -352,  324,   332,   -600,  -312,  292,   508,  -144,
-8,    484,   48,    284,   -260,  -240,  256,   -100,  -292,  -204, -44,
472,   -204,  908,   -188,  -1000, -256,  92,    1164,  -392,  564,  356,
652,   -28,   -884,  256,   484,   -192,  760,   -176,  376,   -524, -452,
-436,  860,   -736,  212,   124,   504,   -476,  468,   76,    -472, 552,
-692,  -944,  -620,  740,   -240,  400,   132,   20,    192,   -196, 264,
-668,  -1012, -60,   296,   -316,  -828,  76,    -156,  284,   -768, -448,
-832,  148,   248,   652,   616,   1236,  288,   -328,  -400,  -124, 588,
220,   520,   -696,  1032,  768,   -740,  -92,   -272,  296,   448,  -464,
412,   -200,  392,   440,   -200,  264,   -152,  -260,  320,   1032, 216,
320,   -8,    -64,   156,   -1016, 1084,  1172,  536,   484,   -432, 132,
372,   -52,   -256,  84,    116,   -352,  48,    116,   304,   -384, 412,
924,   -300,  528,   628,   180,   648,   44,    -980,  -220,  1320, 48,
332,   748,   524,   -268,  -720,  540,   -276,  564,   -344,  -208, -196,
436,   896,   88,    -392,  132,   80,    -964,  -288,  568,   56,   -48,
-456,  888,   8,     552,   -156,  -292,  948,   288,   128,   -716, -292,
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1192,  -152,  876,   352,   -600,  -260,  -812,  -468,  -28,   -120, -32,
-44,   1284,  496,   192,   464,   312,   -76,   -516,  -380,  -456, -1012,
-48,   308,   -156,  36,    492,   -156,  -808,  188,   1652,  68,   -120,
-116,  316,   160,   -140,  352,   808,   -416,  592,   316,   -480, 56,
528,   -204,  -568,  372,   -232,  752,   -344,  744,   -4,    324,  -416,
-600,  768,   268,   -248,  -88,   -132,  -420,  -432,  80,    -288, 404,
-316,  -1216, -588,  520,   -108,  92,    -320,  368,   -480,  -216, -92,
1688,  -300,  180,   1020,  -176,  820,   -68,   -228,  -260,  436,  -904,
20,    40,    -508,  440,   -736,  312,   332,   204,   760,   -372, 728,
96,    -20,   -632,  -520,  -560,  336,   1076,  -64,   -532,  776,  584,
192,   396,   -728,  -520,  276,   -188,  80,    -52,   -612,  -252, -48,
648,   212,   -688,  228,   -52,   -260,  428,   -412,  -272,  -404, 180,
816,   -796,  48,    152,   484,   -88,   -216,  988,   696,   188,  -528,
648,   -116,  -180,  316,   476,   12,    -564,  96,    476,   -252, -364,
-376,  -392,  556,   -256,  -576,  260,   -352,  120,   -16,   -136, -260,
-492,  72,    556,   660,   580,   616,   772,   436,   424,   -32,  -324,
-1268, 416,   -324,  -80,   920,   160,   228,   724,   32,    -516, 64,
384,   68,    -128,  136,   240,   248,   -204,  -68,   252,   -932, -120,
-480,  -628,  -84,   192,   852,   -404,  -288,  -132,  204,   100,  168,
-68,   -196,  -868,  460,   1080,  380,   -80,   244,   0,     484,  -888,
64,    184,   352,   600,   460,   164,   604,   -196,  320,   -64,  588,
-184,  228,   12,    372,   48,    -848,  -344,  224,   208,   -200, 484,
128,   -20,   272,   -468,  -840,  384,   256,   -720,  -520,  -464, -580,
112,   -120,  644,   -356,  -208,  -608,  -528,  704,   560,   -424, 392,
828,   40,    84,    200,   -152,  0,     -144,  584,   280,   -120, 80,
-556,  -972,  -196,  -472,  724,   80,    168,   -32,   88,    160,  -688,
0,     160,   356,   372,   -776,  740,   -128,  676,   -248,  -480, 4,
-364,  96,    544,   232,   -1032, 956,   236,   356,   20,    -40,  300,
24,    -676,  -596,  132,   1120,  -104,  532,   -1096, 568,   648,  444,
508,   380,   188,   -376,  -604,  1488,  424,   24,    756,   -220, -192,
716,   120,   920,   688,   168,   44,    -460,  568,   284,   1144, 1160,
600,   424,   888,   656,   -356,  -320,  220,   316,   -176,  -724, -188,
-816,  -628,  -348,  -228,  -380,  1012,  -452,  -660,  736,   928,  404,
-696,  -72,   -268,  -892,  128,   184,   -344,  -780,  360,   336,  400,
344,   428,   548,   -112,  136,   -228,  -216,  -820,  -516,  340,  92,
-136,  116,   -300,  376,   -244,  100,   -316,  -520,  -284,  -12,  824,
164,   -548,  -180,  -128,  116,   -924,  -828,  268,   -368,  -580, 620,
192,   160,   0,     -1676, 1068,  424,   -56,   -360,  468,   -156, 720,
288,   -528,  556,   -364,  548,   -148,  504,   316,   152,   -648, -620,
-684,  -24,   -376,  -384,  -108,  -920,  -1032, 768,   180,   -264, -508,
-1268, -260,  -60,   300,   -240,  988,   724,   -376,  -576,  -212, -736,
556,   192,   1092,  -620,  -880,  376,   -56,   -4,    -216,  -32,  836,
268,   396,   1332,  864,   -600,  100,   56,    -412,  -92,   356,  180,
884,   -468,  -436,  292,   -388,  -804,  -704,  -840,  368,   -348, 140,
-724,  1536,  940,   372,   112,   -372,  436,   -480,  1136,  296,  -32,
-228,  132,   -48,   -220,  868,   -1016, -60,   -1044, -464,  328,  916,
244,   12,    -736,  -296,  360,   468,   -376,  -108,  -92,   788,  368,
-56,   544,   400,   -672,  -420,  728,   16,    320,   44,    -284, -380,
-796,  488,   132,   204,   -596,  -372,  88,    -152,  -908,  -636, -572,
-624,  -116,  -692,  -200,  -56,   276,   -88,   484,   -324,  948,  864,
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  1000,  -456,  -184,  -276,  292,   -296,  156,   676,   320,   160,  908,
  -84,   -1236, -288,  -116,  260,   -372,  -644,  732,   -756,  -96,  84,
  344,   -520,  348,   -688,  240,   -84,   216,   -1044, -136,  -676, -396,
  -1500, 960,   -40,   176,   168,   1516,  420,   -504,  -344,  -364, -360,
  1216,  -940,  -380,  -212,  252,   -660,  -708,  484,   -444,  -152, 928,
  -120,  1112,  476,   -260,  560,   -148,  -344,  108,   -196,  228,  -288,
  504,   560,   -328,  -88,   288,   -1008, 460,   -228,  468,   -836, -196,
  76,    388,   232,   412,   -1168, -716,  -644,  756,   -172,  -356, -504,
  116,   432,   528,   48,    476,   -168,  -608,  448,   160,   -532, -272,
  28,    -676,  -12,   828,   980,   456,   520,   104,   -104,  256,  -344,
  -4,    -28,   -368,  -52,   -524,  -572,  -556,  -200,  768,   1124, -208,
  -512,  176,   232,   248,   -148,  -888,  604,   -600,  -304,  804,  -156,
  -212,  488,   -192,  -804,  -256,  368,   -360,  -916,  -328,  228,  -240,
  -448,  -472,  856,   -556,  -364,  572,   -12,   -156,  -368,  -340, 432,
  252,   -752,  -152,  288,   268,   -580,  -848,  -592,  108,   -76,  244,
  312,   -716,  592,   -80,   436,   360,   4,     -248,  160,   516,  584,
  732,   44,    -468,  -280,  -292,  -156,  -588,  28,    308,   912,  24,
  124,   156,   180,   -252,  944,   -924,  -772,  -520,  -428,  -624, 300,
  -212,  -1144, 32,    -724,  800,   -1128, -212,  -1288, -848,  180,  -416,
  440,   192,   -576,  -792,  -76,   -1080, 80,    -532,  -352,  -132, 380,
  -820,  148,   1112,  128,   164,   456,   700,   -924,  144,   -668, -384,
  648,   -832,  508,   552,   -52,   -100,  -656,  208,   -568,  748,  -88,
  680,   232,   300,   192,   -408,  -1012, -152,  -252,  -268,  272,  -876,
  -664,  -648,  -332,  -136,  16,    12,    1152,  -28,   332,   -536, 320,
  -672,  -460,  -316,  532,   -260,  228,   -40,   1052,  -816,  180,  88,
  -496,  -556,  -672,  -368,  428,   92,    356,   404,   -408,  252,  196,
  -176,  -556,  792,   268,   32,    372,   40,    96,    -332,  328,  120,
  372,   -900,  -40,   472,   -264,  -592,  952,   128,   656,   112,  664,
  -232,  420,   4,     -344,  -464,  556,   244,   -416,  -32,   252,  0,
  -412,  188,   -696,  508,   -476,  324,   -1096, 656,   -312,  560,  264,
  -136,  304,   160,   -64,   -580,  248,   336,   -720,  560,   -348, -288,
  -276,  -196,  -500,  852,   -544,  -236,  -1128, -992,  -776,  116,  56,
  52,    860,   884,   212,   -12,   168,   1020,  512,   -552,  924,  -148,
  716,   188,   164,   -340,  -520,  -184,  880,   -152,  -680,  -208, -1156,
  -300,  -528,  -472,  364,   100,   -744,  -1056, -32,   540,   280,  144,
  -676,  -32,   -232,  -280,  -224,  96,    568,   -76,   172,   148,  148,
  104,   32,    -296,  -32,   788,   -80,   32,    -16,   280,   288,  944,
  428,   -484
}
```

9.4. Default CDF tables

This section contains the default values for the cumulative distributions.

```
Default_Intra_Frame_Y_Mode_Cdf[ INTRA_MODE_CONTEXTS ][ INTRA_MODE_CONTEXTS ][ INTRA_MODES + 1 ] = {
  {
    { 15588, 17027, 19338, 20218, 20682, 21110, 21825, 23244,
                24189, 28165, 29093, 30466, 32768, 0 },
    { 12016, 18066, 19516, 20303, 20719, 21444, 21888, 23032,
                24434, 28658, 30172, 31409, 32768, 0 },
    { 10052, 10771, 22296, 22788, 23055, 23239, 24133, 25620,
                26160, 29336, 29929, 31567, 32768, 0 },
    { 14091, 15406, 16442, 18808, 19136, 19546, 19998, 22096,
                24746, 29585, 30958, 32462, 32768, 0 },
    { 12122, 13265, 15603, 16501, 18609, 20033, 22391, 25583,
                26437, 30261, 31073, 32475, 32768, 0 }
  },
  {
    { 10023, 19585, 20848, 21440, 21832, 22760, 23089, 24023,
                25381, 29014, 30482, 31436, 32768, 0 },
    { 5983, 24099, 24560, 24886, 25066, 25795, 25913, 26423,
                27610, 29905, 31276, 31794, 32768, 0 },
    { 7444, 12781, 20177, 20728, 21077, 21607, 22170, 23405,
                24469, 27915, 29090, 30492, 32768, 0 },
    { 8537, 14689, 15432, 17087, 17408, 18172, 18408, 19825,
                24649, 29153, 31096, 32210, 32768, 0 },
    { 7543, 14231, 15496, 16195, 17905, 20717, 21984, 24516,
                26001, 29675, 30981, 31994, 32768, 0 }
  },
  {
    { 12613, 13591, 21383, 22004, 22312, 22577, 23401, 25055,
                25729, 29538, 30305, 32077, 32768, 0 },
    { 9687, 13470, 18506, 19230, 19604, 20147, 20695, 22062,
                23219, 27743, 29211, 30907, 32768, 0 },
    { 6183, 6505, 26024, 26252, 26366, 26434, 27082, 28354, 28555,
                30467, 30794, 32086, 32768, 0 },
    { 10718, 11734, 14954, 17224, 17565, 17924, 18561, 21523,
                23878, 28975, 30287, 32252, 32768, 0 },
    { 9194, 9858, 16501, 17263, 18424, 19171, 21563, 25961, 26561,
                30072, 30737, 32463, 32768, 0 }
  },
  {
    { 12602, 14399, 15488, 18381, 18778, 19315, 19724, 21419,
                25060, 29696, 30917, 32409, 32768, 0 },
    { 8203, 13821, 14524, 17105, 17439, 18131, 18404, 19468,
                25225, 29485, 31158, 32342, 32768, 0 },
    { 8451, 9731, 15004, 17643, 18012, 18425, 19070, 21538, 24605,
                29118, 30078, 32018, 32768, 0 },
    { 7714, 9048, 9516, 16667, 16817, 16994, 17153, 18767, 26743,
                30389, 31536, 32528, 32768, 0 },
    { 8843, 10280, 11496, 15317, 16652, 17943, 19108, 22718,
                25769, 29953, 30983, 32485, 32768, 0 }
  },
  {
```

```
    { 12578, 13671, 15979, 16834, 19075, 20913, 22989, 25449,
                26219, 30214, 31150, 32477, 32768, 0 },
    { 9563, 13626, 15080, 15892, 17756, 20863, 22207, 24236,
                25380, 29653, 31143, 32277, 32768, 0 },
    { 8356, 8901, 17616, 18256, 19350, 20106, 22598, 25947, 26466,
                29900, 30523, 32261, 32768, 0 },
    { 10835, 11815, 13124, 16042, 17018, 18039, 18947, 22753,
                24615, 29489, 30883, 32482, 32768, 0 },
    { 7618, 8288, 9859, 10509, 15386, 18657, 22903, 28776, 29180,
                31355, 31802, 32593, 32768, 0 }
  }
}
```

```
Default_Y_Mode_Cdf[ BLOCK_SIZE_GROUPS ][ INTRA_MODES + 1 ] = {
  { 22801, 23489, 24293, 24756,
    25601, 26123, 26606, 27418,
    27945, 29228, 29685, 30349,
    32768, 0 },
  { 18673, 19845, 22631, 23318,
    23950, 24649, 25527, 27364,
    28152, 29701, 29984, 30852,
    32768, 0 },
  { 19770, 20979, 23396, 23939,
    24241, 24654, 25136, 27073,
    27830, 29360, 29730, 30659,
    32768, 0 },
  { 20155, 21301, 22838, 23178,
    23261, 23533, 23703, 24804,
    25352, 26575, 27016, 28049,
    32768, 0 }
}
```

```
Default_Uv_Mode_Cfl_Not_Allowed_Cdf[ INTRA_MODES ][ UV_INTRA_MODES_CFL_NOT_ALLOWED + 1 ] = {
  { 22631, 24152, 25378, 25661, 25986, 26520, 27055, 27923,
    28244, 30059, 30941, 31961, 32768, 0 },
  { 9513, 26881, 26973, 27046, 27118, 27664, 27739, 27824,
    28359, 29505, 29800, 31796, 32768, 0 },
  { 9845, 9915, 28663, 28704, 28757, 28780, 29198, 29822, 29854,
    30764, 31777, 32029, 32768, 0 },
  { 13639, 13897, 14171, 25331, 25606, 25727, 25953, 27148,
    28577, 30612, 31355, 32493, 32768, 0 },
  { 9764, 9835, 9930, 9954, 25386, 27053, 27958, 28148, 28243,
    31101, 31744, 32363, 32768, 0 },
  { 11825, 13589, 13677, 13720, 15048, 29213, 29301, 29458,
    29711, 31161, 31441, 32550, 32768, 0 },
  { 14175, 14399, 16608, 16821, 17718, 17775, 28551, 30200,
    30245, 31837, 32342, 32667, 32768, 0 },
  { 12885, 13038, 14978, 15590, 15673, 15748, 16176, 29128,
    29267, 30643, 31961, 32461, 32768, 0 },
  { 12026, 13661, 13874, 15305, 15490, 15726, 15995, 16273,
    28443, 30388, 30767, 32416, 32768, 0 },
  { 19052, 19840, 20579, 20916, 21150, 21467, 21885, 22719,
    23174, 28861, 30379, 32175, 32768, 0 },
  { 18627, 19649, 20974, 21219, 21492, 21816, 22199, 23119,
    23527, 27053, 31397, 32148, 32768, 0 },
  { 17026, 19004, 19997, 20339, 20586, 21103, 21349, 21907,
    22482, 25896, 26541, 31819, 32768, 0 },
  { 12124, 13759, 14959, 14992, 15007, 15051, 15078, 15166,
    15255, 15753, 16039, 16606, 32768, 0 }
}
```

```
Default_Uv_Mode_Cfl_Allowed_Cdf[ INTRA_MODES ][ UV_INTRA_MODES_CFL_ALLOWED + 1 ] = {
  { 10407, 11208, 12900, 13181, 13823, 14175, 14899, 15656,
    15986, 20086, 20995, 22455, 24212, 32768, 0 },
  { 4532, 19780, 20057, 20215, 20428, 21071, 21199, 21451,
    22099, 24228, 24693, 27032, 29472, 32768, 0 },
  { 5273, 5379, 20177, 20270, 20385, 20439, 20949, 21695, 21774,
    23138, 24256, 24703, 26679, 32768, 0 },
  { 6740, 7167, 7662, 14152, 14536, 14785, 15034, 16741, 18371,
    21520, 22206, 23389, 24182, 32768, 0 },
  { 4987, 5368, 5928, 6068, 19114, 20315, 21857, 22253, 22411,
    24911, 25380, 26027, 26376, 32768, 0 },
  { 5370, 6889, 7247, 7393, 9498, 21114, 21402, 21753, 21981,
    24780, 25386, 26517, 27176, 32768, 0 },
  { 4816, 4961, 7204, 7326, 8765, 8930, 20169, 20682, 20803,
    23188, 23763, 24455, 24940, 32768, 0 },
  { 6608, 6740, 8529, 9049, 9257, 9356, 9735, 18827, 19059,
    22336, 23204, 23964, 24793, 32768, 0 },
  { 5998, 7419, 7781, 8933, 9255, 9549, 9753, 10417, 18898,
    22494, 23139, 24764, 25989, 32768, 0 },
  { 10660, 11298, 12550, 12957, 13322, 13624, 14040, 15004,
    15534, 20714, 21789, 23443, 24861, 32768, 0 },
  { 10522, 11530, 12552, 12963, 13378, 13779, 14245, 15235,
    15902, 20102, 22696, 23774, 25838, 32768, 0 },
  { 10099, 10691, 12639, 13049, 13386, 13665, 14125, 15163,
    15636, 19676, 20474, 23519, 25208, 32768, 0 },
  { 3144, 5087, 7382, 7504, 7593, 7690, 7801, 8064, 8232, 9248,
    9875, 10521, 29048, 32768, 0 }
}
```

```
Default_Angle_Delta_Cdf[ DIRECTIONAL_MODES ][(2 * MAX_ANGLE_DELTA + 1) + 1] = {
  { 2180, 5032, 7567, 22776, 26989, 30217, 32768, 0 },
  { 2301, 5608, 8801, 23487, 26974, 30330, 32768, 0 },
  { 3780, 11018, 13699, 19354, 23083, 31286, 32768, 0 },
  { 4581, 11226, 15147, 17138, 21834, 28397, 32768, 0 },
  { 1737, 10927, 14509, 19588, 22745, 28823, 32768, 0 },
  { 2664, 10176, 12485, 17650, 21600, 30495, 32768, 0 },
  { 2240, 11096, 15453, 20341, 22561, 28917, 32768, 0 },
  { 3605, 10428, 12459, 17676, 21244, 30655, 32768, 0 }
}
```

```
Default_Intrabc_Cdf[ 2 + 1 ] = { 30531, 32768, 0 }
```

```
Default_Partition_W8_Cdf[ PARTITION_CONTEXTS ][ 5 ] = {
  { 19132, 25510, 30392, 32768, 0 },
  { 13928, 19855, 28540, 32768, 0 },
  { 12522, 23679, 28629, 32768, 0 },
  { 9896, 18783, 25853, 32768, 0 },
}
```

```
Default_Partition_W16_Cdf[ PARTITION_CONTEXTS ][ 11 ] = {
  { 15597, 20929, 24571, 26706, 27664, 28821, 29601, 30571, 31902, 32768, 0 },
  { 7925, 11043, 16785, 22470, 23971, 25043, 26651, 28701, 29834, 32768, 0 },
  { 5414, 13269, 15111, 20488, 22360, 24500, 25537, 26336, 32117, 32768, 0 },
  { 2662, 6362, 8614, 20860, 23053, 24778, 26436, 27829, 31171, 32768, 0 }
}
```

```
Default_Partition_W32_Cdf[ PARTITION_CONTEXTS ][ 11 ] = {
  { 18462, 20920, 23124, 27647, 28227, 29049, 29519, 30178, 31544, 32768, 0 },
  { 7689, 9060, 12056, 24992, 25660, 26182, 26951, 28041, 29052, 32768, 0 },
  { 6015, 9009, 10062, 24544, 25409, 26545, 27071, 27526, 32047, 32768, 0 },
  { 1394, 2208, 2796, 28614, 29061, 29466, 29840, 30185, 31899, 32768, 0 }
}
```

```
Default_Partition_W64_Cdf[ PARTITION_CONTEXTS ][ 11 ] = {
  { 20137, 21547, 23078, 29566, 29837, 30261, 30524, 30892, 31724, 32768, 0 },
  { 6732, 7490, 9497, 27944, 28250, 28515, 28969, 29630, 30104, 32768, 0 },
  { 5945, 7663, 8348, 28683, 29117, 29749, 30064, 30298, 32238, 32768, 0 },
  { 870, 1212, 1487, 31198, 31394, 31574, 31743, 31881, 32332, 32768, 0 }
}
```

```
Default_Partition_W128_Cdf[ PARTITION_CONTEXTS ][ 9 ] = {
  { 27899, 28219, 28529, 32484, 32539, 32619, 32639, 32768, 0 },
  { 6607, 6990, 8268, 32060, 32219, 32338, 32371, 32768, 0 },
  { 5429, 6676, 7122, 32027, 32227, 32531, 32582, 32768, 0 },
  { 711, 966, 1172, 32448, 32538, 32617, 32664, 32768, 0 }
}
```

```
Default_Tx_8x8_Cdf[ TX_SIZE_CONTEXTS ][ MAX_TX_DEPTH + 1 ] = {
  { 19968, 32768, 0 },
  { 19968, 32768, 0 },
  { 24320, 32768, 0 }
}
```

```
Default_Tx_16x16_Cdf[ TX_SIZE_CONTEXTS ][ MAX_TX_DEPTH + 2 ] = {
  { 12272, 30172, 32768, 0 },
  { 12272, 30172, 32768, 0 },
  { 18677, 30848, 32768, 0 }
}
```

```
Default_Tx_32x32_Cdf[ TX_SIZE_CONTEXTS ][ MAX_TX_DEPTH + 2 ] = {
  { 12986, 15180, 32768, 0 },
  { 12986, 15180, 32768, 0 },
  { 24302, 25602, 32768, 0 }
}
```

```
Default_Tx_64x64_Cdf[ TX_SIZE_CONTEXTS ][ MAX_TX_DEPTH + 2 ] = {
  { 5782, 11475, 32768, 0 },
  { 5782, 11475, 32768, 0 },
  { 16803, 22759, 32768, 0 }
}
```

```
Default_Txfm_Split_Cdf[ TXFM_PARTITION_CONTEXTS ][ 3 ] = {
  { 28581, 32768, 0 }, { 23846, 32768, 0 }, { 20847, 32768, 0 },
  { 24315, 32768, 0 }, { 18196, 32768, 0 }, { 12133, 32768, 0 },
  { 18791, 32768, 0 }, { 10887, 32768, 0 }, { 11005, 32768, 0 },
  { 27179, 32768, 0 }, { 20004, 32768, 0 }, { 11281, 32768, 0 },
  { 26549, 32768, 0 }, { 19308, 32768, 0 }, { 14224, 32768, 0 },
  { 28015, 32768, 0 }, { 21546, 32768, 0 }, { 14400, 32768, 0 },
  { 28165, 32768, 0 }, { 22401, 32768, 0 }, { 16088, 32768, 0 }
}
```

```
Default_Filter_Intra_Mode_Cdf[ 6 ] = { 8949, 12776, 17211, 29558, 32768, 0 }
```

```
Default_Filter_Intra_Cdf[ BLOCK_SIZES ][ 3 ] = {
  {  4621, 32768, 0 }, {  6743, 32768, 0 }, {  5893, 32768, 0 },
  {  7866, 32768, 0 }, { 12551, 32768, 0 }, {  9394, 32768, 0 },
  { 12408, 32768, 0 }, { 14301, 32768, 0 }, { 12756, 32768, 0 },
  { 22343, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
  { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
  { 16384, 32768, 0 }, { 12770, 32768, 0 }, { 10368, 32768, 0 },
  { 20229, 32768, 0 }, { 18101, 32768, 0 }, { 16384, 32768, 0 },
  { 16384, 32768, 0 }
}
```

Note: Indices 10 to 15 and 20 to 21 inclusive are never used in the first dimension of the Default_Filter_Intra_Cdf CDF table.

```
Default_Segment_Id_Cdf[ SEGMENT_ID_CONTEXTS ][ MAX_SEGMENTS + 1 ] = {
  { 5622, 7893, 16093, 18233, 27809, 28373, 32533, 32768, 0 },
  { 14274, 18230, 22557, 24935, 29980, 30851, 32344, 32768, 0 },
  { 27527, 28487, 28723, 28890, 32397, 32647, 32679, 32768, 0 }
}
```

```
Default_Segment_Id_Predicted_Cdf[ SEGMENT_ID_PREDICTED_CONTEXTS ][ 3 ] = {
  { 128 * 128, 32768, 0 },
  { 128 * 128, 32768, 0 },
  { 128 * 128, 32768, 0 }
}
```

```
Default_Mv_Class0_Hp_Cdf[ 3 ] = {
  160*128, 32768, 0
}
```

```
Default_Mv_Hp_Cdf[ 3 ] = {
  128*128, 32768, 0
}
```

```
Default_Mv_Sign_Cdf[3] = {
  128*128, 32768, 0
}
```

```
Default_Mv_Bit_Cdf[ MV_OFFSET_BITS ][ 3 ] = {
  { 136*128, 32768, 0 },
  { 140*128, 32768, 0 },
  { 148*128, 32768, 0 },
  { 160*128, 32768, 0 },
  { 176*128, 32768, 0 },
  { 192*128, 32768, 0 },
  { 224*128, 32768, 0 },
  { 234*128, 32768, 0 },
  { 234*128, 32768, 0 },
  { 240*128, 32768, 0 }
}
```

```
Default_Mv_Class0_Bit_Cdf[ 3 ] = {
  216*128, 32768, 0
}
```

```
Default_New_Mv_Cdf[ NEW_MV_CONTEXTS ][ 3 ] = {
  { 24035, 32768, 0 },
  { 16630, 32768, 0 },
  { 15339, 32768, 0 },
  { 8386, 32768, 0 },
  { 12222, 32768, 0 },
  { 4676, 32768, 0 }
}
```

```
Default_Zero_Mv_Cdf[ ZERO_MV_CONTEXTS ][ 3 ] = {
  { 2175, 32768, 0 },
  { 1054, 32768, 0 }
}
```

```
Default_Ref_Mv_Cdf[ REF_MV_CONTEXTS ][ 3 ] = {
  { 23974, 32768, 0 },
  { 24188, 32768, 0 },
  { 17848, 32768, 0 },
  { 28622, 32768, 0 },
  { 24312, 32768, 0 },
  { 19923, 32768, 0 }
}
```

```
Default_Drl_Mode_Cdf[ DRL_MODE_CONTEXTS ][ 3 ] = {
  { 13104, 32768, 0 },
  { 24560, 32768, 0 },
  { 18945, 32768, 0 }
}
```

```
Default_Is_Inter_Cdf[ IS_INTER_CONTEXTS ][ 3 ] = {
  { 806, 32768, 0 },
  { 16662, 32768, 0 },
  { 20186, 32768, 0 },
  { 26538, 32768, 0 }
}
```

```
Default_Comp_Mode_Cdf[ COMP_INTER_CONTEXTS ][ 3 ] = {
  { 26828, 32768, 0 },
  { 24035, 32768, 0 },
  { 12031, 32768, 0 },
  { 10640, 32768, 0 },
  { 2901, 32768, 0 }
}
```

```
Default_Skip_Mode_Cdf[ SKIP_MODE_CONTEXTS ][ 3 ] = {
  {32621, 32768, 0},
  {20708, 32768, 0},
  {8127, 32768, 0}
}
```

```
Default_Skip_Cdf[ SKIP_CONTEXTS ][ 3 ] = {
  { 31671, 32768, 0 },
  { 16515, 32768, 0 },
  { 4576, 32768, 0 }
}
```

```
Default_Comp_Ref_Cdf[ REF_CONTEXTS ][ FWD_REFS - 1 ][ 3 ] = {
  { { 4946, 32768, 0 },
    { 9468, 32768, 0 },
    { 1503, 32768, 0 } },
  { { 19891, 32768, 0 },
    { 22441, 32768, 0 },
    { 15160, 32768, 0 } },
  { { 30731, 32768, 0 },
    { 31059, 32768, 0 },
    { 27544, 32768, 0 } }
}
```

```
Default_Comp_Bwd_Ref_Cdf[ REF_CONTEXTS ][ BWD_REFS - 1 ][ 3 ] = {
  { {  2235, 32768, 0 }, {  1423, 32768, 0 } },
  { { 17182, 32768, 0 }, { 15175, 32768, 0 } },
  { { 30606, 32768, 0 }, { 30489, 32768, 0 } }
}
```

```
Default_Single_Ref_Cdf[ REF_CONTEXTS ][ SINGLE_REFS - 1 ][ 3 ] = {
  { { 4897, 32768, 0 }, { 1555, 32768, 0 }, { 4236, 32768, 0 },
    { 8650, 32768, 0 }, { 904, 32768, 0 }, { 1444, 32768, 0 } },
  { { 16973, 32768, 0 }, { 16751, 32768, 0 }, { 19647, 32768, 0 },
    { 24773, 32768, 0 }, { 11014, 32768, 0 }, { 15087, 32768, 0 } },
  { { 29744, 32768, 0 }, { 30279, 32768, 0 }, { 31194, 32768, 0 },
    { 31895, 32768, 0 }, { 26875, 32768, 0 }, { 30304, 32768, 0 } }
}
```

```
Default_Compound_Mode_Cdf[ COMPOUND_MODE_CONTEXTS ][ COMPOUND_MODES + 1 ] = {
  { 7760, 13823, 15808, 17641, 19156, 20666, 26891, 32768, 0 },
  { 10730, 19452, 21145, 22749, 24039, 25131, 28724, 32768, 0 },
  { 10664, 20221, 21588, 22906, 24295, 25387, 28436, 32768, 0 },
  { 13298, 16984, 20471, 24182, 25067, 25736, 26422, 32768, 0 },
  { 18904, 23325, 25242, 27432, 27898, 28258, 30758, 32768, 0 },
  { 10725, 17454, 20124, 22820, 24195, 25168, 26046, 32768, 0 },
  { 17125, 24273, 25814, 27492, 28214, 28704, 30592, 32768, 0 },
  { 13046, 23214, 24505, 25942, 27435, 28442, 29330, 32768, 0 }
}
```

```
Default_Interp_Filter_Cdf[ INTERP_FILTER_CONTEXTS ][ INTERP_FILTERS + 1 ] = {
  { 31935, 32720, 32768, 0 },
  { 5568, 32719, 32768, 0 },
  { 422, 2938, 32768, 0 },
  { 28244, 32608, 32768, 0 },
  { 31206, 31953, 32768, 0 },
  { 4862, 32121, 32768, 0 },
  { 770, 1152, 32768, 0 },
  { 20889, 25637, 32768, 0 },
  { 31910, 32724, 32768, 0 },
  { 4120, 32712, 32768, 0 },
  { 305, 2247, 32768, 0 },
  { 27403, 32636, 32768, 0 },
  { 31022, 32009, 32768, 0 },
  { 2963, 32093, 32768, 0 },
  { 601, 943, 32768, 0 },
  { 14969, 21398, 32768, 0 }
}
```

```
Default_Motion_Mode_Cdf[ BLOCK_SIZES ][ MOTION_MODES + 1 ] = {
  { 10923, 21845, 32768, 0 },
  { 10923, 21845, 32768, 0 },
  { 10923, 21845, 32768, 0 },
  { 7651, 24760, 32768, 0 },
  { 4738, 24765, 32768, 0 },
  { 5391, 25528, 32768, 0 },
  { 19419, 26810, 32768, 0 },
  { 5123, 23606, 32768, 0 },
  { 11606, 24308, 32768, 0 },
  { 26260, 29116, 32768, 0 },
  { 20360, 28062, 32768, 0 },
  { 21679, 26830, 32768, 0 },
  { 29516, 30701, 32768, 0 },
  { 28898, 30397, 32768, 0 },
  { 30878, 31335, 32768, 0 },
  { 32507, 32558, 32768, 0 },
  { 10923, 21845, 32768, 0 },
  { 10923, 21845, 32768, 0 },
  { 28799, 31390, 32768, 0 },
  { 26431, 30774, 32768, 0 },
  { 28973, 31594, 32768, 0 },
  { 29742, 31203, 32768, 0 }
}
```

Note: Indices 0 to 2 and 16 to 17 inclusive are never used in the first dimension of the Default_Motion_Mode_Cdf CDF table.

```
Default_Mv_Joint_Cdf[ MV_JOINTS + 1 ] = {
  4096, 11264, 19328, 32768, 0
}
```

```
Default_Mv_Class_Cdf[ 2 ][ MV_CLASSES + 1 ] = {
  { 28672, 30976, 31858, 32320,
    32551, 32656, 32740, 32757,
    32762, 32767, 32768, 0 },
  { 28672, 30976, 31858, 32320,
    32551, 32656, 32740, 32757,
    32762, 32767, 32768, 0 }
}
```

```
Default_Mv_Class0_Fr_Cdf[ 2 ][ CLASS0_SIZE ][ MV_JOINTS + 1 ] = {
  { { 16384, 24576, 26624, 32768, 0 },
    { 12288, 21248, 24128, 32768, 0 } },
  { { 16384, 24576, 26624, 32768, 0 },
    { 12288, 21248, 24128, 32768, 0 } },
}
```

```
Default_Mv_Fr_Cdf[ 2 ][ MV_JOINTS + 1 ] = {
  { 8192, 17408, 21248, 32768, 0 },
  { 8192, 17408, 21248, 32768, 0 },
}
```

```
Default_Palette_Y_Size_Cdf[ PALETTE_BLOCK_SIZE_CONTEXTS ][ PALETTE_SIZES + 1 ] = {
  { 7952, 13000, 18149, 21478, 25527, 29241, 32768, 0 },
  { 7139, 11421, 16195, 19544, 23666, 28073, 32768, 0 },
  { 7788, 12741, 17325, 20500, 24315, 28530, 32768, 0 },
  { 8271, 14064, 18246, 21564, 25071, 28533, 32768, 0 },
  { 12725, 19180, 21863, 24839, 27535, 30120, 32768, 0 },
  { 9711, 14888, 16923, 21052, 25661, 27875, 32768, 0 },
  { 14940, 20797, 21678, 24186, 27033, 28999, 32768, 0 }
}
```

```
Default_Palette_Uv_Size_Cdf[ PALETTE_BLOCK_SIZE_CONTEXTS ][ PALETTE_SIZES + 1 ] = {
  { 8713, 19979, 27128, 29609, 31331, 32272, 32768, 0 },
  { 5839, 15573, 23581, 26947, 29848, 31700, 32768, 0 },
  { 4426, 11260, 17999, 21483, 25863, 29430, 32768, 0 },
  { 3228, 9464, 14993, 18089, 22523, 27420, 32768, 0 },
  { 3768, 8886, 13091, 17852, 22495, 27207, 32768, 0 },
  { 2464, 8451, 12861, 21632, 25525, 28555, 32768, 0 },
  { 1269, 5435, 10433, 18963, 21700, 25865, 32768, 0 }
}
```

```
Default_Palette_Size_2_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 3 ] = {
  { 28710, 32768, 0 },
  { 16384, 32768, 0 },
  { 10553, 32768, 0 },
  { 27036, 32768, 0 },
  { 31603, 32768, 0 }
}

Default_Palette_Size_3_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 4 ] = {
  { 27877, 30490, 32768, 0 },
  { 11532, 25697, 32768, 0 },
  { 6544, 30234, 32768, 0 },
  { 23018, 28072, 32768, 0 },
  { 31915, 32385, 32768, 0 }
}

Default_Palette_Size_4_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 5 ] = {
  { 25572, 28046, 30045, 32768, 0 },
  { 9478, 21590, 27256, 32768, 0 },
  { 7248, 26837, 29824, 32768, 0 },
  { 19167, 24486, 28349, 32768, 0 },
  { 31400, 31825, 32250, 32768, 0 }
}

Default_Palette_Size_5_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 6 ] = {
  { 24779, 26955, 28576, 30282, 32768, 0 },
  { 8669, 20364, 24073, 28093, 32768, 0 },
  { 4255, 27565, 29377, 31067, 32768, 0 },
  { 19864, 23674, 26716, 29530, 32768, 0 },
  { 31646, 31893, 32147, 32426, 32768, 0 }
}

Default_Palette_Size_6_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 7 ] = {
  { 23132, 25407, 26970, 28435, 30073, 32768, 0 },
  { 7443, 17242, 20717, 24762, 27982, 32768, 0 },
  { 6300, 24862, 26944, 28784, 30671, 32768, 0 },
  { 18916, 22895, 25267, 27435, 29652, 32768, 0 },
  { 31270, 31550, 31808, 32059, 32353, 32768, 0 }
}

Default_Palette_Size_7_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 8 ] = {
  { 23105, 25199, 26464, 27684, 28931, 30318, 32768, 0 },
  { 6950, 15447, 18952, 22681, 25567, 28563, 32768, 0 },
  { 7560, 23474, 25490, 27203, 28921, 30708, 32768, 0 },
  { 18544, 22373, 24457, 26195, 28119, 30045, 32768, 0 },
  { 31198, 31451, 31670, 31882, 32123, 32391, 32768, 0 }
}

Default_Palette_Size_8_Y_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 9 ] = {
  { 21689, 23883, 25163, 26352, 27506, 28827, 30195, 32768, 0 },
```

```
  { 6892, 15385, 17840, 21606, 24287, 26753, 29204, 32768, 0 },
  { 5651, 23182, 25042, 26518, 27982, 29392, 30900, 32768, 0 },
  { 19349, 22578, 24418, 25994, 27524, 29031, 30448, 32768, 0 },
  { 31028, 31270, 31504, 31705, 31927, 32153, 32392, 32768, 0 }
}
```

```
Default_Palette_Size_2_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 3 ] = {
  { 29089, 32768, 0 },
  { 16384, 32768, 0 },
  { 8713, 32768, 0 },
  { 29257, 32768, 0 },
  { 31610, 32768, 0 }
}

Default_Palette_Size_3_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 4 ] = {
  { 25257, 29145, 32768, 0 },
  { 12287, 27293, 32768, 0 },
  { 7033, 27960, 32768, 0 },
  { 20145, 25405, 32768, 0 },
  { 30608, 31639, 32768, 0 }
}

Default_Palette_Size_4_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 5 ] = {
  { 24210, 27175, 29903, 32768, 0 },
  { 9888, 22386, 27214, 32768, 0 },
  { 5901, 26053, 29293, 32768, 0 },
  { 18318, 22152, 28333, 32768, 0 },
  { 30459, 31136, 31926, 32768, 0 }
}

Default_Palette_Size_5_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 6 ] = {
  { 22980, 25479, 27781, 29986, 32768, 0 },
  { 8413, 21408, 24859, 28874, 32768, 0 },
  { 2257, 29449, 30594, 31598, 32768, 0 },
  { 19189, 21202, 25915, 28620, 32768, 0 },
  { 31844, 32044, 32281, 32518, 32768, 0 }
}

Default_Palette_Size_6_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 7 ] = {
  { 22217, 24567, 26637, 28683, 30548, 32768, 0 },
  { 7307, 16406, 19636, 24632, 28424, 32768, 0 },
  { 4441, 25064, 26879, 28942, 30919, 32768, 0 },
  { 17210, 20528, 23319, 26750, 29582, 32768, 0 },
  { 30674, 30953, 31396, 31735, 32207, 32768, 0 }
}

Default_Palette_Size_7_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 8 ] = {
  { 21239, 23168, 25044, 26962, 28705, 30506, 32768, 0 },
  { 6545, 15012, 18004, 21817, 25503, 28701, 32768, 0 },
  { 3448, 26295, 27437, 28704, 30126, 31442, 32768, 0 },
  { 15889, 18323, 21704, 24698, 26976, 29690, 32768, 0 },
  { 30988, 31204, 31479, 31734, 31983, 32325, 32768, 0 }
}

Default_Palette_Size_8_Uv_Color_Cdf[ PALETTE_COLOR_CONTEXTS ][ 9 ] = {
  { 21442, 23288, 24758, 26246, 27649, 28980, 30563, 32768, 0 },
```

```
  { 5863, 14933, 17552, 20668, 23683, 26411, 29273, 32768, 0 },
  { 3415, 25810, 26877, 27990, 29223, 30394, 31618, 32768, 0 },
  { 17965, 20084, 22232, 23974, 26274, 28402, 30390, 32768, 0 },
  { 31190, 31329, 31516, 31679, 31825, 32026, 32322, 32768, 0 }
}
```

```
Default_Palette_Y_Mode_Cdf[ PALETTE_BLOCK_SIZE_CONTEXTS ][ PALETTE_Y_MODE_CONTEXTS ][ 3 ] = {
  { { 31676, 32768, 0 }, {  3419, 32768, 0 }, {  1261, 32768, 0 } },
  { { 31912, 32768, 0 }, {  2859, 32768, 0 }, {   980, 32768, 0 } },
  { { 31823, 32768, 0 }, {  3400, 32768, 0 }, {   781, 32768, 0 } },
  { { 32030, 32768, 0 }, {  3561, 32768, 0 }, {   904, 32768, 0 } },
  { { 32309, 32768, 0 }, {  7337, 32768, 0 }, {  1462, 32768, 0 } },
  { { 32265, 32768, 0 }, {  4015, 32768, 0 }, {  1521, 32768, 0 } },
  { { 32450, 32768, 0 }, {  7946, 32768, 0 }, {   129, 32768, 0 } }
}
```

```
Default_Palette_Uv_Mode_Cdf[ PALETTE_UV_MODE_CONTEXTS ][ 3 ] = {
  { 32461, 32768, 0 }, { 21488, 32768, 0 }
}
```

```
Default_Delta_Q_Cdf[ DELTA_Q_SMALL + 2 ] = {
  28160, 32120, 32677, 32768, 0
}
```

```
Default_Delta_Lf_Cdf[ DELTA_LF_SMALL + 2 ] = {
  28160, 32120, 32677, 32768, 0
}
```

```
Default_Intra_Tx_Type_Set1_Cdf[ 2 ][ INTRA_MODES ][ 8 ] = {
    {
        { 1535, 8035, 9461, 12751, 23467, 27825, 32768, 0 },
        { 564, 3335, 9709, 10870, 18143, 28094, 32768, 0 },
        { 672, 3247, 3676, 11982, 19415, 23127, 32768, 0 },
        { 5279, 13885, 15487, 18044, 23527, 30252, 32768, 0 },
        { 4423, 6074, 7985, 10416, 25693, 29298, 32768, 0 },
        { 1486, 4241, 9460, 10662, 16456, 27694, 32768, 0 },
        { 439, 2838, 3522, 6737, 18058, 23754, 32768, 0 },
        { 1190, 4233, 4855, 11670, 20281, 24377, 32768, 0 },
        { 1045, 4312, 8647, 10159, 18644, 29335, 32768, 0 },
        { 202, 3734, 4747, 7298, 17127, 24016, 32768, 0 },
        { 447, 4312, 6819, 8884, 16010, 23858, 32768, 0 },
        { 277, 4369, 5255, 8905, 16465, 22271, 32768, 0 },
        { 3409, 5436, 10599, 15599, 19687, 24040, 32768, 0 }
    },
    {
        { 1870, 13742, 14530, 16498, 23770, 27698, 32768, 0 },
        { 326, 8796, 14632, 15079, 19272, 27486, 32768, 0 },
        { 484, 7576, 7712, 14443, 19159, 22591, 32768, 0 },
        { 1126, 15340, 15895, 17023, 20896, 30279, 32768, 0 },
        { 655, 4854, 5249, 5913, 22099, 27138, 32768, 0 },
        { 1299, 6458, 8885, 9290, 14851, 25497, 32768, 0 },
        { 311, 5295, 5552, 6885, 16107, 22672, 32768, 0 },
        { 883, 8059, 8270, 11258, 17289, 21549, 32768, 0 },
        { 741, 7580, 9318, 10345, 16688, 29046, 32768, 0 },
        { 110, 7406, 7915, 9195, 16041, 23329, 32768, 0 },
        { 363, 7974, 9357, 10673, 15629, 24474, 32768, 0 },
        { 153, 7647, 8112, 9936, 15307, 19996, 32768, 0 },
        { 3511, 6332, 11165, 15335, 19323, 23594, 32768, 0 }
    }
}
```

```
Default_Intra_Tx_Type_Set2_Cdf[ 3 ][ INTRA_MODES ][ 6 ] = {
    {
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 }
    },
    {
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 },
        { 6554, 13107, 19661, 26214, 32768, 0 }
    },
    {
        { 1127, 12814, 22772, 27483, 32768, 0 },
        { 145, 6761, 11980, 26667, 32768, 0 },
        { 362, 5887, 11678, 16725, 32768, 0 },
        { 385, 15213, 18587, 30693, 32768, 0 },
        { 25, 2914, 23134, 27903, 32768, 0 },
        { 60, 4470, 11749, 23991, 32768, 0 },
        { 37, 3332, 14511, 21448, 32768, 0 },
        { 157, 6320, 13036, 17439, 32768, 0 },
        { 119, 6719, 12906, 29396, 32768, 0 },
        { 47, 5537, 12576, 21499, 32768, 0 },
        { 269, 6076, 11258, 23115, 32768, 0 },
        { 83, 5615, 12001, 17228, 32768, 0 },
        { 1968, 5556, 12023, 18547, 32768, 0 }
    }
}
```

```
Default_Inter_Tx_Type_Set1_Cdf[ 2 ][ 17 ] = {
    { 4458, 5560, 7695, 9709, 13330, 14789, 17537, 20266, 21504,
      22848, 23934, 25474, 27727, 28915, 30631, 32768, 0 },
    { 1645, 2573, 4778, 5711, 7807, 8622, 10522, 15357, 17674,
      20408, 22517, 25010, 27116, 28856, 30749, 32768, 0 }
}
```

```
Default_Inter_Tx_Type_Set2_Cdf[ 13 ] = {
    770, 2421, 5225, 12907, 15819, 18927, 21561, 24089, 26595,
    28526, 30529, 32768, 0
}
```

```
Default_Inter_Tx_Type_Set3_Cdf[ 4 ][ 3 ] = {
    { 16384, 32768, 0 },
    { 4167, 32768, 0 },
    { 1998, 32768, 0 },
    { 748, 32768, 0 }
}
```

```
Default_Compound_Idx_Cdf[ COMPOUND_IDX_CONTEXTS ][ 3 ] = {
  { 18244, 32768, 0 },
  { 12865, 32768, 0 },
  { 7053,  32768, 0 },
  { 13259, 32768, 0 },
  { 9334,  32768, 0 },
  { 4644,  32768, 0 }
}
```

```
Default_Comp_Group_Idx_Cdf[ COMP_GROUP_IDX_CONTEXTS ][ 3 ] = {
  { 26607, 32768, 0 },
  { 22891, 32768, 0 },
  { 18840, 32768, 0 },
  { 24594, 32768, 0 },
  { 19934, 32768, 0 },
  { 22674, 32768, 0 }
}
```

```
Default_Compound_Type_Cdf[ BLOCK_SIZES ][ COMPOUND_TYPES + 1 ] = {
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 23431, 32768, 0 },
  { 13171, 32768, 0 },
  { 11470, 32768, 0 },
  { 9770, 32768, 0 },
  { 9100, 32768, 0 },
  { 8233, 32768, 0 },
  { 6172, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 11820, 32768, 0 },
  { 7701, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 }
}
```

Note: Indices 0 to 2, 10 to 17, and 20 to 21 inclusive are never used in the first dimension of the Default_Compound_Type_Cdf CDF table.

```
Default_Inter_Intra_Cdf[ BLOCK_SIZE_GROUPS - 1 ][ 3 ] = {
  { 26887, 32768, 0},
  { 27597, 32768, 0},
  { 30237, 32768, 0}
}
```

```
Default_Inter_Intra_Mode_Cdf[ BLOCK_SIZE_GROUPS - 1 ][ INTERINTRA_MODES + 1 ] = {
  { 1875, 11082, 27332, 32768, 0 },
  { 2473, 9996, 26388, 32768, 0 },
  { 4238, 11537, 25926, 32768, 0 }
}
```

```
Default_Wedge_Index_Cdf[ BLOCK_SIZES ][ 16+1 ] = {
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2438, 4440, 6599, 8663, 11005, 12874, 15751, 18094, 20359, 22362, 24127, 25702, 27752, 29450,
31171, 32768, 0 },
  { 806, 3266, 6005, 6738, 7218, 7367, 7771, 14588, 16323, 17367, 18452, 19422, 22839, 26127, 29629,
32768, 0 },
  { 2779, 3738, 4683, 7213, 7775, 8017, 8655, 14357, 17939, 21332, 24520, 27470, 29456, 30529, 31656,
32768, 0 },
  { 1684, 3625, 5675, 7108, 9302, 11274, 14429, 17144, 19163, 20961, 22884, 24471, 26719, 28714,
30877, 32768, 0 },
  { 1142, 3491, 6277, 7314, 8089, 8355, 9023, 13624, 15369, 16730, 18114, 19313, 22521, 26012, 29550,
32768, 0 },
  { 2742, 4195, 5727, 8035, 8980, 9336, 10146, 14124, 17270, 20533, 23434, 25972, 27944, 29570,
31416, 32768, 0 },
  { 1727, 3948, 6101, 7796, 9841, 12344, 15766, 18944, 20638, 22038, 23963, 25311, 26988, 28766,
31012, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 154, 987, 1925, 2051, 2088, 2111, 2151, 23033, 23703, 24284, 24985, 25684, 27259, 28883, 30911,
32768, 0 },
  { 1135, 1322, 1493, 2635, 2696, 2737, 2770, 21016, 22935, 25057, 27251, 29173, 30089, 30960, 31933,
32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 },
  { 2048, 4096, 6144, 8192, 10240, 12288, 14336, 16384, 18432, 20480, 22528, 24576, 26624, 28672,
30720, 32768, 0 }
}
```

Note: Indices 0 to 2, 10 to 17, and 20 to 21 inclusive are never used in the first dimension of the Default_Wedge_Index_Cdf CDF table.

```
Default_Wedge_Inter_Intra_Cdf[ BLOCK_SIZES ][ 3 ] = {
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 20036, 32768, 0 },
  { 24957, 32768, 0 },
  { 26704, 32768, 0 },
  { 27530, 32768, 0 },
  { 29564, 32768, 0 },
  { 29444, 32768, 0 },
  { 26872, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 }
}
```

Note: Only indices 3 to 9 inclusive are used in the first dimension of the Default_Wedge_Inter_Intra_Cdf CDF table.

```
Default_Use_Obmc_Cdf[ BLOCK_SIZES ][ 3 ] = {
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 10437, 32768, 0 },
  { 9371, 32768, 0 },
  { 9301, 32768, 0 },
  { 17432, 32768, 0 },
  { 14423, 32768, 0 },
  { 15142, 32768, 0 },
  { 25817, 32768, 0 },
  { 22823, 32768, 0 },
  { 22083, 32768, 0 },
  { 30128, 32768, 0 },
  { 31014, 32768, 0 },
  { 31560, 32768, 0 },
  { 32638, 32768, 0 },
  { 16384, 32768, 0 },
  { 16384, 32768, 0 },
  { 23664, 32768, 0 },
  { 20901, 32768, 0 },
  { 24008, 32768, 0 },
  { 26879, 32768, 0 }
}
```

Note: Indices 0 to 2 and 16 to 17 inclusive are never used in the first dimension of the Default_Use_Obmc_Cdf CDF table.

```
Default_Comp_Ref_Type_Cdf[ COMP_REF_TYPE_CONTEXTS ][ 3 ] = {
  { 1198, 32768, 0 },
  { 2070, 32768, 0 },
  { 9166, 32768, 0 },
  { 7499, 32768, 0 },
  { 22475, 32768, 0 }
}
```

```
Default_Uni_Comp_Ref_Cdf[ REF_CONTEXTS ][ UNIDIR_COMP_REFS - 1 ][ 3 ] = {
  { { 5284, 32768, 0 }, { 3865, 32768, 0 }, { 3128, 32768, 0 } },
  { { 23152, 32768, 0 }, { 14173, 32768, 0 }, { 15270, 32768, 0 } },
  { { 31774, 32768, 0 }, { 25120, 32768, 0 }, { 26710, 32768, 0 } }
}
```

```
Default_Cfl_Sign_Cdf[ CFL_JOINT_SIGNS + 1 ] = {
  1418, 2123, 13340, 18405, 26972, 28343, 32294, 32768, 0
}
```

```
Default_Cfl_Alpha_Cdf[ CFL_ALPHA_CONTEXTS ][ CFL_ALPHABET_SIZE + 1 ] = {
  { 7637, 20719, 31401, 32481, 32657, 32688, 32692, 32696, 32700,
    32704, 32708, 32712, 32716, 32720, 32724, 32768, 0 },
  { 14365, 23603, 28135, 31168, 32167, 32395, 32487, 32573, 32620,
    32647, 32668, 32672, 32676, 32680, 32684, 32768, 0 },
  { 11532, 22380, 28445, 31360, 32349, 32523, 32584, 32649, 32673,
    32677, 32681, 32685, 32689, 32693, 32697, 32768, 0 },
  { 26990, 31402, 32282, 32571, 32692, 32696, 32700, 32704, 32708,
    32712, 32716, 32720, 32724, 32728, 32732, 32768, 0 },
  { 17248, 26058, 28904, 30608, 31305, 31877, 32126, 32321, 32394,
    32464, 32516, 32560, 32576, 32593, 32622, 32768, 0 },
  { 14738, 21678, 25779, 27901, 29024, 30302, 30980, 31843, 32144,
    32413, 32520, 32594, 32622, 32656, 32660, 32768, 0 }
}
```

```
Default_Use_Wiener_Cdf[ 2 + 1 ] = {
  11570, 32768, 0
}
```

```
Default_Use_Sgrproj_Cdf[ 2 + 1 ] = {
  16855, 32768, 0
}
```

```
Default_Restoration_Type_Cdf[ RESTORE_SWITCHABLE + 1 ] = {
  9413, 22581, 32768, 0
}
```

```
Default_Txb_Skip_Cdf[ COEFF_CDF_Q_CTXS ][ TX_SIZES ][ TXB_SKIP_CONTEXTS ][ 3 ] = {
  {
    { { 31849, 32768, 0 },
      { 5892, 32768, 0 },
      { 12112, 32768, 0 },
      { 21935, 32768, 0 },
      { 20289, 32768, 0 },
      { 27473, 32768, 0 },
      { 32487, 32768, 0 },
      { 7654, 32768, 0 },
      { 19473, 32768, 0 },
      { 29984, 32768, 0 },
      { 9961, 32768, 0 },
      { 30242, 32768, 0 },
      { 32117, 32768, 0 } },
    { { 31548, 32768, 0 },
      { 1549, 32768, 0 },
      { 10130, 32768, 0 },
      { 16656, 32768, 0 },
      { 18591, 32768, 0 },
      { 26308, 32768, 0 },
      { 32537, 32768, 0 },
      { 5403, 32768, 0 },
      { 18096, 32768, 0 },
      { 30003, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 29957, 32768, 0 },
      { 5391, 32768, 0 },
      { 18039, 32768, 0 },
      { 23566, 32768, 0 },
      { 22431, 32768, 0 },
      { 25822, 32768, 0 },
      { 32197, 32768, 0 },
      { 3778, 32768, 0 },
      { 15336, 32768, 0 },
      { 28981, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 17920, 32768, 0 },
      { 1818, 32768, 0 },
      { 7282, 32768, 0 },
      { 25273, 32768, 0 },
      { 10923, 32768, 0 },
      { 31554, 32768, 0 },
      { 32624, 32768, 0 },
      { 1366, 32768, 0 },
      { 15628, 32768, 0 },
```

```
      { 30462, 32768, 0 },
      { 146, 32768, 0 },
      { 5132, 32768, 0 },
      { 31657, 32768, 0 } },
    { { 6308, 32768, 0 },
      { 117, 32768, 0 },
      { 1638, 32768, 0 },
      { 2161, 32768, 0 },
      { 16384, 32768, 0 },
      { 10923, 32768, 0 },
      { 30247, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } }
  },
  {
    { { 30371, 32768, 0 },
      { 7570, 32768, 0 },
      { 13155, 32768, 0 },
      { 20751, 32768, 0 },
      { 20969, 32768, 0 },
      { 27067, 32768, 0 },
      { 32013, 32768, 0 },
      { 5495, 32768, 0 },
      { 17942, 32768, 0 },
      { 28280, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 31782, 32768, 0 },
      { 1836, 32768, 0 },
      { 10689, 32768, 0 },
      { 17604, 32768, 0 },
      { 21622, 32768, 0 },
      { 27518, 32768, 0 },
      { 32399, 32768, 0 },
      { 4419, 32768, 0 },
      { 16294, 32768, 0 },
      { 28345, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 31901, 32768, 0 },
      { 10311, 32768, 0 },
      { 18047, 32768, 0 },
      { 24806, 32768, 0 },
      { 23288, 32768, 0 },
```

```
      { 27914, 32768, 0 },
      { 32296, 32768, 0 },
      { 4215, 32768, 0 },
      { 15756, 32768, 0 },
      { 28341, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 26726, 32768, 0 },
      { 1045, 32768, 0 },
      { 11703, 32768, 0 },
      { 20590, 32768, 0 },
      { 18554, 32768, 0 },
      { 25970, 32768, 0 },
      { 31938, 32768, 0 },
      { 5583, 32768, 0 },
      { 21313, 32768, 0 },
      { 29390, 32768, 0 },
      { 641, 32768, 0 },
      { 22265, 32768, 0 },
      { 31452, 32768, 0 } },
    { { 26584, 32768, 0 },
      { 188, 32768, 0 },
      { 8847, 32768, 0 },
      { 24519, 32768, 0 },
      { 22938, 32768, 0 },
      { 30583, 32768, 0 },
      { 32608, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } }
  },
  {
    { { 29614, 32768, 0 },
      { 9068, 32768, 0 },
      { 12924, 32768, 0 },
      { 19538, 32768, 0 },
      { 17737, 32768, 0 },
      { 24619, 32768, 0 },
      { 30642, 32768, 0 },
      { 4119, 32768, 0 },
      { 16026, 32768, 0 },
      { 25657, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 31957, 32768, 0 },
```

```
      { 3230, 32768, 0 },
      { 11153, 32768, 0 },
      { 18123, 32768, 0 },
      { 20143, 32768, 0 },
      { 26536, 32768, 0 },
      { 31986, 32768, 0 },
      { 3050, 32768, 0 },
      { 14603, 32768, 0 },
      { 25155, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 32363, 32768, 0 },
      { 10692, 32768, 0 },
      { 19090, 32768, 0 },
      { 24357, 32768, 0 },
      { 24442, 32768, 0 },
      { 28312, 32768, 0 },
      { 32169, 32768, 0 },
      { 3648, 32768, 0 },
      { 15690, 32768, 0 },
      { 26815, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 30669, 32768, 0 },
      { 3832, 32768, 0 },
      { 11663, 32768, 0 },
      { 18889, 32768, 0 },
      { 19782, 32768, 0 },
      { 23313, 32768, 0 },
      { 31330, 32768, 0 },
      { 5124, 32768, 0 },
      { 18719, 32768, 0 },
      { 28468, 32768, 0 },
      { 3082, 32768, 0 },
      { 20982, 32768, 0 },
      { 29443, 32768, 0 } },
    { { 28573, 32768, 0 },
      { 3183, 32768, 0 },
      { 17802, 32768, 0 },
      { 25977, 32768, 0 },
      { 26677, 32768, 0 },
      { 27832, 32768, 0 },
      { 32387, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
```

```
      { 16384, 32768, 0 } }
  },
  {
    { { 26887, 32768, 0 },
      { 6729, 32768, 0 },
      { 10361, 32768, 0 },
      { 17442, 32768, 0 },
      { 15045, 32768, 0 },
      { 22478, 32768, 0 },
      { 29072, 32768, 0 },
      { 2713, 32768, 0 },
      { 11861, 32768, 0 },
      { 20773, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 31903, 32768, 0 },
      { 2044, 32768, 0 },
      { 7528, 32768, 0 },
      { 14618, 32768, 0 },
      { 16182, 32768, 0 },
      { 24168, 32768, 0 },
      { 31037, 32768, 0 },
      { 2786, 32768, 0 },
      { 11194, 32768, 0 },
      { 20155, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 32510, 32768, 0 },
      { 8430, 32768, 0 },
      { 17318, 32768, 0 },
      { 24154, 32768, 0 },
      { 23674, 32768, 0 },
      { 28789, 32768, 0 },
      { 32139, 32768, 0 },
      { 3440, 32768, 0 },
      { 13117, 32768, 0 },
      { 22702, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } },
    { { 31671, 32768, 0 },
      { 2056, 32768, 0 },
      { 11746, 32768, 0 },
      { 16852, 32768, 0 },
      { 18635, 32768, 0 },
      { 24715, 32768, 0 },
      { 31484, 32768, 0 },
      { 4656, 32768, 0 },
```

```
      { 16074, 32768, 0 },
      { 24704, 32768, 0 },
      { 1806, 32768, 0 },
      { 14645, 32768, 0 },
      { 25336, 32768, 0 } },
    { { 31539, 32768, 0 },
      { 8433, 32768, 0 },
      { 20576, 32768, 0 },
      { 27904, 32768, 0 },
      { 27852, 32768, 0 },
      { 30026, 32768, 0 },
      { 32441, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 },
      { 16384, 32768, 0 } }
  }
}
```

```
Default_Eob_Pt_16_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 2 ][ 6 ] = {
  { { { 840, 1039, 1980, 4895, 32768, 0 },
      { 370, 671, 1883, 4471, 32768, 0 } },
    { { 3247, 4950, 9688, 14563, 32768, 0 },
      { 1904, 3354, 7763, 14647, 32768, 0 } } },
  { { { 2125, 2551, 5165, 8946, 32768, 0 },
      { 513, 765, 1859, 6339, 32768, 0 } },
    { { 7637, 9498, 14259, 19108, 32768, 0 },
      { 2497, 4096, 8866, 16993, 32768, 0 } } },
  { { { 4016, 4897, 8881, 14968, 32768, 0 },
      { 716, 1105, 2646, 10056, 32768, 0 } },
    { { 11139, 13270, 18241, 23566, 32768, 0 },
      { 3192, 5032, 10297, 19755, 32768, 0 } } },
  { { { 6708, 8958, 14746, 22133, 32768, 0 },
      { 1222, 2074, 4783, 15410, 32768, 0 } },
    { { 19575, 21766, 26044, 29709, 32768, 0 },
      { 7297, 10767, 19273, 28194, 32768, 0 } } }
}
```

```
Default_Eob_Pt_32_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 2 ][ 7 ] = {
  { { { 400, 520, 977, 2102, 6542, 32768, 0 },
      { 210, 405, 1315, 3326, 7537, 32768, 0 } },
    { { 2636, 4273, 7588, 11794, 20401, 32768, 0 },
      { 1786, 3179, 6902, 11357, 19054, 32768, 0 } } },
  { { { 989, 1249, 2019, 4151, 10785, 32768, 0 },
      { 313, 441, 1099, 2917, 8562, 32768, 0 } },
    { { 8394, 10352, 13932, 18855, 26014, 32768, 0 },
      { 2578, 4124, 8181, 13670, 24234, 32768, 0 } } },
  { { { 2515, 3003, 4452, 8162, 16041, 32768, 0 },
      { 574, 821, 1836, 5089, 13128, 32768, 0 } },
    { { 13468, 16303, 20361, 25105, 29281, 32768, 0 },
      { 3542, 5502, 10415, 16760, 25644, 32768, 0 } } },
  { { { 4617, 5709, 8446, 13584, 23135, 32768, 0 },
      { 1156, 1702, 3675, 9274, 20539, 32768, 0 } },
    { { 22086, 24282, 27010, 29770, 31743, 32768, 0 },
      { 7699, 10897, 20891, 26926, 31628, 32768, 0 } } }
}
```

```
Default_Eob_Pt_64_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 2 ][ 8 ] = {
  { { { 329, 498, 1101, 1784, 3265, 7758, 32768, 0 },
      { 335, 730, 1459, 5494, 8755, 12997, 32768, 0 } },
    { { 3505, 5304, 10086, 13814, 17684, 23370, 32768, 0 },
      { 1563, 2700, 4876, 10911, 14706, 22480, 32768, 0 } } },
  { { { 1260, 1446, 2253, 3712, 6652, 13369, 32768, 0 },
      { 401, 605, 1029, 2563, 5845, 12626, 32768, 0 } },
    { { 8609, 10612, 14624, 18714, 22614, 29024, 32768, 0 },
      { 1923, 3127, 5867, 9703, 14277, 27100, 32768, 0 } } },
  { { { 2374, 2772, 4583, 7276, 12288, 19706, 32768, 0 },
      { 497, 810, 1315, 3000, 7004, 15641, 32768, 0 } },
    { { 15050, 17126, 21410, 24886, 28156, 30726, 32768, 0 },
      { 4034, 6290, 10235, 14982, 21214, 28491, 32768, 0 } } },
  { { { 6307, 7541, 12060, 16358, 22553, 27865, 32768, 0 },
      { 1289, 2320, 3971, 7926, 14153, 24291, 32768, 0 } },
    { { 24212, 25708, 28268, 30035, 31307, 32049, 32768, 0 },
      { 8726, 12378, 19409, 26450, 30038, 32462, 32768, 0 } } }
}
```

```
Default_Eob_Pt_128_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 2 ][ 9 ] = {
  { { { 219, 482, 1140, 2091, 3680, 6028, 12586, 32768, 0 },
      { 371, 699, 1254, 4830, 9479, 12562, 17497, 32768, 0 } },
    { { 5245, 7456, 12880, 15852, 20033, 23932, 27608, 32768, 0 },
      { 2054, 3472, 5869, 14232, 18242, 20590, 26752, 32768, 0 } } },
  { { { 685, 933, 1488, 2714, 4766, 8562, 19254, 32768, 0 },
      { 217, 352, 618, 2303, 5261, 9969, 17472, 32768, 0 } },
    { { 8045, 11200, 15497, 19595, 23948, 27408, 30938, 32768, 0 },
      { 2310, 4160, 7471, 14997, 17931, 20768, 30240, 32768, 0 } } },
  { { { 1366, 1738, 2527, 5016, 9355, 15797, 24643, 32768, 0 },
      { 354, 558, 944, 2760, 7287, 14037, 21779, 32768, 0 } },
    { { 13627, 16246, 20173, 24429, 27948, 30415, 31863, 32768, 0 },
      { 6275, 9889, 14769, 23164, 27988, 30493, 32272, 32768, 0 } } },
  { { { 3472, 4885, 7489, 12481, 18517, 24536, 29635, 32768, 0 },
      { 886, 1731, 3271, 8469, 15569, 22126, 28383, 32768, 0 } },
    { { 24313, 26062, 28385, 30107, 31217, 31898, 32345, 32768, 0 },
      { 9165, 13282, 21150, 30286, 31894, 32571, 32712, 32768, 0 } } }
}
```

```
Default_Eob_Pt_256_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 2 ][ 10 ] = {
  { { { 310, 584, 1887, 3589, 6168, 8611, 11352, 15652, 32768, 0 },
      { 998, 1850, 2998, 5604, 17341, 19888, 22899, 25583, 32768, 0 } },
    { { 2520, 3240, 5952, 8870, 12577, 17558, 19954, 24168, 32768, 0 },
      { 2203, 4130, 7435, 10739, 20652, 23681, 25609, 27261, 32768, 0 } } },
  { { { 1448, 2109, 4151, 6263, 9329, 13260, 17944, 23300, 32768, 0 },
      { 399, 1019, 1749, 3038, 10444, 15546, 22739, 27294, 32768, 0 } },
    { { 6402, 8148, 12623, 15072, 18728, 22847, 26447, 29377, 32768, 0 },
      { 1674, 3252, 5734, 10159, 22397, 23802, 24821, 30940, 32768, 0 } } },
  { { { 3089, 3920, 6038, 9460, 14266, 19881, 25766, 29176, 32768, 0 },
      { 1084, 2358, 3488, 5122, 11483, 18103, 26023, 29799, 32768, 0 } },
    { { 11514, 13794, 17480, 20754, 24361, 27378, 29492, 31277, 32768, 0 },
      { 6571, 9610, 15516, 21826, 29092, 30829, 31842, 32708, 32768, 0 } } },
  { { { 5348, 7113, 11820, 15924, 22106, 26777, 30334, 31757, 32768, 0 },
      { 2453, 4474, 6307, 8777, 16474, 22975, 29000, 31547, 32768, 0 } },
    { { 23110, 24597, 27140, 28894, 30167, 30927, 31392, 32094, 32768, 0 },
      { 9998, 17661, 25178, 28097, 31308, 32038, 32403, 32695, 32768, 0 } } }
}
```

```
Default_Eob_Pt_512_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 11 ] = {
  { { 641, 983, 3707, 5430, 10234, 14958, 18788, 23412, 26061, 32768, 0 },
    { 5095, 6446, 9996, 13354, 16017, 17986, 20919, 26129, 29140, 32768, 0 } },
  { { 1230, 2278, 5035, 7776, 11871, 15346, 19590, 24584, 28749, 32768, 0 },
    { 7265, 9979, 15819, 19250, 21780, 23846, 26478, 28396, 31811, 32768, 0 } },
  { { 2624, 3936, 6480, 9686, 13979, 17726, 23267, 28410, 31078, 32768, 0 },
    { 12015, 14769, 19588, 22052, 24222, 25812, 27300, 29219, 32114, 32768, 0 } },
  { { 5927, 7809, 10923, 14597, 19439, 24135, 28456, 31142, 32060, 32768, 0 },
    { 21093, 23043, 25742, 27658, 29097, 29716, 30073, 30820, 31956, 32768, 0 } }
}
```

```
Default_Eob_Pt_1024_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ 12 ] = {
  { { 393, 421, 751, 1623, 3160, 6352, 13345, 18047, 22571, 25830, 32768, 0 },
    { 1865, 1988, 2930, 4242, 10533, 16538, 21354, 27255, 28546, 31784, 32768, 0 } },
  { { 696, 948, 3145, 5702, 9706, 13217, 17851, 21856, 25692, 28034, 32768, 0 },
    { 2672, 3591, 9330, 17084, 22725, 24284, 26527, 28027, 28377, 30876, 32768, 0 } },
  { { 2784, 3831, 7041, 10521, 14847, 18844, 23155, 26682, 29229, 31045, 32768, 0 },
    { 9577, 12466, 17739, 20750, 22061, 23215, 24601, 25483, 25843, 32056, 32768, 0 } },
  { { 6698, 8334, 11961, 15762, 20186, 23862, 27434, 29326, 31082, 32050, 32768, 0 },
    { 20569, 22426, 25569, 26859, 28053, 28913, 29486, 29724, 29807, 32570, 32768, 0 } }
}
```

```
Default_Eob_Extra_Cdf[ COEFF_CDF_Q_CTXS ][ TX_SIZES ][ PLANE_TYPES ][ EOB_COEF_CONTEXTS ][ 3 ] = {
  { { { { 16961, 32768, 0 }, { 17223, 32768, 0 }, { 7621, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 19069, 32768, 0 }, { 22525, 32768, 0 }, { 13377, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 20401, 32768, 0 }, { 17025, 32768, 0 }, { 12845, 32768, 0 },
        { 12873, 32768, 0 }, { 14094, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 20681, 32768, 0 }, { 20701, 32768, 0 }, { 15250, 32768, 0 },
        { 15017, 32768, 0 }, { 14928, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 23905, 32768, 0 }, { 17194, 32768, 0 }, { 16170, 32768, 0 },
        { 17695, 32768, 0 }, { 13826, 32768, 0 }, { 15810, 32768, 0 },
        { 12036, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 23959, 32768, 0 }, { 20799, 32768, 0 }, { 19021, 32768, 0 },
        { 16203, 32768, 0 }, { 17886, 32768, 0 }, { 14144, 32768, 0 },
        { 12010, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 27399, 32768, 0 }, { 16327, 32768, 0 }, { 18071, 32768, 0 },
        { 19584, 32768, 0 }, { 20721, 32768, 0 }, { 18432, 32768, 0 },
        { 19560, 32768, 0 }, { 10150, 32768, 0 }, { 8805, 32768, 0 }
      },
      { { 24932, 32768, 0 }, { 20833, 32768, 0 }, { 12027, 32768, 0 },
        { 16670, 32768, 0 }, { 19914, 32768, 0 }, { 15106, 32768, 0 },
        { 17662, 32768, 0 }, { 13783, 32768, 0 }, { 28756, 32768, 0 }
      } },
    { { { 23406, 32768, 0 }, { 21845, 32768, 0 }, { 18432, 32768, 0 },
        { 16384, 32768, 0 }, { 17096, 32768, 0 }, { 12561, 32768, 0 },
        { 17320, 32768, 0 }, { 22395, 32768, 0 }, { 21370, 32768, 0 }
      },
      { { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } } },
  { { { { 17471, 32768, 0 }, { 20223, 32768, 0 }, { 11357, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 20335, 32768, 0 }, { 21667, 32768, 0 }, { 14818, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 20430, 32768, 0 }, { 20662, 32768, 0 }, { 15367, 32768, 0 },
```

```
        { 16970, 32768, 0 }, { 14657, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 22117, 32768, 0 }, { 22028, 32768, 0 }, { 18650, 32768, 0 },
        { 16042, 32768, 0 }, { 15885, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 22409, 32768, 0 }, { 21012, 32768, 0 }, { 15650, 32768, 0 },
        { 17395, 32768, 0 }, { 15469, 32768, 0 }, { 20205, 32768, 0 },
        { 19511, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 24220, 32768, 0 }, { 22480, 32768, 0 }, { 17737, 32768, 0 },
        { 18916, 32768, 0 }, { 19268, 32768, 0 }, { 18412, 32768, 0 },
        { 18844, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 25991, 32768, 0 }, { 20314, 32768, 0 }, { 17731, 32768, 0 },
        { 19678, 32768, 0 }, { 18649, 32768, 0 }, { 17307, 32768, 0 },
        { 21798, 32768, 0 }, { 17549, 32768, 0 }, { 15630, 32768, 0 }
      },
      { { 26585, 32768, 0 }, { 21469, 32768, 0 }, { 20432, 32768, 0 },
        { 17735, 32768, 0 }, { 19280, 32768, 0 }, { 15235, 32768, 0 },
        { 20297, 32768, 0 }, { 22471, 32768, 0 }, { 28997, 32768, 0 }
      } },
    { { { 26605, 32768, 0 }, { 11304, 32768, 0 }, { 16726, 32768, 0 },
        { 16560, 32768, 0 }, { 20866, 32768, 0 }, { 23524, 32768, 0 },
        { 19878, 32768, 0 }, { 13469, 32768, 0 }, { 23084, 32768, 0 }
      },
      { { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } } },
  { { { { 18983, 32768, 0 }, { 20512, 32768, 0 }, { 14885, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 20090, 32768, 0 }, { 19444, 32768, 0 }, { 17286, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 19139, 32768, 0 }, { 21487, 32768, 0 }, { 18959, 32768, 0 },
        { 20910, 32768, 0 }, { 19089, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 20536, 32768, 0 }, { 20664, 32768, 0 }, { 20625, 32768, 0 },
        { 19123, 32768, 0 }, { 14862, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 19833, 32768, 0 }, { 21502, 32768, 0 }, { 17485, 32768, 0 },
        { 20267, 32768, 0 }, { 18353, 32768, 0 }, { 23329, 32768, 0 },
        { 21478, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
```

```
      },
      { { 22041, 32768, 0 }, { 23434, 32768, 0 }, { 20001, 32768, 0 },
        { 20554, 32768, 0 }, { 20951, 32768, 0 }, { 20145, 32768, 0 },
        { 15562, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 23312, 32768, 0 }, { 21607, 32768, 0 }, { 16526, 32768, 0 },
        { 18957, 32768, 0 }, { 18034, 32768, 0 }, { 18934, 32768, 0 },
        { 24247, 32768, 0 }, { 16921, 32768, 0 }, { 17080, 32768, 0 }
      },
      { { 26579, 32768, 0 }, { 24910, 32768, 0 }, { 18637, 32768, 0 },
        { 19800, 32768, 0 }, { 20388, 32768, 0 }, { 9887, 32768, 0 },
        { 15642, 32768, 0 }, { 30198, 32768, 0 }, { 24721, 32768, 0 }
      } },
    { { { 26998, 32768, 0 }, { 16737, 32768, 0 }, { 17838, 32768, 0 },
        { 18922, 32768, 0 }, { 19515, 32768, 0 }, { 18636, 32768, 0 },
        { 17333, 32768, 0 }, { 15776, 32768, 0 }, { 22658, 32768, 0 }
      },
      { { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } } },
  { { { { 20177, 32768, 0 }, { 20789, 32768, 0 }, { 20262, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 21416, 32768, 0 }, { 20855, 32768, 0 }, { 23410, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 20238, 32768, 0 }, { 21057, 32768, 0 }, { 19159, 32768, 0 },
        { 22337, 32768, 0 }, { 20159, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 20125, 32768, 0 }, { 20559, 32768, 0 }, { 21707, 32768, 0 },
        { 22296, 32768, 0 }, { 17333, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 19941, 32768, 0 }, { 20527, 32768, 0 }, { 21470, 32768, 0 },
        { 22487, 32768, 0 }, { 19558, 32768, 0 }, { 22354, 32768, 0 },
        { 20331, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      },
      { { 22752, 32768, 0 }, { 25006, 32768, 0 }, { 22075, 32768, 0 },
        { 21576, 32768, 0 }, { 17740, 32768, 0 }, { 21690, 32768, 0 },
        { 19211, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } },
    { { { 21442, 32768, 0 }, { 22358, 32768, 0 }, { 18503, 32768, 0 },
        { 20291, 32768, 0 }, { 19945, 32768, 0 }, { 21294, 32768, 0 },
        { 21178, 32768, 0 }, { 19400, 32768, 0 }, { 10556, 32768, 0 }
      },
      { { 24648, 32768, 0 }, { 24949, 32768, 0 }, { 20708, 32768, 0 },
```

```
        { 23905, 32768, 0 }, { 20501, 32768, 0 }, { 9558, 32768, 0 },
        { 9423, 32768, 0 },  { 30365, 32768, 0 }, { 19253, 32768, 0 }
      } },
    { { { 26064, 32768, 0 }, { 22098, 32768, 0 }, { 19613, 32768, 0 },
        { 20525, 32768, 0 }, { 17595, 32768, 0 }, { 16618, 32768, 0 },
        { 20497, 32768, 0 }, { 18989, 32768, 0 }, { 15513, 32768, 0 }
      },
      { { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 },
        { 16384, 32768, 0 }, { 16384, 32768, 0 }, { 16384, 32768, 0 }
      } } }
}
```

```
Default_Dc_Sign_Cdf[ COEFF_CDF_Q_CTXS ][ PLANE_TYPES ][ DC_SIGN_CONTEXTS ][ 3 ] = {
  { {
      { 128 * 125, 32768, 0 },
      { 128 * 102, 32768, 0 },
      { 128 * 147, 32768, 0 },
    },
    {
      { 128 * 119, 32768, 0 },
      { 128 * 101, 32768, 0 },
      { 128 * 135, 32768, 0 },
    } },
  { {
      { 128 * 125, 32768, 0 },
      { 128 * 102, 32768, 0 },
      { 128 * 147, 32768, 0 },
    },
    {
      { 128 * 119, 32768, 0 },
      { 128 * 101, 32768, 0 },
      { 128 * 135, 32768, 0 },
    } },
  { {
      { 128 * 125, 32768, 0 },
      { 128 * 102, 32768, 0 },
      { 128 * 147, 32768, 0 },
    },
    {
      { 128 * 119, 32768, 0 },
      { 128 * 101, 32768, 0 },
      { 128 * 135, 32768, 0 },
    } },
  { {
      { 128 * 125, 32768, 0 },
      { 128 * 102, 32768, 0 },
      { 128 * 147, 32768, 0 },
    },
    {
      { 128 * 119, 32768, 0 },
      { 128 * 101, 32768, 0 },
      { 128 * 135, 32768, 0 },
    } }
}
```

```
Default_Coeff_Base_Eob_Cdf[ COEFF_CDF_Q_CTXS ][ TX_SIZES ][ PLANE_TYPES ][ SIG_COEF_CONTEXTS_EOB ][ 4
] = {
  { { { { 17837, 29055, 32768, 0 },
        { 29600, 31446, 32768, 0 },
        { 30844, 31878, 32768, 0 },
        { 24926, 28948, 32768, 0 } },
      { { 21365, 30026, 32768, 0 },
        { 30512, 32423, 32768, 0 },
        { 31658, 32621, 32768, 0 },
        { 29630, 31881, 32768, 0 } } },
    { { { 5717, 26477, 32768, 0 },
        { 30491, 31703, 32768, 0 },
        { 31550, 32158, 32768, 0 },
        { 29648, 31491, 32768, 0 } },
      { { 12608, 27820, 32768, 0 },
        { 30680, 32225, 32768, 0 },
        { 30809, 32335, 32768, 0 },
        { 31299, 32423, 32768, 0 } } },
    { { { 1786, 12612, 32768, 0 },
        { 30663, 31625, 32768, 0 },
        { 32339, 32468, 32768, 0 },
        { 31148, 31833, 32768, 0 } },
      { { 18857, 23865, 32768, 0 },
        { 31428, 32428, 32768, 0 },
        { 31744, 32373, 32768, 0 },
        { 31775, 32526, 32768, 0 } } },
    { { { 1787, 2532, 32768, 0 },
        { 30832, 31662, 32768, 0 },
        { 31824, 32682, 32768, 0 },
        { 32133, 32569, 32768, 0 } },
      { { 13751, 22235, 32768, 0 },
        { 32089, 32409, 32768, 0 },
        { 27084, 27920, 32768, 0 },
        { 29291, 32594, 32768, 0 } } },
    { { { 1725, 3449, 32768, 0 },
        { 31102, 31935, 32768, 0 },
        { 32457, 32613, 32768, 0 },
        { 32412, 32649, 32768, 0 } },
      { { 10923, 21845, 32768, 0 },
        { 10923, 21845, 32768, 0 },
        { 10923, 21845, 32768, 0 },
        { 10923, 21845, 32768, 0 } } } },
  { { { { 17560, 29888, 32768, 0 },
        { 29671, 31549, 32768, 0 },
        { 31007, 32056, 32768, 0 },
        { 27286, 30006, 32768, 0 } },
      { { 26594, 31212, 32768, 0 },
        { 31208, 32582, 32768, 0 },
        { 31835, 32637, 32768, 0 },
        { 30595, 32206, 32768, 0 } } },
```

```
    { { { { 15239, 29932, 32768, 0 },
        { 31315, 32095, 32768, 0 },
        { 32130, 32434, 32768, 0 },
        { 30864, 31996, 32768, 0 } },
      { { 26279, 30968, 32768, 0 },
        { 31142, 32495, 32768, 0 },
        { 31713, 32540, 32768, 0 },
        { 31929, 32594, 32768, 0 } } },
    { { { 2644, 25198, 32768, 0 },
        { 32038, 32451, 32768, 0 },
        { 32639, 32695, 32768, 0 },
        { 32166, 32518, 32768, 0 } },
      { { 17187, 27668, 32768, 0 },
        { 31714, 32550, 32768, 0 },
        { 32283, 32678, 32768, 0 },
        { 31930, 32563, 32768, 0 } } },
    { { { 1044, 2257, 32768, 0 },
        { 30755, 31923, 32768, 0 },
        { 32208, 32693, 32768, 0 },
        { 32244, 32615, 32768, 0 } },
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}
```

9.5. Quantizer matrix tables

9.5.1. General

There are three fundamental quantizer matrix sizes: 32x32, 32x16 and 16x32. One set of these three sizes of matrix is defined for each quantizer level (except level 15) and for each plane type (luma or chroma). All other quantizer matrix sizes are subsampled from these. All matrix sizes, including derived ones, are defined in the table Quantizer_Matrix in section 9.5.3. For informative purposes the subsampling process is defined in section 9.5.2.

9.5.2. Derivation process (Informative)

> **Note:** This subsection is provided for information only regarding the derivation of Quantizer_Matrix, and is not required to correctly decode AV1 bitstreams (and therefore not invoked by this specification). All required tables are defined in section 9.5.3.

The input to this process is a transform size txSz.

The output is an array derivedMatrix of size Tx_Width[txSz] * Tx_Height[txSz], containing the derived matrix.

- The array fundamentalMatrix is derived as follows.
    - If Tx_Width[txSz] is equal to Tx_Height[txSz], fundamentalMatrix is set equal to the 32x32 fundamental matrix for the quantizer level and plane type in question.
    - If Tx_Width[txSz] is greater than Tx_Height[txSz], fundamentalMatrix is set equal to the 32x16 fundamental matrix for the quantizer level and plane type in question.
    - Otherwise (Tx_Width[txSz] is less than Tx_Height[txSz]), fundamentalMatrix is set equal to the 16x32 fundamental matrix for the quantizer level and plane type in question.
- The variable fW is set equal to the width of fundamentalMatrix.
- The variable fH is set equal to the height of fundamentalMatrix.
- The variable ratioW is set equal to fW / Tx_Width[txSz].
- The variable ratioH is set equal to fH / Tx_Height[txSz].
- The variable phaseW is set equal to (ratioW + 1) / 2 - 1.
- The variable phaseH is set equal to (ratioH + 1) / 2 - 1.
- The array element derivedMatrix[i * Tx_Width[txSz] + j] is set equal to fundamentalMatrix[(ratioH * i + phaseH) * fW + ratioW * j + phaseW] for i=0..Tx_Height[txSz] - 1, for j=0..Tx_Width[txSz] - 1.

9.5.3. Tables

```
Qm_Offset[ TX_SIZES_ALL ] = { 0, 16, 80, 336, 336, 1360, 1392, 1424, 1552, 1680, 2192,
                              336, 336, 2704, 2768, 2832, 3088, 1680, 2192 }
```

```
Quantizer_Matrix[ 15 ][ 2 ][ QM_TOTAL_SIZE ] = {
  {
      { /* Luma */
        /* Size 4x4 */
        32, 43, 73, 97, 43, 67, 94, 110, 73, 94, 137, 150, 97, 110, 150, 200,
        /* Size 8x8 */
        32, 32, 38, 51, 68, 84, 95, 109, 32, 35, 40, 49, 63, 76, 89, 102, 38,
        40, 54, 65, 78, 91, 98, 106, 51, 49, 65, 82, 97, 111, 113, 121, 68, 63,
        78, 97, 117, 134, 138, 142, 84, 76, 91, 111, 134, 152, 159, 168, 95, 89,
        98, 113, 138, 159, 183, 199, 109, 102, 106, 121, 142, 168, 199, 220,
        /* Size 16x16 */
        32, 31, 31, 34, 36, 44, 48, 59, 65, 80, 83, 91, 97, 104, 111, 119, 31,
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        67, 75, 79, 90, 92, 95, 100, 102, 109, 112, 48, 44, 45, 51, 57, 67, 71,
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        231,
        /* Size 32x32 */
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        109, 34, 34, 33, 34, 35, 37, 39, 41, 42, 45, 47, 49, 51, 54, 58, 60, 63,
        68, 74, 75, 76, 80, 81, 82, 84, 87, 90, 93, 97, 101, 105, 110, 35, 34,
        34, 35, 36, 37, 41, 43, 45, 47, 50, 52, 53, 57, 61, 63, 65, 70, 76, 77,
        79, 82, 84, 86, 89, 91, 92, 93, 96, 100, 103, 107, 36, 35, 34, 35, 36,
        38, 42, 45, 48, 50, 54, 55, 57, 60, 64, 66, 68, 73, 79, 80, 81, 85, 88,
        90, 91, 93, 96, 99, 102, 103, 105, 107, 39, 38, 37, 38, 39, 40, 45, 47,
        50, 54, 58, 59, 61, 65, 69, 71, 73, 78, 84, 85, 86, 91, 92, 92, 95, 98,
        100, 101, 103, 106, 110, 114, 44, 42, 41, 41, 42, 42, 47, 50, 54, 58,
        63, 65, 67, 71, 75, 77, 79, 84, 90, 91, 92, 95, 95, 97, 100, 101, 102,
        105, 109, 111, 112, 114, 46, 44, 42, 43, 44, 44, 49, 52, 55, 59, 65, 67,
```

```
69, 74, 78, 80, 82, 87, 93, 94, 95, 98, 100, 103, 102, 105, 108, 110,
111, 113, 117, 121, 48, 46, 44, 45, 45, 46, 51, 53, 57, 61, 67, 69, 71,
76, 80, 83, 85, 90, 96, 97, 99, 103, 107, 105, 108, 111, 111, 113, 117,
119, 120, 122, 54, 51, 49, 49, 50, 49, 54, 57, 60, 65, 71, 74, 76, 82,
87, 89, 92, 97, 104, 105, 106, 111, 110, 111, 114, 113, 116, 120, 120,
121, 125, 130, 59, 56, 54, 54, 54, 53, 58, 61, 64, 69, 75, 78, 80, 87,
92, 95, 98, 103, 110, 111, 113, 115, 115, 119, 116, 120, 122, 122, 125,
129, 130, 130, 62, 59, 56, 56, 56, 55, 60, 63, 66, 71, 77, 80, 83, 89,
95, 98, 101, 107, 114, 115, 117, 119, 123, 121, 125, 126, 125, 129, 131,
131, 135, 140, 65, 62, 59, 59, 59, 58, 63, 65, 68, 73, 79, 82, 85, 92,
98, 101, 105, 111, 118, 119, 121, 126, 127, 128, 130, 130, 134, 133,
135, 140, 140, 140, 71, 68, 65, 64, 64, 63, 68, 70, 73, 78, 84, 87, 90,
97, 103, 107, 111, 117, 125, 126, 128, 134, 132, 136, 133, 138, 137,
140, 143, 142, 145, 150, 80, 76, 72, 72, 71, 69, 74, 76, 79, 84, 90, 93,
96, 104, 110, 114, 118, 125, 134, 135, 137, 139, 140, 139, 143, 142,
144, 146, 146, 151, 152, 151, 81, 77, 73, 73, 72, 70, 75, 77, 80, 85,
91, 94, 97, 105, 111, 115, 119, 126, 135, 137, 138, 144, 147, 146, 148,
149, 151, 150, 156, 155, 157, 163, 83, 78, 75, 74, 74, 72, 76, 79, 81,
86, 92, 95, 99, 106, 113, 117, 121, 128, 137, 138, 140, 147, 151, 156,
152, 157, 155, 161, 158, 162, 165, 164, 88, 84, 80, 79, 78, 76, 80, 82,
85, 91, 95, 98, 103, 111, 115, 119, 126, 134, 139, 144, 147, 152, 154,
158, 163, 159, 165, 163, 168, 168, 169, 176, 91, 86, 83, 82, 81, 79, 81,
84, 88, 92, 95, 100, 107, 110, 115, 123, 127, 132, 140, 147, 151, 154,
159, 161, 166, 171, 169, 173, 173, 176, 179, 177, 94, 89, 86, 85, 84,
82, 82, 86, 90, 92, 97, 103, 105, 111, 119, 121, 128, 136, 139, 146,
156, 158, 161, 166, 168, 174, 179, 178, 180, 183, 183, 190, 97, 92, 90,
88, 86, 85, 84, 89, 91, 95, 100, 102, 108, 114, 116, 125, 130, 133, 143,
148, 152, 163, 166, 168, 174, 176, 182, 187, 189, 188, 193, 191, 101,
95, 93, 91, 89, 89, 87, 91, 93, 98, 101, 105, 111, 113, 120, 126, 130,
138, 142, 149, 157, 159, 171, 174, 176, 183, 184, 191, 195, 199, 197,
204, 104, 99, 97, 94, 93, 93, 90, 92, 96, 100, 102, 108, 111, 116, 122,
125, 134, 137, 144, 151, 155, 165, 169, 179, 182, 184, 191, 193, 200,
204, 210, 206, 107, 102, 101, 97, 96, 96, 93, 93, 99, 101, 105, 110,
113, 120, 122, 129, 133, 140, 146, 150, 161, 163, 173, 178, 187, 191,
193, 200, 202, 210, 214, 222, 111, 105, 104, 101, 100, 99, 97, 96, 102,
103, 109, 111, 117, 120, 125, 131, 135, 143, 146, 156, 158, 168, 173,
180, 189, 195, 200, 202, 210, 212, 220, 224, 115, 109, 108, 104, 104,
102, 101, 100, 103, 106, 111, 113, 119, 121, 129, 131, 140, 142, 151,
155, 162, 168, 176, 183, 188, 199, 204, 210, 212, 220, 222, 230, 119,
113, 112, 107, 107, 106, 105, 103, 105, 110, 112, 117, 120, 125, 130,
135, 140, 145, 152, 157, 165, 169, 179, 183, 193, 197, 210, 214, 220,
222, 231, 232, 123, 116, 116, 111, 111, 109, 110, 107, 107, 114, 114,
121, 122, 130, 130, 140, 140, 150, 151, 163, 164, 176, 177, 190, 191,
204, 206, 222, 224, 230, 232, 242,
/* Size 4x8 */
32, 42, 75, 91, 33, 42, 69, 86, 37, 58, 84, 91, 49, 71, 103, 110, 65,
84, 125, 128, 80, 97, 142, 152, 91, 100, 145, 178, 104, 112, 146, 190,
/* Size 8x4 */
32, 33, 37, 49, 65, 80, 91, 104, 42, 42, 58, 71, 84, 97, 100, 112, 75,
69, 84, 103, 125, 142, 145, 146, 91, 86, 91, 110, 128, 152, 178, 190,
```

```
/* Size 8x16 */
32, 32, 36, 53, 65, 87, 93, 99, 31, 33, 34, 49, 59, 78, 86, 93, 32, 34,
36, 50, 59, 77, 82, 89, 34, 37, 42, 54, 63, 79, 80, 88, 36, 38, 48, 60,
68, 84, 86, 90, 44, 43, 53, 71, 79, 95, 94, 97, 48, 46, 56, 76, 85, 102,
105, 105, 58, 54, 63, 87, 98, 116, 112, 115, 65, 58, 68, 92, 105, 124,
122, 124, 79, 70, 79, 104, 118, 141, 135, 135, 82, 72, 81, 106, 121,
144, 149, 146, 91, 80, 88, 106, 130, 148, 162, 159, 97, 86, 94, 107,
128, 157, 167, 171, 103, 93, 98, 114, 131, 150, 174, 186, 110, 100, 101,
117, 138, 161, 183, 193, 118, 107, 105, 118, 136, 157, 182, 203,
/* Size 16x8 */
32, 31, 32, 34, 36, 44, 48, 58, 65, 79, 82, 91, 97, 103, 110, 118, 32,
33, 34, 37, 38, 43, 46, 54, 58, 70, 72, 80, 86, 93, 100, 107, 36, 34,
36, 42, 48, 53, 56, 63, 68, 79, 81, 88, 94, 98, 101, 105, 53, 49, 50,
54, 60, 71, 76, 87, 92, 104, 106, 106, 107, 114, 117, 118, 65, 59, 59,
63, 68, 79, 85, 98, 105, 118, 121, 130, 128, 131, 138, 136, 87, 78, 77,
79, 84, 95, 102, 116, 124, 141, 144, 148, 157, 150, 161, 157, 93, 86,
82, 80, 86, 94, 105, 112, 122, 135, 149, 162, 167, 174, 183, 182, 99,
93, 89, 88, 90, 97, 105, 115, 124, 135, 146, 159, 171, 186, 193, 203,
/* Size 16x32 */
32, 31, 32, 34, 36, 44, 53, 59, 65, 79, 87, 90, 93, 96, 99, 102, 31, 32,
32, 34, 35, 42, 51, 56, 62, 75, 82, 85, 88, 91, 94, 97, 31, 32, 33, 33,
34, 41, 49, 54, 59, 72, 78, 82, 86, 90, 93, 97, 31, 32, 33, 34, 35, 41,
49, 54, 59, 71, 78, 81, 84, 87, 90, 93, 32, 32, 34, 35, 36, 42, 50, 54,
59, 71, 77, 80, 82, 86, 89, 93, 32, 33, 35, 37, 38, 42, 49, 53, 58, 69,
75, 78, 82, 86, 89, 92, 34, 34, 37, 39, 42, 48, 54, 58, 63, 73, 79, 78,
80, 83, 88, 92, 35, 34, 37, 41, 45, 50, 57, 61, 65, 76, 82, 83, 84, 84,
87, 90, 36, 34, 38, 43, 48, 54, 60, 64, 68, 78, 84, 87, 86, 89, 90, 90,
39, 37, 40, 45, 50, 58, 65, 69, 73, 84, 89, 89, 91, 91, 93, 96, 44, 41,
43, 48, 53, 63, 71, 75, 79, 90, 95, 93, 94, 95, 97, 97, 46, 43, 44, 49,
55, 65, 73, 78, 82, 93, 98, 100, 98, 100, 99, 103, 48, 45, 46, 51, 56,
67, 76, 80, 85, 96, 102, 102, 105, 102, 105, 104, 53, 49, 50, 54, 60,
71, 82, 87, 92, 103, 109, 107, 107, 110, 107, 111, 58, 54, 54, 58, 63,
75, 87, 92, 98, 110, 116, 115, 112, 111, 115, 112, 61, 57, 56, 60, 66,
77, 89, 95, 101, 114, 120, 118, 119, 118, 116, 120, 65, 60, 58, 63, 68,
79, 92, 98, 105, 118, 124, 123, 122, 123, 124, 121, 71, 65, 63, 68, 73,
84, 97, 103, 111, 125, 132, 132, 130, 128, 127, 130, 79, 72, 70, 74, 79,
90, 104, 110, 118, 133, 141, 136, 135, 135, 135, 131, 81, 74, 71, 75,
80, 91, 105, 112, 119, 135, 142, 140, 140, 138, 139, 142, 82, 75, 72,
76, 81, 92, 106, 113, 121, 136, 144, 151, 149, 149, 146, 143, 88, 80,
77, 80, 85, 97, 108, 115, 126, 142, 149, 153, 153, 152, 152, 154, 91,
83, 80, 81, 88, 100, 106, 114, 130, 142, 148, 155, 162, 160, 159, 155,
94, 85, 83, 82, 91, 100, 105, 118, 131, 137, 153, 160, 165, 167, 166,
168, 97, 88, 86, 85, 94, 100, 107, 123, 128, 140, 157, 161, 167, 173,
171, 169, 100, 91, 89, 87, 97, 100, 111, 121, 127, 145, 152, 164, 173,
178, 182, 181, 103, 94, 93, 90, 98, 101, 114, 120, 131, 144, 150, 170,
174, 180, 186, 183, 107, 97, 96, 93, 100, 104, 117, 119, 136, 142, 155,
168, 177, 187, 191, 198, 110, 101, 100, 97, 101, 108, 117, 123, 138,
141, 161, 165, 183, 188, 193, 200, 114, 104, 104, 100, 103, 112, 117,
127, 137, 146, 159, 167, 185, 190, 201, 206, 118, 108, 107, 103, 105,
115, 118, 131, 136, 151, 157, 172, 182, 197, 203, 208, 122, 111, 111,
```

```
107, 107, 119, 119, 136, 136, 156, 156, 178, 179, 203, 204, 217,
/* Size 32x16 */
32, 31, 31, 31, 32, 32, 34, 35, 36, 39, 44, 46, 48, 53, 58, 61, 65, 71,
79, 81, 82, 88, 91, 94, 97, 100, 103, 107, 110, 114, 118, 122, 31, 32,
32, 32, 32, 33, 34, 34, 34, 37, 41, 43, 45, 49, 54, 57, 60, 65, 72, 74,
75, 80, 83, 85, 88, 91, 94, 97, 101, 104, 108, 111, 32, 32, 33, 33, 34,
35, 37, 37, 38, 40, 43, 44, 46, 50, 54, 56, 58, 63, 70, 71, 72, 77, 80,
83, 86, 89, 93, 96, 100, 104, 107, 111, 34, 34, 33, 34, 35, 37, 39, 41,
43, 45, 48, 49, 51, 54, 58, 60, 63, 68, 74, 75, 76, 80, 81, 82, 85, 87,
90, 93, 97, 100, 103, 107, 36, 35, 34, 35, 36, 38, 42, 45, 48, 50, 53,
55, 56, 60, 63, 66, 68, 73, 79, 80, 81, 85, 88, 91, 94, 97, 98, 100,
101, 103, 105, 107, 44, 42, 41, 41, 42, 42, 48, 50, 54, 58, 63, 65, 67,
71, 75, 77, 79, 84, 90, 91, 92, 97, 100, 100, 100, 100, 101, 104, 108,
112, 115, 119, 53, 51, 49, 49, 50, 49, 54, 57, 60, 65, 71, 73, 76, 82,
87, 89, 92, 97, 104, 105, 106, 108, 106, 105, 107, 111, 114, 117, 117,
117, 118, 119, 59, 56, 54, 54, 54, 53, 58, 61, 64, 69, 75, 78, 80, 87,
92, 95, 98, 103, 110, 112, 113, 115, 114, 118, 123, 121, 120, 119, 123,
127, 131, 136, 65, 62, 59, 59, 59, 58, 63, 65, 68, 73, 79, 82, 85, 92,
98, 101, 105, 111, 118, 119, 121, 126, 130, 131, 128, 127, 131, 136,
138, 137, 136, 136, 79, 75, 72, 71, 71, 69, 73, 76, 78, 84, 90, 93, 96,
103, 110, 114, 118, 125, 133, 135, 136, 142, 142, 137, 140, 145, 144,
142, 141, 146, 151, 156, 87, 82, 78, 78, 77, 75, 79, 82, 84, 89, 95, 98,
102, 109, 116, 120, 124, 132, 141, 142, 144, 149, 148, 153, 157, 152,
150, 155, 161, 159, 157, 156, 90, 85, 82, 81, 80, 78, 78, 83, 87, 89,
93, 100, 102, 107, 115, 118, 123, 132, 136, 140, 151, 153, 155, 160,
161, 164, 170, 168, 165, 167, 172, 178, 93, 88, 86, 84, 82, 82, 80, 84,
86, 91, 94, 98, 105, 107, 112, 119, 122, 130, 135, 140, 149, 153, 162,
165, 167, 173, 174, 177, 183, 185, 182, 179, 96, 91, 90, 87, 86, 86, 83,
84, 89, 91, 95, 100, 102, 110, 111, 118, 123, 128, 135, 138, 149, 152,
160, 167, 173, 178, 180, 187, 188, 190, 197, 203, 99, 94, 93, 90, 89,
89, 88, 87, 90, 93, 97, 99, 105, 107, 115, 116, 124, 127, 135, 139, 146,
152, 159, 166, 171, 182, 186, 191, 193, 201, 203, 204, 102, 97, 97, 93,
93, 92, 92, 90, 90, 96, 97, 103, 104, 111, 112, 120, 121, 130, 131, 142,
143, 154, 155, 168, 169, 181, 183, 198, 200, 206, 208, 217,
/* Size 4x16 */
31, 44, 79, 96, 32, 41, 72, 90, 32, 42, 71, 86, 34, 48, 73, 83, 34, 54,
78, 89, 41, 63, 90, 95, 45, 67, 96, 102, 54, 75, 110, 111, 60, 79, 118,
123, 72, 90, 133, 135, 75, 92, 136, 149, 83, 100, 142, 160, 88, 100,
140, 173, 94, 101, 144, 180, 101, 108, 141, 188, 108, 115, 151, 197,
/* Size 16x4 */
31, 32, 32, 34, 34, 41, 45, 54, 60, 72, 75, 83, 88, 94, 101, 108, 44,
41, 42, 48, 54, 63, 67, 75, 79, 90, 92, 100, 100, 101, 108, 115, 79, 72,
71, 73, 78, 90, 96, 110, 118, 133, 136, 142, 140, 144, 141, 151, 96, 90,
86, 83, 89, 95, 102, 111, 123, 135, 149, 160, 173, 180, 188, 197,
/* Size 8x32 */
32, 32, 36, 53, 65, 87, 93, 99, 31, 32, 35, 51, 62, 82, 88, 94, 31, 33,
34, 49, 59, 78, 86, 93, 31, 33, 35, 49, 59, 78, 84, 90, 32, 34, 36, 50,
59, 77, 82, 89, 32, 35, 38, 49, 58, 75, 82, 89, 34, 37, 42, 54, 63, 79,
80, 88, 35, 37, 45, 57, 65, 82, 84, 87, 36, 38, 48, 60, 68, 84, 86, 90,
39, 40, 50, 65, 73, 89, 91, 93, 44, 43, 53, 71, 79, 95, 94, 97, 46, 44,
```

```
    55, 73, 82, 98, 98, 99, 48, 46, 56, 76, 85, 102, 105, 105, 53, 50, 60,
    82, 92, 109, 107, 107, 58, 54, 63, 87, 98, 116, 112, 115, 61, 56, 66,
    89, 101, 120, 119, 116, 65, 58, 68, 92, 105, 124, 122, 124, 71, 63, 73,
    97, 111, 132, 130, 127, 79, 70, 79, 104, 118, 141, 135, 135, 81, 71, 80,
    105, 119, 142, 140, 139, 82, 72, 81, 106, 121, 144, 149, 146, 88, 77,
    85, 108, 126, 149, 153, 152, 91, 80, 88, 106, 130, 148, 162, 159, 94,
    83, 91, 105, 131, 153, 165, 166, 97, 86, 94, 107, 128, 157, 167, 171,
    100, 89, 97, 111, 127, 152, 173, 182, 103, 93, 98, 114, 131, 150, 174,
    186, 107, 96, 100, 117, 136, 155, 177, 191, 110, 100, 101, 117, 138,
    161, 183, 193, 114, 104, 103, 117, 137, 159, 185, 201, 118, 107, 105,
    118, 136, 157, 182, 203, 122, 111, 107, 119, 136, 156, 179, 204,
    /* Size 32x8 */
    32, 31, 31, 31, 32, 32, 34, 35, 36, 39, 44, 46, 48, 53, 58, 61, 65, 71,
    79, 81, 82, 88, 91, 94, 97, 100, 103, 107, 110, 114, 118, 122, 32, 32,
    33, 33, 34, 35, 37, 37, 38, 40, 43, 44, 46, 50, 54, 56, 58, 63, 70, 71,
    72, 77, 80, 83, 86, 89, 93, 96, 100, 104, 107, 111, 36, 35, 34, 35, 36,
    38, 42, 45, 48, 50, 53, 55, 56, 60, 63, 66, 68, 73, 79, 80, 81, 85, 88,
    91, 94, 97, 98, 100, 101, 103, 105, 107, 53, 51, 49, 49, 50, 49, 54, 57,
    60, 65, 71, 73, 76, 82, 87, 89, 92, 97, 104, 105, 106, 108, 106, 105,
    107, 111, 114, 117, 117, 117, 118, 119, 65, 62, 59, 59, 59, 58, 63, 65,
    68, 73, 79, 82, 85, 92, 98, 101, 105, 111, 118, 119, 121, 126, 130, 131,
    128, 127, 131, 136, 138, 137, 136, 136, 87, 82, 78, 78, 77, 75, 79, 82,
    84, 89, 95, 98, 102, 109, 116, 120, 124, 132, 141, 142, 144, 149, 148,
    153, 157, 152, 150, 155, 161, 159, 157, 156, 93, 88, 86, 84, 82, 82, 80,
    84, 86, 91, 94, 98, 105, 107, 112, 119, 122, 130, 135, 140, 149, 153,
    162, 165, 167, 173, 174, 177, 183, 185, 182, 179, 99, 94, 93, 90, 89,
    89, 88, 87, 90, 93, 97, 99, 105, 107, 115, 116, 124, 127, 135, 139, 146,
    152, 159, 166, 171, 182, 186, 191, 193, 201, 203, 204 },
  { /* Chroma */
    /* Size 4x4 */
    35, 46, 57, 66, 46, 60, 69, 71, 57, 69, 90, 90, 66, 71, 90, 109,
    /* Size 8x8 */
    31, 38, 47, 50, 57, 63, 67, 71, 38, 47, 46, 47, 52, 57, 62, 67, 47, 46,
    54, 57, 61, 66, 67, 68, 50, 47, 57, 66, 72, 77, 75, 75, 57, 52, 61, 72,
    82, 88, 86, 84, 63, 57, 66, 77, 88, 96, 95, 95, 67, 62, 67, 75, 86, 95,
    104, 107, 71, 67, 68, 75, 84, 95, 107, 113,
    /* Size 16x16 */
    32, 30, 33, 41, 49, 49, 50, 54, 57, 63, 65, 68, 70, 72, 74, 76, 30, 32,
    35, 42, 46, 45, 46, 49, 52, 57, 58, 62, 64, 67, 70, 72, 33, 35, 39, 45,
    47, 45, 46, 49, 51, 56, 57, 60, 62, 64, 66, 69, 41, 42, 45, 48, 50, 49,
    50, 52, 53, 57, 58, 59, 60, 61, 64, 67, 49, 46, 47, 50, 53, 53, 54, 55,
    56, 60, 61, 64, 64, 65, 66, 66, 49, 45, 45, 49, 53, 58, 60, 62, 63, 67,
    68, 67, 69, 68, 70, 70, 50, 46, 46, 50, 54, 60, 61, 65, 67, 71, 71, 74,
    73, 73, 74, 74, 54, 49, 49, 52, 55, 62, 65, 71, 73, 78, 79, 78, 77, 78,
    78, 78, 57, 52, 51, 53, 56, 63, 67, 73, 76, 82, 83, 84, 84, 84, 82, 83,
    63, 57, 56, 57, 60, 67, 71, 78, 82, 89, 90, 90, 89, 88, 87, 88, 65, 58,
    57, 58, 61, 68, 71, 79, 83, 90, 91, 94, 93, 93, 92, 93, 68, 62, 60, 59,
    64, 67, 74, 78, 84, 90, 94, 98, 99, 98, 98, 98, 70, 64, 62, 60, 64, 69,
    73, 77, 84, 89, 93, 99, 102, 103, 104, 104, 72, 67, 64, 61, 65, 68, 73,
    78, 84, 88, 93, 98, 103, 106, 108, 109, 74, 70, 66, 64, 66, 70, 74, 78,
```

```
82, 87, 92, 98, 104, 108, 111, 112, 76, 72, 69, 67, 66, 70, 74, 78, 83,
88, 93, 98, 104, 109, 112, 116,
/* Size 32x32 */
32, 31, 30, 32, 33, 36, 41, 45, 49, 48, 49, 50, 50, 52, 54, 56, 57, 60,
63, 64, 65, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 78, 31, 31, 31, 33,
34, 38, 42, 45, 47, 47, 47, 47, 48, 50, 52, 53, 54, 57, 60, 61, 61, 63,
64, 65, 66, 67, 68, 69, 70, 71, 72, 74, 30, 31, 32, 33, 35, 40, 42, 44,
46, 45, 45, 45, 46, 47, 49, 51, 52, 54, 57, 58, 58, 61, 62, 63, 64, 66,
67, 68, 70, 71, 72, 74, 32, 33, 33, 35, 37, 41, 43, 45, 47, 46, 45, 46,
46, 47, 49, 50, 51, 54, 57, 57, 58, 60, 61, 62, 63, 64, 65, 66, 67, 68,
69, 70, 33, 34, 35, 37, 39, 43, 45, 46, 47, 46, 45, 46, 46, 47, 49, 50,
51, 53, 56, 57, 57, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 36, 38,
40, 41, 43, 47, 47, 47, 48, 46, 45, 46, 46, 47, 48, 49, 50, 52, 54, 55,
55, 57, 58, 59, 61, 62, 64, 65, 66, 67, 68, 69, 41, 42, 42, 43, 45, 47,
48, 49, 50, 49, 49, 49, 50, 50, 52, 52, 53, 55, 57, 58, 58, 60, 59, 59,
60, 61, 61, 63, 64, 66, 67, 69, 45, 45, 44, 45, 46, 47, 49, 50, 51, 51,
51, 51, 52, 52, 53, 54, 55, 57, 59, 59, 60, 61, 61, 62, 63, 63, 63, 63,
63, 64, 65, 66, 49, 47, 46, 47, 47, 48, 50, 51, 53, 53, 53, 54, 54, 54,
55, 56, 56, 58, 60, 61, 61, 63, 64, 64, 64, 64, 65, 66, 66, 66, 66, 66,
48, 47, 45, 46, 46, 46, 49, 51, 53, 54, 55, 56, 56, 57, 58, 59, 60, 61,
63, 64, 64, 66, 66, 65, 66, 67, 67, 67, 67, 68, 69, 70, 49, 47, 45, 45,
45, 45, 49, 51, 53, 55, 58, 59, 60, 61, 62, 63, 63, 65, 67, 67, 68, 69,
67, 68, 69, 68, 68, 69, 70, 70, 70, 70, 50, 47, 45, 46, 46, 46, 49, 51,
54, 56, 59, 60, 60, 62, 64, 64, 65, 67, 69, 69, 70, 70, 71, 71, 70, 70,
71, 71, 71, 71, 72, 74, 50, 48, 46, 46, 46, 46, 50, 52, 54, 56, 60, 60,
61, 63, 65, 66, 67, 68, 71, 71, 71, 73, 74, 72, 73, 74, 73, 73, 74, 74,
74, 74, 52, 50, 47, 47, 47, 47, 50, 52, 54, 57, 61, 62, 63, 66, 68, 69,
70, 72, 75, 75, 75, 77, 75, 75, 76, 75, 75, 76, 75, 75, 76, 77, 54, 52,
49, 49, 49, 48, 52, 53, 55, 58, 62, 64, 65, 68, 71, 72, 73, 75, 78, 78,
79, 79, 78, 79, 77, 78, 78, 77, 78, 79, 78, 78, 56, 53, 51, 50, 50, 49,
52, 54, 56, 59, 63, 64, 66, 69, 72, 73, 75, 77, 80, 80, 81, 81, 82, 80,
81, 81, 79, 81, 80, 79, 81, 82, 57, 54, 52, 51, 51, 50, 53, 55, 56, 60,
63, 65, 67, 70, 73, 75, 76, 79, 82, 82, 83, 85, 84, 83, 84, 83, 84, 82,
82, 84, 83, 82, 60, 57, 54, 54, 53, 52, 55, 57, 58, 61, 65, 67, 68, 72,
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99, 100, 102, 102, 103, 104, 104, 103, 104, 102, 71, 67, 66, 64, 63, 62,
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101, 102, 104, 104, 105, 106, 107, 105, 107, 72, 68, 67, 65, 64, 64, 61,
```

```
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103, 104, 106, 106, 108, 108, 109, 107, 73, 69, 68, 66, 65, 65, 63, 63,
66, 67, 69, 71, 73, 76, 77, 81, 82, 85, 88, 90, 94, 95, 99, 101, 104,
105, 106, 109, 108, 110, 111, 112, 74, 70, 70, 67, 66, 66, 64, 63, 66,
67, 70, 71, 74, 75, 78, 80, 82, 86, 87, 91, 92, 96, 98, 101, 104, 106,
108, 108, 111, 111, 112, 113, 75, 71, 71, 68, 68, 67, 66, 64, 66, 68,
70, 71, 74, 75, 79, 79, 84, 84, 88, 90, 93, 95, 98, 101, 103, 107, 108,
110, 111, 113, 113, 115, 76, 72, 72, 69, 69, 68, 67, 65, 66, 69, 70, 72,
74, 76, 78, 81, 83, 85, 88, 90, 93, 95, 98, 100, 104, 105, 109, 111,
112, 113, 116, 115, 78, 74, 74, 70, 70, 69, 69, 66, 66, 70, 70, 74, 74,
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115, 115, 118,
/* Size 4x8 */
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91, 101, 109,
/* Size 16x8 */
32, 30, 33, 42, 49, 49, 50, 54, 57, 63, 64, 68, 70, 72, 74, 76, 37, 40,
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76, 82, 83, 86, 83, 83, 84, 82, 66, 60, 59, 60, 62, 69, 73, 80, 84, 92,
93, 94, 96, 92, 94, 91, 68, 63, 60, 59, 62, 66, 72, 76, 80, 87, 93, 98,
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104, 106, 109,
/* Size 16x32 */
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46, 49, 53, 58, 61, 62, 64, 67, 69, 67, 66, 66, 66, 65, 49, 46, 46, 49,
53, 59, 62, 64, 65, 69, 71, 70, 68, 68, 67, 68, 50, 46, 46, 50, 54, 59,
64, 65, 67, 71, 73, 72, 72, 70, 70, 69, 52, 48, 47, 50, 54, 61, 66, 68,
71, 75, 77, 74, 73, 73, 71, 72, 54, 50, 49, 52, 55, 62, 68, 71, 73, 78,
```

```
80, 78, 76, 74, 75, 73, 55, 51, 49, 52, 56, 63, 69, 72, 75, 80, 82, 80,
79, 78, 76, 77, 57, 52, 50, 53, 56, 64, 70, 73, 76, 82, 84, 82, 80, 80,
79, 77, 60, 54, 52, 55, 58, 65, 72, 75, 79, 85, 88, 86, 84, 82, 81, 81,
63, 57, 55, 58, 60, 67, 75, 78, 82, 89, 92, 88, 87, 85, 84, 81, 64, 58,
55, 58, 61, 68, 75, 78, 82, 89, 92, 90, 89, 87, 86, 86, 64, 59, 56, 58,
61, 68, 75, 79, 83, 90, 93, 95, 93, 91, 89, 87, 67, 61, 58, 60, 63, 69,
76, 79, 85, 92, 95, 96, 94, 92, 91, 91, 68, 62, 59, 60, 64, 71, 74, 78,
86, 91, 94, 96, 98, 96, 94, 91, 69, 62, 60, 60, 65, 70, 72, 79, 85, 88,
95, 98, 99, 98, 97, 96, 70, 63, 62, 60, 66, 69, 73, 81, 83, 89, 96, 97,
99, 101, 98, 97, 71, 64, 63, 61, 67, 68, 74, 79, 82, 90, 93, 98, 102,
102, 102, 101, 72, 65, 64, 62, 66, 68, 75, 78, 83, 89, 92, 100, 101,
103, 104, 102, 73, 66, 65, 63, 66, 69, 75, 76, 84, 87, 93, 98, 102, 105,
106, 107, 74, 67, 67, 64, 66, 70, 74, 77, 84, 86, 94, 96, 103, 105, 106,
107, 75, 68, 68, 65, 66, 71, 74, 78, 83, 87, 93, 96, 103, 105, 109, 109,
76, 69, 69, 66, 67, 72, 73, 80, 82, 88, 91, 97, 101, 107, 109, 110, 77,
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/* Size 32x16 */
32, 31, 30, 32, 33, 37, 42, 45, 49, 48, 49, 49, 50, 52, 54, 55, 57, 60,
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36, 40, 43, 44, 46, 46, 45, 46, 46, 48, 50, 51, 52, 54, 57, 58, 59, 61,
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48, 47, 46, 46, 46, 47, 49, 49, 50, 52, 55, 55, 56, 58, 59, 60, 62, 63,
64, 65, 67, 68, 69, 70, 42, 42, 42, 44, 45, 47, 48, 49, 50, 50, 49, 49,
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89, 89, 90, 92, 91, 88, 89, 90, 89, 87, 86, 87, 88, 90, 66, 63, 60, 59,
59, 57, 60, 61, 62, 66, 69, 71, 73, 77, 80, 82, 84, 88, 92, 92, 93, 95,
94, 95, 96, 93, 92, 93, 94, 93, 91, 90, 67, 64, 62, 61, 60, 58, 58, 61,
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100, 98, 96, 96, 97, 99, 68, 65, 63, 62, 60, 60, 59, 61, 62, 65, 66, 68,
72, 73, 76, 79, 80, 84, 87, 89, 93, 94, 98, 99, 99, 102, 101, 102, 103,
103, 101, 99, 69, 66, 65, 63, 62, 61, 60, 60, 63, 64, 66, 68, 70, 73,
74, 78, 80, 82, 85, 87, 91, 92, 96, 98, 101, 102, 103, 105, 105, 105,
107, 108, 71, 67, 66, 64, 63, 62, 62, 61, 62, 64, 66, 67, 70, 71, 75,
76, 79, 81, 84, 86, 89, 91, 94, 97, 98, 102, 104, 106, 106, 109, 109,
108, 72, 68, 68, 65, 65, 63, 63, 61, 62, 65, 65, 68, 69, 72, 73, 77, 77,
81, 81, 86, 87, 91, 91, 96, 97, 101, 102, 107, 107, 109, 110, 113,
/* Size 4x16 */
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57, 67, 89, 85, 59, 68, 90, 91, 62, 71, 91, 96, 63, 69, 89, 101, 65, 68,
```

```
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        31, 32, 36, 43, 46, 45, 46, 50, 52, 57, 59, 62, 63, 65, 67, 69, 49, 45,
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        99, 102, 101, 102, 103, 103, 101, 99, 71, 67, 66, 64, 63, 62, 62, 61,
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        104, 106, 106, 109, 109, 108 },
    },
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        /* Size 4x4 */
        32, 41, 69, 92, 41, 63, 88, 103, 69, 88, 127, 140, 92, 103, 140, 184,
        /* Size 8x8 */
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```

```
32, 32, 33, 34, 37, 44, 50, 56, 65, 73, 79, 85, 91, 98, 105, 31, 32, 33,
34, 36, 39, 45, 50, 56, 64, 71, 77, 82, 88, 94, 100, 32, 33, 34, 36, 40,
42, 47, 51, 57, 65, 71, 76, 80, 85, 91, 98, 36, 34, 36, 40, 48, 50, 56,
60, 65, 73, 79, 84, 86, 90, 95, 98, 39, 37, 39, 42, 50, 54, 60, 65, 70,
78, 84, 89, 95, 96, 102, 105, 47, 44, 45, 47, 56, 60, 69, 75, 81, 89,
95, 100, 102, 104, 109, 112, 54, 50, 50, 51, 60, 65, 75, 82, 89, 97,
104, 109, 110, 114, 117, 121, 61, 56, 56, 57, 65, 70, 81, 89, 97, 106,
113, 119, 122, 126, 125, 130, 71, 65, 64, 65, 73, 78, 89, 97, 106, 117,
125, 131, 134, 134, 136, 141, 80, 73, 71, 71, 79, 84, 95, 104, 113, 125,
134, 140, 142, 145, 146, 152, 86, 79, 77, 76, 84, 89, 100, 109, 119,
131, 140, 147, 154, 157, 160, 165, 92, 85, 82, 80, 86, 95, 102, 110,
122, 134, 142, 154, 162, 168, 174, 178, 98, 91, 88, 85, 90, 96, 104,
114, 126, 134, 145, 157, 168, 176, 184, 193, 104, 98, 94, 91, 95, 102,
109, 117, 125, 136, 146, 160, 174, 184, 193, 201, 111, 105, 100, 98, 98,
105, 112, 121, 130, 141, 152, 165, 178, 193, 201, 210,
/* Size 32x32 */
32, 31, 31, 31, 31, 32, 32, 34, 36, 38, 39, 44, 47, 49, 54, 59, 61, 65,
71, 76, 80, 83, 86, 89, 92, 95, 98, 101, 104, 108, 111, 114, 31, 32, 32,
32, 32, 32, 32, 33, 34, 35, 37, 38, 42, 45, 47, 51, 56, 58, 62, 68, 72, 76,
78, 82, 85, 88, 90, 93, 96, 99, 102, 105, 109, 31, 32, 32, 32, 32, 32,
33, 33, 34, 36, 37, 41, 44, 46, 50, 54, 56, 60, 65, 70, 73, 76, 79, 82,
85, 88, 91, 95, 98, 101, 105, 109, 31, 32, 32, 32, 32, 33, 33, 34, 35,
36, 38, 41, 44, 45, 49, 54, 56, 59, 65, 69, 72, 75, 78, 81, 84, 86, 89,
92, 95, 98, 101, 104, 31, 32, 32, 32, 33, 34, 34, 35, 36, 38, 39, 42,
45, 46, 50, 54, 56, 59, 64, 68, 71, 74, 77, 79, 82, 85, 88, 91, 94, 97,
100, 104, 32, 32, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 45, 46, 49,
53, 55, 58, 63, 66, 69, 72, 74, 78, 81, 84, 87, 90, 93, 96, 99, 102, 32,
33, 33, 33, 34, 36, 36, 38, 40, 41, 42, 44, 47, 48, 51, 55, 57, 60, 65,
68, 71, 73, 76, 78, 80, 82, 85, 88, 91, 95, 98, 102, 34, 34, 33, 34, 35,
37, 38, 39, 42, 44, 45, 47, 50, 51, 54, 58, 60, 63, 68, 71, 74, 76, 79,
82, 85, 86, 87, 88, 90, 93, 96, 99, 36, 35, 34, 35, 36, 38, 40, 42, 48,
50, 50, 54, 56, 57, 60, 64, 65, 68, 73, 76, 79, 81, 84, 86, 86, 88, 90,
93, 95, 97, 98, 100, 38, 37, 36, 36, 38, 39, 41, 44, 50, 51, 52, 56, 58,
60, 63, 67, 68, 71, 76, 79, 82, 84, 87, 87, 90, 93, 94, 95, 96, 100,
103, 106, 39, 38, 37, 38, 39, 40, 42, 45, 50, 52, 54, 58, 60, 62, 65,
69, 70, 73, 78, 81, 84, 86, 89, 92, 95, 95, 96, 99, 102, 104, 105, 106,
44, 42, 41, 41, 42, 42, 44, 47, 54, 56, 58, 63, 66, 68, 71, 75, 77, 79,
84, 88, 90, 92, 95, 97, 97, 99, 102, 103, 103, 106, 109, 113, 47, 45,
44, 44, 45, 45, 47, 50, 56, 58, 60, 66, 69, 71, 75, 79, 81, 84, 89, 92,
95, 97, 100, 100, 102, 105, 104, 106, 109, 111, 112, 113, 49, 47, 46,
45, 46, 46, 48, 51, 57, 60, 62, 68, 71, 73, 77, 81, 83, 87, 92, 95, 98,
100, 103, 105, 107, 106, 109, 112, 112, 113, 117, 120, 54, 51, 50, 49,
50, 49, 51, 54, 60, 63, 65, 71, 75, 77, 82, 87, 89, 92, 97, 101, 104,
106, 109, 112, 110, 113, 114, 114, 117, 121, 121, 121, 59, 56, 54, 54,
54, 53, 55, 58, 64, 67, 69, 75, 79, 81, 87, 92, 94, 98, 103, 107, 110,
113, 116, 114, 117, 118, 117, 121, 122, 122, 125, 129, 61, 58, 56, 56,
56, 55, 57, 60, 65, 68, 70, 77, 81, 83, 89, 94, 97, 101, 106, 110, 113,
116, 119, 120, 122, 121, 126, 124, 125, 130, 130, 130, 65, 62, 60, 59,
59, 58, 60, 63, 68, 71, 73, 79, 84, 87, 92, 98, 101, 105, 111, 115, 118,
121, 124, 128, 125, 129, 128, 131, 133, 132, 135, 139, 71, 68, 65, 65,
```

```
64, 63, 65, 68, 73, 76, 78, 84, 89, 92, 97, 103, 106, 111, 117, 122,
125, 128, 131, 131, 134, 132, 134, 136, 136, 140, 141, 140, 76, 72, 70,
69, 68, 66, 68, 71, 76, 79, 81, 88, 92, 95, 101, 107, 110, 115, 122,
127, 130, 133, 136, 136, 138, 139, 141, 140, 145, 143, 146, 151, 80, 76,
73, 72, 71, 69, 71, 74, 79, 82, 84, 90, 95, 98, 104, 110, 113, 118, 125,
130, 134, 137, 140, 146, 142, 146, 145, 149, 146, 150, 152, 151, 83, 78,
76, 75, 74, 72, 73, 76, 81, 84, 86, 92, 97, 100, 106, 113, 116, 121,
128, 133, 137, 140, 144, 147, 152, 148, 154, 151, 156, 155, 156, 162,
86, 82, 79, 78, 77, 74, 76, 79, 84, 87, 89, 95, 100, 103, 109, 116, 119,
124, 131, 136, 140, 144, 147, 150, 154, 159, 157, 160, 160, 162, 165,
162, 89, 85, 82, 81, 79, 78, 78, 82, 86, 87, 92, 97, 100, 105, 112, 114,
120, 128, 131, 136, 146, 147, 150, 155, 156, 161, 166, 165, 167, 169,
169, 175, 92, 88, 85, 84, 82, 81, 80, 85, 86, 90, 95, 97, 102, 107, 110,
117, 122, 125, 134, 138, 142, 152, 154, 156, 162, 163, 168, 173, 174,
174, 178, 176, 95, 90, 88, 86, 85, 84, 82, 86, 88, 93, 95, 99, 105, 106,
113, 118, 121, 129, 132, 139, 146, 148, 159, 161, 163, 169, 170, 176,
180, 183, 181, 187, 98, 93, 91, 89, 88, 87, 85, 87, 90, 94, 96, 102,
104, 109, 114, 117, 126, 128, 134, 141, 145, 154, 157, 166, 168, 170,
176, 178, 184, 188, 193, 188, 101, 96, 95, 92, 91, 90, 88, 88, 93, 95,
99, 103, 106, 112, 114, 121, 124, 131, 136, 140, 149, 151, 160, 165,
173, 176, 178, 184, 186, 192, 196, 203, 104, 99, 98, 95, 94, 93, 91, 90,
95, 96, 102, 103, 109, 112, 117, 122, 125, 133, 136, 145, 146, 156, 160,
167, 174, 180, 184, 186, 193, 194, 201, 204, 108, 102, 101, 98, 97, 96,
95, 93, 97, 100, 104, 106, 111, 113, 121, 122, 130, 132, 140, 143, 150,
155, 162, 169, 174, 183, 188, 192, 194, 201, 202, 210, 111, 105, 105,
101, 100, 99, 98, 96, 98, 103, 105, 109, 112, 117, 121, 125, 130, 135,
141, 146, 152, 156, 165, 169, 178, 181, 193, 196, 201, 202, 210, 211,
114, 109, 109, 104, 104, 102, 102, 99, 100, 106, 106, 113, 113, 120,
121, 129, 130, 139, 140, 151, 151, 162, 162, 175, 176, 187, 188, 203,
204, 210, 211, 219,
/* Size 4x8 */
32, 42, 69, 88, 33, 42, 64, 83, 36, 56, 77, 88, 46, 67, 93, 105, 60, 79,
112, 122, 75, 92, 130, 144, 86, 95, 136, 167, 98, 105, 136, 177,
/* Size 8x4 */
32, 33, 36, 46, 60, 75, 86, 98, 42, 42, 56, 67, 79, 92, 95, 105, 69, 64,
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/* Size 8x16 */
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101, 101, 53, 50, 60, 75, 92, 103, 108, 110, 61, 56, 65, 81, 100, 113,
116, 118, 71, 64, 73, 89, 111, 125, 129, 129, 79, 70, 79, 95, 118, 133,
142, 138, 86, 76, 84, 100, 124, 140, 153, 150, 92, 82, 89, 101, 121,
148, 157, 161, 98, 88, 93, 108, 124, 141, 163, 174, 104, 94, 95, 110,
129, 151, 171, 181, 110, 100, 98, 111, 127, 147, 169, 188,
/* Size 16x8 */
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32, 34, 35, 37, 40, 45, 50, 56, 64, 70, 76, 82, 88, 94, 100, 36, 35, 36,
40, 48, 50, 56, 60, 65, 73, 79, 84, 89, 93, 95, 98, 47, 44, 45, 47, 56,
60, 69, 75, 81, 89, 95, 100, 101, 108, 110, 111, 65, 60, 59, 60, 68, 73,
```

```
84, 92, 100, 111, 118, 124, 121, 124, 129, 127, 79, 72, 71, 71, 78, 84,
95, 103, 113, 125, 133, 140, 148, 141, 151, 147, 90, 84, 80, 78, 83, 91,
101, 108, 116, 129, 142, 153, 157, 163, 171, 169, 96, 90, 87, 85, 87,
94, 101, 110, 118, 129, 138, 150, 161, 174, 181, 188,
/* Size 16x32 */
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84, 86, 36, 34, 37, 40, 48, 54, 56, 60, 68, 74, 78, 84, 83, 86, 87, 87,
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40, 42, 50, 58, 60, 65, 73, 79, 84, 90, 91, 92, 94, 93, 44, 41, 42, 45,
53, 63, 66, 71, 79, 85, 90, 96, 94, 96, 96, 99, 47, 44, 45, 47, 56, 66,
69, 75, 84, 90, 95, 99, 101, 98, 101, 99, 49, 46, 47, 48, 57, 67, 71,
77, 86, 93, 97, 103, 103, 105, 102, 106, 53, 49, 50, 51, 60, 71, 75, 82,
92, 99, 103, 111, 108, 107, 110, 107, 58, 54, 54, 55, 63, 75, 79, 87,
98, 105, 110, 114, 114, 113, 111, 115, 61, 56, 56, 57, 65, 77, 81, 89,
100, 107, 113, 118, 116, 117, 118, 116, 65, 60, 59, 60, 68, 79, 84, 92,
105, 112, 118, 126, 124, 122, 121, 124, 71, 65, 64, 65, 73, 84, 89, 97,
111, 119, 125, 130, 129, 129, 129, 125, 76, 69, 68, 69, 76, 88, 92, 101,
115, 123, 130, 134, 134, 131, 132, 135, 79, 72, 70, 71, 79, 90, 95, 104,
118, 127, 133, 143, 142, 141, 138, 136, 82, 75, 73, 74, 81, 92, 97, 106,
121, 130, 136, 146, 145, 144, 144, 145, 86, 78, 76, 77, 84, 95, 100,
109, 124, 133, 140, 147, 153, 151, 150, 146, 89, 81, 79, 78, 87, 95, 99,
112, 124, 130, 145, 152, 156, 157, 156, 158, 92, 84, 82, 80, 89, 95,
101, 116, 121, 132, 148, 151, 157, 163, 161, 159, 95, 86, 85, 83, 92,
95, 105, 114, 120, 136, 143, 155, 163, 167, 171, 170, 98, 89, 88, 85,
93, 95, 108, 113, 124, 136, 141, 160, 163, 169, 174, 171, 101, 92, 91,
88, 94, 98, 110, 112, 128, 133, 146, 158, 166, 175, 179, 185, 104, 95,
94, 91, 95, 101, 110, 115, 129, 132, 151, 154, 171, 175, 181, 186, 107,
98, 97, 94, 96, 105, 110, 119, 128, 136, 149, 156, 173, 177, 188, 192,
110, 101, 100, 97, 98, 108, 111, 123, 127, 141, 147, 161, 169, 183, 188,
193, 114, 104, 104, 100, 100, 111, 111, 126, 127, 145, 145, 166, 166,
189, 190, 201,
/* Size 32x16 */
32, 31, 31, 31, 32, 32, 32, 34, 36, 38, 39, 44, 47, 49, 53, 58, 61, 65,
71, 76, 79, 82, 86, 89, 92, 95, 98, 101, 104, 107, 110, 114, 31, 32, 32,
32, 32, 33, 33, 34, 34, 36, 37, 41, 44, 46, 49, 54, 56, 60, 65, 69, 72,
75, 78, 81, 84, 86, 89, 92, 95, 98, 101, 104, 32, 32, 32, 33, 34, 35,
35, 36, 37, 39, 40, 42, 45, 47, 50, 54, 56, 59, 64, 68, 70, 73, 76, 79,
82, 85, 88, 91, 94, 97, 100, 104, 32, 33, 33, 33, 34, 36, 36, 38, 40,
41, 42, 45, 47, 48, 51, 55, 57, 60, 65, 69, 71, 74, 77, 78, 80, 83, 85,
88, 91, 94, 97, 100, 36, 35, 35, 35, 36, 38, 40, 42, 48, 49, 50, 53, 56,
57, 60, 63, 65, 68, 73, 76, 79, 81, 84, 87, 89, 92, 93, 94, 95, 96, 98,
100, 44, 42, 41, 41, 42, 42, 44, 48, 54, 56, 58, 63, 66, 67, 71, 75, 77,
79, 84, 88, 90, 92, 95, 95, 95, 95, 95, 98, 101, 105, 108, 111, 47, 45,
44, 44, 45, 45, 47, 50, 56, 58, 60, 66, 69, 71, 75, 79, 81, 84, 89, 92,
```

```
95, 97, 100, 99, 101, 105, 108, 110, 110, 110, 111, 111, 53, 51, 49, 49,
50, 49, 51, 54, 60, 63, 65, 71, 75, 77, 82, 87, 89, 92, 97, 101, 104,
106, 109, 112, 116, 114, 113, 112, 115, 119, 123, 126, 65, 62, 60, 59,
59, 58, 60, 63, 68, 71, 73, 79, 84, 86, 92, 98, 100, 105, 111, 115, 118,
121, 124, 124, 121, 120, 124, 128, 129, 128, 127, 127, 73, 69, 67, 66,
65, 64, 66, 69, 74, 77, 79, 85, 90, 93, 99, 105, 107, 112, 119, 123,
127, 130, 133, 130, 132, 136, 136, 133, 132, 136, 141, 145, 79, 75, 72,
71, 71, 69, 71, 73, 78, 81, 84, 90, 95, 97, 103, 110, 113, 118, 125,
130, 133, 136, 140, 145, 148, 143, 141, 146, 151, 149, 147, 145, 87, 83,
80, 79, 78, 76, 76, 80, 84, 86, 90, 96, 99, 103, 111, 114, 118, 126,
130, 134, 143, 146, 147, 152, 151, 155, 160, 158, 154, 156, 161, 166,
90, 86, 84, 82, 80, 80, 78, 82, 83, 88, 91, 94, 101, 103, 108, 114, 116,
124, 129, 134, 142, 145, 153, 156, 157, 163, 163, 166, 171, 173, 169,
166, 93, 88, 87, 84, 83, 83, 81, 81, 86, 88, 92, 96, 98, 105, 107, 113,
117, 122, 129, 131, 141, 144, 151, 157, 163, 167, 169, 175, 175, 177,
183, 189, 96, 91, 90, 87, 87, 86, 85, 84, 87, 90, 94, 96, 101, 102, 110,
111, 118, 121, 129, 132, 138, 144, 150, 156, 161, 171, 174, 179, 181,
188, 188, 190, 99, 94, 94, 90, 90, 88, 89, 86, 87, 93, 93, 99, 99, 106,
107, 115, 116, 124, 125, 135, 136, 145, 146, 158, 159, 170, 171, 185,
186, 192, 193, 201,
/* Size 4x16 */
31, 44, 73, 93, 32, 41, 67, 87, 32, 42, 65, 83, 33, 44, 66, 81, 34, 54,
74, 86, 37, 58, 79, 92, 44, 66, 90, 98, 49, 71, 99, 107, 56, 77, 107,
117, 65, 84, 119, 129, 72, 90, 127, 141, 78, 95, 133, 151, 84, 95, 132,
163, 89, 95, 136, 169, 95, 101, 132, 175, 101, 108, 141, 183,
/* Size 16x4 */
31, 32, 32, 33, 34, 37, 44, 49, 56, 65, 72, 78, 84, 89, 95, 101, 44, 41,
42, 44, 54, 58, 66, 71, 77, 84, 90, 95, 95, 95, 101, 108, 73, 67, 65,
66, 74, 79, 90, 99, 107, 119, 127, 133, 132, 136, 132, 141, 93, 87, 83,
81, 86, 92, 98, 107, 117, 129, 141, 151, 163, 169, 175, 183,
/* Size 8x32 */
32, 32, 36, 47, 65, 79, 90, 96, 31, 32, 35, 45, 62, 75, 86, 91, 31, 32,
35, 44, 60, 72, 84, 90, 31, 33, 35, 44, 59, 71, 82, 87, 32, 34, 36, 45,
59, 71, 80, 87, 32, 35, 38, 45, 58, 69, 80, 86, 32, 35, 40, 47, 60, 71,
78, 85, 34, 36, 42, 50, 63, 73, 82, 84, 36, 37, 48, 56, 68, 78, 83, 87,
38, 39, 49, 58, 71, 81, 88, 90, 39, 40, 50, 60, 73, 84, 91, 94, 44, 42,
53, 66, 79, 90, 94, 96, 47, 45, 56, 69, 84, 95, 101, 101, 49, 47, 57,
71, 86, 97, 103, 102, 53, 50, 60, 75, 92, 103, 108, 110, 58, 54, 63, 79,
98, 110, 114, 111, 61, 56, 65, 81, 100, 113, 116, 118, 65, 59, 68, 84,
105, 118, 124, 121, 71, 64, 73, 89, 111, 125, 129, 129, 76, 68, 76, 92,
115, 130, 134, 132, 79, 70, 79, 95, 118, 133, 142, 138, 82, 73, 81, 97,
121, 136, 145, 144, 86, 76, 84, 100, 124, 140, 153, 150, 89, 79, 87, 99,
124, 145, 156, 156, 92, 82, 89, 101, 121, 148, 157, 161, 95, 85, 92,
105, 120, 143, 163, 171, 98, 88, 93, 108, 124, 141, 163, 174, 101, 91,
94, 110, 128, 146, 166, 179, 104, 94, 95, 110, 129, 151, 171, 181, 107,
97, 96, 110, 128, 149, 173, 188, 110, 100, 98, 111, 127, 147, 169, 188,
114, 104, 100, 111, 127, 145, 166, 190,
/* Size 32x8 */
32, 31, 31, 31, 32, 32, 32, 34, 36, 38, 39, 44, 47, 49, 53, 58, 61, 65,
71, 76, 79, 82, 86, 89, 92, 95, 98, 101, 104, 107, 110, 114, 32, 32, 32,
```

```
    33, 34, 35, 35, 36, 37, 39, 40, 42, 45, 47, 50, 54, 56, 59, 64, 68, 70,
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    40, 42, 48, 49, 50, 53, 56, 57, 60, 63, 65, 68, 73, 76, 79, 81, 84, 87,
    89, 92, 93, 94, 95, 96, 98, 100, 47, 45, 44, 44, 45, 45, 47, 50, 56, 58,
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    110, 110, 110, 111, 111, 65, 62, 60, 59, 59, 58, 60, 63, 68, 71, 73, 79,
    84, 86, 92, 98, 100, 105, 111, 115, 118, 121, 124, 124, 121, 120, 124,
    128, 129, 128, 127, 127, 79, 75, 72, 71, 71, 69, 71, 73, 78, 81, 84, 90,
    95, 97, 103, 110, 113, 118, 125, 130, 133, 136, 140, 145, 148, 143, 141,
    146, 151, 149, 147, 145, 90, 86, 84, 82, 80, 80, 78, 82, 83, 88, 91, 94,
    101, 103, 108, 114, 116, 124, 129, 134, 142, 145, 153, 156, 157, 163,
    163, 166, 171, 173, 169, 166, 96, 91, 90, 87, 87, 86, 85, 84, 87, 90,
    94, 96, 101, 102, 110, 111, 118, 121, 129, 132, 138, 144, 150, 156, 161,
    171, 174, 179, 181, 188, 188, 190 },
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    /* Size 4x4 */
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    /* Size 8x8 */
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    101, 103, 69, 65, 66, 73, 82, 92, 103, 109,
    /* Size 16x16 */
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    71, 71, 72, 72, 52, 48, 47, 48, 54, 57, 63, 66, 69, 72, 75, 76, 75, 76,
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    62, 65, 72, 76, 81, 87, 91, 94, 96, 95, 95, 95, 68, 63, 60, 58, 62, 67,
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    85, 90, 95, 100, 105, 108, 111,
    /* Size 32x32 */
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```

```
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53, 55, 55, 58, 59, 60, 61, 62, 63, 63, 65, 66, 67, 68, 69, 69, 68, 68,
69, 69, 69, 69, 70, 71, 50, 48, 46, 46, 46, 46, 47, 50, 54, 55, 56, 59,
61, 61, 63, 64, 65, 66, 68, 69, 70, 71, 72, 71, 71, 72, 71, 71, 72, 72,
72, 71, 51, 48, 47, 46, 47, 46, 47, 50, 54, 55, 56, 60, 61, 62, 64, 66,
66, 67, 69, 70, 71, 72, 73, 73, 74, 73, 73, 74, 73, 73, 74, 75, 52, 50,
48, 47, 47, 47, 48, 50, 54, 56, 57, 61, 63, 64, 66, 68, 69, 70, 72, 74,
75, 75, 76, 77, 75, 76, 76, 75, 76, 77, 76, 75, 54, 52, 50, 49, 49, 48,
49, 52, 55, 57, 58, 62, 64, 66, 68, 71, 72, 73, 75, 77, 78, 79, 80, 78,
79, 78, 77, 78, 78, 77, 78, 79, 55, 53, 51, 50, 50, 49, 50, 52, 56, 58,
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70, 73, 74, 76, 79, 80, 82, 83, 84, 85, 83, 84, 83, 83, 83, 82, 82, 83,
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82, 84, 85, 86, 87, 86, 87, 85, 85, 85, 84, 86, 85, 84, 62, 59, 57, 56,
55, 53, 54, 56, 59, 61, 63, 66, 69, 70, 74, 77, 78, 80, 84, 86, 87, 88,
90, 89, 89, 88, 88, 87, 88, 87, 87, 88, 63, 60, 58, 57, 56, 54, 55, 57,
60, 62, 63, 67, 70, 71, 75, 78, 79, 82, 85, 87, 89, 90, 91, 93, 91, 91,
90, 91, 89, 90, 90, 89, 65, 61, 59, 58, 57, 55, 56, 58, 61, 63, 64, 68,
71, 72, 75, 79, 80, 83, 86, 88, 90, 91, 93, 94, 95, 92, 94, 92, 93, 92,
91, 93, 66, 63, 60, 59, 58, 56, 58, 59, 62, 64, 65, 69, 72, 73, 76, 80,
81, 84, 87, 90, 91, 93, 94, 95, 96, 97, 95, 95, 95, 95, 95, 93, 67, 64,
62, 61, 59, 58, 58, 60, 63, 64, 66, 69, 71, 73, 77, 78, 81, 85, 86, 89,
93, 94, 95, 97, 97, 98, 99, 97, 97, 97, 96, 98, 68, 65, 63, 62, 60, 59,
58, 61, 62, 64, 67, 68, 71, 74, 75, 79, 81, 83, 87, 89, 91, 95, 96, 97,
99, 98, 100, 100, 100, 99, 100, 98, 69, 66, 64, 63, 61, 61, 59, 61, 62,
65, 66, 68, 72, 73, 76, 78, 80, 84, 85, 88, 91, 92, 97, 98, 98, 101,
100, 102, 102, 103, 101, 102, 70, 67, 65, 63, 62, 62, 60, 61, 63, 65,
66, 69, 71, 73, 76, 77, 81, 83, 85, 88, 90, 94, 95, 99, 100, 100, 103,
102, 104, 104, 105, 103, 71, 67, 67, 64, 63, 63, 61, 61, 64, 65, 67, 69,
71, 74, 75, 78, 80, 83, 85, 87, 91, 92, 95, 97, 100, 102, 102, 105, 104,
106, 106, 108, 72, 68, 68, 65, 65, 64, 62, 62, 64, 65, 68, 69, 72, 73,
76, 78, 80, 83, 84, 88, 89, 93, 95, 97, 100, 102, 104, 104, 107, 106,
108, 108, 73, 69, 69, 66, 66, 65, 64, 63, 64, 66, 68, 69, 72, 73, 77,
77, 81, 82, 86, 87, 90, 92, 95, 97, 99, 103, 104, 106, 106, 109, 108,
110, 74, 70, 70, 67, 67, 66, 65, 63, 64, 67, 68, 70, 72, 74, 76, 78, 80,
82, 85, 87, 90, 91, 95, 96, 100, 101, 105, 106, 108, 108, 111, 110, 75,
71, 71, 68, 68, 66, 66, 64, 64, 68, 68, 71, 71, 75, 75, 79, 79, 83, 84,
88, 89, 93, 93, 98, 98, 102, 103, 108, 108, 110, 110, 113,
/* Size 4x8 */
31, 47, 57, 65, 40, 45, 52, 61, 46, 55, 61, 63, 47, 60, 70, 72, 52, 64,
79, 81, 59, 68, 87, 90, 63, 66, 88, 99, 66, 69, 85, 102,
```

```
/* Size 8x4 */
31, 40, 46, 47, 52, 59, 63, 66, 47, 45, 55, 60, 64, 68, 66, 69, 57, 52,
61, 70, 79, 87, 88, 85, 65, 61, 63, 72, 81, 90, 99, 102,
/* Size 8x16 */
32, 35, 48, 50, 57, 63, 68, 70, 30, 38, 46, 46, 52, 58, 63, 65, 33, 41,
47, 46, 51, 56, 60, 63, 39, 46, 48, 47, 51, 55, 58, 61, 49, 48, 53, 54,
57, 60, 61, 61, 48, 46, 53, 56, 60, 64, 65, 65, 50, 46, 54, 61, 66, 70,
71, 69, 52, 47, 54, 63, 71, 75, 75, 74, 55, 49, 56, 65, 74, 79, 79, 78,
60, 53, 58, 68, 79, 85, 85, 82, 63, 55, 60, 70, 82, 89, 91, 87, 66, 58,
62, 72, 84, 91, 95, 91, 68, 60, 64, 71, 81, 94, 97, 96, 70, 62, 65, 73,
81, 89, 98, 101, 72, 65, 65, 72, 82, 92, 100, 103, 74, 67, 65, 71, 79,
89, 98, 105,
/* Size 16x8 */
32, 30, 33, 39, 49, 48, 50, 52, 55, 60, 63, 66, 68, 70, 72, 74, 35, 38,
41, 46, 48, 46, 46, 47, 49, 53, 55, 58, 60, 62, 65, 67, 48, 46, 47, 48,
53, 53, 54, 54, 56, 58, 60, 62, 64, 65, 65, 65, 50, 46, 46, 47, 54, 56,
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74, 79, 82, 84, 81, 81, 82, 79, 63, 58, 56, 55, 60, 64, 70, 75, 79, 85,
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101, 103, 105,
/* Size 16x32 */
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93, 96, 96, 96, 94, 94, 68, 62, 60, 59, 64, 67, 71, 79, 81, 86, 94, 95,
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72, 65, 65, 62, 65, 68, 72, 75, 82, 83, 92, 93, 100, 102, 103, 104, 73,
66, 66, 63, 65, 69, 72, 76, 81, 85, 90, 93, 100, 102, 105, 106, 74, 67,
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```

```
65, 65, 71, 71, 78, 78, 87, 87, 96, 96, 105, 105, 109,
/* Size 32x16 */
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91, 93, 94, 91, 89, 90, 92, 90, 89, 87, 67, 63, 61, 60, 59, 57, 57, 60,
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76, 78, 81, 84, 85, 89, 90, 93, 96, 98, 99, 100, 102, 102, 102, 103,
105, 70, 66, 65, 63, 63, 62, 61, 60, 61, 63, 65, 66, 69, 70, 74, 74, 78,
79, 82, 84, 87, 89, 91, 94, 96, 100, 101, 103, 103, 105, 105, 105, 71,
67, 67, 64, 64, 62, 62, 60, 61, 64, 64, 67, 67, 71, 71, 75, 75, 79, 80,
84, 84, 89, 89, 94, 94, 98, 99, 104, 104, 106, 106, 109,
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/* Size 16x4 */
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```

```
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        107, 109, 112, 58, 54, 53, 52, 59, 68, 74, 81, 90, 97, 102, 110, 114,
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        125, 126, 130, 71, 66, 64, 63, 70, 78, 84, 92, 102, 111, 117, 127, 133,
        134, 136, 141, 81, 75, 73, 71, 77, 85, 91, 99, 110, 120, 127, 137, 143,
        145, 148, 152, 87, 81, 78, 75, 82, 90, 96, 103, 114, 125, 133, 143, 150,
        156, 160, 163, 93, 86, 83, 80, 85, 90, 98, 107, 118, 125, 134, 145, 156,
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        152, 163, 177, 184, 191,
```

```
/* Size 32x32 */
32, 31, 31, 31, 31, 32, 32, 34, 34, 36, 39, 41, 44, 48, 49, 54, 58, 59,
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32, 32, 32, 32, 34, 34, 35, 38, 39, 42, 46, 47, 51, 55, 57, 62, 66, 68,
76, 77, 78, 83, 85, 88, 90, 93, 96, 99, 101, 31, 32, 32, 32, 32, 32, 32,
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83, 86, 89, 92, 95, 98, 101, 31, 32, 32, 32, 32, 32, 32, 33, 34, 34, 37,
38, 41, 44, 45, 49, 53, 54, 59, 63, 65, 72, 74, 75, 79, 81, 84, 86, 89,
91, 94, 97, 31, 32, 32, 32, 33, 33, 34, 35, 36, 36, 39, 40, 42, 45, 46,
50, 53, 54, 59, 63, 64, 71, 73, 74, 78, 80, 83, 85, 88, 91, 94, 97, 32,
32, 32, 32, 33, 34, 34, 36, 36, 37, 40, 40, 42, 45, 46, 49, 53, 54, 58,
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34, 35, 37, 37, 38, 40, 41, 42, 45, 46, 49, 52, 54, 58, 61, 63, 69, 71,
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37, 39, 40, 40, 45, 47, 50, 54, 55, 58, 61, 62, 65, 68, 69, 73, 76, 78,
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102, 104, 104, 105, 48, 46, 45, 44, 45, 45, 45, 50, 53, 56, 61, 62, 66,
70, 71, 76, 79, 80, 85, 88, 90, 96, 97, 98, 101, 100, 102, 105, 105,
105, 109, 112, 49, 47, 46, 45, 46, 46, 46, 51, 53, 57, 62, 63, 68, 71,
73, 77, 81, 82, 87, 90, 92, 98, 99, 100, 103, 106, 107, 106, 109, 112,
112, 112, 54, 51, 50, 49, 50, 49, 49, 54, 56, 60, 65, 67, 71, 76, 77,
82, 86, 87, 92, 96, 97, 104, 105, 106, 110, 110, 109, 113, 114, 113,
116, 120, 58, 55, 54, 53, 53, 53, 52, 57, 59, 63, 68, 70, 74, 79, 81,
86, 90, 91, 97, 100, 102, 109, 110, 111, 114, 114, 118, 116, 117, 121,
121, 120, 59, 57, 55, 54, 54, 54, 54, 59, 61, 64, 69, 71, 75, 80, 82,
87, 91, 93, 99, 102, 104, 111, 112, 113, 117, 121, 120, 122, 124, 122,
125, 129, 65, 62, 60, 59, 59, 58, 58, 63, 65, 68, 73, 75, 79, 85, 87,
92, 97, 99, 105, 109, 111, 118, 120, 121, 125, 124, 125, 127, 126, 130,
130, 129, 69, 66, 64, 63, 63, 62, 61, 66, 68, 71, 76, 78, 83, 88, 90,
96, 100, 102, 109, 113, 115, 123, 125, 126, 129, 130, 131, 130, 134,
133, 135, 139, 71, 68, 66, 65, 64, 63, 63, 68, 70, 73, 78, 80, 84, 90,
92, 97, 102, 104, 111, 115, 117, 125, 127, 128, 133, 136, 134, 139, 136,
139, 141, 140, 80, 76, 73, 72, 71, 70, 69, 74, 76, 79, 84, 86, 90, 96,
98, 104, 109, 111, 118, 123, 125, 134, 136, 137, 142, 138, 143, 140,
144, 144, 144, 149, 81, 77, 75, 74, 73, 72, 71, 75, 77, 80, 85, 87, 91,
97, 99, 105, 110, 112, 120, 125, 127, 136, 137, 139, 143, 148, 145, 148,
148, 150, 152, 149, 83, 78, 76, 75, 74, 73, 72, 76, 78, 81, 86, 88, 92,
98, 100, 106, 111, 113, 121, 126, 128, 137, 139, 140, 145, 149, 153,
153, 154, 155, 155, 161, 87, 83, 81, 79, 78, 77, 75, 80, 82, 85, 90, 91,
96, 101, 103, 110, 114, 117, 125, 129, 133, 142, 143, 145, 150, 151,
156, 159, 160, 160, 163, 161, 90, 85, 83, 81, 80, 79, 78, 81, 83, 87,
89, 93, 98, 100, 106, 110, 114, 121, 124, 130, 136, 138, 148, 149, 151,
```

```
156, 157, 162, 166, 168, 166, 172, 93, 88, 86, 84, 83, 82, 80, 82, 85,
89, 90, 96, 98, 102, 107, 109, 118, 120, 125, 131, 134, 143, 145, 153,
156, 157, 163, 164, 169, 172, 177, 172, 95, 90, 89, 86, 85, 85, 83, 83,
88, 89, 93, 97, 99, 105, 106, 113, 116, 122, 127, 130, 139, 140, 148,
153, 159, 162, 164, 169, 170, 176, 179, 185, 98, 93, 92, 89, 88, 87, 86,
85, 89, 90, 96, 97, 102, 105, 109, 114, 117, 124, 126, 134, 136, 144,
148, 154, 160, 166, 169, 170, 176, 177, 184, 186, 101, 96, 95, 91, 91,
90, 89, 87, 90, 93, 97, 99, 104, 105, 112, 113, 121, 122, 130, 133, 139,
144, 150, 155, 160, 168, 172, 176, 177, 184, 185, 191, 104, 99, 98, 94,
94, 92, 92, 90, 92, 96, 98, 102, 104, 109, 112, 116, 121, 125, 130, 135,
141, 144, 152, 155, 163, 166, 177, 179, 184, 185, 191, 192, 107, 101,
101, 97, 97, 95, 95, 93, 93, 99, 99, 105, 105, 112, 112, 120, 120, 129,
129, 139, 140, 149, 149, 161, 161, 172, 172, 185, 186, 191, 192, 199,
/* Size 4x8 */
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98, 117, 72, 84, 118, 136, 82, 89, 129, 157, 92, 98, 127, 165,
/* Size 8x4 */
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68, 85, 98, 118, 129, 127, 86, 80, 85, 101, 117, 136, 157, 165,
/* Size 8x16 */
32, 32, 36, 44, 58, 79, 88, 93, 31, 32, 35, 41, 54, 73, 81, 88, 32, 33,
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113, 65, 59, 68, 79, 97, 118, 123, 122, 71, 64, 73, 84, 102, 125, 135,
131, 81, 72, 80, 91, 110, 135, 145, 141, 87, 77, 85, 96, 114, 140, 148,
151, 92, 83, 88, 102, 117, 133, 153, 163, 98, 88, 89, 103, 121, 141,
160, 169, 103, 94, 92, 103, 119, 137, 158, 175,
/* Size 16x8 */
32, 31, 32, 32, 34, 39, 44, 49, 57, 65, 71, 81, 87, 92, 98, 103, 32, 32,
33, 34, 36, 39, 42, 46, 53, 59, 64, 72, 77, 83, 88, 94, 36, 35, 36, 38,
44, 50, 53, 57, 63, 68, 73, 80, 85, 88, 89, 92, 44, 41, 42, 42, 50, 58,
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81, 90, 97, 102, 110, 114, 117, 121, 119, 79, 73, 71, 69, 75, 84, 90,
97, 108, 118, 125, 135, 140, 133, 141, 137, 88, 81, 78, 76, 81, 88, 97,
104, 111, 123, 135, 145, 148, 153, 160, 158, 93, 88, 84, 82, 84, 90, 97,
105, 113, 122, 131, 141, 151, 163, 169, 175,
/* Size 16x32 */
32, 31, 32, 32, 36, 39, 44, 53, 58, 65, 79, 81, 88, 90, 93, 96, 31, 32,
32, 32, 35, 38, 42, 51, 55, 62, 75, 77, 83, 86, 88, 91, 31, 32, 32, 32,
35, 38, 41, 50, 54, 60, 73, 75, 81, 84, 88, 91, 31, 32, 32, 33, 34, 37,
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51, 55, 59, 67, 70, 75, 85, 87, 91, 92, 92, 95, 44, 41, 42, 43, 53, 58,
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```

```
  79, 85, 95, 97, 99, 101, 98, 102, 49, 46, 46, 47, 57, 62, 67, 77, 81,
  86, 97, 99, 104, 102, 105, 102, 53, 49, 50, 50, 60, 65, 71, 82, 86, 92,
  103, 105, 109, 108, 106, 110, 57, 53, 53, 53, 63, 68, 74, 86, 90, 97,
  108, 110, 111, 112, 113, 110, 59, 54, 54, 54, 64, 69, 75, 87, 91, 98,
  111, 112, 119, 117, 115, 118, 65, 60, 59, 58, 68, 73, 79, 92, 97, 105,
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86, 90, 91, 94, 96, 99, 100, 100, 103, 102, 104, 104, 71, 67, 67, 64,
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100, 102,
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57, 54, 53, 52, 51, 50, 50, 53, 54, 57, 60, 61, 64, 66, 68, 71, 73, 74,
```

```
76, 78, 79, 82, 82, 83, 84, 85, 84, 82, 81, 82, 83, 84, 63, 60, 58, 57,
56, 55, 54, 57, 59, 60, 64, 65, 67, 70, 71, 75, 77, 78, 82, 84, 85, 89,
89, 90, 91, 88, 87, 88, 89, 88, 86, 84, 64, 61, 59, 58, 57, 56, 55, 58,
59, 61, 64, 65, 68, 71, 72, 75, 78, 79, 82, 85, 86, 90, 90, 91, 93, 93,
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70, 70, 73, 76, 77, 81, 83, 85, 89, 90, 93, 94, 94, 96, 96, 96, 97, 97,
95, 93, 68, 64, 63, 61, 60, 60, 58, 58, 61, 62, 64, 66, 67, 71, 71, 75,
77, 79, 82, 83, 87, 88, 91, 93, 95, 97, 97, 99, 99, 99, 100, 101, 69,
65, 65, 62, 62, 61, 60, 59, 61, 62, 64, 65, 68, 68, 72, 73, 76, 77, 81,
82, 85, 87, 89, 92, 93, 97, 98, 100, 100, 102, 102, 101, 69, 66, 66, 63,
63, 61, 61, 59, 60, 63, 63, 66, 66, 70, 70, 73, 74, 78, 78, 82, 82, 86,
87, 91, 91, 95, 96, 101, 101, 103, 103, 105,
/* Size 4x16 */
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52, 60, 76, 82, 54, 62, 79, 87, 58, 64, 82, 91, 60, 66, 84, 95, 62, 64,
84, 97, 64, 66, 81, 99, 65, 68, 83, 100,
/* Size 16x4 */
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/* Size 8x32 */
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76, 73, 54, 49, 55, 62, 70, 77, 77, 76, 54, 49, 55, 62, 70, 78, 81, 77,
57, 51, 56, 64, 73, 82, 83, 81, 59, 52, 58, 65, 74, 84, 85, 82, 60, 53,
58, 65, 75, 85, 89, 85, 63, 56, 60, 67, 77, 89, 90, 87, 64, 57, 61, 68,
78, 89, 93, 89, 64, 57, 61, 68, 78, 90, 94, 92, 66, 59, 63, 69, 79, 91,
94, 93, 67, 60, 63, 70, 78, 88, 96, 97, 68, 61, 63, 71, 79, 87, 96, 98,
69, 62, 63, 71, 80, 88, 96, 100, 70, 63, 63, 70, 80, 89, 97, 100, 71,
64, 63, 70, 78, 88, 97, 102, 72, 65, 63, 69, 77, 86, 95, 102, 73, 66,
63, 69, 76, 84, 93, 101,
/* Size 32x8 */
32, 31, 31, 30, 33, 35, 37, 42, 44, 49, 48, 48, 49, 50, 51, 52, 54, 54,
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40, 42, 44, 45, 46, 47, 46, 46, 45, 46, 47, 47, 49, 49, 51, 52, 53, 56,
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70, 70, 73, 74, 75, 77, 78, 78, 79, 78, 79, 80, 80, 78, 77, 76, 63, 60,
58, 57, 56, 55, 54, 57, 59, 60, 64, 65, 67, 70, 71, 75, 77, 78, 82, 84,
85, 89, 89, 90, 91, 88, 87, 88, 89, 88, 86, 84, 67, 63, 62, 60, 59, 58,
```

```
      57, 59, 60, 63, 64, 66, 70, 70, 73, 76, 77, 81, 83, 85, 89, 90, 93, 94,
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  },
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      /* Size 4x4 */
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      /* Size 8x8 */
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      86, 100, 109, 114, 68, 64, 72, 84, 100, 117, 128, 133, 78, 74, 80, 92,
      109, 128, 140, 155, 90, 84, 87, 98, 114, 133, 155, 168,
      /* Size 16x16 */
      32, 31, 31, 32, 34, 36, 41, 47, 54, 59, 65, 74, 82, 87, 92, 97, 31, 32,
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      102, 104, 54, 50, 49, 49, 54, 60, 67, 75, 82, 87, 92, 100, 106, 110,
      109, 112, 59, 55, 54, 53, 58, 64, 71, 79, 87, 92, 98, 106, 112, 117,
      117, 121, 65, 61, 59, 58, 63, 68, 75, 84, 92, 98, 105, 114, 120, 125,
      126, 130, 74, 69, 67, 65, 70, 75, 83, 91, 100, 106, 114, 123, 131, 135,
      137, 140, 82, 76, 73, 71, 76, 80, 88, 97, 106, 112, 120, 131, 139, 144,
      148, 150, 87, 81, 78, 75, 80, 85, 92, 100, 110, 117, 125, 135, 144, 150,
      155, 162, 92, 87, 83, 80, 84, 90, 95, 102, 109, 117, 126, 137, 148, 155,
      162, 168, 97, 92, 88, 86, 85, 91, 97, 104, 112, 121, 130, 140, 150, 162,
      168, 174,
      /* Size 32x32 */
      32, 31, 31, 31, 31, 31, 32, 32, 34, 35, 36, 39, 41, 44, 47, 48, 54, 56,
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      34, 34, 35, 38, 39, 42, 45, 45, 50, 52, 55, 60, 61, 67, 69, 74, 76, 77,
      81, 84, 87, 89, 92, 95, 31, 32, 32, 32, 32, 32, 32, 33, 33, 34, 34, 37,
      38, 41, 44, 44, 49, 51, 54, 58, 59, 65, 68, 72, 74, 75, 79, 81, 84, 86,
      88, 90, 31, 32, 32, 32, 33, 33, 33, 34, 35, 36, 36, 39, 40, 42, 44, 45,
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```

```
36, 36, 38, 40, 42, 47, 48, 50, 52, 54, 56, 57, 60, 61, 64, 67, 68, 73,
75, 79, 80, 81, 85, 87, 90, 91, 91, 92, 39, 38, 38, 37, 39, 39, 40, 42,
45, 49, 50, 54, 55, 58, 60, 61, 65, 66, 69, 72, 73, 78, 80, 84, 86, 86,
90, 91, 91, 92, 95, 97, 41, 40, 39, 38, 40, 40, 41, 43, 46, 50, 52, 55,
57, 60, 62, 63, 67, 69, 71, 75, 75, 80, 83, 86, 88, 89, 92, 93, 95, 97,
97, 98, 44, 42, 42, 41, 42, 42, 42, 44, 47, 52, 54, 58, 60, 63, 66, 67,
71, 73, 75, 79, 79, 84, 86, 90, 92, 92, 96, 98, 98, 98, 101, 104, 47,
45, 45, 44, 44, 45, 45, 47, 50, 55, 56, 60, 62, 66, 69, 70, 75, 77, 79,
83, 84, 89, 91, 95, 97, 97, 100, 99, 102, 105, 104, 104, 48, 46, 45, 44,
45, 45, 46, 47, 51, 55, 57, 61, 63, 67, 70, 71, 76, 78, 80, 84, 85, 90,
93, 96, 98, 99, 102, 106, 106, 105, 108, 111, 54, 51, 50, 49, 49, 50,
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104, 106, 106, 110, 108, 109, 112, 112, 111, 56, 53, 52, 51, 51, 51, 51,
53, 56, 60, 61, 66, 69, 73, 77, 78, 84, 86, 89, 93, 94, 100, 102, 106,
108, 109, 112, 113, 115, 114, 116, 119, 59, 56, 55, 54, 54, 54, 53, 55,
58, 62, 64, 69, 71, 75, 79, 80, 87, 89, 92, 97, 98, 103, 106, 110, 112,
113, 117, 118, 117, 121, 121, 119, 64, 61, 60, 58, 58, 58, 57, 59, 62,
66, 67, 72, 75, 79, 83, 84, 91, 93, 97, 102, 103, 109, 112, 116, 118,
119, 122, 121, 125, 123, 125, 128, 65, 62, 61, 59, 59, 59, 58, 60, 63,
67, 68, 73, 75, 79, 84, 85, 92, 94, 98, 103, 105, 111, 114, 118, 120,
121, 125, 129, 126, 129, 130, 129, 71, 68, 67, 65, 64, 64, 63, 65, 68,
72, 73, 78, 80, 84, 89, 90, 97, 100, 103, 109, 111, 117, 120, 125, 127,
128, 133, 130, 134, 133, 133, 137, 74, 71, 69, 68, 67, 67, 65, 67, 70,
74, 75, 80, 83, 86, 91, 93, 100, 102, 106, 112, 114, 120, 123, 128, 131,
131, 135, 137, 137, 138, 140, 137, 80, 76, 74, 72, 71, 71, 69, 71, 74,
78, 79, 84, 86, 90, 95, 96, 104, 106, 110, 116, 118, 125, 128, 134, 136,
137, 142, 141, 142, 143, 143, 147, 82, 78, 76, 74, 73, 73, 71, 73, 76,
79, 80, 86, 88, 92, 97, 98, 106, 108, 112, 118, 120, 127, 131, 136, 139,
139, 144, 147, 148, 147, 150, 148, 83, 78, 77, 75, 74, 74, 72, 73, 76,
80, 81, 86, 89, 92, 97, 99, 106, 109, 113, 119, 121, 128, 131, 137, 139,
140, 145, 150, 152, 155, 152, 157, 87, 83, 81, 79, 78, 78, 75, 77, 80,
83, 85, 90, 92, 96, 100, 102, 110, 112, 117, 122, 125, 133, 135, 142,
144, 145, 150, 151, 155, 158, 162, 158, 90, 85, 84, 81, 80, 80, 78, 78,
82, 84, 87, 91, 93, 98, 99, 106, 108, 113, 118, 121, 129, 130, 137, 141,
147, 150, 151, 156, 156, 161, 164, 169, 92, 88, 87, 84, 83, 82, 80, 80,
84, 85, 90, 91, 95, 98, 102, 106, 109, 115, 117, 125, 126, 134, 137,
142, 148, 152, 155, 156, 162, 162, 168, 170, 95, 90, 89, 86, 85, 84, 83,
82, 85, 87, 91, 92, 97, 98, 105, 105, 112, 114, 121, 123, 129, 133, 138,
143, 147, 155, 158, 161, 162, 168, 168, 174, 97, 92, 92, 88, 88, 86, 86,
84, 85, 90, 91, 95, 97, 101, 104, 108, 112, 116, 121, 125, 130, 133,
140, 143, 150, 152, 162, 164, 168, 168, 174, 175, 100, 95, 95, 90, 90,
89, 89, 86, 86, 92, 92, 97, 98, 104, 104, 111, 111, 119, 119, 128, 129,
137, 137, 147, 148, 157, 158, 169, 170, 174, 175, 181,
/* Size 4x8 */
32, 35, 59, 83, 32, 36, 57, 78, 34, 47, 65, 82, 41, 53, 78, 97, 51, 61,
92, 111, 65, 73, 108, 129, 75, 81, 117, 148, 86, 92, 119, 154,
/* Size 8x4 */
32, 32, 34, 41, 51, 65, 75, 86, 35, 36, 47, 53, 61, 73, 81, 92, 59, 57,
65, 78, 92, 108, 117, 119, 83, 78, 82, 97, 111, 129, 148, 154,
/* Size 8x16 */
```

```
32, 31, 35, 44, 53, 65, 82, 90, 31, 32, 34, 41, 50, 61, 76, 85, 31, 33,
35, 42, 49, 59, 73, 81, 32, 34, 37, 42, 49, 58, 71, 79, 34, 35, 41, 48,
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88, 93, 47, 44, 53, 66, 75, 84, 97, 101, 53, 50, 57, 71, 82, 92, 106,
108, 58, 54, 61, 75, 87, 98, 112, 116, 65, 59, 66, 79, 92, 105, 120,
124, 74, 67, 73, 86, 100, 113, 131, 134, 82, 73, 79, 92, 105, 120, 139,
142, 87, 78, 83, 96, 110, 125, 144, 153, 92, 83, 84, 97, 114, 132, 150,
157, 97, 88, 86, 97, 111, 128, 147, 163,
/* Size 16x8 */
32, 31, 31, 32, 34, 36, 41, 47, 53, 58, 65, 74, 82, 87, 92, 97, 31, 32,
33, 34, 35, 36, 40, 44, 50, 54, 59, 67, 73, 78, 83, 88, 35, 34, 35, 37,
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60, 66, 71, 75, 79, 86, 92, 96, 97, 97, 53, 50, 49, 49, 54, 60, 67, 75,
82, 87, 92, 100, 105, 110, 114, 111, 65, 61, 59, 58, 63, 68, 76, 84, 92,
98, 105, 113, 120, 125, 132, 128, 82, 76, 73, 71, 76, 80, 88, 97, 106,
112, 120, 131, 139, 144, 150, 147, 90, 85, 81, 79, 81, 87, 93, 101, 108,
116, 124, 134, 142, 153, 157, 163,
/* Size 16x32 */
32, 31, 31, 32, 35, 36, 44, 47, 53, 62, 65, 79, 82, 88, 90, 93, 31, 32,
32, 32, 35, 35, 42, 45, 51, 59, 62, 75, 78, 83, 86, 88, 31, 32, 32, 32,
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41, 44, 49, 57, 59, 72, 74, 79, 82, 84, 31, 32, 33, 34, 35, 36, 42, 44,
49, 57, 59, 71, 73, 79, 81, 84, 32, 32, 33, 34, 36, 36, 42, 45, 50, 57,
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71, 76, 79, 83, 32, 33, 34, 36, 39, 40, 44, 47, 51, 58, 60, 71, 73, 76,
78, 80, 34, 34, 35, 37, 41, 42, 48, 50, 54, 61, 63, 73, 76, 81, 81, 80,
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36, 38, 46, 48, 54, 56, 60, 66, 68, 78, 80, 85, 87, 86, 39, 37, 39, 40,
48, 50, 58, 60, 65, 71, 73, 84, 86, 89, 88, 91, 41, 39, 40, 41, 49, 51,
60, 62, 67, 74, 76, 86, 88, 91, 93, 91, 44, 41, 42, 43, 51, 53, 63, 66,
71, 78, 79, 90, 92, 97, 94, 97, 47, 44, 44, 45, 53, 56, 66, 69, 75, 82,
84, 95, 97, 98, 101, 98, 48, 45, 45, 46, 54, 56, 67, 70, 76, 83, 85, 96,
98, 104, 101, 105, 53, 49, 50, 50, 57, 60, 71, 75, 82, 90, 92, 103, 106,
107, 108, 105, 55, 51, 51, 51, 59, 61, 72, 77, 84, 92, 94, 106, 108,
111, 110, 112, 58, 54, 54, 54, 61, 63, 75, 79, 87, 95, 98, 110, 112,
117, 116, 113, 63, 58, 58, 57, 65, 67, 78, 83, 91, 100, 103, 116, 118,
119, 119, 121, 65, 60, 59, 58, 66, 68, 79, 84, 92, 102, 105, 118, 120,
127, 124, 122, 71, 65, 64, 63, 71, 73, 84, 89, 97, 108, 111, 125, 127,
129, 129, 130, 74, 68, 67, 66, 73, 75, 86, 91, 100, 110, 113, 128, 131,
135, 134, 130, 79, 72, 71, 70, 77, 79, 90, 95, 104, 115, 118, 133, 136,
140, 139, 140, 82, 75, 73, 72, 79, 81, 92, 97, 105, 117, 120, 136, 139,
145, 142, 140, 82, 75, 74, 72, 79, 81, 92, 97, 106, 117, 121, 136, 139,
148, 150, 149, 87, 79, 78, 76, 83, 85, 96, 100, 110, 120, 125, 141, 144,
148, 153, 150, 89, 82, 81, 78, 83, 87, 97, 99, 113, 118, 128, 139, 145,
153, 157, 161, 92, 84, 83, 80, 84, 89, 97, 101, 114, 116, 132, 135, 150,
153, 157, 162, 94, 86, 85, 82, 85, 92, 97, 104, 112, 119, 130, 136, 151,
154, 163, 166, 97, 88, 88, 85, 86, 94, 97, 107, 111, 123, 128, 140, 147,
159, 163, 167, 99, 91, 91, 87, 87, 97, 97, 110, 110, 126, 126, 144, 144,
163, 163, 173,
/* Size 32x16 */
```

```
32, 31, 31, 31, 31, 32, 32, 32, 34, 35, 36, 39, 41, 44, 47, 48, 53, 55,
58, 63, 65, 71, 74, 79, 82, 82, 87, 89, 92, 94, 97, 99, 31, 32, 32, 32,
32, 32, 33, 33, 34, 34, 34, 37, 39, 41, 44, 45, 49, 51, 54, 58, 60, 65,
68, 72, 75, 75, 79, 82, 84, 86, 88, 91, 31, 32, 32, 32, 33, 33, 34, 34,
35, 36, 36, 39, 40, 42, 44, 45, 50, 51, 54, 58, 59, 64, 67, 71, 73, 74,
78, 81, 83, 85, 88, 91, 32, 32, 32, 33, 34, 34, 35, 36, 37, 38, 38, 40,
41, 43, 45, 46, 50, 51, 54, 57, 58, 63, 66, 70, 72, 72, 76, 78, 80, 82,
85, 87, 35, 35, 34, 34, 35, 36, 37, 39, 41, 45, 46, 48, 49, 51, 53, 54,
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68, 73, 75, 79, 81, 81, 85, 87, 89, 92, 94, 97, 44, 42, 41, 41, 42, 42,
42, 44, 48, 52, 54, 58, 60, 63, 66, 67, 71, 72, 75, 78, 79, 84, 86, 90,
92, 92, 96, 97, 97, 97, 97, 97, 47, 45, 45, 44, 44, 45, 45, 47, 50, 55,
56, 60, 62, 66, 69, 70, 75, 77, 79, 83, 84, 89, 91, 95, 97, 97, 100, 99,
101, 104, 107, 110, 53, 51, 50, 49, 49, 50, 49, 51, 54, 59, 60, 65, 67,
71, 75, 76, 82, 84, 87, 91, 92, 97, 100, 104, 105, 106, 110, 113, 114,
112, 111, 110, 62, 59, 58, 57, 57, 57, 56, 58, 61, 65, 66, 71, 74, 78,
82, 83, 90, 92, 95, 100, 102, 108, 110, 115, 117, 117, 120, 118, 116,
119, 123, 126, 65, 62, 61, 59, 59, 59, 58, 60, 63, 67, 68, 73, 76, 79,
84, 85, 92, 94, 98, 103, 105, 111, 113, 118, 120, 121, 125, 128, 132,
130, 128, 126, 79, 75, 74, 72, 71, 71, 69, 71, 73, 77, 78, 84, 86, 90,
95, 96, 103, 106, 110, 116, 118, 125, 128, 133, 136, 136, 141, 139, 135,
136, 140, 144, 82, 78, 76, 74, 73, 73, 71, 73, 76, 79, 80, 86, 88, 92,
97, 98, 106, 108, 112, 118, 120, 127, 131, 136, 139, 139, 144, 145, 150,
151, 147, 144, 88, 83, 82, 79, 79, 78, 76, 76, 81, 82, 85, 89, 91, 97,
98, 104, 107, 111, 117, 119, 127, 129, 135, 140, 145, 148, 148, 153,
153, 154, 159, 163, 90, 86, 85, 82, 81, 80, 79, 78, 81, 83, 87, 88, 93,
94, 101, 101, 108, 110, 116, 119, 124, 129, 134, 139, 142, 150, 153,
157, 157, 163, 163, 163, 93, 88, 88, 84, 84, 82, 83, 80, 80, 86, 86, 91,
91, 97, 98, 105, 105, 112, 113, 121, 122, 130, 130, 140, 140, 149, 150,
161, 162, 166, 167, 173,
/* Size 4x16 */
31, 36, 62, 88, 32, 35, 58, 82, 32, 36, 57, 79, 33, 38, 56, 76, 34, 42,
61, 81, 34, 48, 66, 85, 39, 51, 74, 91, 44, 56, 82, 98, 49, 60, 90, 107,
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/* Size 16x4 */
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81, 85, 91, 98, 107, 117, 127, 135, 145, 148, 153, 159,
/* Size 8x32 */
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```

```
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    129, 74, 67, 73, 86, 100, 113, 131, 134, 79, 71, 77, 90, 104, 118, 136,
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    163,
    /* Size 32x8 */
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    163, 163 },
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```

```
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84, 85, 83, 84, 84, 82, 60, 57, 56, 54, 53, 53, 52, 53, 55, 58, 58, 61,
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80, 81, 85, 86, 89, 91, 93, 94, 95, 97, 97, 98, 98, 100, 68, 65, 64, 62,
```

```
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100, 100, 102, 101, 71, 67, 67, 64, 64, 62, 62, 60, 60, 64, 64, 67, 67,
70, 70, 74, 74, 78, 78, 82, 82, 86, 86, 91, 91, 95, 95, 100, 100, 101,
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77, 84, 93, 95, 68, 61, 61, 68, 77, 86, 94, 97, 70, 63, 61, 67, 75, 83,
92, 98,
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97, 98,
/* Size 16x32 */
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54, 50, 49, 49, 54, 55, 62, 65, 68, 72, 73, 78, 79, 80, 79, 76, 56, 51,
```

```
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```

```
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```

```
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95, 97, 48, 46, 45, 45, 50, 57, 61, 67, 71, 76, 80, 86, 93, 98, 101,
104, 54, 51, 49, 49, 53, 60, 65, 71, 76, 82, 87, 93, 100, 105, 109, 112,
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77, 75, 78, 84, 89, 95, 101, 109, 116, 125, 135, 142, 147, 153, 91, 86,
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89, 93, 94, 95, 98, 98, 100, 103, 48, 46, 46, 44, 45, 45, 45, 46, 50,
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99, 101, 104, 104, 103, 52, 50, 49, 48, 48, 48, 48, 48, 52, 53, 59, 59,
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106, 107, 110, 54, 51, 51, 49, 49, 50, 49, 49, 53, 54, 60, 60, 65, 67,
71, 74, 76, 80, 82, 86, 87, 92, 93, 97, 100, 104, 105, 106, 109, 112,
112, 110, 58, 56, 55, 53, 53, 53, 53, 53, 57, 58, 63, 64, 68, 70, 75,
77, 80, 84, 86, 91, 91, 97, 98, 103, 105, 110, 111, 112, 115, 114, 115,
118, 59, 56, 56, 54, 54, 54, 53, 53, 57, 58, 64, 64, 69, 70, 75, 78, 80,
85, 87, 91, 92, 98, 99, 103, 106, 110, 112, 113, 116, 119, 120, 119, 65,
62, 61, 59, 59, 59, 58, 58, 62, 63, 68, 68, 73, 75, 79, 82, 85, 90, 92,
```

```
97, 98, 105, 106, 111, 114, 118, 120, 121, 124, 123, 123, 126, 66, 63,
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99, 106, 107, 112, 115, 119, 121, 122, 125, 128, 129, 126, 71, 68, 67,
65, 65, 64, 63, 63, 67, 68, 73, 73, 78, 80, 84, 87, 90, 95, 97, 103,
103, 111, 112, 117, 120, 125, 127, 128, 131, 132, 132, 135, 74, 71, 70,
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106, 114, 115, 120, 123, 128, 130, 131, 135, 135, 138, 136, 80, 76, 75,
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110, 118, 119, 125, 128, 134, 136, 137, 140, 142, 140, 144, 81, 77, 77,
74, 73, 73, 71, 71, 74, 75, 80, 80, 85, 87, 91, 94, 98, 103, 105, 111,
112, 120, 121, 127, 130, 136, 137, 139, 142, 145, 148, 144, 83, 78, 78,
75, 74, 74, 72, 72, 75, 76, 81, 81, 86, 88, 92, 95, 99, 104, 106, 112,
113, 121, 122, 128, 131, 137, 139, 140, 144, 148, 150, 155, 86, 82, 81,
78, 77, 77, 75, 74, 78, 79, 84, 84, 89, 91, 95, 98, 101, 106, 109, 115,
116, 124, 125, 131, 135, 140, 142, 144, 147, 149, 153, 155, 89, 84, 84,
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119, 123, 128, 132, 135, 142, 145, 148, 149, 153, 154, 159, 91, 86, 86,
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120, 123, 129, 132, 138, 140, 148, 150, 153, 154, 159, 159, 93, 88, 88,
84, 84, 83, 83, 80, 81, 86, 86, 91, 91, 96, 97, 103, 103, 110, 110, 118,
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60, 63, 75, 90, 106, 119, 126, 74, 67, 69, 81, 97, 113, 128, 134, 81,
73, 75, 86, 102, 120, 135, 143, 86, 78, 78, 90, 106, 124, 140, 147, 91,
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111, 118, 126, 134, 143, 147, 151,
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80, 77, 80, 86, 90, 98, 105, 112, 122, 127, 140, 144, 152, 155, 91, 83,
82, 79, 80, 88, 90, 100, 103, 114, 119, 130, 137, 148, 151, 155, 93, 85,
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73, 74, 78, 80, 82, 85, 32, 32, 32, 33, 33, 34, 35, 35, 36, 37, 38, 38,
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90, 92, 97, 98, 105, 106, 111, 113, 118, 120, 121, 124, 122, 119, 117,
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93, 98, 99, 106, 107, 112, 115, 119, 121, 122, 125, 127, 130, 134, 79,
75, 74, 72, 71, 71, 69, 69, 72, 73, 78, 79, 84, 85, 90, 93, 96, 101,
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```
103, 109, 110, 118, 119, 125, 128, 133, 135, 136, 140, 140, 137, 134,
81, 77, 76, 74, 73, 72, 71, 70, 74, 75, 80, 80, 85, 87, 91, 94, 98, 103,
105, 111, 112, 119, 121, 127, 130, 135, 137, 139, 142, 144, 148, 151,
87, 83, 82, 79, 79, 78, 77, 75, 78, 80, 84, 85, 89, 90, 96, 97, 103,
105, 111, 113, 118, 122, 126, 131, 134, 141, 143, 147, 147, 152, 151,
152, 90, 85, 85, 81, 81, 80, 80, 77, 78, 83, 83, 87, 88, 93, 93, 100,
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155, 160,
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49, 60, 82, 105, 54, 63, 87, 112, 61, 69, 93, 121, 68, 75, 100, 130, 74,
80, 105, 137, 78, 84, 109, 142, 83, 88, 114, 148,
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80, 85, 91, 98, 105, 112, 121, 130, 137, 142, 148,
/* Size 8x32 */
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42, 51, 59, 68, 79, 85, 39, 38, 44, 54, 63, 73, 84, 89, 40, 39, 45, 56,
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73, 75, 86, 102, 120, 135, 143, 82, 74, 75, 87, 103, 121, 136, 147, 86,
78, 78, 90, 106, 124, 140, 147, 88, 80, 80, 90, 105, 122, 140, 152, 91,
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32, 31, 31, 31, 31, 32, 32, 32, 33, 34, 36, 36, 39, 40, 44, 46, 48, 52,
53, 58, 58, 65, 66, 71, 74, 79, 81, 82, 86, 88, 91, 93, 31, 32, 32, 32,
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65, 62, 61, 59, 59, 59, 58, 58, 62, 63, 68, 68, 73, 75, 79, 82, 85, 90,
92, 97, 98, 105, 106, 111, 113, 118, 120, 121, 124, 122, 119, 117, 79,
75, 74, 72, 71, 71, 69, 69, 72, 73, 78, 79, 84, 85, 90, 93, 96, 101,
103, 109, 110, 118, 119, 125, 128, 133, 135, 136, 140, 140, 137, 134,
87, 83, 82, 79, 79, 78, 77, 75, 78, 80, 84, 85, 89, 90, 96, 97, 103,
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```
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```
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110, 118, 125, 133, 136,
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```

```
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/* Size 16x4 */
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```

```
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134, 134,
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114, 120, 71, 66, 65, 64, 63, 68, 73, 76, 84, 85, 97, 97, 108, 111, 119,
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103, 108, 108, 115, 115, 65, 62, 62, 60, 59, 59, 59, 59, 58, 58, 63, 63,
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111, 118, 118, 73, 70, 69, 67, 66, 66, 65, 65, 64, 64, 69, 69, 73, 74,
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```
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        37, 37, 37, 37, 38, 38, 38, 38, 38, 38, 38, 38, 39, 40, 40, 41, 41, 41,
        41, 41, 41, 42 },
    },
    {
        { /* Luma */
        /* Size 4x4 */
        31, 31, 31, 31, 31, 32, 32, 32, 31, 32, 32, 32, 31, 32, 32, 32,
        /* Size 8x8 */
        31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31, 31,
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        /* Size 16x16 */
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/* Size 4x8 */
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/* Size 8x4 */
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/* Size 8x16 */
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/* Size 16x8 */
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/* Size 16x32 */
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/* Size 32x16 */
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/* Size 4x16 */
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    /* Size 16x4 */
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    /* Size 8x32 */
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    /* Size 32x8 */
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    32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32, 32,
    32, 32, 32, 32 },
  { /* Chroma */
    /* Size 4x4 */
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    /* Size 8x8 */
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    31, 31, 30, 31, 31, 31, 31, 31, 31, 31,
    /* Size 16x16 */
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        32, 32, 32, 32 },
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}
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Annex A: Profiles and levels

A.1. General

Profiles and levels specify restrictions on the capabilities needed to decode the bitstreams.

The profile specifies the bit depth and subsampling formats supported, while the level defines resolution and performance characteristics.

A.2. Profiles

There are three named profiles:

- “Main” compliant decoders must be able to decode streams with seq_profile equal to 0.
- “High” compliant decoders must be able to decode streams with seq_profile less than or equal to 1.
- “Professional” compliant decoders must be able to decode streams with seq_profile less than or equal to 2.

Note: The Main profile supports YUV 4:2:0 or monochrome bitstreams with bit depth equal to 8 or 10. The High profile further adds support for 4:4:4 bitstreams with the same bit depth constraints. Finally, the Professional profile extends support over the High profile to also bitstreams with bit depth equal to 12, and also adds support for the 4:2:2 video format.

A.3. Levels

Each operating point contains a syntax element seq_level_idx.

The following table defines the mapping from the syntax element (which takes integer values) to the defined levels:

Value of seq_level_idx	Level
0	2.0
1	2.1
2	2.2
3	2.3
4	3.0
5	3.1
6	3.2
7	3.3
8	4.0

Value of seq_level_idx	Level
9	4.1
10	4.2
11	4.3
12	5.0
13	5.1
14	5.2
15	5.3
16	6.0
17	6.1
18	6.2
19	6.3
20	7.0
21	7.1
22	7.2
23	7.3
24-30	Reserved
31	Maximum parameters

Note: The level uses a X.Y format. X is equal to 2 + (seq_level_idx >> 2). Y is given by (seq_level_idx & 3).

The level defines variables as specified in the following tables:

Level	MaxPicSize (Samples)	MaxHSize (Samples)	MaxVSize (Samples)	MaxDisplayRate (Samples/sec)	MaxDecodeRate (Samples/sec)
2.0	147456	2048	1152	4,423,680	5,529,600
2.1	278784	2816	1584	8,363,520	10,454,400
3.0	665856	4352	2448	19,975,680	24,969,600
3.1	1065024	5504	3096	31,950,720	39,938,400
4.0	2359296	6144	3456	70,778,880	77,856,768
4.1	2359296	6144	3456	141,557,760	155,713,536

Level	MaxPicSize	MaxHSize	MaxVSize	MaxDisplayRate	MaxDecodeRate
	(Samples)	(Samples)	(Samples)	(Samples/sec)	(Samples/sec)
5.0	8912896	8192	4352	267,386,880	273,715,200
5.1	8912896	8192	4352	534,773,760	547,430,400
5.2	8912896	8192	4352	1,069,547,520	1,094,860,800
5.3	8912896	8192	4352	1,069,547,520	1,176,502,272
6.0	35651584	16384	8704	1,069,547,520	1,176,502,272
6.1	35651584	16384	8704	2,139,095,040	2,189,721,600
6.2	35651584	16384	8704	4,278,190,080	4,379,443,200
6.3	35651584	16384	8704	4,278,190,080	4,706,009,088

Note: The missing entries in these tables (for example level 2.2 and 7.0) represent levels that are not yet defined.

Level	MaxHeaderRate	MainMbps	HighMbps	MainCR	HighCR	MaxTiles	MaxTileCols	Example
	(/sec)	(MBits/ sec)	(MBits/ sec)					
2.0	150	1.5	-	2	-	8	4	426x240@30fps
2.1	150	3.0	-	2	-	8	4	640x360@30fps
3.0	150	6.0	-	2	-	16	6	854x480@30fps
3.1	150	10.0	-	2	-	16	6	1280x720@30fps
4.0	300	12.0	30.0	4	4	32	8	1920x1080@30fps
4.1	300	20.0	50.0	4	4	32	8	1920x1080@60fps
5.0	300	30.0	100.0	6	4	64	8	3840x2160@30fps
5.1	300	40.0	160.0	8	4	64	8	3840x2160@60fps
5.2	300	60.0	240.0	8	4	64	8	3840x2160@120fps
5.3	300	60.0	240.0	8	4	64	8	3840x2160@120fps
6.0	300	60.0	240.0	8	4	128	16	7680x4320@30fps
6.1	300	100.0	480.0	8	4	128	16	7680x4320@60fps
6.2	300	160.0	800.0	8	4	128	16	7680x4320@120fps
6.3	300	160.0	800.0	8	4	128	16	7680x4320@120fps

Note: Examples are given for non-scalable cases, but the constraints also apply to each operating point of a scalable stream. For example, consider a 60fps spatial scalable stream with a base layer at 960x540, and an enhancement layer at 1920x1080. The operating point containing just the base layer may be labelled as level 3.0, while the operating point containing both the base and enhancement layer may be labelled as level 4.1.

Note: HighMbps and HighCR values are not defined for levels below level 4.0. seq_tier equal to 1 can only be signaled for level 4.0 and above.

The bitstream constraints depend on the variables in the table, and additional variables derived as follows:

- TileWidth is defined as (MiColEnd - MiColStart) * MI_SIZE
- TileHeight is defined as (MiRowEnd - MiRowStart) * MI_SIZE
- RightMostTile is defined as MiColEnd == MiCols
- CroppedTileWidth is defined as FrameWidth - MiColStart * MI_SIZE
- CroppedTileHeight is defined as FrameHeight - MiRowStart * MI_SIZE
- MaxTileSizeInLumaSamples is defined as the largest product of TileWidth * TileHeight for all tiles within the coded video sequence
- showCount for a particular frame is defined as the number of times the frame is shown (either due to show_frame equal to 1, or via the show_existing_frame mechanism)
- TotalDisplayLumaSampleRate is defined as the sum of the UpscaledWidth * FrameHeight * showCount of all frames that belong to the temporal unit that belongs to the operating point, divided by the time difference between the display time of the first frame of the current temporal unit and the display time of the first frame of the next temporal unit (if present). For the last temporal unit in the bitstream, the time difference from the previous temporal unit is used. In particular, for spatial and quality scalability, this limit applies to output pictures that belong to this particular layer. For temporal scalability, this restriction applies to the output pictures that belong to the indicated scalability layer and to the layers below.
- TotalDecodedLumaSampleRate is defined as the sum of the UpscaledWidth * FrameHeight of all frames with show_existing_frame equal to 0 that belong to the temporal unit that belongs to the operating point, divided by the time difference between the decoding time of the first frame of the current temporal unit and the decoding time of the first frame of the next temporal unit (if present). For the last temporal unit in the bitstream, the time difference from the previous temporal unit is used.
- NumFrameHeadersSec is defined as the number of OBU_FRAME and OBU_FRAME_HEADER OBUs received per second (this number does not include duplicate frame headers or frame headers with show_existing_frame equal to 1)

- CompressedSize is defined for each frame as the total bytes in the OBUs related to this frame (OBU_FRAME, OBU_FRAME_HEADER, OBU_METADATA, OBU_TILE_GROUP), minus 128 (to allow for overhead of metadata and header data)
- If seq_profile is equal to 0, PicSizeProfileFactor is set equal to 15, else if seq_profile is equal to 1, PicSizeProfileFactor is set equal to 30, otherwise PicSizeProfileFactor is set equal to 36
- UnCompressedSize is defined for each frame as (UpscaledWidth * FrameHeight * PicSizeProfileFactor) » 3
- SpeedAdj is defined as TotalDecodedLumaSampleRate ÷ MaxDisplayRate
- If seq_tier is equal to 0, MinCompBasis is set equal to MainCR, otherwise MinCompBasis is set equal to HighCR
- If still_picture is equal to 0, MinPicCompressRatio is set equal to Max(0.8, MinCompBasis * SpeedAdj), otherwise MinPicCompressRatio is set equal to 0.8
- CompressedRatio is defined as UnCompressedSize ÷ CompressedSize

Note: The ÷ operator represents standard mathematical division (in contrast to the / operator which represents integer division).

If scalability_mode_idc is not present or equal to a reserved value, then TemporalParallelNum and TemporalParallelDen are defined to be equal to 1.

Otherwise, if scalability_mode_idc is not equal to SCALABILITY_SS, TemporalParallelDen is defined as 1 and TemporalParallelNum is defined as (1 << (TemporalLayers - 1)) where TemporalLayers is the number of temporal layers as defined in the semantics for scalability_mode_idc.

Otherwise (scalability_mode_idc is equal to SCALABILITY_SS), TemporalParallelNum and TemporalParallelDen are defined as follows:

```
NumIndependent = 0
for ( i = 0; i < temporal_group_size; i++ ) {
  if ( temporal_group_temporal_id[ i ] ) {
    independent = 1
    for ( j = 0; j < temporal_group_ref_cnt[ i ]; j++ ) {
      ref = (i - temporal_group_ref_pic_diff[ i ][ j ] + temporal_group_size) % temporal_group_size
      if ( temporal_group_temporal_id[ ref ] == temporal_group_temporal_id[ i ] )
        independent = 0
    }
    NumIndependent += independent
  }
}
TemporalParallelNum = temporal_group_size
TemporalParallelDen = temporal_group_size - NumIndependent
```

When the mapped level is contained in the tables above, it is a requirement of bitstream conformance that the following constraints hold:

- UpscaledWidth * FrameHeight is less than or equal to MaxPicSize
- UpscaledWidth is less than or equal to MaxHSize
- FrameHeight is less than or equal to MaxVSize
- TotalDisplayLumaSampleRate is less than or equal to MaxDisplayRate
- TotalDecodedLumaSampleRate is less than or equal to MaxDecodeRate
- NumFrameHeadersSec is less than or equal to MaxHeaderRate
- The number of tiles per second is less than or equal to MaxTiles * 120
- NumTiles is less than or equal to MaxTiles
- TileCols is less than or equal to MaxTileCols
- CompressedRatio is greater than or equal to MinPicCompressRatio
- (TileWidth * SuperresDenom / SUPERRES_NUM) is less than or equal to MAX_TILE_WIDTH for each tile
- For each tile, if use_superres is equal to 0 and RightMostTile is equal to 0, then TileWidth is greater than or equal to 64
- For each tile, if use_superres is equal to 1 and RightMostTile is equal to 0, then TileWidth is greater than or equal to 128
- TileWidth * TileHeight is less than or equal to 4096 * 2304 for each tile
- FrameWidth is greater than or equal to 16
- FrameHeight is greater than or equal to 16
- CroppedTileWidth is greater than or equal to 8 for each tile
- CroppedTileHeight is greater than or equal to 8 for each tile
- MaxTileSizeInLumaSamples * NumFrameHeadersSec * TemporalParallelDen/TemporalParallelNum is less than or equal to 588,251,136 (where this number is the decode luma sample rate of 4096x2176 * 60fps * 1.1)

Note: The purpose of this constraint is to ensure that for decode luma sample rates above 4K60 there is sufficient parallelism for decoder implementations. Parallelism can be chosen by the encoder as either tile level parallelism or temporal layer parallelism or a combination provided the above constraint holds. The constraint has no effect on levels 5.1 and below.

If seq_level_idx is equal to 31 (indicating the maximum parameters level), then there are no level-based constraints on the bitstream.

> **Note:** The maximum parameters level should only be set for bitstreams that do not conform to any other level. Typically this would be used for large resolution still images.

The buffer model is used to define additional conformance requirements.

These requirements depend on the following level, tier, and profile dependent variables:

- If seq_tier is equal to 0, MaxBitrate is equal to MainMbps multiplied by 1,000,000
- Otherwise (seq_tier is equal to 1), MaxBitrate is equal to HighMbps multiplied by 1,000,000
- MaxBufferSize is equal to MaxBitrate multiplied by 1 second
- If seq_profile is equal to 0, BitrateProfileFactor is equal to 1.0
- If seq_profile is equal to 1, BitrateProfileFactor is equal to 2.0
- If seq_profile is equal to 2, BitrateProfileFactor is equal to 3.0

A.4. Decoder Conformance

A level X.Y compliant decoder must be able to decode all bitstreams (that can be decoded by the general decoding process) that conform to that level.

When doing that, the decoder must be able to display output frames according to the display schedule if such is indicated by the bitstream.

> **Note:** If the level of a bitstream is equal to 31 (indicating the maximum parameters level), the decoder should examine the properties of the bitstream and decide whether to decode it or not. There is no assurance that all pictures will be decoded. A decoder would typically decode pictures up to a certain maximum uncompressed picture size (or maximum compressed picture size or maximum width or maximum tile size) that the decoder maker considers sufficiently extreme for their use case, and not decode anything bigger than that.

A level X.Y compliant decoder should be able to decode tile list OBUs (via the large scale tile decoding process) at a rate of 180 tile list OBUs per second subject to the following level-dependent constraints:

- UpscaledWidth * FrameHeight is less than or equal to MaxPicSize
- UpscaledWidth is less than or equal to MaxHSize
- FrameHeight is less than or equal to MaxVSize
- TileWidth * TileHeight * (tile_count_minus_1 + 1) * 180 is less than or equal to (MaxDecodeRate / 2)

- For each tile list OBU, BytesPerTileList * 8 * 180 is less than or equal to MaxBitrate

Where BytesPerTileList is defined as the sum of (coded_tile_data_size_minus_1 + 1) for each tile list entry in the tile list OBU.

Annex B: Length delimited bitstream format

B.1. Overview

Section 5 defines the syntax for OBUs. Section 5.2 defines the low-overhead bitstream format. This annex defines a length-delimited format for packing OBUs into a format that enables skipping through temporal units and frames more easily.

B.2. Length delimited bitstream syntax

bitstream( ) {	Type
while (more_data_in_bitstream()) {	
temporal_unit_size	leb128()
temporal_unit(temporal_unit_size)	
}	
}	

temporal_unit(sz) {	Type
while (sz > 0) {	
frame_unit_size	leb128()
sz -= Leb128Bytes	
frame_unit(frame_unit_size)	
sz -= frame_unit_size	
}	
}	

frame_unit(sz) {	Type
while (sz > 0) {	
obu_length	leb128()
sz -= Leb128Bytes	
open_bitstream_unit(obu_length)	
sz -= obu_length	
}	
}	

B.3. Length delimited bitstream semantics

more_data_in_bitstream() is a system-dependent method of determining whether the end of the bitstream has been reached. It returns 1 when there is more data to be read, or 0 when the end of the bitstream has been reached.

temporal_unit_size specifies the length in bytes of the next temporal unit.

frame_unit_size specifies the length in bytes of the next frame unit.

obu_length specifies the length in bytes of the next OBU.

> **Note:** It is allowed for the OBU to set obu_has_size_field equal to 1 to indicate that the obu_size syntax element is present. In this case, the decoding process assumes that obu_size and obu_length are set consistently. If obu_size and obu_length are both present, but inconsistent, then the packed bitstream is deemed invalid.

The first OBU in the first frame_unit of each temporal_unit must be a temporal delimiter OBU (and this is the only place temporal delimiter OBUs can appear).

All the frame header and tile group OBUs required for decoding a single frame must be within the same frame_unit (and a frame_unit must not contain frame headers for more than one frame).

Annex C: Error resilience behavior (informative)

C.1. General

This annex defines additional starting points for decoding.

It is recommended that decoders should support these starting points. (This annex is marked as informative because it is not mandatory for a conformant decoder to support these starting points.)

The intention is to allow decoders to start even when the decoded output may be corrupted.

A property of a bitstream is defined in section C.2.

The recommendations are expressed in section C.3.

The consequences for encoders are specified in section C.4.

The consequences for decoders are specified in section C.5.

C.2. Definition of processable frames

This section defines a property of frames that is called being “processable”.

Informally, a frame is processable if it is certain (based on the current state and information in the frame header) that everything other than the sample values can be decoded correctly.

In particular, a frame that is processable will have correct values for:

- All syntax elements
- The size, bitdepth, subsampling structure of any output frames
- All values written in the reference frame update process specified in section 7.20, except for the contents of FrameStore (which may or may not be correct).

In most codecs, this concept is unnecessary because it is trivial to determine if frames are processable (either because all frames are automatically processable, or because the conditions are straightforward). However, AV1 makes greater use of state in the reference frames and so the condition for being processable is more complicated.

Formally, the property of being processable is defined as follows.

A frame with show_existing_frame equal to 0 is defined to be processable if the following conditions are met:

- Either primary_ref_frame is equal to PRIMARY_REF_NONE or ref_frame_idx[primary_ref_frame] indicates a frame that has been processed
- Either use_ref_frame_mvs is equal to 0, or ref_frame_idx[i] indicates a frame that has been processed for all i = 0..REFS_PER_FRAME-1

- Either allow_warped_motion is equal to 0, or ref_frame_idx[i] indicates a frame that has been processed for all i = 0..REFS_PER_FRAME-1 (this is necessary because the motion_mode syntax parsing depends on whether the reference frame has been scaled - but this is not known unless the frame has been processed)
- The decoding process for the frame does not use values in RefOrderHint before they have been written (written either by the decoding process for the current frame, or written when a previous frame was processed)
- If the syntax element found_ref is equal to 1, ref_frame_idx[i] indicates a frame that has been processed (this is necessary because the frame dimensions are only correct for processed frames)

A frame with show_existing_frame equal to 1 is processable if the following condition is met:

- frame_to_show_map_idx indicates a frame that has been processed

(A frame being “processed” means that the frame was processable and has been decoded.)

C.3. Recommendation for processable frames

It is recommended that decoders should support decoding bitstreams if the first temporal unit contains a sequence header and all frames contained in the bitstream are processable according to the definition above.

As the inter prediction may depend on missing reference frames, there is not a requirement that exactly the same output samples as the reference code are produced.

In certain cases (e.g. when the first frame only contains intra coded blocks), it is possible that correct output is produced, but, in general, error concealment techniques may be required.

C.4. Encoder consequences of processable frames

If an application chooses to use a non-key frame starting point, then the encoder needs to be careful that the resulting bitstream is processable.

There are some features of the bitstream specification that make this easier to achieve:

- primary_ref_frame, use_ref_frame_mvs, and allow_warped_motion can be controlled at a frame level to satisfy the corresponding conditions
- setting error_resilient_mode equal to 1 causes the order hints to be transmitted if necessary
- found_ref can be cleared to allow the frame resolution to be sent explicitly

C.5. Decoder consequences of processable frames

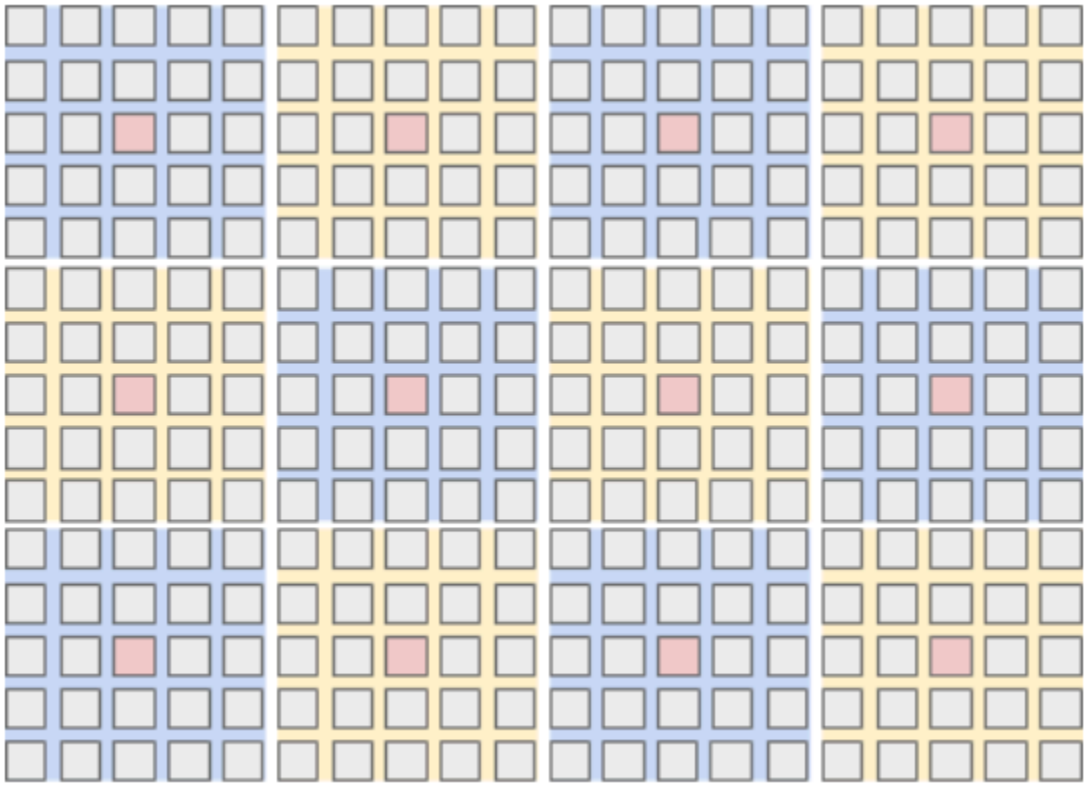
For the decoding process to handle this mode of operation, the following modifications should be used:

- RefValid[i] should be set equal to 0 for i = 0..NUM_REF_FRAMES-1 before the decoding process begins

- If frame_id_numbers_present_flag is equal to 1, for the first frame current_frame_id should not be compared to PrevFrameID (because PrevFrameID is uninitialized).
- When the syntax element ref_order_hint[i] is read, RefOrderHint[i] is set equal to ref_order_hint[i].
- The requirement for bitstream conformance described in the semantics for ref_frame_idx[i] (that uses RefValid to check that the reference frames are available) should be ignored
- When using the inter prediction process, if RefValid[refIdx] is equal to 0, then the motion vector scaling and block inter prediction processes are not followed. Instead, preds[refList] should be generated using an alternative approach. For conformance testing, it may help to define the predicted samples in a standard way. The suggested approach is to fill preds[refList] with neutral gray samples, i.e. all values equal to 1 << (BitDepth - 1) .

Annex D: Large scale tile use case (informative)

One potential use-case for this process is the representation and rendering of a 3-dimensional environment as seen through an array of cameras that together capture a 360 degree view of the surrounding environment. One such arrangement of cameras is shown in the figure below where each small rectangle represents a full frame captured by a camera placed at a given latitude (row in the diagram) or longitude (column in the diagram), but other variants are possible.



Example array of 15x20 "camera" frames partitioned into 5x5 sub-arrays, where each sub-array has a central "anchor" frame (in red). Each small rectangle represents a frame.

In order to create a rendered view in an arbitrary direction in the 3-D scene the decoder will potentially need a small number of pixels from many of these frames. Providing a process to decode only a sparsely distributed subset of small regions, each defined as an AV1 tile, can significantly improve efficiency.

The algorithm for constructing the 3-dimensional view from the set of decoded tiles is beyond the scope of this specification; two possible schemes can be found in [8][9].

To reduce the amount of memory required and to improve decoder efficiency, a certain subset of the frames are denoted as “Anchor Frames” and it is assumed that the application makes these frames available to the decoder in uncompressed form. The example presented in the figure above highlights anchor frames in red.

The other (non-anchor) frames are referred to as “Camera Frames” and each one is encoded using only the nearest anchor frame as a reference. Camera frames are highlighted in gray in the figure above, and are shown clustered into 5x5 groups to indicate which anchor fame each uses for prediction.

The application is required to render a new 3-dimensional view at a rate of 90 fps. Each rendered frame may require at most two tile list OBU as defined in section 5.12 to be decoded, resulting in a maximum decode rate of 180 tile list OBU per second. Each decoded tile list OBU produces one output frame.

Annex E: Decoder model

E.1. General

The decoder model is used to verify that a bitstream can be decoded within the constraints imposed by one of the coding levels defined in section A.3. The decoder model is also used to verify conformance for a decoder that claims conformance to a certain coding level.

A set of decoder model parameters may be optionally specified for zero or more operating points. If the new Sequence Header OBU does not signal decoder model parameters for a given operating point the previous set of decoder model parameters does not persist.

The decoder model describes the smoothing buffer, decoding process, operation of the frame buffers and the frame output process.

The decoder model is applied to an operating point of a bitstream. Different operating points can have different decoder models that specify conformance to the levels signaled for these operating points.

The decoder model defines two modes of operation. A conformant bitstream shall satisfy constraints imposed by one of these two modes of the decoder model depending on which mode is applicable.

Section E.2 defines additional concepts used by the decoder model.

Section E.3 defines the operating modes.

Section E.4 specifies how the frame timings can be computed in the different operating modes.

Section E.5 specifies the decoder model process.

Section E.6 specifies the conformance requirements.

E.2. Decoder model definitions

The decoder model uses the following elements to verify bitstream conformance that are not part of the decoding process specified in section 7.

> **Note:** The elements defined in this section do not have to be present in a conformant decoder implementation. These elements may be considered examples of elements of a conformant decoder, although the actual decoder implementation may differ.

BufferPool is a storage area for a set of frame buffers. Buffer pool area allocated for storing separate frames is defined as BufferPool[i], where i takes values from 0 to BUFFER_POOL_MAX_SIZE - 1. When a frame buffer is used for storing a decoded frame, it is indicated by a VBI slot that points to this frame buffer.

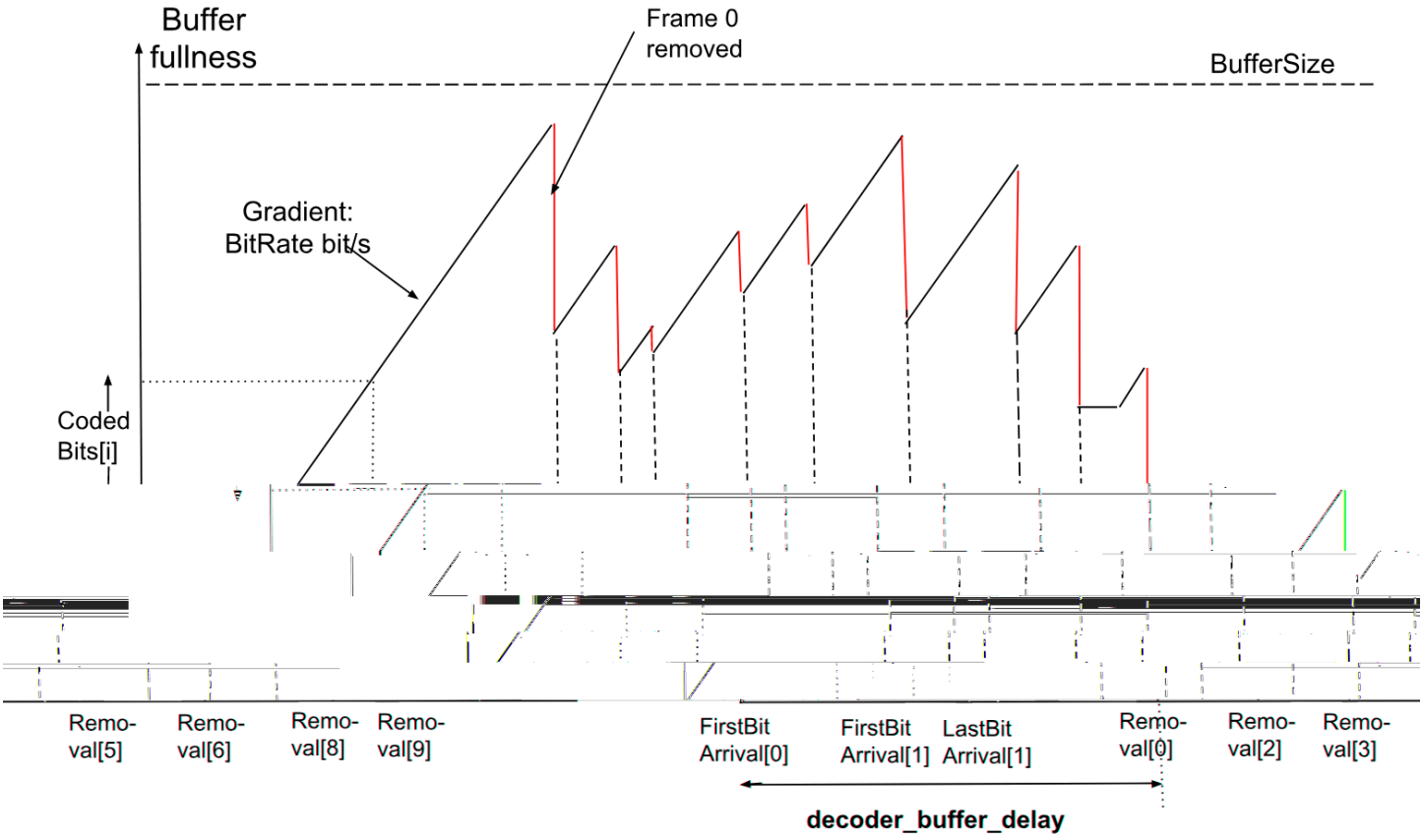
VBI (virtual buffer index) is an array of indices of the frame areas in the BufferPool. VBI elements which do not point to any slot in the VBI are set to -1. VBI array size is equal to 8, with the indices taking values from 0 to 7.

cfbi (current frame buffer index) is the variable that contains the index to the area in the BufferPool that contains the current frame.

DecoderRefCount[i] is a variable associated with a frame buffer i. DecoderRefCount[i] is initialized to 0, and incremented by 1 each time the decoder adds the buffer i to a VBI index slot. It is decremented by 1 each time the decoder removes the buffer from a VBI index slot i. The decoder may update multiple VBI index slots with the same frame buffer, as specified by refresh_frame_flags, so the counter may be incremented several times. The counter is only modified in this way when refresh_frame_flags is used to update the VBI index once the frame has been fully decoded. The decoder also increments the counter as it begins the decode process and decrements it again once complete. When the counter is 0 the pixel data becomes permanently invalid and shall not be used by the decode process.

PlayerRefCount[i] is a variable associated with a frame buffer i. PlayerRefCount[i] is initialized to 0, incremented by 1 each time the decoder determines that the frame is a presentation frame. It is reset to 0 after the last time the frame is presented.

PresentationTimes[i] is an array corresponding to the BufferPool [i] that holds the last presentation time for the decoded frame that is kept in the BufferPool [i].



Example of how the coded frame buffer fullness varies as data arrives from the stream, and is subsequently removed for decoding. Relevant timing points and values are indicated.

Coded frames arrive at the decoder smoothing buffer of the size BufferSize at a rate defined by BitRate. The following variables are used in this section and below:

BitRate is set to a value equal to MaxBitrate * BitrateProfileFactor specified for the level signaled for the operating point that is being decoded.

BufferSize is set to a value equal to MaxBufferSize * BitrateProfileFactor value specified for the level signaled for the operating point that is being decoded.

Decodable Frame Group i (DFG i) consists of all OBUs, including headers, between the end of the last OBU associated with the previous frame with show_existing_frame flag equal to 0 (frame k), and the end of the last OBU associated with the current frame with show_existing_frame flag equal to 0 (frame p). This comprises the OBUs that make up frame p, plus any additional OBUs present in the bitstream that belong to frame p (such as the metadata OBU), and OBU that belong to frames with show_existing_frame flag equal to 1 which are located between frame k and frame p. The decoder model assumes that the decoding time for processing a frame with show_existing_frame flag equal to 1, a header, or a metadata OBU is 0, hence the smoothing buffer operates in the units of DFG.

CodedBits[i] is the amount of data, in bits, that belongs to DFG i. Note that the index i of the DFG only increases with frames with show_existing_frame flag equal to 0, i.e. frames that need to be decoded by the decoding process.

FirstBitArrival[i] is the time when the first bit of the i-th DFG starts entering the decoder smoothing buffer. For the first coded DFG in the sequence, DFG 0 (or after updating decoder model parameters at RAP), FirstBitArrival[0] = 0.

LastBitArrival[i] is the time when the last bit of DFG i finishes entering the smoothing buffer.

Each **shown frame** j has a scheduled presentation time, **PresentationTime[j]**, defined to be a multiple of the display clock tick DispCT.

DispCT represents the expected time interval between displaying two consecutive frames, or a common divisor of the expected times between displaying two consecutive frames if the encoded bitstream has a variable display frame rate.

E.3. Operating modes

E.3.1. Resource availability mode

In this mode the model simulates the operation of the decoder under the assumption that the complete coded frame is available in the smoothing buffer when decoding of that frame begins. In addition, it is assumed that the decoder will begin to decode a frame immediately after it finishes decoding the previous frame or when a frame buffer becomes available, whichever is later. This model uses the generated time moment, when the decoding of a frame begins, as times when the data is removed from the smoothing buffer to check the conformance of a bitstream to the bitrate specified for a level signaled for the Operating Point of a bitstream.

To verify that a bitstream can be decoded by a decoder under the constraints of a particular level it is assumed that the decoder performs the decoding operations at maximum speed (the minimum time interval) specified for that level in section A.3.

To use Resource Availability mode, the following parameters should be set in the encoded video bitstream:

- timing_info_present_flag equal to 1
- decoder_model_info_present_flag equal to 0
- equal_picture_interval equal to 1

If the parameters listed above are not specified by the bitstream, the parameters necessary to input into this model can be signaled by the application or some other means. If the parameters necessary to run this model are not signaled, it is not possible to check the conformance of the stream to the claimed level.

In this mode of operation, the decoder model parameters below take the following (default) values:

- encoder_buffer_delay = 20 000
- decoder_buffer_delay = 70 000
- low_delay_mode_flag[op] = 0

The decoder writes the decoded frame into one of the 10 available frame buffers. Decoding must be delayed until a frame buffer becomes available.

E.3.2. Decoding schedule mode

This mode imposes additional constraints relating to the operation of the smoothing buffer and the timing points, specified for each frame, defining exactly when the decoder should start decoding a frame and when that frame should be presented.

To use Decoding Schedule Mode, the following parameters should be signaled by the encoded video bitstream:

- timing_info_present_flag equal to 1
- decoder_model_info_present_flag equal to 1
- decoder_model_present_for_this_op[op] equal to 1

When these flags are signaled, the bitstream should provide the associated information specified in decoder_model_info( ), operating_parameters_info( ) and initial_display_delay_minus_1[op].

In addition each frame must specify, for operating point op, the following parameters:

- buffer_removal_time[op]
- frame_presentation_time

If the parameters listed above are not specified by the bitstream, the parameters necessary to input into this model can be signaled by the application or some other means. If the parameters necessary to run this model are not signaled, it is not possible to check the conformance of the stream to the claimed level with this model.

E.3.3. When timing information is not present in the bitstream

When the timing_info(), and other info necessary as the input to one of the decoder models and associated information is not present in the bitstream, it is impossible to verify whether the bitstream satisfy the levels constraints according to either of the decoder models. In order to enable the verification of the decoder conformance, the equivalent information necessary to verify the bitstream compliance can be provided by some external means.

E.4. Frame timing definitions

E.4.1. Start of DFG bits arrival

The bits arrive in the smoothing buffer at a constant bitrate BitRate or the bitrate equal to 0. Hence, the average bitrate can be lower than the bitrate BitRate specified in the level definition, which, in this case, represents a peak bitrate. The first bit of DFG i is expected to arrive by the latest time that would guarantee timely reception of the entire DFG by the time when the decodable frame in the DFG i is due to be decoded:

```
FirstBitArrival[ i ]  = max ( LastBitArrival[ i - 1 ], LatestArrivalTime[ i ] ),
```

where LatestArrivalTime[i] is the latest time when the first bit of DFG i must arrive in the smoothing buffer to ensure that the complete DFG is available at the scheduled removal time, ScheduledRemoval [i], in units of seconds, unless the new set of decoding model parameters is received. In its turn, the latest time the DFG data should start being received is determined as follows:

```
LatestArrivalTime[ i ]  = ScheduledRemoval[ i ]  -  ( encoder_buffer_delay  + decoder_buffer_delay )
÷ 90 000
```

E.4.2. End of DFG bits arrival

For the bits that belong to the DFG i, the time of arrival of the last bit of the DFG i is determined as follows:

```
LastBitArrival[ i ] = FirstBitArrival[ i ] + CodedBits[ i ] ÷ BitRate
```

E.4.3. Scheduled removal times

The decoder starts to decode a frame exactly at the moment when the data corresponding to its DFG is removed from the smoothing buffer. Each DFG has a scheduled removal time and an actual removal time. Under certain circumstances these times may be different.

The ScheduledRemoval[i] time is determined differently in the resource availability and the decoding schedule mode.

When the decoder model operates in the decoding schedule mode

```
ScheduledRemoval[ i ] = ScheduledRemovalTiming[ i ]
```

When the decoder model operates in the resource availability mode

```
ScheduledRemoval[ i ] = ScheduledRemovalResource[ i ]
```

Derivation of ScheduledRemovalTiming[i] in the decoding schedule mode is described in section E.4.4, and derivation of ScheduledRemovalResource[i] in the resource availability mode is described in section E.4.5.

E.4.4. Removal times in decoding schedule mode

DFG i is scheduled for removal from the smoothing buffer at time ScheduledRemovalTiming [i] which is defined as an offset, buffer_removal_time[i], signaled for the frame of the DFG with show_existing_frame flag equal to 0, relative to the moment of time when the first DFG is removed from the smoothing buffer, decoder_buffer_delay:

```
ScheduledRemovalTiming[ 0 ] = decoder_buffer_delay ÷ 90 000

ScheduledRemovalTiming[ i ] = ScheduledRemovalTiming[ 0 ]  + buffer_removal_time[ i ] * DecCT
```

DFG i is removed from the smoothing buffer at time Removal[i].

There are two modes of operation of a decoder which determine whether the actual DFG removal time Removal[i] may be different from the scheduled DFG removal timing ScheduledRemovalTiming [i]. As was mentioned earlier, the decoder starts decoding a frame instantaneously when the data that belongs to its DFG is removed from the smoothing buffer.

In this mode, frame decoding start times / DFG removal times are determined by the buffer_removal_time [i] for the chosen operating point, op.

If low_delay_mode_flag[op] is equal to 0 the decoder operates in Strict Arrival Mode, and DFG is removed from the smoothing buffer at the scheduled time, that is:

```
Removal[ i ] = ScheduledRemovalTiming[ i ]
```

Otherwise, low_delay_mode_flag[op] is equal to 1 and the decoder operates in Low-Delay Mode, where the DFG data may not be available in the smoothing buffer at the scheduled removal time, i.e. ScheduledRemovalTiming[i] < LastBitArrival[i]. In that case the removal of the DFG is deferred until the first decode clock tick after the complete DFG is present in the smoothing buffer, that is:

```
Removal[ i ] = ceil ( LastBitArrival[ i ] ÷ DecCT ) * DecCT
```

If the entire DFG is available in the smoothing buffer at the scheduled removal time, i.e. ScheduledRemovalTiming[i] >= LastBitArrival[i], then it is removed at the scheduled time, that is:

```
Removal[ i ]  =  ScheduledRemovalTiming[ i ]
```

E.4.5. Removal times in resource availability mode

In the resource availability mode, buffer_removal_time[i] are not signaled for the chosen operating point. In this mode, timing of the decoder model is driven by the availability of the resources in the decoder, in particular, by times when the decoding of the previous frame with show_existing_frame flag equal to 0 has been completed and a free frame buffer is available.

In particular, ScheduledRemovalResource [i] times are generated as the earliest time that a non-assigned frame buffer becomes available for decoding of the frame i. In this mode, the decoder starts to decode a frame as fast as it can after completing decoding of the previous frame and a free frame buffer is available. A frame buffer is defined as being available if it is no longer being used and its content can be overwritten.

Removal times in the resource availability mode are produced by the decode process in section E.5.2

The following function, time_next_buffer_is_free, is used by the decode process to determine the Removal[i] time for the next DFG and generate the value of ScheduledRemovalResource[i].

```
time_next_buffer_is_free ( i, time ) {
    if ( i == 0 ) {
        time = decoder_buffer_delay ÷ 90000
    }
    foundBuffer = 0
    for ( k = 0; k < BUFFER_POOL_MAX_SIZE; k++ ) {
        if ( DecoderRefCount[ k ] == 0 ) {
            if ( PlayerRefCount[ k ] == 0 ) {
                ScheduledRemovalResource[ i ] = time
                return time
            }
            if ( !foundBuffer || PresentationTimes[ k ] < bufFreeTime ) {
                bufFreeTime = PresentationTimes[ k ]
                foundBuffer = 1
            }
        }
    }
    ScheduledRemovalResource[ i ] = bufFreeTime
    return bufFreeTime
}
```

E.4.6. Frame decode timing

The time required to decode a frame (i.e. to process the decodable frame's DFG), TimeToDecode [i], is calculated based on the frame type, a maximum number of luma pixels for the frame, and the throughput of the decoder as specified in the definition of the level assigned to the operating point that the frame belongs.

The time that it takes the decoder to decode a frame according to the decoder model is estimated by using the function time_to_decode_frame( ) as follows.

```
time_to_decode_frame( ) {
    if ( show_existing_frame == 1 ) {
        lumaSamples = 0
    } else if ( frame_type == KEY_FRAME ||
                frame_type == INTRA_ONLY ) {
        lumaSamples = UpscaledWidth * FrameHeight
    } else {
        if ( spatial_layer_dimensions_present_flag )
             lumaSamples =  (spatial_layer_max_width[ spatial_id ]) *
                                (spatial_layer_max_height[ spatial_id ])
        else
             lumaSamples =  (max_frame_width_minus_1 + 1) *
                                (max_frame_height_minus_1 + 1)
    }
    return  lumaSamples ÷ MaxDecodeRate
}
```

If the spatial_layer_dimensions_present_flag syntax element is not present in the coded video sequence, it is taken to be equal to 0.

The MaxDecodeRate value is defined in section A.3 for the level signaled for the operating point the decoder has chosen to decode.

E.4.7. Frame presentation timing

Initial presentation delay is determined as follows:

```
InitialPresentationDelay =  Removal [ initial_display_delay_minus_1 ] + TimeToDecode [
initial_display_delay_minus_1 ]
```

When equal_picture_interval is equal to 0, the decoder operates in variable frame rate mode, the frame presentation time is defined as follows:

```
PresentationTime[ 0 ] = InitialPresentationDelay

PresentationTime[ j ] = InitialPresentationDelay + ( frame_presentation_time[ j ] -
frame_presentation_time[ 0 ] ) * DispCT
```

When equal_picture_interval is equal to 1, the decoder operates in the constant frame rate mode, and the frame presentation time is defined as follows:

```
PresentationTime[ 0 ] = InitialPresentationDelay

PresentationTime[ j ] = PresentationTime[ j - 1 ] + ( num_ticks_per_picture_minus_1 + 1 ) * DispCT
```

where PresentationTime[j - 1] refers to the previous frame in presentation order.

The presentation interval, i.e. the time interval between the display of consecutive frames j and j + 1 in presentation order, is defined as follows:

```
PresentationInterval[ j ] = PresentationTime[ j + 1 ] - PresentationTime[ j ]
```

E.5. Decoder model

E.5.1. Decoder model functions

This section defines the buffer management functions invoked by the decoder model process.

The free_buffer function clears the variables for a particular index in the BufferPool.

```
free_buffer( idx ) {
    DecoderRefCount[ idx ] = 0
    PlayerRefCount[ idx ] = 0
    PresentationTimes[ idx ] =  -1
}
```

The initialize_buffer_pool function resets the BufferPool and the VBI.

```
initialize_buffer_pool( ) {
    for ( i = 0; i < BUFFER_POOL_MAX_SIZE; i++ )
        free_buffer( i )
    for ( i = 0; i < 8; i++ )
        VBI[ i ] = -1
}
```

The get_free_buffer function searches for an un-assigned frame in the BufferPool. (The decoder needs an un-assigned frame buffer from the BufferPool for each frame that it decodes.)

```
get_free_buffer( ) {
    for ( i = 0; i < BUFFER_POOL_MAX_SIZE; i++ ) {
        if ( DecoderRefCount[ i ] == 0 &&
             PlayerRefCount[ i ] == 0 )
            return i
    }
    return -1
}
```

Once decoded, frames may update one or more of the VBI index slots, as defined by refresh_frame_flags. Each time a VBI index slot is updated the decoder reference count is incremented by 1 for the corresponding frame buffer. If the VBI index slot being updated is currently occupied, the decoder reference count for the frame buffer being displaced must be decremented by 1.

The update_ref_buffers function updates the VBI and reference counts when the reference frames are updated.

```
update_ref_buffers ( idx, refresh_frame_flags ) {
    for ( i = 0; i < 8; i++ ) {
        if ( refresh_frame_flags & ( 1 << i ) ) {
            if ( VBI[ i ] != -1 )
                DecoderRefCount[ VBI[ i ] ] --
            VBI[ i ] = idx
            DecoderRefCount[ idx ] ++
        }
    }
}
```

In decoding schedule mode the decoder only starts to decode a frame at the time designated by a Removal time associated with that frame, and expects a free frame buffer to be immediately available.

In resource availability mode the decoder may start to decode the next frame as soon as a free reference buffer is available. If a free frame buffer is not available immediately, the PresentationTimes[i] may be used to compute the time when such a buffer will become available.

The function start_decode_at_removal_time returns buffers to the BufferPool when they are no longer required for decode or display.

```
start_decode_at_removal_time( removal ) {
    for ( i = 0; i < BUFFER_POOL_MAX_SIZE; i++ ) {
        if ( PlayerRefCount[ i ] > 0) {
            if ( PresentationTimes[ i ] < removal ) {
                PlayerRefCount[ i ] = 0
                if ( DecoderRefCount[ i ] == 0 )
                    free_buffer( i )
            }
            break
        }
    }
    return removal
}
```

The decoder needs to know the number of decoded frames in the BufferPool in order to determine the presentation delay for the first frame. A buffer is un-assigned if both DecoderRefCount[i] is equal to 0, and PlayerRefCount[i] is equal to 0.

The function frames_in_buffer_pool returns the number of assigned frames in the BufferPool.

```
frames_in_buffer_pool( ) {
    framesInPool = 0
    for ( i = 0; i < BUFFER_POOL_MAX_SIZE; i++ )
        if ( DecoderRefCount[ i ] != 0 || PlayerRefCount[ i ] != 0 )
            framesInPool++
    return framesInPool
}
```

The function get_next_frame switches to decoding the next frame in decoding order for the operating point. Variable DfgNum increments with each frame that needs decoding and corresponds to the DFG index. Variable ShownFrameNum increments with each shown frame read from the bitstream.

```
get_next_frame( frameNum )
{
    if ( read_frame_header( ) ) {
        frameNum++
        if ( !show_existing_frame ) {
            DfgNum++
        }
        if ( show_frame || show_existing_frame) {
            ShownFrameNum++
        }
        return frameNum
    } else {
        return -1
    }
}
```

When the function read_frame_header() is invoked, the syntax elements and variables are set to the values at the conceptual point (in the decoding process specified in section 7) when the next uncompressed header has just been parsed. If there are no more frame headers in the bitstream, then a value of 0 is returned. Otherwise, a value of 1 is returned.

E.5.2. Decoder model process

The decoder model process simulates the values of selected timing points as successive frames are decoded. This timing incorporates the time that the decoder has to wait for a free frame buffer, the time required to decode the frame and various basic checks to make sure that buffer slots are occupied when they are supposed to be. Non-conformance is signaled by a call to the function bitstream_non_conformant; the various error codes are tabulated below.

```
decode_process ( ) {
    initialize_buffer_pool( )
    time = 0
    frameNum = -1
    DfgNum = -1
    ShownFrameNum = -1
    cfbi = -1
    InitialPresentationDelay = 0
    while( (frameNum = get_next_frame( frameNum ) ) != - 1) {
        // Decode.
        if ( !show_existing_frame ) {
            if ( UsingResourceAvailabilityMode )
                Removal [ DfgNum ] = time_next_buffer_is_free( DfgNum, time )
            time = start_decode_at_removal_time( Removal[ DfgNum ] )
            if ( show_frame == 1 && time > PresentationTime[ ShownFrameNum ] )
                bitstream_non_conformant( DECODE_BUFFER_AVAILABLE_LATE )
            cfbi = get_free_buffer( )
            if ( cfbi == -1 )
                bitstream_non_conformant( DECODE_FRAME_BUF_UNAVAILABLE )
            time += time_to_decode_frame ( )
            update_ref_buffers ( cfbi, refresh_frame_flags )
            displayIdx = cfbi
            if ( InitialPresentationDelay == 0 &&
                 ( frames_in_buffer_pool( ) >= initial_display_delay_minus_1[ operatingPoint ] + 1 ) )
                InitialPresentationDelay = time
        } else {
            displayIdx = VBI[ frame_to_show_map_idx ]
            if ( displayIdx == -1 )
                bitstream_non_conformant( DECODE_EXISTING_FRAME_BUF_EMPTY )
            if ( RefFrameType[ frame_to_show_map_idx ] == KEY_FRAME )
                update_ref_buffers( displayIdx, 0xFF )
        }
        // Display.
        if ( InitialPresentationDelay != 0 &&
            ( show_existing_frame == 1 || show_frame == 1 )) {
            // Presentation frame.
            if ( time > PresentationTime[ ShownFrameNum ] )
                bitstream_non_conformant( DISPLAY_FRAME_LATE )
            PresentationTimes[ displayIdx ]= PresentationTime[ ShownFrameNum ]
            PlayerRefCount[ displayIdx ] ++
        }
    }
}
```

where UsingResourceAvailabilityMode is a variable that is set to 1 when using resource availability mode, or 0 when using decoding schedule mode.

The various non-conformant error codes are:

Error Type	Description
DECODE_BUFFER_AVAILABLE_LATE	A free frame buffer only became available to the decoder after the time that the frame should have been displayed.
DECODE_FRAME_BUF_UNAVAILABLE	All the frame buffers were in use.
DECODE_EXISTING_FRAME_BUF_EMPTY	The index of the frame designated for display by a frame with show_existing_frame = 1 was empty.
DISPLAY_FRAME_LATE	The frame was decoded too late for timely display, i.e. by the PresentationTime[i] time associated with the frame.

E.6. Bitstream conformance

E.6.1. General

A conformant coded bitstream shall satisfy the following set of constraints.

For the decoder model a DFG shall be available in the smoothing buffer at the scheduled removal time, i.e. ScheduledRemoval[i] >= LastBitArrival[i].

It is a requirement of the bitstream conformance that after each RAP, the PresentationTime[j], where j corresponds to the frame decoding order is strictly increasing until the next RAP or the end of the coded video sequence, i.e. PresentationTime[j + 1] > PresentationTime[j].

When buffer_removal_time[i] is not present in the bitstream, a bitstream is conformant if the decoder model in resource availability mode can decode pictures successfully before they are scheduled for presentation.

If buffer_removal_time[i] is signaled, it shall have a value greater or equal than the equivalent value that would have been assigned if the decoder model was decoding frames in the resource availability mode.

Conformance requirements based on a decoder model are not applicable to a bitstream with seq_level_idx equal to 31.

In addition to these, a conformant bitstream shall satisfy the constraints specified in the following sections.

E.6.2. Decoder buffer delay consistency across RAP (applies to decoding schedule mode)

For frame i, where i > 0, TimeDelta[i] is defined as follows:

```
TimeDelta[ i ] = ( ScheduledRemoval[ i ] - LastBitArrival[ i -1 ] ) * 90 000
```

For the video sequence that includes one or more random access points, for each key frame, where the decoder_buffer_delay is signaled, the following expression should hold to provide smooth playback without the need to rebuffer.

```
decoder_buffer_delay <= ceil( TimeDelta[ i ] )
```

E.6.3. Smoothing buffer overflow

Smoothing buffer overflow is defined as the state where the total number of bits in the smoothing buffer exceeds the size of the smoothing buffer BufferSize. The smoothing buffer shall never overflow.

E.6.4. Smoothing buffer underflow

Smoothing buffer underflow is defined as the state where a complete DFG is not present in the smoothing buffer at the scheduled removal time, ScheduledRemoval [i]:

```
ScheduledRemoval[ i ] < LastBitArrival[ i ]
```

When the low_delay_mode_flag[op] is equal to 0, the smoothing buffer shall never underflow.

E.6.5. Minimum decode time (applies to decoding schedule mode)

There must be enough time between a DFG being removed from the smoothing buffer, Removal[i], and the scheduled removal of the next DFG, ScheduledRemoval[i + 1]:

```
ScheduledRemoval[ i + 1] - Removal[ i ]  >= Max( TimeToDecode[ i ], 1 ÷ MaxNumFrameHeadersPerSec ),
```

where MaxNumFrameHeadersPerSec is defined in the level constraints.

E.6.6. Minimum presentation Interval

The difference between presentation times for consecutive shown frames, shall satisfy the following constraint:

```
MinFrameTime = MaxTotalDecodedSampleRate ÷ ( MaxNumFrameHeadersSec * MaxTotalDisplaySampleRate )

PresentationInterval[ j ]  >= Max( LumaPels ÷ MaxTotalDisplaySampleRate, MinFrameTime )
```

Where MaxTotalDecodedSampleRate, MaxNumFrameHeadersPerSec, and MaxTotalDisplaySampleRate are defined in the level constraints.

E.6.7. Decode deadline

It is a requirement of the bitstream conformance that each frame shall be fully decoded at, or before, the time that it is scheduled for presentation:

```
Removal[ i ] + TimeToDecode[ i ] <= PresentationTime[ i ]
```

E.6.8. Level imposed constraints

When operating in the decoding schedule mode mode, decoder_buffer_delay shall not be equal to 0 and shall not exceed 90000 * (BufferSize ÷ BitRate).

> **Note:** It is common to choose ((encoder_buffer_delay + decoder_buffer_delay) ÷ 90000) * BitRate equal to a constant within a coded video sequence, and for this constant to be equal to BufferSize, but these are not strict requirements for bitstream conformance.

E.6.9. Decode Process constraints

It is a requirement of bitstream conformance that the decoder model process can be invoked with the bitstream data for any signaled operating point without triggering a call to the bitstream_non_conformant function.

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