# 3 Definitions

1. **3.x decoding unit**: An access unit or a subset of an access unit. If sub\_pic\_cpb\_flag is equal to 0, a decoding unit is an access unit; otherwise, a decoding unit consists of a VCL NAL unit and the associated non-VCL NAL units. For the first VCL NAL unit in an access unit, the assoicated non-VCL NAL units are all non-VCL NAL units in the access unit and before the first VCL NAL unit and the filler data NAL units, if any, immediately following the first non-VCL NAL unit. For a VCL NAL unit that is not the first VCL NAL unit in an access unit, the assoicated non-VCL NAL units are the filler data NAL unt, if any, immediately following the non-VCL NAL unit.
2. Annex A  
     
   Profiles and levels

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

* 1. Overview of profiles and levels

1. Annex B  
     
   Byte stream format

1. Annex C  
     
   Hypothetical reference decoder

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

C.1 General

This annex specifies the hypothetical reference decoder (HRD) and its use to check bitstream and decoder conformance.

**...**

The CPB size (number of bits) is CpbSize[ SchedSelIdx ]. The DPB size (number of picture storage buffers) for temporal layer X is max\_dec\_pic\_buffering[ X ] + 1 for each X in the range of 0 to max\_temporal\_layers\_minus1, inclusive.

The HRD operates as follows. Data associated with access units that flow into the CPB according to a specified arrival schedule are delivered by the HSS. The data associated with each decoding unit are removed and decoded instantaneously by the instantaneous decoding process at CPB removal times. Each decoded picture is placed in the DPB. A decoded picture is removed from the DPB at the later of the DPB output time or the time that it becomes no longer needed for inter-prediciton reference.

The operation of the CPB is specified in subclause C.1. The instantaneous decoder operation is specified in clauses 2-9. The operation of the DPB is specified in subclause C.2. The output cropping is specified in subclause C.2.2.

HSS and HRD information concerning the number of enumerated delivery schedules and their associated bit rates and buffer sizes is specified in subclauses E.1.1, E.1.2, E.2.1, and E.2.2. The HRD is initialised as specified by the buffering period SEI message as specified in subclauses D.1.1 and D.2.1. The removal timing of decoding units from the CPB and output timing of decoded pictures from the DPB are specified in the picture timing SEI message as specified in subclauses D.1.2 and D.2.2. All timing information relating to a specific decoding unit shall arrive prior to the CPB removal time of the decoding unit.

The HRD is used to check conformance of bitstreams and decoders as specified in subclauses C.4 and C.5, respectively.

NOTE 7 – While conformance is guaranteed under the assumption that all frame-rates and clocks used to generate the bitstream match exactly the values signalled in the bitstream, in a real system each of these may vary from the signalled or specified value.

All the arithmetic in this annex is done with real values, so that no rounding errors can propagate. For example, the number of bits in a CPB just prior to or after removal of a decoding unit is not necessarily an integer.

The variable tc is derived as follows and is called a clock tick:

tc = num\_units\_in\_tick  time\_scale (C‑1)

The following is specified for expressing the constraints in this annex:

– Let access unit n be the n-th access unit in decoding order with the first access unit being access unit 0.

– Let picture n be the coded picture or the decoded picture of access unit n.

– Let decoding unit m be the m-th decoding unit in decoding order with the first decoding unit being decoding unit 0.

C.2 Operation of coded picture buffer (CPB)

The specifications in this subclause apply independently to each set of CPB parameters that is present and to both the Type I and Type II conformance points shown in Figure C‑1.

C.2.1 Timing of bitstream arrival

The HRD may be initialised at any one of the buffering period SEI messages. Prior to initialisation, the CPB is empty.

NOTE – After initialisation, the HRD is not initialised again by subsequent buffering period SEI messages.

Each access unit is referred to as access unit n, where the number n identifies the particular access unit. The access unit that is associated with the buffering period SEI message that initialises the CPB is referred to as access unit 0. The value of n is incremented by 1 for each subsequent access unit in decoding order.

Each decoding unit is referred to as decoding unit m, where the number m identifies the particular decoding unit. The first decoding unit in decoding order in access unit 0 is referred to as decoding unit 0. The value of m is incremented by 1 for each subsequent decoding unit in decoding order.

The time at which the first bit of decoding unit n begins to enter the CPB is referred to as the initial arrival time tai( m ).

The initial arrival time of decoding units is derived as follows.

– If the decoding unit is decoding unit 0, tai( 0 ) = 0,

– Otherwise (the decoding unit is decoding unit m with m > 0), the following applies.

– If cbr\_flag[ SchedSelIdx ] is equal to 1, the initial arrival time for decoding unit m, is equal to the final arrival time (which is derived below) of access unit m − 1, i.e.,

tai( m ) = taf( m − 1 ) (C‑2)

– Otherwise (cbr\_flag[ SchedSelIdx ] is equal to 0), the initial arrival time for decoding unit m is derived by

tai( m ) = Max( taf( m − 1 ), tai,earliest( m ) ) (C‑3)

where tai,earliest( m ) is derived as follows.

– If decoding unit n is not the first decoding unit of a subsequent buffering period, tai,earliest( m ) is derived as

tai,earliest( m ) = tr,n( m ) − ( initial\_cpb\_removal\_delay[ SchedSelIdx ] +  
 initial\_cpb\_removal\_delay\_offset[ SchedSelIdx ] )  90000 (C‑4)

with tr,n( m ) being the nominal removal time of decoding unit m from the CPB as specified in subclause C.1.2 and initial\_cpb\_removal\_delay[ SchedSelIdx ] and initial\_cpb\_removal\_delay\_offset[ SchedSelIdx ] being specified in the previous buffering period SEI message.

– Otherwise (decoding unit m is the first decoding unit of a subsequent buffering period), tai,earliest( m ) is derived as

tai,earliest( m ) = tr,n( m ) − ( initial\_cpb\_removal\_delay[ SchedSelIdx ]  90000 ) (C‑5)

with initial\_cpb\_removal\_delay[ SchedSelIdx ] being specified in the buffering period SEI message associated with the access unit containing decoding unit m.

The final arrival time for decoding unit m is derived by

taf( m ) = tai( m ) + b( m )  BitRate[ SchedSelIdx ] (C‑6)

where b( m ) is the size in bits of decoding unit m, counting the bits of the VCL NAL units and the filler data NAL units for the Type I conformance point or all bits of the Type II bitstream for the Type II conformance point, where the Type I and Type II conformance points are as shown in Figure C‑1.

The values of SchedSelIdx, BitRate[ SchedSelIdx ], and CpbSize[ SchedSelIdx ] are constrained as follows.

– If the content of the active sequence parameter sets for the access unit containing decoding unit m and the previous access unit differ, the HSS selects a value SchedSelIdx1 of SchedSelIdx from among the values of SchedSelIdx provided in the active sequence parameter set for the access unit contaning decoding unit m that results in a BitRate[ SchedSelIdx1 ] or CpbSize[ SchedSelIdx1 ] for the access unit contaning decoding unit m. The value of BitRate[ SchedSelIdx1 ] or CpbSize[ SchedSelIdx1 ] may differ from the value of BitRate[ SchedSelIdx0 ] or CpbSize[ SchedSelIdx0 ] for the value SchedSelIdx0 of SchedSelIdx that was in use for the previous access unit.

– Otherwise, the HSS continues to operate with the previous values of SchedSelIdx, BitRate[ SchedSelIdx ] and CpbSize[ SchedSelIdx ].

When the HSS selects values of BitRate[ SchedSelIdx ] or CpbSize[ SchedSelIdx ] that differ from those of the previous access unit, the following applies.

– the variable BitRate[ SchedSelIdx ] comes into effect at time tai( m )

– the variable CpbSize[ SchedSelIdx ] comes into effect as follows.

– If the new value of CpbSize[ SchedSelIdx ] exceeds the old CPB size, it comes into effect at time tai( m ),

– Otherwise, the new value of CpbSize[ SchedSelIdx ] comes into effect at the CPB removal time of the last decoding unit of the access unit containing decoding unit m.

1. When sub\_pic\_cpb\_flag is equal to 1, the initial CPB arrival time of access unit n tai( n ) is set to the initial CPB arrival time of the first decoding unit in access unit n, the final CPB arrival time of access unit n taf( n ) is set to the final CPB arrival time of the last decoding unit in access unit n.

C.2.2 Timing of decoding unit removal and decoding of decoding unit

When an decoding unit m is the decoding unit with m equal to 0 (the first decoding unit of the access unit that initialises the HRD), the nominal removal time of the decoding unit from the CPB is specified by

tr,n( 0 ) = initial\_cpb\_removal\_delay[ SchedSelIdx ]  90000 (C‑7)

When a decoding unit m is the first decoding unit of the first access unit of a buffering period that does not initialise the HRD, the nominal removal time of the decoding unit from the CPB is specified by

tr,n( m ) = tr,n( mb ) + tc \* cpb\_removal\_delay( m ) (C‑8)

where tr,n( mb ) is the nominal removal time of the first decoding unit of the previous buffering period and cpb\_removal\_delay( m ) is the value of cpb\_removal\_delay[ i ] for decoding unit m specified in the picture timing SEI message associated with the access unit containing decoding unit m.

When a decoding unit m is the first decoding unit of a buffering period, mb is set equal to m at the removal time tr,n( m ) of the decoding unit m.

The nominal removal time tr,n( m ) of a decoding unit m that is not the first decoding unit of a buffering period is given by

tr,n( m ) = tr,n( mb ) + tc \* cpb\_removal\_delay( m ) (C‑9)

where tr,n( mb ) is the nominal removal time of the first decoding unit of the current buffering period and cpb\_removal\_delay( m ) is the value of cpb\_removal\_delay[ i ] specified in the picture timing SEI message associated with the access unit containing decoding unit m.

The removal time of decoding unit m is specified as follows.

– If low\_delay\_hrd\_flag is equal to 0 or tr,n( m ) >= taf( m ), the removal time of decoding unit m is specified by

tr( m ) = tr,n( m ) (C‑10)

– Otherwise (low\_delay\_hrd\_flag is equal to 1 and tr,n( m ) < taf( m )), the removal time of decoding unit m is specified by

tr( m ) = tr,n( m ) + tc \* Ceil( ( taf( m ) − tr,n( m ) ) tc ) (C‑11)

NOTE – The latter case indicates that the size of decoding unit m, b( m ), is so large that it prevents removal at the nominal removal time.

When sub\_pic\_cpb\_flag is equal to 1, the nominal CPB removal time of access unit n tr,n( n ) is set to the normail CPB removal time of the last decoding unit in access unit n, the CPB removal time of access unit n tr( n ) is set to the CPB removal time of the last decoding unit in access unit n.

At CPB removal time of decoding unit m, the decoding unit is instantaneously decoded.

C.3 Operation of the decoded picture buffer (DPB)

The decoded picture buffer contains picture storage buffers. Each of the picture storage buffers may contain a decoded picture that is marked as "used for reference" or is held for future output. Prior to initialization, the DPB is empty (the DPB fullness is set to zero). The following steps of the subclauses of this subclause happen in the sequence listed.

**C.3.1 Removal of pictures from the DPB**

The removal of pictures from the DPB before decoding of the current picture (but after parsing the slice header of the first slice of the current picture) happens instantaneously at the CPB removal time of the first decoding unit of access unit n (containing the current picture) and proceeds as follows.

The decoding process for reference picture set as specified in subclause 8.3.2 is invoked.

If the current picture is an IDR picture, the following applies:

* When the IDR picture is not the first IDR picture decoded and the value of pic\_width\_in\_luma\_samples or pic\_height\_in\_luma\_samples or max\_dec\_pic\_buffering derived from the active sequence parameter set is different from the value of pic\_width\_in\_luma\_samples or pic\_height\_in\_luma\_samples or max\_dec\_pic\_buffering derived from the sequence parameter set that was active for the preceding picture, respectively, no\_output\_of\_prior\_pics\_flag is inferred to be equal to 1 by the HRD, regardless of the actual value of no\_output\_of\_prior\_pics\_flag.

NOTE – Decoder implementations should try to handle picture or DPB size changes more gracefully than the HRD in regard to changes in pic\_width\_in\_luma\_samples or pic\_height\_in\_luma\_samples.

* When no\_output\_of\_prior\_pics\_flag is equal to 1 or is inferred to be equal to 1, all picture storage buffers in the DPB are emptied without output of the pictures they contain, and DPB fullness is set to 0.

All pictures k in the DPB, for which all of the following conditions are true, are removed from the DPB:

– picture k is marked as "unused for reference",

– picture k has PicOutputFlag equal to 0 or its DPB output time is less than or equal to the CPB removal time of the first decoding unit (denoted as decoding unit m) of current picture n; i.e., to,dpb( k ) <= tr( m )

When a picture is removed from the DPB, the DPB fullness is decremented by one.

**C.3.2 Picture output**

1. The following happens instantaneously at the CPB removal time of access unit n, tr( n ).

Picture n is considered as decoded after the last decoding unit of the picture is decoded.

The variable maxPicOrderCnt is set equal to the maximum of the PicOrderCntVal values for the current picture and all pictures in the DPB that are currently marked as "used for short-term reference" or "needed for output".

The variable minPicOrderCnt is set equal to the minimum of the PicOrderCntVal for the current picture and all pictures in the DPB that are currently marked as "used for short-term reference" or "needed for output".

It is a requirement of bitstream conformance that the value of maxPicOrderCnt – minPicOrderCnt shall be less than MaxPicOrderCntLsb / 2.

When picture n has PicOutputFlag equal to 1, its DPB output time to,dpb( n ) is derived by

to,dpb( n ) = tr( n ) + tc \* dpb\_output\_delay( n ) (C‑12)

where dpb\_output\_delay( n ) is the value of dpb\_output\_delay specified in the picture timing SEI message associated with access unit n.

The output of the current picture is specified as follows.

– If PicOutputFlag is equal to 1 and to,dpb( n ) = tr( n ), the current picture is output.

– Otherwise, if PicOutputFlag is equal to 0, the current picture is not output, but will be stored in the DPB as specified in subclause C.3.3.

– Otherwise (PicOutputFlag is equal to 1 and to,dpb( n ) > tr( n ) ), the current picture is output later and will be stored in the DPB (as specified in subclause C.3.3) and is output at time to,dpb( n ) unless indicated not to be output by the decoding or inference of no\_output\_of\_prior\_pics\_flag equal to 1 at a time that precedes to,dpb( n ).

When output, the picture shall be cropped, using the cropping rectangle specified in the active sequence parameter set.

When picture n is a picture that is output and is not the last picture of the bitstream that is output, the value of Δto,dpb( n ) is defined as:

Δto,dpb( n ) = to,dpb( nn ) − to,dpb( n ) (C‑13)

where nn indicates the picture that follows after picture n in output order and has PicOutputFlag equal to 1.

**C.3.3 Current decoded picture marking and storage**

1. The following happens instantaneously at the CPB removal time of access unit n, tr( n ).

The current decoded picture is stored in the DPB in an empty picture storage buffer, and the DPB fullness is incremented by one. If the current picture is a reference picture, it is marked as "used for reference", otherwise it is marked as "unused for reference".

C.4 Bitstream conformance

A bitstream of coded data conforming to this Recommendation | International Standard shall fulfil the following requirements.

It is a requirement of bitstream conformance that the bitstream shall be constructed according to the syntax, semantics, and constraints specified in this Recommendation | International Standard outside of this annex.

It is a requirement of bitstream conformance that first coded picture in a bitstream shall be an IDR picture or a CRA picture.

The bitstream is tested by the HRD for conformance as specified below:

For Type I bitstreams, the number of tests carried out is equal to cpb\_cnt\_minus1 + 1 where cpb\_cnt\_minus1 is either the syntax element of hrd\_parameters( ) following the vcl\_hrd\_parameters\_present\_flag or is determined by the application by other means not specified in this Recommendation | International Standard. One test is carried out for each bit rate and CPB size combination specified by hrd\_parameters( ) following the vcl\_hrd\_parameters\_present\_flag. Each of these tests is conducted at the Type I conformance point shown in Figure C‑1.

For Type II bitstreams there are two sets of tests. The number of tests of the first set is equal to cpb\_cnt\_minus1 + 1 where cpb\_cnt\_minus1 is either the syntax element of hrd\_parameters( ) following the vcl\_hrd\_parameters\_present\_flag or is determined by the application by other means not specified in this Recommendation | International Standard. One test is carried out for each bit rate and CPB size combination. Each of these tests is conducted at the Type I conformance point shown in Figure C‑1. For these tests, only VCL and filler data NAL units are counted for the input bit rate and CPB storage.

The number of tests of the second set, for Type II bitstreams, is equal to cpb\_cnt\_minus1 + 1 where cpb\_cnt\_minus1 is either the syntax element of hrd\_parameters( ) following the nal\_hrd\_parameters\_present\_flag or is determined by the application by other means not specified in this Recommendation | International Standard. One test is carried out for each bit rate and CPB size combination specified by hrd\_parameters( ) following the nal\_hrd\_parameters\_present\_flag. Each of these tests is conducted at the Type II conformance point shown in Figure C‑1. For these tests, all NAL units (of a Type II NAL unit stream) or all bytes (of a byte stream) are counted for the input bit rate and CPB storage.

NOTE 1 – NAL HRD parameters established by a value of SchedSelIdx for the Type II conformance point shown in Figure C‑1 are sufficient to also establish VCL HRD conformance for the Type I conformance point shown in Figure C‑1 for the same values of initial\_cpb\_removal\_delay[ SchedSelIdx ], BitRate[ SchedSelIdx ], and CpbSize[ SchedSelIdx ] for the VBR case (cbr\_flag[ SchedSelIdx ] equal to 0). This is because the data flow into the Type I conformance point is a subset of the data flow into the Type II conformance point and because, for the VBR case, the CPB is allowed to become empty and stay empty until the time a next picture is scheduled to begin to arrive. For example, when decoding a coded video sequence conforming to one or more of the profiles specified in Annex A using the decoding process specified in clauses 2-9, when NAL HRD parameters are provided for the Type II conformance point that not only fall within the bounds set for NAL HRD parameters for profile conformance in item j) of subclause A.3.1 or item h) of subclause A.3.3 (depending on the profile in use) but also fall within the bounds set for VCL HRD parameters for profile conformance in item i) of subclause A.3.1 or item g) of subclause A.3.3 (depending on the profile in use), conformance of the VCL HRD for the Type I conformance point is also assured to fall within the bounds of item i) of subclause A.3.1.

It is a requirement of bitstream conformance that all of the following conditions shall be fulfilled for each of the tests:

1. For each access unit n, with n>0, associated with a buffering period SEI message, with Δtg,90( n ) specified by

Δtg,90( n ) = 90000 \* ( tr,n( n ) − taf( n − 1 ) ) (C‑14)

the value of initial\_cpb\_removal\_delay[ SchedSelIdx ] shall be constrained as follows.

– If cbr\_flag[ SchedSelIdx ] is equal to 0,

initial\_cpb\_removal\_delay[ SchedSelIdx ] <= Ceil( Δtg,90( n ) ) (C‑15)

– Otherwise (cbr\_flag[ SchedSelIdx ] is equal to 1),

Floor( Δtg,90( n ) ) <= initial\_cpb\_removal\_delay[ SchedSelIdx ] <= Ceil( Δtg,90( n ) ) (C‑16)

NOTE 2 – The exact number of bits in the CPB at the removal time of each picture may depend on which buffering period SEI message is selected to initialise the HRD. Encoders must take this into account to ensure that all specified constraints must be obeyed regardless of which buffering period SEI message is selected to initialise the HRD, as the HRD may be initialised at any one of the buffering period SEI messages.

1. A CPB overflow is specified as the condition in which the total number of bits in the CPB is larger than the CPB size. The CPB shall never overflow.
2. A CPB underflow is specified as the condition in which the norminal CPB removal time of decoding unit m tr,n( m ) is less than the CPB removal time of decoding unig m taf( m ) for any value of m. When low\_delay\_hrd\_flag is equal to 0, the CPB shall never underflow.
3. The nominal removal times of pictures from the CPB (starting from the second picture in decoding order), shall satisfy the constraints on tr,n( n ) and tr( n ) expressed in subclauses A.3.1 through A.3.3.
4. After the decoding process for reference picture set as specified in subclause 8.2.2 has been invoked, the number of decoded pictures in the DPB, not including the current picture, with temporal\_id lower than or equal to the temporal\_id of the current picture, shall be less than or equal to max\_dec\_pic\_buffering[ temporal\_id ].
5. All reference pictures shall be present in the DPB when needed for prediction. Each picture shall be present in the DPB at its DPB output time unless it is removed from the DPB before its output time by one of the processes specified in subclause C.2.
6. The value of Δto,dpb( n ) as given by Equation C‑13, which is the difference between the output time of a picture and that of the first picture following it in output order and having pic\_output\_flag equal to 1, shall satisfy the constraint expressed in subclause A.3.1 for the profile and level specified in the bitstream using the decoding process specified in clauses 2-9.

C.5 Decoder conformance

A decoder conforming to this Recommendation | International Standard shall fulfil the following requirements.

A decoder claiming conformance to a specific profile and level shall be able to decode successfully all conforming bitstreams specified for decoder conformance in subclause C.3, provided that all sequence parameter sets and picture parameter sets referred to in the VCL NAL units, and appropriate buffering period and picture timing SEI messages are conveyed to the decoder, in a timely manner, either in the bitstream (by non-VCL NAL units), or by external means not specified by this Recommendation | International Standard.

There are two types of conformance that can be claimed by a decoder: output timing conformance and output order conformance.

To check conformance of a decoder, test bitstreams conforming to the claimed profile and level, as specified by subclause C.3 are delivered by a hypothetical stream scheduler (HSS) both to the HRD and to the decoder under test (DUT). All pictures output by the HRD shall also be output by the DUT and, for each picture output by the HRD, the values of all samples that are output by the DUT for the corresponding picture shall be equal to the values of the samples output by the HRD.

For output timing decoder conformance, the HSS operates as described above, with delivery schedules selected only from the subset of values of SchedSelIdx for which the bit rate and CPB size are restricted as specified in Annex A for the specified profile and level, or with "interpolated" delivery schedules as specified below for which the bit rate and CPB size are restricted as specified in Annex A. The same delivery schedule is used for both the HRD and DUT.

When the HRD parameters and the buffering period SEI messages are present with cpb\_cnt\_minus1 greater than 0, the decoder shall be capable of decoding the bitstream as delivered from the HSS operating using an "interpolated" delivery schedule specified as having peak bit rate r, CPB size c( r ), and initial CPB removal delay ( f( r )r ) as follows:

 = ( r − BitRate[ SchedSelIdx − 1 ] )  ( BitRate[ SchedSelIdx ] − BitRate[ SchedSelIdx − 1 ] ), (C‑17)

c( r ) =  \* CpbSize[ SchedSelIdx ] + (1 −  \* CpbSize[ SchedSelIdx−1 ], (C‑18)

f( r ) = initial\_cpb\_removal\_delay[ SchedSelIdx ] \* BitRate[ SchedSelIdx ] +   
 ( 1 −  initial\_cpb\_removal\_delay[ SchedSelIdx − 1 ] \* BitRate[ SchedSelIdx − 1 ] (C‑19)

for any SchedSelIdx > 0 and r such that BitRate[ SchedSelIdx − 1 ] <= r <= BitRate[ SchedSelIdx ] such that r and c( r ) are within the limits as specified in Annex A for the maximum bit rate and buffer size for the specified profile and level.

NOTE 1 – initial\_cpb\_removal\_delay[ SchedSelIdx ] can be different from one buffering period to another and have to be re‑calculated.

For output timing decoder conformance, an HRD as described above is used and the timing (relative to the delivery time of the first bit) of picture output is the same for both HRD and the DUT up to a fixed delay.

For output order decoder conformance, the HSS delivers the bitstream to the DUT "by demand" from the DUT, meaning that the HSS delivers bits (in decoding order) only when the DUT requires more bits to proceed with its processing.

NOTE 2 – This means that for this test, the coded picture buffer of the DUT could be as small as the size of the largest access unit.

A modified HRD as described below is used, and the HSS delivers the bitstream to the HRD by one of the schedules specified in the bitstream such that the bit rate and CPB size are restricted as specified in Annex A. The order of pictures output shall be the same for both HRD and the DUT.

For output order decoder conformance, the HRD CPB size is equal to CpbSize[ SchedSelIdx ] for the selected schedule and the DPB size is equal to MaxDpbSize. Removal time from the CPB for the HRD is equal to final bit arrival time and decoding is immediate. The operation of the DPB of this HRD is described below.

C.5.1 Operation of the output order DPB

The decoded picture buffer contains picture storage buffers. Each of the picture storage buffers contains a decoded picture that is marked as "used for reference" or is held for future output. At HRD initialization, the DPB is empty. The following steps all happen in the order listed.

C.5.2 Removal of pictures from the DPB

The removal of pictures from the DPB before decoding of the current picture (but after parsing the slice header of the first slice of the current picture) happens instantaneously when the first decoding unit of the access unit containing the curent picture is removed from the CPB and proceeds as follows.

The decoding process for reference picture set as specified in subclause 8.3.4.3 is invoked.

– If the current picture is an IDR picture, the following applies.

1. When the IDR picture is not the first IDR picture decoded and the value of pic\_width\_in\_luma\_samples or pic\_height\_in\_luma\_samples or max\_dec\_pic\_buffering derived from the active sequence parameter set is different from the value of pic\_width\_in\_luma\_samples or pic\_height\_in\_luma\_samples or max\_dec\_pic\_buffering derived from the sequence parameter set that was active for the preceding picture, respectively, no\_output\_of\_prior\_pics\_flag is inferred to be equal to 1 by the HRD, regardless of the actual value of no\_output\_of\_prior\_pics\_flag.

NOTE – Decoder implementations should try to handle changes in the value of pic\_width\_in\_luma\_samples or pic\_height\_in\_luma\_samples or max\_dec\_pic\_buffering more gracefully than the HRD.

1. When no\_output\_of\_prior\_pics\_flag is equal to 1 or is inferred to be equal to 1, all picture storage buffers in the DPB are emptied without output of the pictures they contain.

– Otherwise (the current picture is not an IDR picture), picture storage buffers containing a picture which are marked as "not needed for output" and "unused for reference" are emptied (without output). When any of the following conditions is true, the "bumping" process specified in subclause C.5.2.1 is invoked repeatedly until there is an empty picture storage buffer to store the current decoded picture.

1. The number of pictures in the DPB that are marked as "needed for output" is greater than num\_reorder\_pics[ temporal\_id ],
2. The number of pictures in the DPB with temporal\_id lower than or equal to the temporal\_id of the current picture is equal to max\_dec\_pic\_buffering[ temporal\_id ] + 1.

When the current picture is an IDR picture for which no\_output\_of\_prior\_pics\_flag is not equal to 1 and is not inferred to be equal to 1, the following two steps are performed.

1. Picture storage buffers containing a picture that is marked as "not needed for output" and "unused for reference" are emptied (without output).

2. All non-empty picture storage buffers in the DPB are emptied by repeatedly invoking the "bumping" process specified in subclause C.5.2.1.

C.5.2.1 "Bumping" process

The "bumping" process is invoked in the following cases.

– The current picture is an IDR picture and no\_output\_of\_prior\_pics\_flag is not equal to 1 and is not inferred to be equal to 1, as specified in subclause C.5.2.

– The number of pictures in the DPB that are marked "needed for output" is greater than num\_reorder\_pics[ temporal\_id ], as specified in subclause C.5.2.

– The number of pictures in the DPB with temporal\_id lower than or equal to the temporal\_id of the current picture is equal to max\_dec\_pic\_buffering[ temporal\_id ] + 1, as specified in subclause C.5.2.

The "bumping" process consists of the following ordered steps:

1. The picture that is first for output is selected as the one having the smallest value of PicOrderCntVal of all pictures in the DPB marked as "needed for output".
2. The picture is cropped, using the cropping rectangle specified in the active sequence parameter set for the picture, the cropped picture is output, and the picture is marked as "not needed for output".
3. If the picture storage buffer that included the picture that was cropped and output contains a picture marked as "unused for reference", the picture storage buffer is emptied.

C.5.3 Picture decoding, marking and storage

1. The following happens instantaneously when the last decoding unit of access unit n containing the curent picture is removed from the CPB.

The current picture is considered as decoded after the last decoding unit of the picture is decoded. The current decoded picture is stored in an empty picture storage buffer in the DPB, and the following applies.

– If the current decoded picture has PicOutputFlag equal to 1, it is marked as "needed for output".

– Otherwise (the current decoded picture has PicOutputFlag equal to 0), it is marked as "not needed for output".

If the current decoded picture is a reference picture, it is marked as "used for reference", otherwise (the current decoded picture is a non-reference picture), it is marked as "unused for reference".

1. Annex D  
     
   Supplemental enhancement information

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

This annex specifies syntax and semantics for SEI message payloads.

SEI messages assist in processes related to decoding, display or other purposes. However, SEI messages are not required for constructing the luma or chroma samples by the decoding process. Conforming decoders are not required to process this information for output order conformance to this Recommendation | International Standard (see Annex C for the specification of conformance). Some SEI message information is required to check bitstream conformance and for output timing decoder conformance.

In Annex C.5.1, specification for presence of SEI messages are also satisfied when those messages (or some subset of them) are conveyed to decoders (or to the HRD) by other means not specified by this Recommendation | International Standard. When present in the bitstream, SEI messages shall obey the syntax and semantics specified in subclauses 7.3.2.9.1 and this annex. When the content of an SEI message is conveyed for the application by some means other than presence within the bitstream, the representation of the content of the SEI message is not required to use the same syntax specified in this annex. For the purpose of counting bits, only the appropriate bits that are actually present in the bitstream are counted.

1. D.1 SEI payload syntax
2. D.1.1 Buffering period SEI message syntax
3. The syntax table is specifed in subclause D.1.1 of Rec. ITU-T H.264 | ISO/IEC 14496-10.
4. D.1.2 Picture timing SEI message syntax

|  |  |
| --- | --- |
| pic\_timing( payloadSize ) { | Descriptor |
| if( CpbDpbDelaysPresentFlag ) { |  |
| if( sub\_pic\_cpb\_flag ) |  |
| **num\_decoding\_units\_minus1** | ue(v) |
| for( i = 0; i <= num\_decoding\_units\_minus1; i++ ) |  |
| **cpb\_removal\_delay[**i**]** | u(v) |
| **dpb\_output\_delay** | u(v) |
| } |  |
| } |  |

D.2 SEI payload semantics

D.2.1 Buffering period SEI message semantics

The semantics specifed in subclause D.2.1 of ITU-T Rec. H.264 | ISO/IEC 14496-10 apply, with the following changed semantics to initial\_cpb\_removal\_delay[ SchedSelIdx ] and initial\_cpb\_removal\_delay\_offset[ SchedSelIdx ]:

**initial\_cpb\_removal\_delay**[ SchedSelIdx ] specifies the delay for the SchedSelIdx-th CPB between the time of arrival in the CPB of the first bit of the coded data associated with the first decoding unit in the access unit associated with the buffering period SEI message and the time of removal from the CPB of the coded data associated with the same decoding unit, for the first buffering period after HRD initialisation. The syntax element has a length in bits given by initial\_cpb\_removal\_delay\_length\_minus1 + 1. It is in units of a 90 kHz clock. initial\_cpb\_removal\_delay[ SchedSelIdx ] shall not be equal to 0 and shall not exceed 90000 \* ( CpbSize[ SchedSelIdx ] ÷ BitRate[ SchedSelIdx ] ), the time-equivalent of the CPB size in 90 kHz clock units.

**initial\_cpb\_removal\_delay\_offset**[ SchedSelIdx ] is used for the SchedSelIdx-th CPB in combination with the cpb\_removal\_delay to specify the initial delivery time of decoding units to the CPB. initial\_cpb\_removal\_delay\_offset[ SchedSelIdx ] is in units of a 90 kHz clock. The initial\_cpb\_removal\_delay\_offset[ SchedSelIdx ] syntax element is a fixed length code whose length in bits is given by initial\_cpb\_removal\_delay\_length\_minus1 + 1. This syntax element is not used by decoders and is needed only for the delivery scheduler (HSS) specified in Annex C.

D.2.2 Picture timing SEI message semantics

NOTE 1 – The syntax of the picture timing SEI message is dependent on the content of the sequence parameter set that is active for the coded picture associated with the picture timing SEI message. However, unless the picture timing SEI message of an IDR access unit is preceded by a buffering period SEI message within the same access unit, the activation of the associated sequence parameter set (and, for IDR pictures that are not the first picture in the bitstream, the determination that the coded picture is an IDR picture) does not occur until the decoding of the first coded slice NAL unit of the coded picture. Since the coded slice NAL unit of the coded picture follows the picture timing SEI message in NAL unit order, there may be cases in which it is necessary for a decoder to store the RBSP containing the picture timing SEI message until determining the parameters of the sequence parameter that will be active for the coded picture, and then perform the parsing of the picture timing SEI message.

The presence of picture timing SEI message in the bitstream is specified as follows.

– If CpbDpbDelaysPresentFlag is equal to 1, one picture timing SEI message shall be present in every access unit of the coded video sequence.

– Otherwise (CpbDpbDelaysPresentFlag is equal to 0), no picture timing SEI messages shall be present in any access unit of the coded video sequence.

**num\_decoding\_units\_minus1** plus 1 specifies the number of decoding units in the access unit the picture timing SEI message is associasted with. The value of num\_decoding\_units\_minus1 shall be in the range of 0 to X, inclusive. When sub\_pic\_cpb\_flag is equal to 0, num\_decoding\_units\_minus1 is not present and the value is inferred to be 0.

**cpb\_removal\_delay[**i**]** specifies how many clock ticks (see subclause E.2.1) to wait after removal from the CPB of the first decoding unit in the access unit associated with the most recent buffering period SEI message in a preceding access unit before removing from the CPB the i-th decoding unit in the access unit associated with the picture timing SEI message. This value is also used to calculate an earliest possible time of arrival of decoding unit data into the CPB for the HSS, as specified in Annex C. The syntax element is a fixed length code whose length in bits is given by cpb\_removal\_delay\_length\_minus1 + 1. The cpb\_removal\_delay[ i ] is the remainder of a modulo 2(cpb\_removal\_delay\_length\_minus1 + 1) counter.

NOTE 2 – The value of cpb\_removal\_delay\_length\_minus1 that determines the length (in bits) of the syntax element cpb\_removal\_delay[ i ] is the value of cpb\_removal\_delay\_length\_minus1 coded in the sequence parameter set that is active for the coded picture associated with the picture timing SEI message, although cpb\_removal\_delay[ i ] specifies a number of clock ticks relative to the removal time of the first decoding unit in the preceding access unit containing a buffering period SEI message, which may be an access unit of a different coded video sequence.

**dpb\_output\_delay** is used to compute the DPB output time of the picture. It specifies how many clock ticks to wait after removal of the last decoding unit in an access unit from the CPB before the decoded picture is output from the DPB (see subclause C.2).

NOTE 3 – A picture is not removed from the DPB at its output time when it is still marked as "used for short-term reference" or "used for long-term reference".

NOTE 4 – Only one dpb\_output\_delay is specified for a decoded picture.

The length of the syntax element dpb\_output\_delay is given in bits by dpb\_output\_delay\_length\_minus1 + 1. When max\_dec\_pic\_buffering[ max\_temporal\_layers\_minus1 ] is equal to 0, dpb\_output\_delay shall be equal to 0.

The output time derived from the dpb\_output\_delay of any picture that is output from an output timing conforming decoder as specified in subclause C.2 shall precede the output time derived from the dpb\_output\_delay of all pictures in any subsequent coded video sequence in decoding order.

The picture output order established by the values of this syntax element shall be the same order as established by the values of PicOrderCnt( ) as specified by subclause C.5.

For pictures that are not output by the "bumping" process of subclause C.5 because they precede, in decoding order, an IDR picture with no\_output\_of\_prior\_pics\_flag equal to 1 or inferred to be equal to 1, the output times derived from dpb\_output\_delay shall be increasing with increasing value of PicOrderCnt( ) relative to all pictures within the same coded video sequence.

1. Annex E  
     
   Video usability information

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

This annex specifies syntax and semantics of the VUI parameters of the sequence parameter sets.

VUI parameters are not required for constructing the luma or chroma samples by the decoding process. Conforming decoders are not required to process this information for output order conformance to this Recommendation | International Standard (see Annex C for the specification of output order conformance). Some VUI parameters are required to check bitstream conformance and for output timing decoder conformance.

In Annex E, specification for presence of VUI parameters is also satisfied when those parameters (or some subset of them) are conveyed to decoders (or to the HRD) by other means not specified by this Recommendation | International Standard. When present in the bitstream, VUI parameters shall follow the syntax and semantics specified in subclauses 7.3.2.1 and 7.4.2.1 and this annex. When the content of VUI parameters is conveyed for the application by some means other than presence within the bitstream, the representation of the content of the VUI parameters is not required to use the same syntax specified in this annex. For the purpose of counting bits, only the appropriate bits that are actually present in the bitstream are counted.

* 1. VUI syntax
     1. VUI parameters syntax

|  |  |
| --- | --- |
| vui\_parameters( ) { | Descriptor |
| **aspect\_ratio\_info\_present\_flag** | u(1) |
| if( aspect\_ratio\_info\_present\_flag ) { |  |
| **aspect\_ratio\_idc** | u(8) |
| if( aspect\_ratio\_idc = = Extended\_SAR ) { |  |
| **sar\_width** | u(16) |
| **sar\_height** | u(16) |
| } |  |
| } |  |
| **overscan\_info\_present\_flag** | u(1) |
| if( overscan\_info\_present\_flag ) |  |
| **overscan\_appropriate\_flag** | u(1) |
| **video\_signal\_type\_present\_flag** | u(1) |
| if( video\_signal\_type\_present\_flag ) { |  |
| **video\_format** | u(3) |
| **video\_full\_range\_flag** | u(1) |
| **colour\_description\_present\_flag** | u(1) |
| if( colour\_description\_present\_flag ) { |  |
| **colour\_primaries** | u(8) |
| **transfer\_characteristics** | u(8) |
| **matrix\_coefficients** | u(8) |
| } |  |
| } |  |
| **chroma\_loc\_info\_present\_flag** | u(1) |
| if( chroma\_loc\_info\_present\_flag ) { |  |
| **chroma\_sample\_loc\_type\_top\_field** | ue(v) |
| **chroma\_sample\_loc\_type\_bottom\_field** | ue(v) |
| } |  |
| **neutral\_chroma\_indication\_flag** | u(1) |
| **field\_indication\_presence\_flag** | u(1) |
| **timing\_info\_present\_flag** | u(1) |
| if( timing\_info\_present\_flag ) { |  |
| **num\_units\_in\_tick** | u(32) |
| **time\_scale** | u(32) |
| **fixed\_pic\_rate\_flag** | u(1) |
| } |  |
| **nal\_hrd\_parameters\_present\_flag** | u(1) |
| if( nal\_hrd\_parameters\_present\_flag ) |  |
| hrd\_parameters( ) |  |
| **vcl\_hrd\_parameters\_present\_flag** | u(1) |
| if( vcl\_hrd\_parameters\_present\_flag ) |  |
| hrd\_parameters( ) |  |
| if( nal\_hrd\_parameters\_present\_flag | | vcl\_hrd\_parameters\_present\_flag ) { |  |
| **sub\_pic\_cpb\_flag** | u(1) |
| **low\_delay\_hrd\_flag** | u(1) |
| } |  |
| **bitstream\_restriction\_flag** | u(1) |
| if( bitstream\_restriction\_flag ) { |  |
| **motion\_vectors\_over\_pic\_boundaries\_flag** | u(1) |
| **max\_bytes\_per\_pic\_denom** | ue(v) |
| **max\_bits\_per\_mincu\_denom** | ue(v) |
| **log2\_max\_mv\_length\_horizontal** | ue(v) |
| **log2\_max\_mv\_length\_vertical** | ue(v) |
| } |  |
| } |  |

* 1. VUI semantics
     1. VUI parameters semantics

**...**

**sub\_pic\_cpb\_flag** equal to 0 specifies that the CPB operates at access unit level. sub\_pic\_cpb\_flag equal to 1 specifies that the CPB operates at decoding unit level. When sub\_pic\_cpb\_flag is not present, its value is inferred to be equal to 0.

**low\_delay\_hrd\_flag** specifies the HRD operational mode as specified in Annex C. When fixed\_pic\_rate\_flag is equal to 1, low\_delay\_hrd\_flag shall be equal to 0. When low\_delay\_hrd\_flag is not present, its value is inferred to be equal to 1 − fixed\_pic\_rate\_flag.

NOTE 10 – When low\_delay\_hrd\_flag is equal to 1, "big pictures" that violate the nominal CPB removal times due to the number of bits used by an access unit are permitted. It is expected, but not required, that such "big pictures" occur only occasionally.

**...**