UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE PATENT TRIAL AND APPEAL BOARD

INTEL CORPORATION
Petitioner

v.

TELEFONAKTIEBOLAGET LM ERICSSON,
Patent Owner

INTER PARTES REVIEW OF U.S. PATENT NO. 9,641,841

DECLARATION OF DR. CLIFFORD READER

Declaration

I declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

By: C. Reader

Clifford Reader, Ph.D.

6/12/24

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I, Dr. Clifford Reader, do hereby declare:

1. I am making this declaration at the request of Petitioner Intel Corporation ("Intel") in the matter of *Intel Corporation v. Telefonaktiebolaget LM Ericsson*, IPR2024-01008.

2. I am being compensated for my work in this matter at my standard hourly rate of $850 for consulting services. My compensation in no way depends on the outcome of this proceeding or the content of my testimony.

3. In preparing this Declaration, I considered the following materials, along with the exhibits that I cite throughout this Declaration:

a. *Extended video procedures and control signals for H.300-series terminals*, ITU-T – Telecommunication Standardization Sector, H.241 (May 29, 2006) ("H.241") (Ex-1017);

b. *Test Model under Consideration*, Joint Collaborative Team on Video Coding (JCTVC) of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11, JCTVC-B205, (July 2010) ("B205") (Ex-1018);

c. Thomas Wiegand, *Working Draft Number 2, Revision 2 (WD-2)*, Joint Video Team (JVT) of ISO/IEC MPEG and ITU-T VCEG, JVT-B118r2, (March 15, 2002) ("B118") (Ex-1023);

d. Gisle Bjontegaard, *Deblocking filter for 4x4 based coding*, ITU – Telecommunications Standardization Sector, Study Group 16, Q15-J-27 (May 5, 2000) ("Bjontegaard Cover") (Ex-1016).

e. Gisle Bjontegaard, *Definition of the new coding elements from Telenor*, ITU – Telecommunications Standardization Sector, Study Group 16, Q15-J-28 (May 5, 2000) ("Bjontegaard") (Ex-1009).

f. Gisle Bjontegaard, *Software Including Proposed New H.26L Coding Elements from Telenor*, ITU – Telecommunications Standardization Sector, Study Group 16, Q15-J-29 (May 9, 2000) ("Bjontegaard's Code") (Ex-1010-1015).

A. Professional Background

1. Summary

4. I am a digital media consultant providing technical, business development and intellectual property consulting services in the areas of digital media, including digital imaging, digital video, digital audio and digital speech. Applications include consumer radio and video transmission and storage, video, audio and speech compression, real-time video processing and display, digital speech processing, image/video/audio systems architecture, and image/video/audio

chip architecture. I have held this position since 2001 and have consulted for over 80 clients.

2. Education

5. I received my Doctoral degree in 1974 from the University of Sussex, England. My thesis was titled "Orthogonal Transform Coding of Still and Moving Pictures." My research for my thesis was performed in residence at the Imaging Processing Institute, University of Southern California, Los Angeles.

6. I received my B. Eng. Degree with Honors in 1970 from the University of Liverpool, England, in the field of electronics.

3. Work Experience

7. From 1970 to 1973, I performed my graduate research in video compression. I was one of the first to perform a type of image coding (adaptive block transform coding) and the first to apply this type of coding to video. This is described in my thesis[1] and summarized in an SPIE paper.[2] These techniques underlie the audiovisual coding standards known as MPEG (Moving Pictures Experts Group), H.26x, and virtually all other video compression schemes today.

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[1] Reader C., "Orthogonal Transform Coding of Still and Moving Pictures", U. Sussex, England, 1973.
[2] Reader C., "Intraframe and Interframe Adaptive Transform Coding", SPIE Vol. 66, 1975.

8. From 1975 to 1981, I studied, designed and developed systems for military imaging systems, including real-time image and video reconnaissance systems and battlefield management systems.

9. In the early 1980s, I taught classes at Santa Clara University, California in digital signal processing and digital image processing.

10. From 1982 to 1989, I architected and led hardware and software engineering teams in the design of systems for real-time imaging for military, medial and earth resources applications.

11. From 1990 to 2001, I architected and led hardware and software engineering teams in the design of semiconductor chips and systems for real-time imaging in digital consumer audio/video applications, including videoconferencing (with speech coding), broadcast TV and DVD.

4. Standardization

12. In 1990, I became an accredited delegate to the Moving Pictures Experts Group ("MPEG") – an alliance of working groups established by the International Organization for Standardization ("ISO") and International Electrotechnical Commission ("IEC"). My team and I contributed to the technical work for all three parts of the MPEG 1 standard – Systems, Video and Audio – and I participated in the management of MPEG.

13. I was Head of Delegation to MPEG for the United States in 1991-1992, and Editor in Chief of the MPEG 1 standard. I personally reviewed and edited all three parts of the standard in detail, and wrote much of the informative annex for the MPEG 1 standard.

14. I chaired the implementation subcommittee that analyzed MPEG 1 Audio (Levels I & II aka MUSICAM; Level 3 aka mp3), Dolby AC3 and other proposed audio compression algorithms, including legacy algorithms for complexity and cost of implementation.

15. I was a co-founder of the MPEG 4 standard and chaired the subcommittee from inception for two and a half years, beginning in 1993. I then chaired the MPEG 4 Requirements subcommittee for two years. These subcommittees established many of the fundamental principles of the MPEG 4 standard, including object-based coding, software-based implementation, and development of the bitstream as a syntactic language.[3] MPEG 4 focused on audiovisual low bitrate coding, including low bitrate speech coding.

16. MPEG 4 was developed in close cooperation with the International Telecommunication Union ("ITU") subcommittee[4] developing the H.263 standard

[3] Reader C, "MPEG4: Coding for Content, Interactivity, and Universal Accessibility", Optical Engineering, Vol. 35, No. 1, pp. 104-108, Jan 1996.
[4] Originally called "LBC" for low-bitrate coding subcommittee. Later called "VCEG" for video coding experts group.

and the H.264 standard. The ITU rapporteur and I co-sited many of our meetings, and in many cases, we and experts from both subcommittees attended both meetings. A profile of MPEG 4 Part 2 Visual and H.263 have identical specifications and are interoperable. The H.264 standard is a "long-term" development of the H.263 standard.

17. I was instrumental in establishing the work on Audio Advanced Coding.

18. I initiated the work in Synthetic-Natural Hybrid Coding and personally contributed to the work on compression of 3D graphics in the area of error resilient coding.

19. I was an invited expert to the H.264/MPEG 4 Pt. 10 standard development by the JVT committee, for which I contributed to and participated in multiple meetings in person.

20. I have chaired the AVS China IPR Subgroup for over twenty years and attend multiple meetings each year.

21. I have personally tracked the development of all the international video coding standards since 1990 and have accessed all the documents related to the respective ISO and ITU committees.

5. Intellectual Property Rights

22. In 1993, I was hired by CableLabs to be the technical expert for establishing the MPEG Patent Pool (now MPEG LA). In the course of creating a list of essential IP to practice the standard, I reviewed approximately 10,000 abstracts and 1,000 patents. This is summarized in a chapter of the MPEG book by Mitchell et al.[5]

23. In 2002, I was hired by ten companies to evaluate the standards essential patent environment for the nascent H.264 standard. I was an invited expert to the Joint Video Team (JVT) established by ISO and ITU to develop the H.264 standard (also denoted MPEG 4 Pt. 10, AVC).

24. In 2003, I was hired to evaluate the standards essential patent environment for the nascent national China AVS standards.

25. In 2013, I was hired to evaluate the standards essential patent environment for the emerging AV1 standard.

26. In 2017, I was hired to evaluate the standard essential patent environment for the H.265/HEVC standard.

27. I am the Co-Director of the China AVS Patent Pool Administration. I lead the negotiations for sub-licensing of the AVS standards.

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[5] "MPEG Video Compression Standard", edited by J. L. Mitchell et al, Chapter 16, "MPEG Patents", pp.357-62.

28. I have performed expert consulting and expert witness work for patent holders and defendants in patent licensing negotiations and litigation.

6. Curriculum Vitae

29. Additional information concerning my professional publications and presentations in the field of digital video and cases in which I have served as an expert are set forth in my current Curriculum Vitae, a copy of which may be found at Ex-1006. This Curriculum Vitae lists many publications authored and co-authored by me; and lists the cases in which I have testified via depositions and trials.

B. The ’841 Patent and Person of Ordinary Skill

30. I understand that Intel is challenging the validity of U.S. Patent No. 9,641,841 (“’841 Patent”).

31. The ’841 Patent originated from an international patent application PCT/SE2011/051526, which was filed on December 16, 2011. The ’841 Patent claims priority to U.S. Provisional Application No. 61/447,862, filed on March 1, 2011. I therefore understand that the earliest possible priority date of the ’841 Patent is March 1, 2011.

32. I understand that the ’841 Patent is alleged to be relevant to the High-Efficiency Video Coding (“HEVC” or “H.265”) standard. I have been asked to provide my opinions as to the public availability and accessibility of certain prior art to the ’841 Patent.

33. I also understand that Intel has proposed a definition for a person of ordinary skill in the art ("POSITA") that requires a bachelor's degree in electrical engineering, computer science, or a similar field and two to three years of experience in the design and development of relevant multimedia processing, such as video and/or image coding or compression. Advanced graduate studies with coursework and/or research focusing on topics of video encoding/decoding and processing could substitute for working experience in the field.

34. I am not providing an opinion as to this definition of a POSITA. However, as of the earliest possibly priority date of the '841 Patent, I was a POSITA under this definition. I have also applied this definition to assess whether, in my opinion, a POSITA would have been able to locate the prior art on which I have been asked to opine on the public availability and accessibility.

C. Legal Standard

35. Counsel has informed me of the legal principles that apply in determining whether a prior-art reference was publicly available and accessible. Paragraphs in this section beginning with "I understand" or "I have been informed" are my understanding of the law as provided to me by counsel. The other paragraphs are my opinion.

36. I understand that 35 U.S.C. § 102 sets forth the requirements for a reference to be considered "prior art," which can include among other things: patents

and patent applications that were filed and/or published before the patent-at-issue's priority date, *see, e.g.*, 35 U.S.C. § 102(b), (e), or "printed publications" that were published before the patent-at-issue's priority date, *see, e.g.*, 35 U.S.C. § 102(a), (b).

37. I understand that for a reference to be considered a "printed publication" under § 102, it must have been disseminated and publicly accessible to at least the pertinent part of the public who would be interested in the subject matter to which the reference pertains. In other words, a POSITA exercising reasonable diligence must be able to locate it.

38. For instance, I understand that if a reference is indexed or cataloged in some way (e.g., by a library or industry group), or if research tools were provided, such that a POSITA exercising reasonable diligence could locate it, that may be sufficient to demonstrate the reference constitutes a "printed publication," but simply e-mailing a document to a select group of individuals may not. But I also understand that whether a reference constitutes a printed publication depends on the facts of each particular case. I also understand that whether a reference qualifies as a printed publication does not require showing a member of the public actually located and read the reference.

D. Brief Overview of the Standardization Process

39. Before addressing the prior art, it is worth providing an overview of the standardization process followed by standardization organizations such as the ITU-

VCEG and ISO-MPEG – two of the dominant organizations in developing video-coding standards. In my opinion, a POSITA would have understood the general procedures of the standardization process, and a POSITA interested in video coding would have been following video-coding standards developments closely, as many in the industry did to ensure any product involving video coding would be compliant with the relevant standards as soon as the standard was published.

40. For context, the ITU is a "United Nations specialized agency for information and communication technologies (ICTs)." Ex-1075. The ITU is headquartered in Geneva. *Id*. The ITU's Telecommunication Standardization Sector ("ITU-T") facilitates the development of international standards, called ITU Recommendations, that help define a global infrastructure of information and communication technologies. *See* Ex-1085. Within ITU-T is a working group called the Video Coding Experts Group ("VCEG"), which focuses on standards for compression coding of video signals.

41. MPEG is a subcommittee under a joint venture between the International Organization for Standardization ("ISO") and International Electrotechnical Commission ("IEC"), and, like the ITU VCEG, develops "international standards for compression, decompression, processing, and coded representation of moving pictures." Ex-1076.

42. Although I am not a member of the ITU, I have been accredited to ITU as an invited expert, I am aware of the ITU's website – including as of the earliest possible priority date of the '841 Patent – the accuracy of the dates on the ITU's website and the process for documents being uploaded to the ITU's website. I am also intimately familiar with the MPEG's website.

43. The ITU-VCEG's and ISO-MPEG's development of video coding standards generally comprises a two-stage process. In the first so-called competitive phase, the standards body conducts a requirements analysis to determine market need for a new standard and develops specific requirements for functionality and performance to meet those needs. The committee evaluates the evolving state of the art in relevant technologies to assess the degree to which a new standard would out-perform a current standard. The standards body develops a call for proposals that typically includes a provision of test materials that will allow the proposals to be evaluated on equal terms, test procedures that lay out what each proponent must provide and how evaluation will be conducted, as well as written submission requirements to describe the proposed coding tools and complexity/cost of implementing such tools.

44. The proposals are received, evaluated, and ideally one is selected to be the foundation of the new standard. In practice, the foundation may comprise an amalgam of several proposals.

45. The second so-called collaborative phase then begins, with the establishment of a "working draft" of the standard, plus a "test model" and "reference software," that will support a recursive development process over a succession of meetings. Although the final video coding standard will only normatively specify the coded data format and decoding process, the test model and reference software comprise an end-to-end encoding and decoding process, so that independent parties can conduct experiments that are directly comparable.

46. At each meeting, proponents can submit contributions that may comprise proposals for enhancing existing video coding tools or adding new tools. The proposals will generally include testing of the proposal by implementing it on the reference software and testing it with the test sequences. Other parties cross-check or validate each proposal by reading the description provided by the proponent and independently implementing the proposal on the reference software and testing it. This is facilitated by the uploading of such proposals before a meeting and of course open access to such documents. At the corresponding meeting, the standards body can review the proposal and test results from both the proponent and cross-checkers, and can decide whether or not to adopt the proposal into the draft standard. If adopted, the proposed tool will be added to the working draft, test model and reference software. In this manner, the standard recursively advances toward maturity.

47. At meetings, the standards body may specify "core experiments" that describe in detail a particular problem or area of work where advancement is needed. Between meetings, the standards body may establish "ad hoc groups" – open to everyone – that may collaborate on specific developments, e.g., core experiments and exchange ideas via email.

48. At each meeting, the chairpersons develop a meeting report, published at the end of the meeting. The meeting report provides a summary and disposition of each contribution to the meeting, summaries of ad hoc group reports, results of core experiments, and administration activities, such as reminders of obligations under the IPR policy. In some cases an "AgendaWithNotes" running account of activities is created progressively during the meeting and is posted online.

49. The openness and timeliness of this process means that any interested person can track the development of the standard – even without attending the meetings. For example, semiconductor companies can have their research and product development departments port the reference software to their proprietary firmware environment after it is updated each meeting and simulate the nascent standard on their own chip development platform. In that way, the companies can be prepared to release new chips supporting the new standard as soon after the final specification is frozen as possible.

E. The ITU Documents Were Publicly Available

50. I have been asked to provide my knowledge of the public availability and accessibility of several prior-art references that arose as a result of several different ITU-T and/or joint-MPEG video-coding standards, including:

- The H.26L standard – an evolution of the H.263 standard that ultimately launched as the H.264 standard – under development by the ITU-T Question 6, Study Group 16 (VCEG), which began development in earnest around 1997. Around 2001, however, the VCEG joined with MPEG to form the "Joint Video Team" ("JVT"), which took over the work of VCEG to finalize the H.26L standard. *See, e.g.*, Ex-1038, 3. I was actively monitoring, and as noted above, participating in the development of standards through meetings of ISO/MPEG, ITU/VCEG, and ISO/ITU JVT.
- The H.241 standard, which was developed by the ITU-T to provide "[e]xtended video procedures and control signals for H.300-series terminals," H.241, Cover, and "defines the procedures for use of advanced video codecs, including ITU-T Rec. H.264, with H.300-series terminals," *id.*, 1. In other words, H.241 was predominantly intended to standardize implementations of the H.264 standard on videoconferencing equipment. Beginning in 2006, however, H.241 also

specified "a reduced-complexity decoding process to be applied to H.264 Baseline profile bitstreams when such use has been negotiated using ITU-T Rec. H.241." H.241, i, 1. Although I am not a member of the ITU, as an interested participant in the field, I was aware of the ITU standardization process (*see* Section A above) and where documents are available to the public on the ITU's website.

- The HEVC or H.265 standard, which was developed by the Joint Collaborative Team on Video Coding ("JCTVC") again formed as a collaboration between the ITU-T-VCEG and ISO-MPEG. Although I did not attend the JCTVC meetings in person, as an interested participant in the field, I was aware of the HEVC standardization process as it was happening and was following its developments in real time.

1. Public Availability of Bjontegaard and Bjontegaard's Code

51. As I previously noted, the ITU's VCEG began working on the H.26L standard in the late 1990s, with the goal of creating the next-generation videoconferencing standard.

52. VCEG followed the same general standards-development procedures I outlined above, using a recursive process conducted from meeting to meeting.

53. In one of the early meetings of VCEG – the February 2000 meeting held in Geneva – VCEG issued a meeting report (labeled "E(WP 3/16)"), which explained that "[t]he primary means of document distribution within the Q15/16 Video Coding Experts Group is electronic, and [their] documents can be found on an ftp site that is maintained at PictureTel: ftp://standard.pictel.com/video-site or http://standard.pictel.com/ftp/video-site," and that "[t]his information is also linked to PictureTel's broader standards web site." Ex-1074, 9.[6] Moreover, the meeting report stated that "[t]he group conducts its email conversations over an email reflector," and that "[r]equests for subscriptions … should be sent to the majordomo automated list manager address: itu-adv-video-request@standard.pictel.com," which included another reflector "to ensure that those subscribing to the ITU-maintained list receive all group communications." *Id.*, 10. Thus, anyone could sign up for the list serve and receive updates on the development of the VCEG. This announcement was made in each meeting report. *See, e.g.*, Ex-1109, 9-10.

54. Those involved in VCEG also announced this website in other publications. For instance, I am aware of at least one 2001 article published by the Institute of Electrical and Electronics Engineers ("IEEE") – an authoritative source

[6] This website has since been moved to the ITU's website at https://www.itu.int/wftp3/av-arch/video-site/, which, based on my personal experience and recollection, is also widely known.

of technical information in many fields, including video-coding technologies – that described "using the draft H.26L video coding standard for mobile applications," and explained that "documents and software for the project can currently be found at http://standard.pictel.com/ftp/video-site." Ex-1079, 573, 576. Thus, readers of IEEE literature – of which there are many – would have known that VCEG was working on an H.26L standard as of at least 2001 (but, in my opinion, they would have been aware from other sources earlier), and would have known to search out further information on the development of H.26L at the identified website.

55. Based on my personal experience and recollection, VCEG's documents were available at the ITU website, as I was able to access them through that website at the time. Accessing these documents on the VCEG website did not require a username or password.

56. Based on my personal experience and recollection, in 2000, documents on the ftp website were organized by meetings. Each meeting was identified with the following convention: [year][month][location] (e.g., 0005_Osa meant the Osaka meeting held in May of 2000; 0008_Por meant the Portland meeting held in August 2000). Ex-1081; Ex-1131 (archive of the original ftp). Once a meeting was selected from the menu, all of the input and output documents associated with that meeting were viewable and downloadable, and included the document number, the various upload dates, the title of the document, and the source. Each document's filename

began with the prefix "q15," which represented the fact that VCEG was exploring Study Group 16's "Question 15" directed to "Advanced video coding." Ex-1092. The documents were organized in numerical order, where different draft versions of the same document were identified with a sequential draft number. The documents were organized reasonably consistently from one meeting to the next.

57. Each meeting was announced in advance, with detail provided in a meeting invitation. *See* Ex-1110 ("Announcement of the Tenth Meeting of the Experts Group for ITU-T Q.15/SG16 - Advanced Video Coding, Osaka, Japan, May 16-19, 2000"). Key elements of the invitation with respect to document accessibility are:

- Openness to all ITU-T Members plus a special invitation to non-members with explicit directions on how such non-members can apply to attend.
- Advance notice of availability of documents on the VCEG's (Q15/16) file transfer protocol ("ftp") website at ftp://standard.pictel.com and encouragement to monitor the site.
- Details on submitting documents for the meeting, including a template, numbering procedure, registration procedure, and more, with a request to upload 10 days in advance.

- Notice of mandatory uploading 4 business days in advance of the meeting.

58. Based on my recollection, in 2000, a "List of Documents" was uploaded to the ftp website just prior to each meeting. This document was typically identified with a numerical suffix ("00," e.g., Q15J00"), and provided an overview of and index to the proposals/documents to be discussed at a particular meeting. Sometimes, multiple versions were uploaded, such as one draft before the meeting took place, and one draft at the end of the meeting or as soon as possible after the meeting. *See, e.g.*, Ex-1107; Ex-1108 ("List of Documents" for the 2000 Osaka meeting). Below are exemplary screenshots from the first version of the Osaka J Meeting list of documents (available at the beginning of the meeting):

ITU-T Q.15/16 Video Coding Experts Group
10th meeting, Osaka, Japan, Oct 19-22, 2000

Document Q15-J-00 rev. 0 (filename q15j00r0.doc)
last date revised: 11 May, 2000

LIST OF DOCUMENTS FOR THE TENTH MEETING
ITU-T Q.15/SG16
VIDEO CODING EXPERTS GROUP

DOCUMENT NO.	SOURCE		PURPOSE	TITLE	ADMIN	H.263	H.263++	H.26L	PRIOR	OTHER
	COUNTRY	EXPERT/ ORGANIZATION								
Meeting Invitation and Meeting Plan										
Q15-J-TD-0	Gary Sullivan, Q15/16 Rapporteur		I	Invitation to the Ninth Meeting of the ITU-T Q.15/SG16 Video Coding Experts Group	X					
Q15-J-TD-1	Gary Sullivan, Q15/16 Rapporteurr		I	Plan of the Ninth Meeting of the ITU-T Q.15/SG16 Video Coding Experts Group	X					
Q15-J-00	Gary Sullivan, Q15/16 Rapporteurr		I	List of Documents of the Ninth Meeting of the ITU-T Q.15/SG16 Video Coding Experts Group	X					
Report of Previous Meeting										
Q15-J-01	Gary Sullivan, Q15/16 Rapporteur		I	Meeting report of Video Activities at the Feb 2000 meeting of ITU-T SG16 (Study Period 1997-2000)	X					
List of Meeting Participants and Experts Group										
Q15-J-02	Gary Sullivan, Q15/16 Rapporteur		I	List of Participants of the Ninth Meeting (Meeting I) of the ITU-T Q.15/SG16 Video Coding Experts Group	X					
Q15-J-03	Gary Sullivan, Q15/16 Rapporteur		I	List of Experts of the ITU-T Q.15/SG16 Video Coding Experts Group	X					
Ad Hoc Reports										
Q15-J-04	Stephan Wenger, AHC Chairperson		I	Report of the Ad Hoc Committee on Consideration of Simulation Conditions and Evaluations for Error Resilience Testing	X	X	X	X		
Q15-J-05	Keiichi Hibi, AHC Chairperson		I	Report of the Ad Hoc Committee on Test Model Enhancement and Software Development	X	X	X	X		
Q15-J-06	Gary Sullivan, AHC Chairperson		I	Report of the Ad Hoc Committee on H.263++ Development	X		X			
Q15-J-07	Keiichi Hibi, AHC Chairperson		I	Report of the Ad Hoc Committee on H.26L Development	X			X		

I = Information, D = Draft, L = Liaison or Letter, P = Proposal
italics = document not uploaded by deadline

Page 1

Ex-1107, 1.[7]

59. The list begins with temporary documents (identified with suffix "TD") for administrative matters, followed by the identification of the "List of Documents" itself (Q15-J-00). Then, the "Meeting Report" for the previous meeting – which is finalized *after* each meeting takes place – is listed, followed by the lists of

[7] This first draft of the List of Documents for the "J" meeting mistakenly identified the meeting dates ("October 19-22") of the prior "I" meeting that was held on October 19-22, 1999 in Red Bank, New Jersey. *See* Ex-1106, 1. These dates were corrected in a subsequent revision to the List of Documents to identify the May 16-19, 2000 date of the Osaka meeting. Ex-1108, 1.

participants and reports from the various ad hoc groups on their activities between the last meeting and this. The meeting contributions follow – including titles that (preferably) identify the topic.

DOCUMENT NO.	SOURCE		PURPOSE	TITLE	ADMIN	H.263	H.263++	H.26L	PRIOR	OTHER
	COUNTRY	EXPERT/ ORGANIZATION								
Geneva Output Supplemental Reports										
Q15-J-08	Gisle Bjøntegaard, Test Model Editor		I	H.26L Test Model Long-Term Number 3 (TML-3)				X		
Q15-J-09	Gisle Bjøntegaard, Louis Kerofsky, Experiment Coordinators		I	H.26L Core Experiment on Adaptive Motion Accuracy (AMA) for 1/2, 1/4, and 1/8 Sample Accuracy Motion Compensation				X		
Meeting Contributions										
Q15-J-10	Canada	Michael Gallant, Faouzi Kossentini, U. Brit. Columbia; Stephan Wenger, T.U.-Berlin/TELES AG	I	Internet Anchor Bitstreams for Experiment Comparisons			X	X		
Q15-J-11	USA	Michael Horowitz, Polycom	I	Real-Time Demonstration of H.263++ Annex U Performance and Implementability			X			
Q15-J-12	USA	Barry G. Haskell, AT&T Bell Labs	P	Proposed Draft for Appendix II of H.263			X			
Q15-J-13	USA	Barry G. Haskell, AT&T Bell Labs	P	Specifying H.263 Profiles in IETF Environments			X			
Q15-J-14	Germany	Thomas Wedi, Univ. Hannover	P	Interpolation filters for motion compensated prediction with 1/4 and 1/8 pel accuracy for H.26L				X		
Q15-J-15	Germany	Thomas Wedi, Univ. Hannover	P	Results of H.26L core experiment on Adaptive Motion Accuracy (AMA) with 1/2, 1/4 and 1/8 pel accuracy				X		

* * *

DOCUMENT NO.	SOURCE		PURPOSE	TITLE	ADMIN	H.263	H.263++	H.26L	PRIOR	OTHER
	COUNTRY	EXPERT/ ORGANIZATION								
Q15-J-53	Germany	Stephan Wenger, T.U.-Berlin/TELES AG	P	H.26L Error Resilience: First Results			X			
Q15-J-54	Sweden	Gunnar Hellström, Swedish National PTT	P	Text Coding for H.263++ Annex W			X			
Q15-J-55	Finland	Miska Hannuksela, Nokia Mobile Phones	P	New Annex W Functions for Error Resilience			X			
Q15-J-56	Korea	Kook-yeol Yoo, Yung-Lyul Lee, Samsung	P	A New Affine Motion Description Method				X		
Q15-J-57 (or Zipped)	Korea	Byeungwoo Jeon, Sung Kyun Kwan Univ.	I	Entropy Coding Efficiency of H.26L				X		
Q15-J-58	USA	Gary Sullivan, Microsoft Corp.	P	Remarks on H.263++ Annex U			X			
Late-Registered Contributions										
Output Documents										
Meeting Report Document										
Q15-J-XX	*Gary Sullivan, Q15/16 Rapporteur*		*I*	*Meeting report of the ninth meeting (meeting J) of the ITU-T Q.15/16 Advanced Video Coding Experts Group – Osaka, Japan, 16-19 May, 2000 (Study Period 1997-2000)*	*X*					
End of Document List										

Ex-1107, 1-6.

60. Late documents – those not uploaded before the deadline prior to the meeting are then listed. In the initial draft of the List of Documents (Q15-J-00r0) shown above, no documents are listed as "late" because this document was generated on May 11th, around the time of the cutoff to submit documents for the May 16th meeting. But in a subsequent revision to the document, late submissions were added. *See* Ex-1108, 6-7.

61. In my experience, because the input and output documents on the early VCEG website were organized by meeting, but their file names alone did not include other identifying information about the contents of each document, those involved in VCEG, as well as those outside of VCEG who were following VCEG's developments, would navigate the VCEG file sharing website by first looking to the List of Documents because it provides an overview of the contributions (including proposals) for any given meeting. *See* Ex-1107; Ex-1108. That would then enable those involved or interested in VCEG's developments to identify any specific proposal documents of interest.

62. Because the List of Documents was labeled with the suffix "00," in my experience, those involved or interested in VCEG's developments knew how to locate the List of Documents for each meeting. *See, e.g.*, Ex-1082; Ex-1032 (archive of original ftp). But even those not already familiar with VCEG's document

numbering would have easily found the List of Documents because, by labeling it with number "00," it was one of the first entries in the directory for each meeting. *Id.* The List of Documents for each meeting would have therefore been a natural place for a POSITA to investigate the VCEG's development process for the H.26L standard because they provided a quick assessment of which proposals were under consideration, and identified at least the title of the proposal that may contain pertinent information about what was being proposed.

63. Upon reviewing the List of Documents for the 2000 Osaka meeting, a POSITA interested in deblocking-filter design would have been drawn to one document identified in the meeting summary of the 2000 Osaka meeting: Q15-J-27 ("Bjontegaard's Cover") – authored by Gisle Bjontegaard at Telenor – because it was titled "Deblocking Filter for 4x4 Based Coding," and was the only document that was directed to a deblocking filter for that meeting. Ex-1107, 4.

64. Document Q15-J-27, however, was just a cover document for Bjontegaard's proposal. Ex-1016. The document stated that "[t]he complete filter description is given in q15j28.doc section 4.5." *Id.* In other words, document Q15-J-27 (Bjontegaard's Cover) expressly directed those interested in the proposed H.26L deblocking filter to document Q15-J-28. *Id.* I understand that document Q15-J-28 is the prior-art reference referred to as "Bjontegaard." Ex-1009. The

Bjontegaard reference explains that it "is a complete description of the Telenor coding model as presented at Osaka." Ex-1009, 4; Ex-1107, 4.

65. Furthermore, the List of Documents for the 2000 Osaka meeting also noted that a third file: Q15-J-29 (Bjontegaard's Code) provided "[s]oftware including proposed new H.26L coding elements from Telenor." Ex-1107, 4. The document and ITU archive also showed Bjontegaard's Code was uploaded on the same date, and by the same contributors, as Q15-J-27. *Id.*; Ex-1082 (showing "q15j27.doc", "q15j28.doc", and "q15j29.zip" all uploaded "5/9/2000"); Ex-1132 (archive of original ftp showing same). In other words, a POSITA would have known to look not only at Q15-J-27 (Bjontegaard's Cover, which directed those interested to look to Q15-J-28, Bjontegaard), but also to Q15-J-29 (Bjontegaard's Code) for the software package embodying Bjontegaard's proposal. Downloading Q15-J-29 provided a software package that included executable program files and source code. Ex-1010. The package also included a "readme" file – which was a known and widely used filename as the first place to look in a software package to provide a directory or overview of the package – disclosed that Q15-J-29 embodies "[t]he new proposed Telenor elements described [in] document Q15J27." Ex-1015. In other words, Q15-J-27 (Bjontegaard's Cover), Q15-J-28 (Bjontegaard), and Q15-J-29 (Bjontegaard's Code) cross-referenced one another, indicating to me that they were one proposal package intended to be read together.

66. Although the "standard.pictel.com" websites that originally hosted the VCEG standardization documents is no longer active, the ITU archive of those documents (https://www.itu.int/wftp3/av-arch/video-site/) is, and preserves the original upload dates and times of each VCEG contribution. *Compare* Ex-1082 (ITU archive), *with* Ex-1132 (archive of the original ftp). The ITU archive notes that documents Q15-J-27 (Bjontegaard's Cover), Q15-J-28 (Bjontegaard), and Q15-J-29 (Bjontegaard's Code) were all uploaded on May 9, 2000, just minutes apart. *Id*. This is consistent with the dates presented on documents themselves. *See* Ex-1016, 1 (Bjontegaard's Cover "Generated: 5 May '00," just days before its recorded submission date); Ex-1009, 1 (Bjontegaard same); Ex-1015 (Bjontegaard's Code readme file dated "May 9, 2000").

67. Moreover, those interested in the video-coding field were citing Bjontegaard's Cover and/or Bjontegaard before the earliest possible priority date of the '841 Patent, *see, e.g.*, Ex-1114, 4 (citing Bjontegaard); Ex-1115, ¶ 2 (citing Bjontegaard's Cover); Ex-1116 (same), ¶ 6, which in my opinion demonstrates that those interested knew where to find them. In fact, I myself had cited Bjontegaard's Cover when I published a summary of H.264's history in 2005. Ex-1113, 8 (ref. no. 14 citing Q15-J-27).

68. Based on my personal experience and recollection, and as confirmed by the ITU archive, Bjontegaard's Cover, Bjontegaard, and Bjontegaard's Code

were distributed and publicly available in May 2000. The copy of Bjontegaard at Ex-1009, Bjontegaard's Cover at Ex-1016, and printouts of Bjontegaard's Code at Ex-1010-1015 are all true and correct copies of the documents and software distributed in May 2000 and is substantially identical to the versions that I have in my personal archive, which I have attached as Appendix 1 (Bjontegaard's Cover) and 2 (Bjontegaard).[8] Because of the nature of Bjontegaard's Code, I have not provided my personal copy, but can confirm the printouts are accurate of the version of Bjontegaard's Code that I possess, including the printout (Ex-1010) that represents the files and file structure provided in Bjontegaard's Code. And although I do not remember exactly when I downloaded Bjontegaard, Bjontegaard's Cover, and Bjontegaard's Code, to the best of my recollection, it was years before the earliest effective filing date of the '841 Patent.

69. The ITU archive as it is presented today, Ex-1082, is consistent with my recollection of how it was presented in 2000, is consistent with archive of the original Pictel ftp website (including the upload dates and times, although apparently

[8] Bjontegaard (and many other standards-development documents) included an automatically updating timestamp in the footer under "Date Printed." Unless the automatic-updating feature is overridden and the original date is intentionally preserved (such as by opening the document in a "Protected Mode"), the date will change each time the document is opened. As shown, the date I had last opened my personal copy of Bjontegaard was March 29, 2017, but that was not the date I first downloaded it.

recorded with reference to different time zones), Ex-1132, and I have no reason to doubt the accuracy of the dates presented on either the ITU or Pictel archives.

70. For these reasons, not only was Bjontegaard and Bjontegaard's Code publicly available as of May 9, 2000, but it would have been routine and straightforward for a POSITA to locate those documents if interested in deblocking-filter design.

2. Public Availability of B118

71. As I had mentioned, in 2001, the ITU-T-VCEG and ISO-MPEG organizations joined forces to create a new standardization group called the JVT, which was "was a group of video coding experts from ITU-T Study Group 16 (VCEG) and ISO/IEC JTC 1 SC 29 / WG 11 (MPEG) created to develop an advanced video coding specification." Ex-1101. The JVT took over the prior work of VCEG, and completed the first version of the H.26L (since-renamed H.264) standard in May 2003. *Id.* JVT held its final meeting in November 2009, at which the work within its charter was considered largely completed. *Id.*

72. The JVT followed the same general standards-development procedures I outlined above, using a recursive process conducted from meeting to meeting.

73. Based on my personal experience and recollection, those in the video-coding industry were closely monitoring the developments of the JVT. Around the time of JVT's formation, I recall that VCEG had established an Intellectual Property

Rights ("IPR") policy to govern the development of the next generation standard.[9] In particular, it established a goal for a baseline profile of the standard to be royalty-free. To implement this goal, the committee adopted a requirement for all contributions to the standard to include an IPR statement, declaring the terms under which the contribution would conform from an IPR standpoint.[10] These were consistent with the ITU IPR policy.

74. I recall discussions with, among others, supporters of royalty-free licensing. For example, for situations in which multiple proposals were received for an addition to the emerging specification of the standard that were technically equal, but on the one hand a proponent supported the royalty-free licensing goal while another proponent only offered RAND licensing terms, we adopted the proposal with the less restrictive terms.

75. In support of the goal to establish a royalty-free standard, I submitted a contribution documenting a draft of the history of video coding – JVT-E066. This document served to show when the various video coding tools were actually first

[9] ITU – Telecommunications Standardization Sector STUDY GROUP 16 Question 6 Video Coding Experts Group (VCEG) Twelfth Meeting: Eibsee, Germany, 9-12 January, 2001, Document VCEG-L37.
[10] ITU – Telecommunications Standardization Sector STUDY GROUP 16 Question 6 Video Coding Experts Group (VCEG) Fourteenth Meeting: Santa Barbara, 24-27 September, 2001, Document VCEG-N70.

conceived and published from the 1950s through the 1980s. As such, the document is a compendium of prior art for the video-coding field.

76. On December 5, 2001, JVT created "terms of reference" for a joint project between ITU-T Q.6/SG16 and ISO/IEC JTC 1/SC 29/ WG11 for the development of new Video Coding Recommendation and International Standard as document VEG-O54 (15th Pattaya Meeting, December 4-6, 2001). The terms of reference were for guiding JVT. I have maintained a copy of that document since the time it was created. A true and correct copy is attached as Appendix 3.

77. A version of these "terms of reference" was later posted publicly on the ITU-T's website, and can be found here: http://web.archive.org/web/20030421170136mp_/http://www.itu.int/ITU-T/studygroups/com16/jvt/JVTToR.pdf. A copy of this version of the "terms of reference" is provided as Ex-1111.

78. According to the JVT's "terms of reference," "JVT will maintain a document registry and electronic distribution archive. The registry and archive will be linked to both the ITU-T Q.6/SG16 and ISO/IEC JTC 1/SC 29/WG 11 web sites." Appendix 3, 3; Ex-1111, 3. JVT's "terms of reference" also describe that "[i]n order to facilitate cross-organisational communication, all input and output documents will be public unless the contributor of an input document indicates otherwise. In that circumstance, the document will be accessible only through a private, password-protected site accessible only to ITU/ISO/IEC members and invited experts regularly

attending the JVT meetings." Appendix 3, 3; Ex-1111, 3. I am not aware of any instance in which this occurred and the document registers for each meeting do not list any documents as being not publicly accessible.

79. Based on my personal experience and recollection, the JVT documents were hosted at the same website as the VCEG's earlier development documents (originally http://standard.pictel.com/ftp/video-site, which was moved to the ITU as a separate directory from the earlier VCEG documents: https://www.itu.int/wftp3/av-arch/jvt-site/).[11] Once again, those interested in the JVT's standardization process knew where the documents were stored. *See, e.g.*, Ex-1117, 1 (noting the JVT process and identifying the "standard.pictel" website).

[11] Unlike the ITU archive for the VCEG documents, it appears that the ITU archive for the JVT submissions did not preserve the original upload dates (probably owing to the changeover of hosting sites). Specifically, the ITU archive for the "B" meeting shows every document was submitted on January 17, 2005, even though this was several years after the original 2002 meeting. Ex-1103. Although I have no reason to doubt the accuracy of the upload dates as presented on the ITU archive, in my opinion, they do not represent the *first* upload dates on the original "standard.pictel" website. This is confirmed by the fact that the JVT issued an "Invitation to the Second JVT Meeting, Geneva, Switzerland, Jan. 29 – Feb. 1, 2002" which stated: "All documents must be uploaded to the ftp site by midnight on Wednesday 23 January in Geneva local time). Late, unannounced documents hand-carried to the meeting will be accepted only with the consensus of the meeting participants." Ex-1112, 3. Furthermore, JVT provided a "List of Documents" for each meeting that identified which documents were available "on-time" for the meeting on "ftp site". *Id.*; *see also, e.g.*, Ex-1106, 1. Finally, an archive of the original Pictel ftp website for the Geneva meeting shows upload dates between January and April 2002, consistent with the dates of the Geneva meeting. Ex-1033.

Moreover, I was personally aware of the JVT document system from its inception because I was involved with standards-document development from early on (e.g., 1990 for MPEG 1).

80. Based on my personal experience and recollection, in 2002, the draft standard to be discussed at any particular meeting – which were labeled by letter to identify which meeting (e.g., "A" was the first meeting; "B" was the second; etc.) – was released to the JVT team members and the public at the end of the meeting or as soon as possible after each meeting. Moreover, documents that "ad hoc" groups would work on after the meeting were publicly available for participants to consider.

81. On occasion, the JVT would assemble a "working draft" that embodied the current state of the standard, incorporating all proposals that had been adopted to-date, from which the JVT could then continue to modify in subsequent meetings. One of the easiest ways to appreciate the current state of standards-development process was to look at the working draft(s) of the standard at the time. The websites for particular meetings also included review "AgendaWithNotes" documents that included notes and an outline of discussions across all topics in the meetings. This is the "running account" referred to earlier that led to the meeting report.

82. Based on my personal experience and recollection, in 2002, documents were organized on the "standard.pictel" website by meetings, using a [Year]_[Month]_[Location] format. *See* Ex-1102; Ex-1131. Once a meeting was

selected from the menu, all of the input and output documents associated with that meeting were viewable and downloadable, and included the document number, the various upload dates (since many documents were revised and had multiple versions), the title of the document, and the source. *See, e.g.*, Ex-1103; Ex-1133. The documents were organized in numerical order. *See id.* Different draft versions of the same document were identified with a sequential draft number. *See, e.g.*, *id.* ("JVT-B001**d1**.doc", "JVT-B001**d2**.doc" or "JVT-B011**r1**.doc", "JVT-B011**r2**.doc"). The documents were organized reasonably consistently from one meeting to the next, for example, a document listing all the documents was available and numbered [meeting letter]000, while the meeting report was numbered [meeting letter]0001.

83. For the second ("B") meeting, the JVT issued a second working draft design that was designated JVT-B118. Ex-1105, 30 (§ 4.2.2). After the January Geneva meeting, the document editor, Thomas Wiegand, was "asked to produce the new version of the working draft within four weeks of the end of the meeting, and the software coordinator (Karsten Suehring) [wa]s asked to produce the corresponding version of the software by the halfway-point between this meeting and the Fairfax [("C")] meeting in May." *Id*. This statement was circulated in a document printed on February 5, 2002. B118 (revision 2) was generated on March 15, 2002, a little after four weeks of the Geneva meeting. And according to the

archive of the original Pictel ftp website, B118 (revision 2) was uploaded on March 15, 2002. Ex-1133.

84. The JVT noted that B118, its working draft document, "is the draft of our future standard, and that it therefore represents the primary and highest-priority representation of our adopted design." *Id*.

85. Based on my personal experience and recollection, B118 was distributed and publicly available on March 15, 2002. Also, based on my personal experience and recollection, an announcement that B118 was sent to the JVT listserv, the recipients of which included members of the public, as well as those on the JVT team. Based on my personal recollection, the version of B118 filed as Ex-1023 is a true and correct copy of the document distributed in March 2002 and is substantially identical to the version I have in my personal archive, which is attached as Appendix 4. For example, both documents show unaccepted revisions. And although I do not remember exactly when I downloaded B118, to the best of my recollection, it was years before the earliest effective filing date of the '841 Patent.

86. Apart from the newer upload dates, as I had previously mentioned, the ITU archive of the JVT submissions as it is presented today is consistent with my recollection of how it was presented in 2002. *Compare* Ex-1103, *with* Ex-1133.

87. Moreover, those interested in the video-coding field were citing B118 before the earliest possible priority date of the '841 Patent, *see, e.g.*, Ex-1118, 20:2-

6, 20:25-29; Ex-1119, Cover, ¶ [0007]; Ex-1120, 2:42-45; Ex-1121, ¶ [0003]; Ex-1122, ¶¶ [0004], [0029], [0033], which in my opinion demonstrates that those interested knew where to find it.

88. For these reasons, not only was B118 available as of March 2002, but it would have been routine and straightforward for a POSITA to locate those documents if interested in deblocking-filter design because B118 – as a working draft of the H.26L standard at the time – would have included (and did include) the current iteration of the deblocking filter proposed at the time.

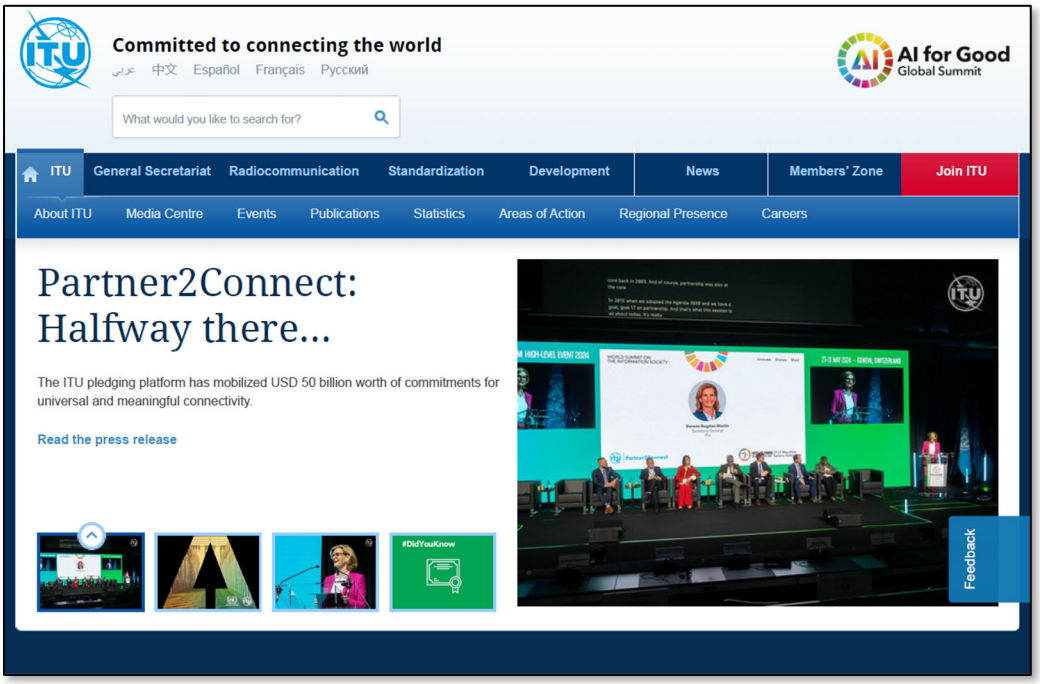
3. Public Availability of H.241

89. Not only does the ITU publish the working standards documents with which it is involved, but it also publishes the final standards once development is complete.

90. Specifically, the ITU publishes standard documents to their website, which are accessible to the public without any restrictions. As the ITU expressly states, "[t]he vast majority of all Recommendations are available in electronic (PDF) form, free of charge to all, once the final, edited version is published." *See* Ex-1091. ITU has followed this approach for as long as I have been following ITU standards developments.

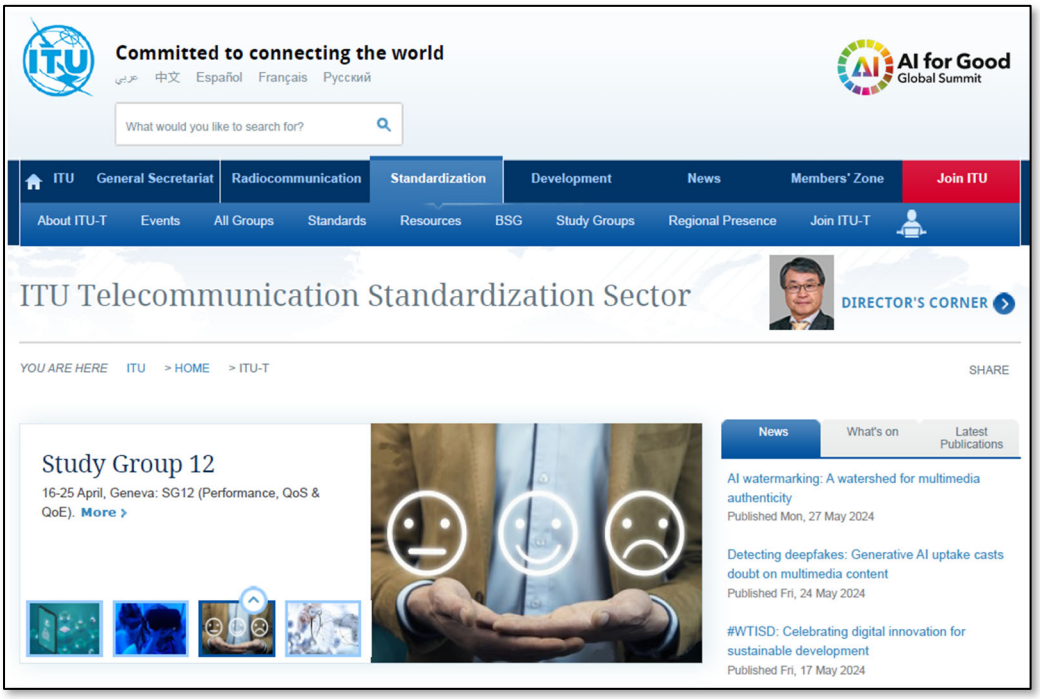
91. In my opinion, if a POSITA were interested in locating technical details regarding the operation of industry-standard video codecs, the ITU's website would

be a natural starting point to look for relevant documents, because the ITU has been publishing widely adopted video-coding standards documents since at least the 1980s. To look up a relevant video-coding standard, a POSITA (or any member of the interested public) would generally start at the home page (https://www.itu.int/en/Pages/default.aspx) of the ITU website. The home page includes a tab for "Standardization," as shown in the excerpt of the ITU home page below.



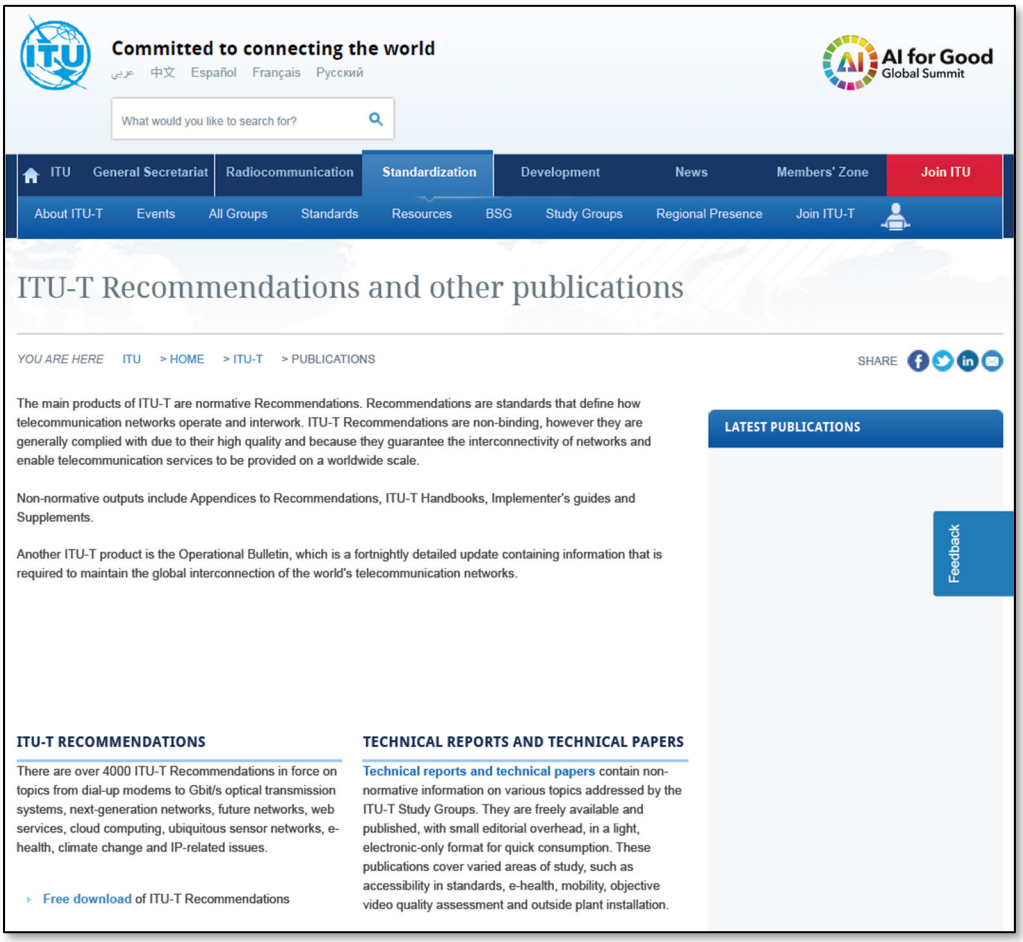
Ex-1080.

92. After clicking on the "Standardization" tab, a sub-tab called "Standards" is shown that would have taken them to the landing page for the ITU-T Recommendations. An excerpt showing that tab is below:



Ex-1084.

93. At the landing page for ITU-T Recommendations, there is a visible "Free download" link that a user can click on to see the ITU Recommendation Series that are available to the public. The "free download" link is shown in the excerpt below:



Ex-1090. The ITU has offered a similar navigation pathway to freely access final standards for as long as I have used the ITU website, including before what I understand is the earliest possible priority date of the '841 Patent. *See* Ex-1089 (showing link for "Free access for all to ITU-T standards" in 2010).

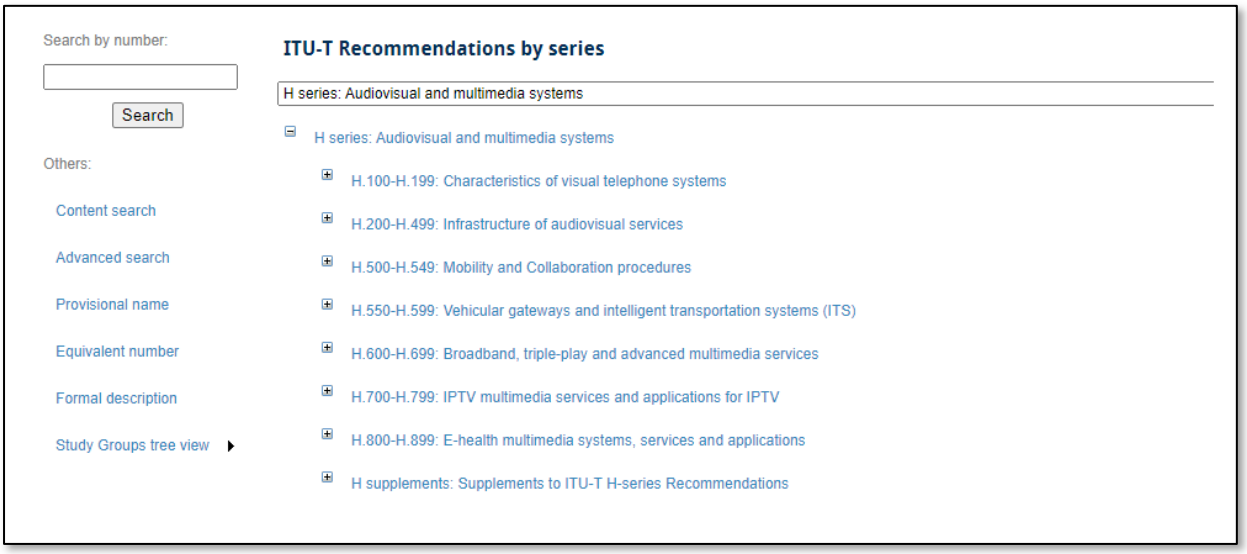
94. A POSITA would have known that standards most relevant to video-coding, generally, and deblocking filters, specifically, would select the "H: Audiovisual and multimedia systems" link (shown below) because that is the section

that contains, e.g., video-coding standards like H.263 and H.264, which would take them to a listing of publications of the H series standards.

A TO M SERIES	N TO Z SERIES
A : Organization of the work of ITU-T	N : Maintenance: international sound programme and television-transmission circuits
D : Tariff and accounting principles and international telecommunication/ICT economic and policy issues	O : Specifications of measuring equipment
E : Overall network operation, telephone service, service operation and human factors	P : Telephone transmission quality, telephone installations, local line networks
F : Non-telephone telecommunication services	Q : Switching and signalling, and associated measurements and tests
G : Transmission systems and media, digital systems and networks	R : Telegraph transmission
H : Audiovisual and multimedia systems	S : Telegraph services terminal equipment
I : Integrated services digital network	T : Terminals for telematic services
J : Cable networks and transmission of television, sound programme and other multimedia signals	U : Telegraph switching
K : Protection against interference	V : Data communication over the telephone network
L : Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant	X : Data networks, open system communications and security
M : Telecommunication management, including TMN and network maintenance	Y : Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
	Z : Languages and general software aspects for telecommunication systems

Ex-1091.

95. The listing of H series publications is shown below:



Ex-1087. The ITU offered similar access for as long as I have used the ITU website, including before what I understand is the earliest possible priority date of the '841 Patent. *See* Ex-1088 (showing same access to H-series documents in 2010).

96. In my opinion, a POSITA interested in viewing the current state of video-coding standards and deblocking filters would have known to search the H.200-series standards. In particular, a POSITA would have likely first begun in the H.26x-series (under section H.260-H.279) standards directed to "Coding of moving videos" – which, as I mentioned, contains the series of video-coding standards like H.263 and H.264 that predominated at the time, but a POSITA would have also looked to other related standards, such as the H.24x series related to

"Communication procedures" to implement these video-coding standards.[12] *See* Ex-1088.

97. Aside from simply navigating the ITU website, however, the ITU also offered a search feature (both today and before the earliest possible priority date of the patent). *See id.* (showing "General search" and "Specific search"). A similar tool appears on the ITU website today. Ex-1087. Running a search for "deblocking" using today's search feature and filtering the results to display only standards publications prior to January 1, 2011 (to limit the results to those available before the earliest possible priority date) reveals just 44 entries. *See* Ex-1083. On the first page of results is the ITU-T H.241 (05/2006) entry indicating a match for "deblocking." *Id.*, 3.

98. Whether navigating to the H.241 standard organically or running a search for "deblocking," in my opinion, a POSITA would have been able to locate the H.241 standard with ease.

99. Upon locating the H.241 standard, the ITU website provides a list of each edition of the H.241 standard published, as well as the date of publication for each standard is below.

[12] In brief, since the beginning of standardization of videoconferencing services in the 1980s, the ITU-T (and its predecessor CCITT) developed a suite of complete standards needed for video coding, speech coding, transmission, terminals, and ancillary services.

ITU-T H.241 (05/2006) عربي | 中文 | English | Español | Français | Русский

Extended video procedures and control signals for H.300-series terminals

This Recommendation defines the use of advanced video codecs, including ITU-T Rec. H.264, in ITU-T Recs H.310, H.320, H.321, H.322, H.323 and H.324 terminals. It also defines generic extended signalling for use with all video codecs in the H.300-series terminals.
This revised version adds clarifications regarding H.264 VCL HRD (Type I HRD) versus NAL HRD (Type II HRD) bit rate usage, sample aspect ratio capabilities for H.264, signalling for Reduced Complexity Decoding Operation (RCDO) for H.264 bitstreams, and a new Annex B, "RCDO for H.264 Baseline Profile bitstreams". Annex A has been replaced with an

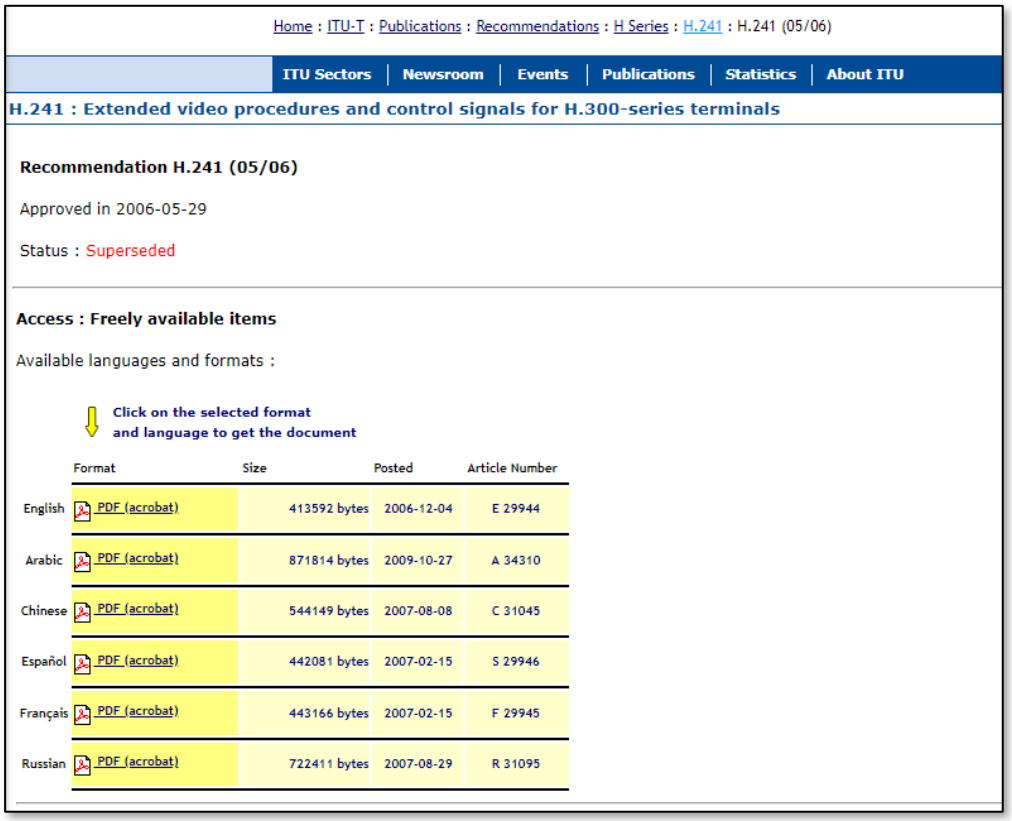
Citation:	https://handle.itu.int/11.1002/1000/8803
Series title:	H series: Audiovisual and multimedia systems H.200-H.499: Infrastructure of audiovisual services H.240-H.259: Communication procedures
Approval date:	2006-05-29
Provisional name:	H.VideoSignaling
Approval process:	AAP
Status:	Superseded
Maintenance responsibility:	ITU-T Study Group 16
Further details:	Patent statement(s) Development history

Editions | Related Supplement(s) | Related technical papers and reports

Ed.	ITU-T Recommendation	Status	Summary	Table of Contents	Download
4.1	H.241 (2012) Amd. 1 (06/2012)	In force	here	here	here
4	H.241 (02/2012)	In force	here	here	here
3.3	H.241 (2006) Cor. 1 (05/2011)	Superseded	here	-	here
3.2	H.241 (2006) Amd. 2 (12/2009)	Superseded	here	-	here
3.1	H.241 (2006) Amd. 1 (06/2008)	Superseded	here	here	here
3	H.241 (05/2006)	Superseded	here	here	here
2	H.241 (09/2005)	Superseded	here	here	here
1.2	H.241 (2003) Amd. 1 (01/2005)	Superseded	here	-	here
1.1	H.241 (2003) Cor. 1 (03/2004)	Superseded	-	-	here
1	H.241 (07/2003)	Superseded	here	here	here

Ex-1086 (H.241 (05/2006) selected).

100. Here, a POSITA would have seen that third edition of the H.241 standard was published in May 2006 – which would have been the most recent full version as of the earliest possible priority date for the '841 Patent – and would have had access to that standard by clicking on the download link "here" to select what language they would like to download the standard in. As shown in the image below, the English version of the H.241 standard (third edition) was posted on the ITU's website on December 4, 2006 and available to the public for free from that date on.



Home : ITU-T : Publications : Recommendations : H Series : H.241 : H.241 (05/06)

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H.241 : Extended video procedures and control signals for H.300-series terminals

Recommendation H.241 (05/06)

Approved in 2006-05-29

Status : Superseded

Access : Freely available items

Available languages and formats :

Click on the selected format and language to get the document

	Format	Size	Posted	Article Number
English	PDF (acrobat)	413592 bytes	2006-12-04	E 29944
Arabic	PDF (acrobat)	871814 bytes	2009-10-27	A 34310
Chinese	PDF (acrobat)	544149 bytes	2007-08-08	C 31045
Español	PDF (acrobat)	442081 bytes	2007-02-15	S 29946
Français	PDF (acrobat)	443166 bytes	2007-02-15	F 29945
Russian	PDF (acrobat)	722411 bytes	2007-08-29	R 31095

Ex-1077.

101. The ITU is a trusted and widely used resource for telecommunication standards, and I have never had any reason to doubt the accuracy of the dates provided on the ITU's website.

102. Moreover, those interested in the video-coding field were citing H.241 before the earliest possible priority date of the '841 Patent, *see, e.g.*, Ex-1123, ¶ [0047]; Ex-1124, ¶ [0007]; Ex-1125, ¶ [0102]; Ex-1126, 2, 14:31-15:5, which in my opinion demonstrates that those interested knew where to find it.

103. For these reasons, not only was the H.241 standard (third edition) publicly available as of December 2006, but it would have been routine and straightforward for a POSITA to locate this standards document if interested in video-coding standards and deblocking-filter design.

4. Public Availability of B205

104. The JCTVC was formed in 2010 as another joint venture between the ITU-T and MPEG, to develop the next generation video codec standard intended to supplant MPEG 4/H.264, which was one of the standards that I personally contributed to, as I mentioned above. Like the VCEG and JVT documents before it, each document submitted during the JCTVC standardization process was also made publicly available at the time of its submission.

105. I have personal knowledge regarding the procedures for publishing JCTVC documents on the Internet.

106. Based on my personal experience and recollection, those in the video coding industry were closely monitoring the developments of JCTVC. In the years leading up to developing the H.265/HEVC standard with JCTVC, a process to develop "KTAs," or key technology areas, was conducted within the standards bodies to identify promising areas for improving the performance of existing video coding tools and developing new video coding tools. Broadly speaking, the decision to launch the development of a new standard was made when it was felt that the performance of the previous generation standard could be improved by approximately 50%. Then following the launch of the standardization process itself, interested parties, such as myself, tracked the progress of the development of the draft standard as it advanced from meeting to meeting. This open process was greatly facilitated by public availability of the associated documents, including the draft standard and reference software. For example, a company may not have been actively attending meetings and contributing new proposals, but it was developing products in-house that would implement the new standard or provide services employing the new standard. By using the reference software from the standards body, the company was ready to enter the market as soon as the standard was finalized.

107. I am also aware of an article published by the IEEE that announced the formation of JCTVC in January 2010, and how meetings were already commencing.

Ex-1078. Thus, readers of the IEEE literature would have known that JCTVC's standardization work was already under way as of 2010 and would have known to search out further information on the development of HEVC.

108. Based upon my personal experience with the MPEG 4/H.264 standardization process, and my knowledge of the HEVC standardization process, I recognized that members of the JCTVC met quarterly to advance the HEVC standardization efforts. *See* Ex-1093. Each meeting was assigned a "Unique Serial Letter" to track (among other things) which documents were attributable to each meeting. In other words, meeting no. 1 was assigned the letter "A," meeting no. 2 was assigned the letter "B" and so on, similar to the JVT process for MPEG 4/H.264.

109. The "terms" which guided the JCTVC were posted publicly on the ITU's website in 2010, and can be found here: https://www.itu.int/oth/T4601000001/en. Ex-1097.

110. According to those terms, before each meeting, JCTVC members were required to upload proposals for incorporation into the standard to be considered at that meeting. *E.g.*, *id.*, 2 ("Every contribution document to a meeting of the JCT should be registered in the document registry and uploaded to the electronic archive several days in advance of the meeting, to ensure that it is available for review by other participants."). These were also referred to as "input" documents. *Id.* After each meeting, a Meeting Report would be issued, and a Working Draft of the

standard would typically be published. *Id.*, 2, 4. These were also referred to as "output" documents. *Id.*, 2.

111. According to the JCTVC terms, "the JCT will maintain a document registry and an electronic archive that are distinct from those of the parent bodies," but may be "linked to both parent bodies web sites" (such as the ITU-T or MPEG websites), "and the parent bodies may ingest the JCT documents for their own reference and archival purposes." *Id.*, 2.

112. The JCTVC terms also declared that "all input and output documents of the JCT will be public." *Id.*, 2.

113. The first report issued after the JCTVC's first April 2010 meeting stated that all documents were being stored at an "FTP" (or "file transfer protocol" website: http://ftp3.itu.int/av-arch/jctvc-site/. Ex-1098, 3. This same website was used for all documents relating to the second meeting. Ex-1099, 2. However, after the third meeting, the JCTVC announced that it was migrating to "[a] new document distribution site http://phenix.it-sudparis.eu/jct/[,which] became operational shortly before the [third] meeting and was exclusively used for distribution of all

documents." Ex-1100, 2.[13] The JCTVC explained that "[t]he new site allows a more automated process of document registration and download." *Id.*

114. Based on my personal experience and recollection, I was aware of the JCTVC document system from inception. I personally accessed documents at the JCTVC website beginning in 2010 and routinely downloaded proposals, working drafts, and meeting reports from that website. I accessed these documents because of my involvement in the MPEG 4/H.264 standardization process, and the development of the HEVC standard was relevant to my area of study and consultation. Documents on the JCTVC website were publicly available without any restrictions, such as requiring an account or password.

115. I understand that the current JCTVC website shows that B205 was first uploaded on March 19, 2012. Ex-1095, 12. However, that date is incorrect and does not reflect the earliest date that B205 was publicly available. As I mentioned above, each meeting was assigned a "Unique Serial Letter" to track (among other things) which documents were attributable to each meeting. B205, therefore, was part of the second meeting in Geneva, Switzerland from July 21 through July 28, 2010, Ex-

[13] I also understand that the exact same website, including all JCT-VC documents and functionality is also available at a different internet address: phenix.int-evry.fr/jct/. I have seen both websites used and cited by others.

1093; Ex-1099, 1, and it would therefore be expected to have been made publicly available around that time.

116. It appears that B205 is identified as having an upload date of March 19, 2012, as a result of the migration from the old JCTVC website to the new JCTVC website. This is evident because, like the ITU archive of the JVT documents, every input and output document associated with the 2010 Geneva meeting is dated March 19, 2012, with a timestamp showing they were uploaded to the new JCTVC website seconds apart from each other. Ex-1095. This understanding would have also been confirmed because the documents at the next "C" meeting in Guangzhou – the first meeting to use the new website – all had 2010 dates around the time of the meeting, as one would expect. Ex-1096. In other words, there appears to have been a two-year delay in migrating the second-meeting "B" documents to the JCTVC's new website.

117. However, even though B205 was uploaded to the new website later, based on my personal knowledge and recollection, it was published and publicly available on the old JCTVC website as of the "B" meeting in 2010.

118. For example, Annex A to the B meeting report[14] lists B205 as one of the documents that was discussed during the July 2010 meeting. Ex-1099, 70. B205

[14] Meeting reports – in Microsoft Word format – each included a list of documents for that meeting, so downloading the meeting report provided a local copy for

was also the subject of discussion of an ad hoc group that was "established to progress work on particular subject areas until the next meeting…." *Id.*, 62. The ad hoc group to discuss B205 and "perform editorial improvements as appropriate" included K. McCann, M. Karczewicz, J. Ridge, S. Sekiguchi, T. Wedi, and T. Wiegand. Finally, during the B meeting, it was agreed that B205 would be produced "as outputs of the meeting" where "[p]reliminary versions of the output documents…were reviewed and approved, and editing periods were authorized for finalization of these documents…." *Id.*, 64.

119. Moreover, the footer of B205 indicates the "date saved" next to the page number. There are multiple "dates saved" for B205, September 29, 2010; October 1, 2010; October 5, 2010; and October 6, 2010. *See, e.g.*, Ex-1018, 1.

120. In fact, the ITU also archived the JCTVC documents in a separate website (https://www.itu.int/wftp3/av-arch/jctvc-site/), which maintained the original upload dates of the "B" meeting documents (https://www.itu.int/wftp3/av-arch/jctvc-site/2010_07_B_Geneva/). Ex-1094. The ITU's archive shows that version 1 of B205 was uploaded July 28, 2010 – during the July 2010 Geneva meeting – and revised version 7 of B205 was uploaded on October 9, 2010, *id.*,

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searching purposes. Specifically, each meeting report contained a section that indexed proposals under consideration and often provided a summary of the proposal's contents. *E.g.*, Ex-1099, 65-70.

which in my opinion is consistent with the timeframe that would have been expected for a working draft of the standard after the meeting.

121. It is my opinion, therefore, that B205 was publicly available on the old JCTVC website at least as of July 28, 2010, which anyone in the public could access. Moreover, as I noted, reviewing the working draft of a standard-in-development, like B205, was a natural starting point for anyone interested in understanding the development of a standard because they summarized the current state of adopted proposals.

122. Moreover, those interested in the video-coding field were citing B205 before the earliest possible priority date of the '841 Patent, *see, e.g.*, Ex-1127, 618 (ref. no. 14); Ex-1128, 76, 11 (ref. no. 1), 22; Ex-1129, ¶ [0084]; Ex-1130, 3, 28:24-25, which in my opinion demonstrates that those interested knew where to find it.

123. Based on my personal experience and recollection, and as confirmed by the ITU archive and JCTVC website, B205 was first distributed and publicly available in July 2010, and version 7 was distributed and publicly available as of October 9, 2010. The copy of B205 (version 7) at Ex-1018 is a true and correct copy of the document distributed on October 9, 2010 and is substantially identical to the version that I have in my personal archive, which is provided at Appendix 5. And although I do not remember exactly when I downloaded B205, to the best of my recollection, it was around the time of its posting on the JCTVC website.

124. For these reasons, not only was B205 (version 7) available as of October 9, 2010, but it would have been routine and straightforward for a POSITA to locate those documents if interested in deblocking-filter design because, as a working draft of the HEVC standard, that would have been one of the first places to look to understand the current state of HEVC's development at the time.

F. Additional Remarks

125. I currently hold the opinions expressed in this Declaration. But my analysis may continue, and I may acquire additional information and/or attain supplemental insights that may result in added observations.

Appendix 1

ITU - Telecommunications Standardization Sector
STUDY GROUP 16
Video Coding Experts Group (Question 15)

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Question: Q.15/SG16

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Title: Deblocking filter for 4x4 based coding

Purpose: Proposal

1 Introduction

The deblocking filter of H.263 seems to be attractive due to its combination of low complexity and coding performance. On the other hand, there are more complex filters that provide better performance. One example is the deblocking filter in the Nokia proposal. Some of the characteristics of the Nokia filter compared to the one in H.263:

- A more detailed analysis of pixel values are performed before filtering
- Longer filters (3,5,7 taps) are used for smoother result
- Due to more powerful in-loop filter there seems to be less need for postfiltering

Hence a deblocking filter suitable for 4x4 structure was designed with an aim of better subjective as well as objective performance compared to the deblocking filter of H.263.

2 The experiment

The complete filter description is given in q15j28.doc section 4.5. Similar to the Nokia filter it uses longer filter (effectively up to 5 taps). Due to the smaller blocksize this seems to be sufficient. It also does separate analysis of pixel values on both sides of the boundary for better performance. RD plots are given in q15j27.xls showing that the declocking filter gives objective gain compared to TML (which have a simpler deblocking filter for intra frames and no filtering for inter frames). Subjective comparisons with TML-2 will also be given.

3 Conclusions

This deblocking filter shows an objective coding gain of (0.2-0.4) dB for most of the test sequences. More important is the subjective improvement. Comparisons between the new declocking filter and TML-2 with postfilter will be demonstrated.

It is proposed that this – or a similar – deblocking filter is included in the test model.

Appendix 2

ITU - Telecommunications Standardization Sector
STUDY GROUP 16
Video Coding Experts Group (Question 15)

Document Q15-J-28
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Question: Q.15/SG16

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Title: Definition of the new coding elements from Telenor

Purpose: Proposal

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1 Scope

This document is a complete description of the Telenor coding model as presented at Osaka. It is based on the TML-1 document. This is for practical reasons only. This is not a TML document.

Some of the differences from H.263 are:

- Only one regular VLC is used for symbol coding
- 1/4 pixel positions are used for motion prediction
- A number of different blocksizes are used for motion prediction
- Residual coding is based on 4x4 blocks and a integer transform is used
- Multiple reference frames may be used for prediction and this is considered to replace any use of B-frames

The first part of the document describes the coding method by mainly defining the decoder actions. Towards the end, 'test model issues' relevant for the encoder to be used as reference for the development of the standard will be covered. This split should make it easy at a later stage to split the document into what is relevant for the standard and a test model. However, at the moment we find it preferable to have one combined document.

2 Organization of source- and compressed data

2.1 Picture formats

At the moment only the QCIF and CIF formats are included in the model.

2.2 Subdivision of a picture into macroblocks

A CIF picture is divided into 18x22 = 396 macroblocks. Similarly a QCIF picture is divided into 99 macroblocks as indicated in Figure 1. At the moment there are no other layers in the described model.

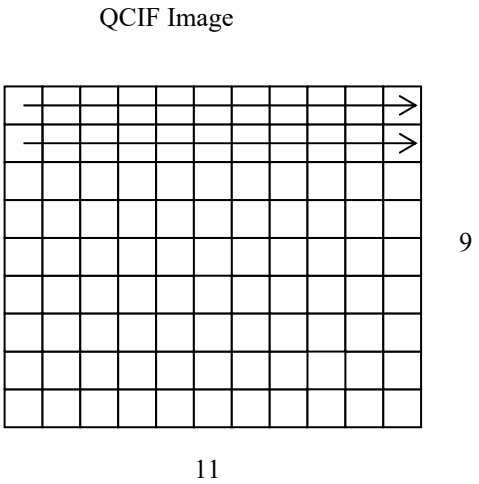


Figure 1 Subdivision of a QCIF picture into 16x16 macroblocks

2.3 Order of the bitstream within a macroblock

Figure 2 and Figure 3 indicates how a macroblock is divided and the order of the different syntax elements resulting from coding a macroblock.

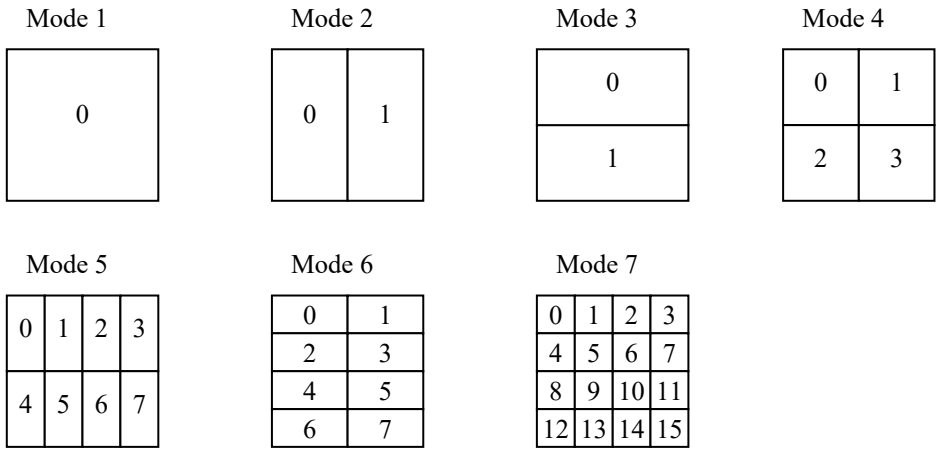


Figure 2 Numbering of the vectors for the different blocks depending on the inter mode. For each block the horizontal component comes first followed by the vertical component

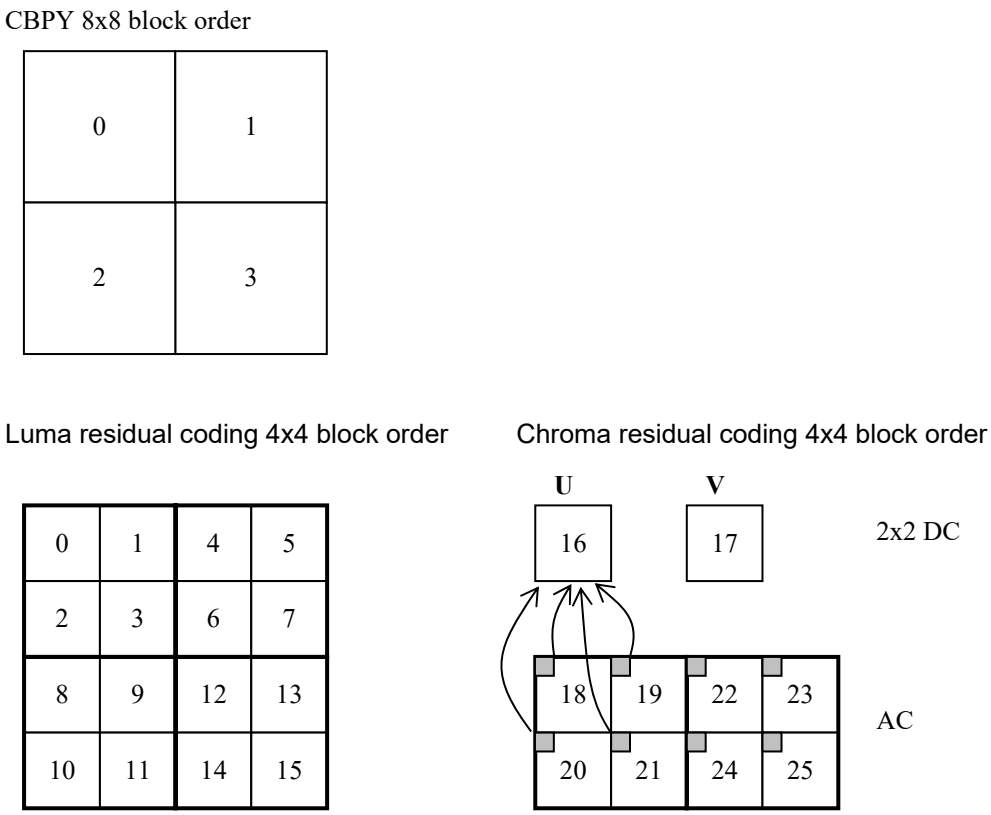


Figure 3 Ordering of blocks for CBPY and residual coding of 4x4 blocks

2.4 Syntax

2.4.1 One VLC to be used for coding

A universal VLC is used to code all syntax elements for the present coding method. The table of codewords may be written in the following compressed form.

$$
\begin{array}{c}
1 \\
0\ x_0\ 1 \\
0\ x_1\ 0\ x_0\ 1 \\
0\ x_2\ 0\ x_1\ 0\ x_0\ 1 \\
0\ x_3\ 0\ x_2\ 0\ x_1\ 0\ x_0\ 1 \\
\cdots\cdots\cdots\cdots\cdots\cdots
\end{array}
$$

where x_n take values 0 or 1. We will sometimes refer to a codeword with its length in bits (L) and INFO = x_n .. x_1 x_0 . Notice that the number of bits in INFO is L/2 (division by truncation). The codewords are numbered from 0 and upwards. The definition of the numbering is:

Code_number = $2^{L/2}$ + INFO -1 (L/2 use division with truncation. INFO = 0 when L = 1)

Some of the first code numbers and codewords are written explicitly in the table below. As an example, for the code number 5, L = 5 and INFO = 10 (binary) = 2 (decimal)

Code number	Codewords in explicit form
0	1
1	0 0 1
2	0 1 1
3	0 0 0 0 1
4	0 0 0 1 1
5	0 1 0 0 1
6	0 1 0 1 1
7	0 0 0 0 0 0 1
8	0 0 0 0 0 1 1
9	0 0 0 1 0 0 1
10	0 0 0 1 0 1 1
11	0 1 0 0 0 0 1
.....	. . . . .

When L and INFO is known, the regular structure of the table makes it easy to create a codeword bit by bit. Similarly, a decoder may easily read bit by bit until the last "1" which gives the end of the codeword. L and INFO is then readily available. For each parameter to be coded, there is a conversion rule from the parameter value to the code number (or L and INFO). Table 1 lists the connection between code number and most of the parameters used in the present coding method.

Table 1 Connection between codeword number and parameter values.

Code_ number	MB_Type		Intra_pred_mode[1]		MVD	CBP		Tcoeff_chroma_DC[2]		Tcoeff_chroma_AC[2] Tcoeff_luma[2] Simple scan		Tcoeff_luma[2] Double scan	
	Intra	Inter	Prob0	Prob1		Intra	Inter	Level	Run	Level	Run	Level	Run
0	Intra4x4	Skip	0	0	0	47	0	EOB	-	EOB	-	EOB	-
1	0,0,0[3]	16x16	1	0	1	31	16	1	0	1	0	1	0
2	1,0,0	8x8	0	1	-1	15	1	-1	0	-1	0	-1	0
3	2,0,0	16x8	0	2	2	0	2	2	0	1	1	1	1
4	3,0,0	8x16	1	1	-2	23	4	-2	0	-1	1	-1	1
5	0,1,0	8x4	2	0	3	27	8	1	1	1	2	2	0
6	1,1,0	4x8	3	0	-3	29	32	-1	1	-1	2	-2	0
7	2,1,0	4x4	2	1	4	30	3	3	0	2	0	1	2
8	3,1,0	Intra4x4	1	2	-4	7	5	-3	0	-2	0	-1	2
9	0,2,0	0,0,0[3]	0	3	5	11	10	2	1	1	3	3	0
10	1,2,0	1,0,0	0	4	-5	13	12	-2	1	-1	3	-3	0
11	2,2,0	2,0,0	1	3	6	14	15	1	2	1	4	4	0
12	3,2,0	3,0,0	2	2	-6	39	47	-1	2	-1	4	-4	0
13	0,0,1	0,1,0	3	1	7	43	7	1	3	1	5	5	0
14	1,0,1	1,1,0	4	0	-7	45	11	-1	3	-1	5	-5	0
15	2,0,1	2,1,0	5	0	8	46	13	4	0	3	0	1	3
16	3,0,1	3,1,0	4	1	-8	16	14	-4	0	-3	0	-1	3
17	0,1,1	0,2,0	3	2	9	3	6	3	1	2	1	1	4
18	1,1,1	1,2,0	2	3	-9	51	9	-3	1	-2	1	-1	4
19	2,1,1	2,2,0	1	4	10	10	31	2	2	2	2	2	1
20	3,1,1	3,2,0	0	5	-10	12	35	-2	2	-2	2	-2	1
21	0,2,1	0,0,1	1	5	11	19	37	2	3	1	6	3	1
22	1,2,1	1,0,1	2	4	-11	21	42	-2	3	-1	6	-3	1
23	2,2,1	2,0,1	3	3	12	26	44	5	0	1	7	6	0
24	3,2,1	3,0,1	4	2	-12	28	33	-5	0	-1	7	-6	0
25		0,1,1	5	1	13	35	34	4	1	1	8	7	0
26		1,1,1	5	2	-13	37	36	-4	1	-1	8	-7	0
27		2,1,1	4	3	14	42	40	3	2	1	9	8	0
28		3,1,1	3	4	-14	44	39	-3	2	-1	9	-8	0
29		0,2,1	2	5	15	1	43	3	3	4	0	9	0
30		1,2,1	3	5	-15	2	45	-3	3	-4	0	-9	0
31		2,2,1	4	4	16	4	46	6	0	5	0	10	0
32		3,2,1	5	3	-16	8	17	-6	0	-5	0	-10	0
33			5	4	17	17	18	5	1	3	1	4	1
34			4	5	-17	18	20	-5	1	-3	1	-4	1
35			5	5	18	20	24	4	2	3	2	2	2
36					-18	24	19	-4	2	-3	2	-2	2
37					19	6	21	4	3	2	3	2	3
38					-19	9	26	-4	3	-2	3	-2	3
39					20	22	28	7	0	2	4	2	4
40					-20	25	23	-7	0	-2	4	-2	4
41					21	32	27	6	1	2	5	2	5
42					-21	33	29	-6	1	-2	5	-2	5
43					22	34	30	5	2	2	6	2	6
44					-22	36	22	-5	2	-2	6	-2	6
45					23	40	25	5	3	2	7	2	7
46					-23	38	38	-5	3	-2	7	-2	7
47					24	41	41	8	0	2	8	11	0
..					..			..	..	..	..	..	..

[1] Prob0 and Prob1 defines the Intra prediction modes of two blocks relative to the prediction of prediction modes (see details in the section for Intra coding).

[2] For the entries above the horizontal line, the table is needed for relation between code number and Level/Run/EOB. For the remaining Level/Run combination there is a simple rule. The Level/Run combinations are assigned a code number according to the following priority: 1) sign of Level (+ -) 2) Run (ascending) 3) absolute value of Level (ascending).

[3.] 16x16 based intra mode. The 3 numbers refer to values for (Imode,AC,nc) - see 3.4.9.3.

2.4.2 Syntax diagram

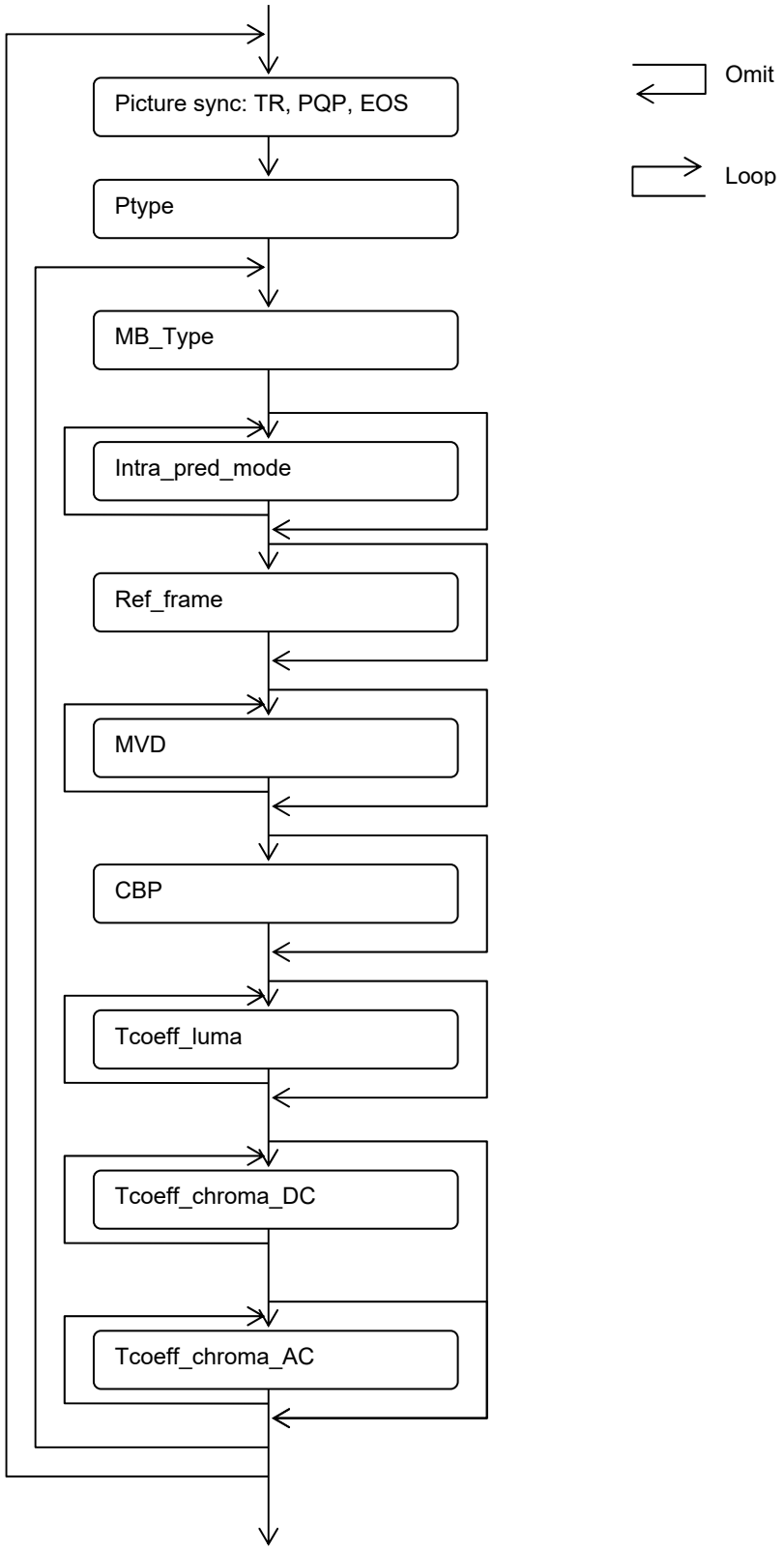


Figure 4 Syntax diagram for all the elements in the video bitstream

3 Description of syntax elements

3.1 Picture sync

The first codeword in a picture is 31 bits long (L = 31). It works as a picture sync, but it also contains an INFO part that has 15 bits. These bits are used for:

TR(8 bits) Temporal reference. The value of TR is formed by incrementing its value in the temporally-previous reference picture header by one plus the number of skipped or non-reference pictures at the picture clock frequency since the previously transmitted one.

PQP(5 bits) Picture QP: Information about the quantizer QUANT to be used for luma for the picture. (See under Quantization concerning QUANT for chroma). The 5 bit representation is the natural binary representations of the values of QP which range from 0 to 31. QP is a pointer to the actual quantization parameter QUANT to be used. (See below under quantization). The range of quantization value is still about the same as for H.263, 1-31. An approximate relation between the QUANT in H.263 and QP is: $QUANT_{H.263}(QP) \approx QP_0(QP) = 2^{QP/6}$. $QP_0()$ will be used later for scaling purposes when selecting prediction modes.

Formats 0 indicates QCIF, 1 indicates CIF

EOS 0 for picture header. 1 indicates End Of Sequence

The sketch below indicates where the different bits are located within INFO.

8b: TR	5b: PQP	1b: Formats	1b: EOS

3.2 Picture type (Ptype)

Code_number =0: Inter picture with prediction from the most recent decoded picture only.

Code_number =1: Inter picture with possibility of prediction from more than one previous decoded picture. For this mode information reference picture for prediction must be signalled for each macroblock.

Code_number =2: Intra picture.

3.3 Macro block type (MB_Type)

Refer to Table 1. There are different MB-Type tables for Intra and Inter frames.

3.3.1 Intra

Intra 4x4 Intra coding as defined in sections 3.4.1 to 3.4.8.

Imode, AC, nc See definition in section 3.4.9.3. These modes refer to 16x16 intra coding.

3.3.2 Inter

Skip No further information about the macroblock is transmitted. A copy of the colocated macroblock in the most recent decoded picture is used as reconstruction for the present macroblock.

NxM (eg. 8x4) The macroblock is predicted from a past picture with block size NxM. For each NxM block motion vector data is provided. Depending on N and M there may be 1 to 16 sets of motion vector data for a macroblock.

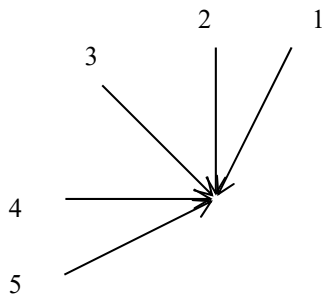
Intra 4x4 4x4 intra coding. Code numbers from 9 and upwards represent 16x16 intra coding.

3.4 Intra prediction mode (Intra_pred_mode)

Even in Intra mode, prediction is always used for each sub block in a macroblock. A 4x4 block is to be coded (pixels labelled a to p below). The pixels A to I from neighbouring blocks are already decoded and may be used for prediction.

```
I A B C D
E a b c d
F e f g h
G i j k l
H m n o p
```

There are 6 intra prediction modes labelled 0 to 5. Mode 0 is 'DC-prediction' (see below). The other modes represent directions of predictions as indicated below.



3.4.1 Mode 0: DC prediction

Generally all pixels are predicted by (A+B+C+D+E+F+G+H)//8. If four of the pixels are outside the picture, the average of the remaining four is used for prediction. If all 8 pixels are outside the picture the prediction for all pixels in the block is 128. A block may therefore always be predicted in this mode.

3.4.2 Mode 1:

This mode is used only if all A,B,C,D are inside the picture.

a is predicted by:	(A+B)/2
e is predicted by	B
b,i are predicted by	(B+C)/2
f,m are predicted by	C
c,j are predicted by	(C+D)/2
d,g,h,k,l,n,o,p are predicted by	D

3.4.3 Mode 2: Vertical prediction

If A,B,C,D are inside the picture, a,e,i,m are predicted by A, b,f,j,n by B etc.

3.4.4 Mode 3: Diagonal prediction

This mode is used only if all A,B,C,D,E,F,G,H,I are inside the picture. This is a 'diagonal' prediction.

m is predicted by:	(H+2G+F)//4
i,n are predicted by	(G+2F+E)//4
e,j,o are predicted by	(F+2E+I)//4

a,f,k,p are predicted by	(E+2I+A)//4
b,g,l are predicted by	(I+2A+B)//4
c,h are predicted by	(A+2B+C)//4
d is predicted by	(B+2C+D)//4

3.4.5 Mode 4:Horizontal prediction

If E,F,G,H are inside the picture, a,b,c,d are predicted by E, e,f,g,h by F etc.

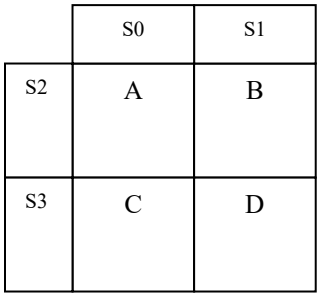
3.4.6 Mode 5:

This mode is used only if all E,F,G,H are inside the picture.

a is predicted by:	(E+F)/2
b is predicted by	F
c,e are predicted by	(F+G)/2
f,d are predicted by	G
i,g are predicted by	(G+H)/2
h,j,k,l,m,n,o,p are predicted by	H

3.4.7 Prediction of chroma blocks

For chroma prediction there is only one mode. No information is therefore needed to be transmitted. The prediction is indicated in the figure below. The 8x8 chroma block consists of 4 4x4 blocks A,B,C,D. S0,1,2,3 are the sums of 4 neighbouring pixels.



If S0, S1, S2, S3 are all inside the frame:
A = (S0 + S2 + 4)/8
B = (S1 + 2)/4
C = (S3 + 2)/4
D = (S1 + S3 + 4)/8

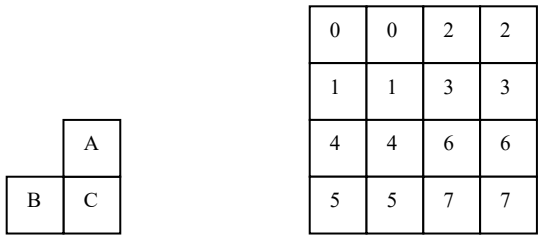
If only S0 and S1 are inside the frame:
A = (S0 + 2)/4
B = (S1 + 2)/4
C = (S0 + 2)/4
D = (S1 + 2)/4

If only S2 and S3 are inside the frame:
A = (S2 + 2)/4
B = (S2 + 2)/4
C = (S3 + 2)/4
D = (S3 + 2)/4
If S0, S1, S2, S3 are all outside the frame: A = B = C = D = 128
(Note: This prediction should be considered changed)

3.4.8 Coding of Intra prediction modes

Since each of the 4x4 luma blocks shall be assigned a prediction mode, this will require a considerable number of bits if coded directly. We have therefore tried to find more efficient ways of coding mode information. First of all we observe that the chosen prediction of a block is highly correlated with the prediction modes of adjacent blocks. This is illustrated in Figure 5 a. When the prediction modes of A and B are known (including the case that A or B or both are outside the picture) an ordering of the most probable, next most probable etc. of C is given. This ordering is listed in Table 2. For each prediction

mode of A and B a list of 5 numbers is given. Example: Prediction mode for A and B is 2. The string 2 0 3 1 4 indicates that mode 2 is also the most probable mode for block C. Mode 0 is the next most probable one etc. In the bitstream there will for instance be information that Prob0 = 1 (see Table 1) indicating that the next most probable mode shall be used for block C. In our example this means Intra prediction mode 0. Use of '–' in the table indicates that this instance can not occur.
For more efficient coding, information on intra prediction of two 4x4 luma blocks are coded in one codeword (Prob0 and Prob1 in Table 1). The order of the resulting 8 codewords is indicated in Figure 5 b.



a) b)

Figure 5 a) Prediction mode of block C shall be established. A and B are adjacent blocks. b) order of intra prediction information in the bitstream

Table 2 Prediction mode as a function of ordering signalled in the bitstream (see text)

B\A	outside	0	1	2	3	4	5
outside	0-----	021---	102---	201---	------	------	------
0	045---	041352	104325	230415	304215	043152	043512
1	------	014325	102435	203145	032145	041325	014352
2	------	012345	102345	210345	302145	042135	013245
3	------	304152	310425	231054	304215	403512	305412
4	405---	403512	401532	240351	430512	403512	405312
5	504---	540312	015432	201453	530412	450312	504132

3.4.9 Intra mode based on 16x16 macroblocks (16x16 intra mode)

This intra mode is particularly suitable for regions with little details, also referred to as 'flat' regions.

3.4.9.1 Prediction modes

Assume that the block to be predicted has pixel locations 0 to 15 horizontally and 0 to 15 vertically. We use the notation P(i,j) where i,j = 0..15. P(i,-1), i=0..15 are the neighboring pixels above the block and P(-1,j), j=0..15 are the neighboring pixels to the left of the block. Pred(i,j) i,j = 0..15 is the prediction for the whole luma macroblock. We have 4 different prediction modes:

<u>IMODE = 0 (vertical)</u>

Pred(i,j) = P(i,-1), i,j=0..15

<u>IMODE = 1 (horizontal)</u>

Pred(i,j) = P(-1,j), i,j=0..15

<u>IMODE = 2 (DC prediction)</u>

Pred(i,j) = $(\sum_{i=0}^{15}(P(-1,i)+P(i,-1)))/32$ i,j=0..15

<u>IMODE = 3 (Plane prediction)</u>

Pred(i,j) = (a + bx(i-7) + cx(j-7) +16)/32

Where:

a = 16x(P(-1,15) + P(15,-1))

b = 5x(*H*/4)/16

c = 5x(*V*/4)/16

$$H = \sum_{i=1}^{8} ix(P(7+i,-1)+P(7-i,-1))$$

$$V = \sum_{j=1}^{8} jx(P(-1,7+j) + P(-1,7-j))$$

3.4.9.2 Residual coding

The residual coding is based on 4x4 transform. But similar to coding of chroma coefficients, another 4x4 transform to the 16 DC coefficients in the macroblock are added. In that way we end up with an overall DC for the whole MB which works well in flat areas.

Since we use the same integer transform to DC coefficients, we have to perform additional normalization to those coefficients, which implies a division by 676. To avoid the division we performed normalization by $49/2^{15}$ on the encoder side and $48/2^{15}$ on the decoder side, which gives sufficient accuracy.

Only single scan is used for 16x16 intra coding.

To produce the bitstream, we first scan through the 16 'DC transform' coefficients. There is no 'CBP' information to indicate no coefficients on this level. If AC = 1 (see below) ac coefficients of the 16 4x4 blocks are scanned. There are 15 coefficients in each block since the DC coefficients are included in the level above.

3.4.9.3 Signalling of mode information for 16x16 intra coding

See Table 1. Three parameters have to be signaled. They are all included in MB-type.

Imode: 0,1,2,3

AC: 0 means there are no ac coefficients in the 16x16 block. 1 means that there is at least one ac coefficient and all 16 blocks are scanned.

nc: CBP for chroma (see 3.7)

3.5 Reference frame (Ref_frame)

If PTYPE indicates possibility of prediction from more than one previous decoded picture, the exact frame to be used must be signalled. This is done according to the following table.

Code_number	Reference frame
0	The last decoded frame (1 frame back)
1	2 frames back
2	3 frames back
..	..

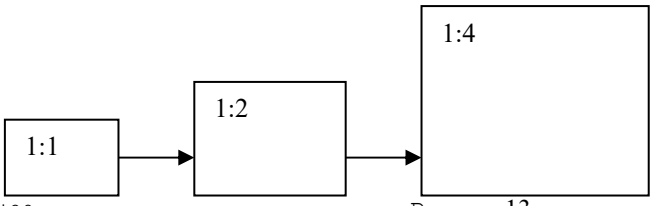
3.6 Motion Vector Data (MVD)

If so indicated by MB_type, vector data for 1-16 blocks are transmitted. For every block a prediction is formed for the horizontal and vertical components of the motion vector. MVD signals the difference between the vector component to be used and this prediction. The order in which vector data is sent is indicated in Figure 2. The reconstructed motion vector shall point to pixels inside the reference frame only.

3.6.1 Fractional pixel accuracy

In the present coding method, 1/4 pixel accuracy is used to define motion vectors. To avoid encoder/decoder mismatch, the interpolation procedure has to be defined in detail.

The figure below indicates that interpolation for luminance may be defined as taking place in two steps.



Interpolation: 6H, 4V bilinear

Step I: Generation of ½ pixel positions

The ‘x’ - es below represent integer pixel positions. First the ‘+’ - es (horizontal ½ pixel positions) are produced by using a 6 tap filter: (1,-5,20,20,-5,1)/32. The result is rounded to the nearest integer and clipped to the range 0 to 255. Then all the ‘*’ – es are produced by using a 4 tap filter: (-1,5, 5,-1)/8. The result is rounded to the nearest integer and clipped to the range 0 to 255. If the filtering process refer to a pixel outside the picture, it is replaced by the nearest picture edge pixel.

```
x + x + x + x + x
* * * * * * * * *
x + x + x + x + x
* * * * * * * * *
x + x + x + x + x
* * * * * * * * *
```

Step II: Generation of ¼ pixel positions

The ‘x’ - es below represent ½ pixel positions (from above). First the ‘+’ - es are produced by linear interpolation (average of the neighbouring ½ pixel positions). The result is truncated to the nearest integer. Then all the ‘*’ – es are produced by vertical linear interpolation with truncation to the nearest integer.

```
x + x + x + x + x
* * * * * * * * *
x + x + x + x + x
* * * * * * * * *
x + x + x + x + x
* * * * * * * * *
```

Interpolation position with more low pass filtering

The figure below indicate a grid with interpolated positions where capital letters represent integer positions, numbers represent ½ pixel positions and lower case letters represent 1/4 pixel positions.

```
A a 1 b B
c d e f g
2 h 3 i 4
j k l m n
C o 5 p D
```

Relative to integer positions, the position m is chosen to represent a position with more low pass filtering. According to the definition above, m ≈ (‘3’ + ‘4’ + ‘5’ + ‘D’)/4. (≈ is used due to possible rounding effects). Instead we define:

m = (‘A’ + ‘B’ + ‘C’ + ‘D’ + 2)/4

3.6.2 Prediction of vector components

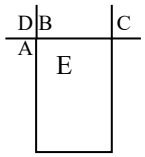
In the figure below the vector component E of the indicated block shall be predicted. The prediction is normally formed as the median of A, B and C.

A The component applying to the pixel to the left of the upper left pixel in E

B The component applying to the pixel just above the upper left pixel in E

C The component applying to the pixel above and to the right of the upper right pixel in E

D The component applying to the pixel above and to the left of the upper left pixel in E



A, B, C, D and E may represent motion vectors from different reference pictures. As an example we may be seeking prediction for a motion vector for E from the last decoded picture. Still A, B, C and D may represent vectors from 2, 3, 4 and 5 pictures back but they shall still be used for prediction.

- If A and D are outside the picture, their values are assumed to be zero.
- If D, B, C are outside the picture, the prediction is equal to A.
- If C is outside the picture or still not available due to the order of vector data (see Figure 2), C is replaced by D.

3.6.3 Chroma vectors

Chroma vectors are derived from the luma vectors. Since chroma has half resolution compared to luma, the chroma vectors are obtained by a division of two:

Croma_vector = Luma_vector/2 - which means that the chroma vectors have a resolution of 1/8 pixel.

Due to the half resolution, a chroma vector applies to 1/4 as many pixels as the luma vector. For example if the luma vector applies to 8x16 luma pixels, the corresponding chroma vector applies to 4x8 chroma pixels and if the luma vector applies to 4x4 luma pixels, the corresponding chroma vector applies to 2x2 chroma pixel.

For fractional pixel interpolation for chroma prediction, bilinear interpolation is used. The result is rounded to the nearest integer.

3.7 Coded Block Pattern (CBP)

The CBP contains information of which 8x8 blocks - luma and chroma - contain transform coefficients. Notice that an 8x8 block contains 4 4x4 blocks meaning that the statement '8x8 block contains coefficients' means that 'one or more of the 4 4x4 blocks contain coefficients'. The 4 least significant bits of CBP contain information on which of 4 8x8 luma blocks in a macroblock contains nonzero coefficients. Let us call these 4 bits CBPY. The ordering of 8x8 blocks is indicated in Figure 3. A 0 in position n of CBP (binary representation) means that the corresponding 8x8 block has no coefficients whereas a 1 means that the 8x8 block has one or more non-zero coefficients.

For chroma we define 3 possibilities:

nc=0: no chroma coefficients at all.

nc=1 There are nonzero 2x2 transform coefficients. All chroma AC coefficients = 0. Therefore we do not send any EOB for chroma AC coefficients.

nc=2 There may be 2x2 nonzero coefficients and there is at least one nonzero chroma AC coefficient present. In this case we need to send 10 EOBs (2 for DC coefficients and 2x4=8 for the 8 4x4 blocks) for chroma in a macroblock.

The total CBP for a macroblock is: **CBP = CBPY + 16xnc**

The CBP is signalled with a different codeword for Inter macroblocks and Intra macroblocks since the statistics of CBP values are different in the two cases.

4 Transform and inverse transform

This section defines all elements related to transform coding and decoding. It is therefore relevant to all the syntax elements 'Tcoeff' in the syntax diagram.

4.1 4x4 block size

Instead of DCT, an integer transform with basically the same coding property as a 4x4 DCT is used. The transformation of the pixels a,b,c,d into 4 transform coefficients A,B,C,D is defined by:

```
A = 13a + 13b + 13c + 13d
B = 17a +  7b -  7c - 17d
C = 13a - 13b - 13c + 13d

D =  7a - 17b + 17c -  7d
```

The inverse transformation of transform coefficients A,B,C,D into 4 pixels a',b',c',d' is defined by:

```
a' = 13A + 17B + 13C +  7D
b' = 13A +  7B - 13C - 17D
c' = 13A -  7B - 13C + 17D
d' = 13A - 17B + 13C -  7D
```

The relation between a and a' is: a' = 676a. This is because the expressions defined above contain no normalisation. Normalisation will be performed in the quantization/dequantisation process and a final shift after inverse quantization.

The transform/inverse is performed both vertically and horizontally in the same manner as in H.263. By the above exact definition of inverse transform, the same operations will be performed on coder and decoder side which means that we have no 'inverse transform mismatch'.

4.2 2x2 transform/inverse transform of chroma DC coefficients

With the low resolution of chroma it seems to be preferable to have larger blocksize than 4x4. Specifically the 8x8 DC coefficient seems very useful for better definition of low resolution chroma. The 2 dimensional 2x2 transform procedure is illustrated below. DC0,1,2,3 are the DC coefficients of 2x2 chroma blocks.

DC0	DC1	**Two dimensional 2x2 transform**	⇒	DDC(0,0)	DDC(1,0)
DC2	DC3			DDC(0,1)	DDC(1,1)

Definition of transform:

DCC(0,0) = (DC0+DC1+DC2+DC3)/2

DCC(1,0) = (DC0-DC1+DC2-DC3)/2

DCC(0,1) = (DC0+DC1-DC2-DC3)/2

DCC(1,1) = (DC0-DC1-DC2+DC3)/2

Definition of inverse transform:

DC0 = (DCC(0,0)+ DCC(1,0)+ DCC(0,1)+ DCC(1,1))/2

DC1 = (DCC(0,0)- DCC(1,0)+ DCC(0,1)- DCC(1,1))/2

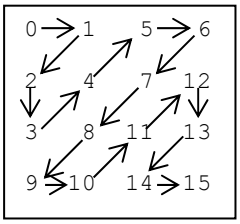
DC2 = (DCC(0,0)+ DCC(1,0)- DCC(0,1)- DCC(1,1))/2

DC3 = (DCC(0,0)- DCC(1,0)- DCC(0,1)+ DCC(1,1))/2

4.3 Scanning and quantization

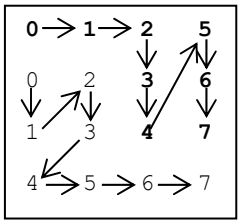
4.3.1 Simple scan

Except for Intra coding of luma with QP<24, simple scan is used. This is basically zig-zag scanning similar to the one used in H.263. The scanning pattern is:



4.3.2 Double scan

When using the VLC defined above, we use a one bit code for EOB. For Inter blocks and Intra with high QP the probability of EOB is typically 50% which is well matched with the VLC. In other words this means that we on average have one non-zero coefficient per 4x4 block in addition to the EOB code (remember that a lot of 4x4 blocks only have EOB). On the other hand, for Intra coding we typically have more than one non-zero coefficient per 4x4 block. This means that the 1 bit EOB becomes inefficient. To improve on this the 4x4 block is subdivided into two parts that are scanned separately and with one EOB each. The two scanning parts are shown below – one of them in bold.



4.3.3 Quantization

The quantization/dequantization process shall perform 'normal' quantization/dequantization as well as take care of the fact that transform operations are kept very simple and therefore do not contain normalization of transform coefficients. 32 different QP values are used. They are arranged so that there is an increase of step size of about 12% from one QP to the next. Increase of QP by 6 means that the step size is about doubled. There is no 'dead zone' in the quantization process and the total range of step size from smallest to largest is about the same as for H.263.

The QP signalled in the bitstream applies for luma quantization/dequantization. This could be called QP_{luma}. For chroma quantization/dequantization a different value - QP_{chroma} - is used. The relation between the two is:

QP_{luma}	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
QP_{chroma}	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	17	18	19	20	20	21	22	22	23	23	24	24	25	25

When QP is used in the following we mean QP_{luma} or QP_{chroma} depending on what is appropriate.

Two arrays of numbers are used for quantization/dequantization.

A(QP=0,..,31)
620,553,492,439,391,348,310,276,246,219,195,174,155,138,123,110,98,87,78,69,62,55,49,44,39,35,
31,27,24,22,19,17

B(QP=0,..,31)

3881,4351,4890,5481,6154,6914,7761,8718,9781,10987,12339,13828,15523,17435,19561,21873,24552,27656,308
47,34870,38807,43747,49103,54683,61694,68745,77615,89113,100253,109366,126635,141533

The relation between A() and B() is: $A(QP) \times B(QP) \times 676^2 = 2^{40}$.

It is assumed that a coefficient K is quantized in the following way:

$LEVEL = (K \times A(QP) + f \times 2^{20})/2^{20}$ $|f|$ is in the range (0-0.5) and f has the same sign as K.

Dequantization:

K' = LEVELxB(QP)

After inverse transform this results in pixel values that are 2^{20} too high. A shift of 20 bits (with rounding) is therefore needed on the reconstruction side. The definition of transform and quantization is designed so that no overflow will occur with use of 32 bit arithmetic.

4.3.4 Scanning and quantization of 2x2 chroma DC coefficients

DDC() is quantized (and dequantized) separately resulting in LEVEL, RUN and EOB. The scanning order is: DCC(0,0), DCC(1,0), DCC(0,1), DCC(1,1). Inverse 2x2 transform as defined above is then performed after dequantization resulting in dequantized 4x4 DC coefficients: DC0' DC1' DC2' DC3'.

Chroma AC coefficients (4x4 based) are then quantized similarly to before. Notice that there are only 15 AC coefficients. The maximum size of RUN is therefore 14. However, for simplicity we use the same relation between LEVEL, RUN and Code no. As defined for 'Simple scan' in Table 1.

4.4 Use of 2-dimensional model for coefficient coding.

In the 3D model for coefficient coding (see H.263) there is no good use of a short codeword of 1 bit. On the other hand, with the use of 2D VLC plus End Of Block (EOB) (as used in H.261, H.262) and with the small block size, 1 bit for EOB is usually well matched to the VLC.

Furthermore, with the fewer non-zero coefficients per block, the advantage of using 3D VLC is reduced.

As a result we use a 2D model plus End Of Block (EOB) in the present model. This means that an event to be coded (RUN, LEVEL) consists of:

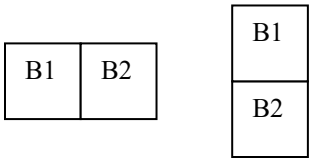
RUN which is the number of zero coefficients since the last nonzero coefficient.

LEVEL the size of the nonzero coefficient

EOB signals that there are no more nonzero coefficients in the block

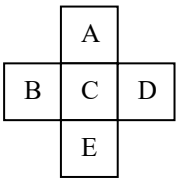
4.5 Deblocking filter

The deblocking filter process takes place both across vertical block edges and horizontal block edges. The filtering is performed first across vertical edges. The filtered pixels are then used when performing filtering across horizontal block edges. As a result block1 and block2 (see below) may be located in one of the positions:



4.5.1 Block strength

The deblocking filter is based on a 4x4 block structure. Each 4x4 block in a reconstructed picture is assigned a **Strength** value ranging from 0 to 3. This value is assigned based on different criteria. The maximum value is chosen. Assume that one criterion results in **value** to be assigned. The new assignment is: **Strength = max(Strength,value),** so that we always keep the maximum value. In the figure below A, B, C and D are 4x4 blocks.



The procedure for assignment is as follows:

- Initially each 4x4 block of a picture is assigned **Strength = 0**
- If C is intra coded: **$Strength_C$ = 3, $Strength_A$ = max($Strength_A$,2), $Strength_B$ = max($Strength_B$,2), $Strength_D$ = max($Strength_D$,2), $Strength_E$ = max($Strength_E$,2)**

- If C has nonzero transform coefficients: **$Strength_C$ = max($Strength_C$,2), $Strength_A$ = max($Strength_A$,1), $Strength_B$ = max($Strength_B$,1), $Strength_D$ = max($Strength_D$,1), $Strength_E$ = max($Strength_E$,1)**
- If the absolute difference between one of the vector components of block A and block C is at least one integer pixel (four ¼ pixels) then: **$Strength_A$ = max($Strength_A$,1), $Strength_C$ = max($Strength_C$,1)**. The same procedure is applied to vector differences between blocks (B and C), (C and D) and (C and E)

4.5.2 Filtering of pixels on both sides of a 4x4 block boundary

Assume that the pixels

a b c d e f g h

belong to two neighbouring blocks (1 and 2). There is a block boundary between pixels d end e.

$Strength_1$ and $Strength_2$ are available. Filtering takes place only if they are both different from 0. In that case pixels c,d,e,f may be modified in the filtering process.

The following parameters are calculated:

S0 = **abs**(4(c-f)+12(e-d)) + **abs**(9(c-d-e+f))

$S0_1$ = 12**abs**(a-2b+c)

$S1_1$ = **abs**(4(a-d)+12(c-b)) + **abs**(9(a-b-c+d))

$S0_2$ = 12**abs**(e-2f+g)

$S1_2$ = **abs**(4(e-h)+12(g-f)) + **abs**(9(e-f-g+h))

abs() is the absolute value function. Lim(qp) is a table defining threshold values for the filtering process depending on qp. As pixels a to h belong to two blocks, qp of the two blocks may differ. In this context qp means the maximum qp for the two blocks. The table is:

QP	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
Lim	7	8	9	10	11	12	14	15	17	20	22	25	28	31	35	39	44	49	55	62	69	78	88	98	110	124	139	156	175	197	221	248

4.5.3 Overall activity – $Act_{overall}$

$Act_{overall}$ = (3-i) where i is the smallest number such that S0 < Lim(qp)x2^i. $Act_{overall}$ is normally clipped to the range (0,3). If $Strength_1$ = 3 or $Strength_2$ = 3 (intra), $Act_{overall}$ is clipped to the range (1,3).

4.5.4 Activity on each side – Act_1, Act_2

- Act_1 is initially set to 1
- If $S0_1$ < Lim(qp), Act_1 is incremented by 1
- If $S1_1$ < Lim(qp), Act_1 is incremented by 1

The same procedure is made for Act_2 .

Finally Act_{11} = min($Act_{overall}$,Act_1), Act_{22} = min($Act_{overall}$,Act_2).

We also need tables depending on qp and Strength for clipping modifications (see below). We call this table Clip(qp,Strength) and the tables are:

QP	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	29	30	31
Clip(qp,1)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	3
Clip(qp,2)	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4	5	5
Clip(qp,3)	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	4	4	5	5	5	7	8	9

4.5.5 Modification of edge pixels – d,e

It has proved advantageous to treat these pixels separately and subtract the same amount to one side as is added to the other as is done in the H.263 filter. Another similarity to the H.263 filter is that the modification is limited.

$Act_{edge} = (Act_{11} + Act_{22})/2$

$Clip_{edge} = (Clip(qp,Strength_1) + Clip(qp,Strength_2) + Act_1 + Act_2 - 2)/2$

Initially set Diff = 0

If Act_{edge} equals 1 or 2: $Diff = (3(c - f) - 8(d - e))/16$

If Act_{edge} equals 3: $Diff = (b + c - 8(d - e) - f - g)/16$

$Diff = max(-Clip_{edge}, min(Clip_{edge}, Diff))$

$d_{modified} = d + Diff$ (clipped to stay in the range 0-255)

$e_{modified} = e - Diff$ (clipped to stay in the range 0-255)

4.5.6 Modification of pixels next to the edge – c,f

4.5.6.1 Modification if c in block 1

Initially set Diff = 0

If Act_{11} equals 2: $Diff = 5(b - 2c + d)/16$

If Act_{11} equals 3: $Diff = 3(a + b - 4c + d + e)/16$

$Diff = max(-Clip(qp,Strength_1), min(Clip(qp,Strength_1), Diff))$

$c_{modified} = c + Diff$ (clipped to stay in the range 0-255)

4.5.6.2 Modification if f in block 2

Initially set Diff = 0

If Act_{22} equals 2: $Diff = 5(e - 2f + g)/16$

If Act_{22} equals 3: $Diff = 3(d + e - 4f + g + h)/16$

$Diff = max(-Clip(qp,Strength_2), min(Clip(qp,Strength_2), Diff))$

$f_{modified} = f + Diff$ (clipped to stay in the range 0-255)

5 Test model issues

5.1 Finding optimum prediction mode

Both for intra prediction and motion compensated prediction, a similar loop as indicated in Figure 6 is run through. The different elements will be described below.

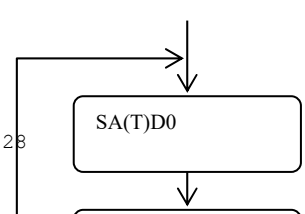


Figure 6 Loop for prediction mode decision

5.1.1 SA(T)D0

The SA(T)D to be minimised is given a 'bias' value initially in order to favour prediction modes that need few bits to be signalled. This bias is basically a parameter representing bit usage times $QP_0(QP)$

Intra mode decision: SA(T)D0 = $QP_0(QP)$xOrder_of_prediction_mode (see above)

Motion vector search: SA(T)D0 = $QP_0(QP)$x(Bits_to_code_vector + 2xcode_number_of_ref_frame)

In addition there are two special cases:

- For motion prediction of a 16x16 block with 0 vector components, 16x$QP_0(QP)$ is subtracted from SA(T)D to favour the skip mode.
- For the whole intra macroblock, 24x$QP_0(QP)$ is added to the SA(T)D before comparison with the best SA(T)D for inter prediction. This is an empirical value to prevent using too many intra blocks.

5.1.2 Block_difference

For the whole block the difference between the original and prediction is produced

Diff(i,j) = Original(i,j) - Prediction(i,j)

5.1.3 Hadamard transform

For integer pixel search (see below) we use SAD based on Diff(i,j) for decision. Hence no Hadamard is done and we use SAD instead of SATD.

$$SAD = \sum_{i,j} \left| Diff(i,j) \right|$$

However, since we will do a transform of Diff(i,j) before transmission, we will do a better optimisation if a transform is done before producing SAD. Therefore a two dimensional transform is performed in the decision loop for selecting intra modes and for fractional pixel search (see below). To simplify implementation, the Hadamard transform is chosen in this mode decision loop. The relation between pixels and basis vectors (BV) in a 4 point Hadamard transform is illustrated below (not normalized):

	Pixels →			
B	1	1	1	1
V	1	1	-1	-1
↓	1	-1	-1	1
	1	-1	1	-1

This transformation is performed horizontally and vertically and result in DiffT(i,j). Finally SATD for the block and for the present prediction mode is produced.

$$SATD = (\sum_{i,j} |DiffT(i,j)|) / 2$$

Choose the prediction mode that results in the minimum SA(T)D_{min}.

5.2 Encoding on macroblock level

5.2.1 Intra coding

When starting to code a macroblock, intra mode is checked first. For each 4x4 block, full coding indicated in Figure 6 is performed. At the end of this loop the complete macroblock is intra coded and a $SATD_{intra}$ is calculated.

5.2.2 Table for intra prediction modes to be used at the encoder side

Table 2 gives the table of intra prediction modes according to probability of each mode to be used on the decoder side. On the encoder side we need a sort of inverse table. Prediction modes for A and B are known as in Table 2. For the encoder we have found a Mode that we want to signal with an ordering number in the bitstream (whereas on the decoder we receive the order in the bitstream and want to convert this to a mode). Table 3 is therefore the relevant table for the encoder. Example: Prediction mode for A and B is 2. The string in Table 3 is 1 3 0 2 4. This indicates that prediction mode 0 has order 1 (second most probable). Prediction mode 1 has order 3 and prediction mode 2 has order 0 (most probable) etc.

Table 3 Prediction ordering to be used in the bitstream as a function of prediction mode (see text).

B\A	outside	0	1	2	3	4	5
outside	0-----	021---	102---	120---	------	------	------
0	0---12	025314	104325	240135	143025	035214	045213
1	------	014325	102435	130245	032145	024315	015324
2	------	012345	102345	210345	132045	032415	013245
3	------	135024	214035	320154	143025	145203	145032
4	1---02	145203	125403	250314	245103	145203	145302
5	1---20	245310	015432	120534	245130	245301	135420

5.2.3 Inter mode selection

Next motion vector search is performed for motion compensated prediction. A search is made for all 7 possible block structures for prediction as well as from the 5 past decoded pictures. This result in 35 combinations of blocksizes and reference frames.

5.2.4 Integer pixel search

The search positions are organised in a 'spiral' structure around the predicted vector (see vector prediction). The numbering from 0 and upwords for the first positions are listed below:

```
. .  .  .  .  .
.15  9 11 13 16
.17  3  1  4 18
.19  5  0  6 20
.21  7  2  8 22
.23 10 12 14 24
```

A parameter MC_range is used as input for each sequence. To speed up the search process, the search range is further reduced:

- Search range is reduced to: Range = MC_range/2 for all block sizes except 16x16 in prediction from the most recent decoded picture.
- The range is further reduced to: Range = Range/2 for search relative to all older pictures.

After Range has been found, the centre for the spiral search is adjusted so that:

- No vector position is outside the picture.
- The (0,0) vector position is within the search range. This is done by clipping the horizontal and vertical positions of the search centre to ±Range.

5.2.5 Fractional pixel search

Fractional pixel search is performed in two steps. This is illustrated below where capital letters represent integer positions, numbers represent ½ pixel positions and lower case letters represent ¼ pixel positions.

```
A       B       C

    1   2   3

D   4   E   5   F
      a b c
    6 d 7 e 8
      f g h
G       H       I
```

Assume that the integer search points to position E. Then ½ pixel positions 1,2,3,4,5,6,7,8 are searched. Assume that 7 is the best position. Then the ¼ pixel positions a,b,c,d,e,f,g,h are searched. (Notice that by this procedure a position with 'more low pass filtering' – see 3.6.1 - is automatically checked).

After fractional pixel search has been performed for the complete macroblock, the SATD for the whole macroblock is computed: $SATD_{inter}$.

5.2.6 Decision between intra and inter

If $SATD_{intra} < SATD_{inter}$ intra coding is used. Otherwise inter coding is used.

5.3 Quantization

5.3.1 Simple quantization

This may be considered as the main quantization method. It is used for chroma coefficients and as a fallback for luma coefficients (see below). For each transform coefficient K the quantized LEVEL is produced in the following way:

$LEVEL = (KxA(QP) + fx2^{20})/2^{20}$ $|f|$ is 1/3 for intra and 1/6 for inter blocks and f has the same sign as K.

5.3.2 Rate Distortion constrained quantization (RDQ)

It is realised that quantization may be done more efficiently if more than one coefficient are considered together in the quantization process. One way of obtaining this is illustrated in Figure 7 and Figure 8. RDQ is performed on all transform coefficient blocks (luma, chroma, inter, intra, 'DC-transform', 'AC-transform'). There are three main loops in the procedure:

Loop I

Loop through all coefficients in a scan (16 coefficients for simple scan, 8 coefficients for double scan) and make a 'prequantization'.

Assume that the coefficient size is indicated by the arrow ↑ below. It is considered that there are two possible reconstruction levels: R_0 and R_1 connected to the current QP. The distance between R_0 and R_1 is d. If the coefficient to be quantized is between R_0 and R_0 + 0.55d the reconstruction level is set to R_0 . If the coefficient is between R_0 + 0.55d and R_1 we still keep the possibility open for both R_0 and R_1 .

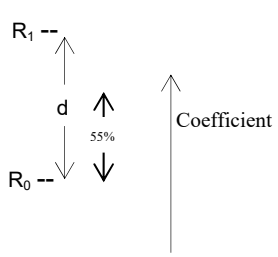


Figure 7 Relation between a coefficient value and reconstruction levels R_0 and R_1

In Figure 8 this is indicated by the calculation of Level0 and Level1. If Level0 $\neq$ Level1, both quantizations will be checked concerning rate distortion gain (see below).

Double_ctr counts the number of coefficients where two quantizations will be considered. In the present method Double_ctr is limited to maximum 3 for complexity reasons.

Level0 and Level1 for all the coefficients in the scan are saved to be used in loops II and III.

Loop II

This loop again scans through all coefficients and accumulates the 'RD_gain' by representing a coefficient by a nonzero reconstruction. The factor 64 is introduced so that integer calculations may be used.

$RD_gain = 64x(Bits + \lambda x((K' - Level)^2 - K'^2)) = 64xBits + \lambda xLevelx(64xLevel-KxA(QP)/2^{13})$

The middle part of the equation include K' which is a floating non-quantized representation of K. Hence $(K' - Level)^2 - K'^2$ is the distortion if Level is used as reconstruction minus the distortion if the reconstruction is set to 0. We call it 'distortion_gain'. The last part of the equation is used for the actual calculations and integer arithmetic is used.

λ is set to 12 for inter blocks and 14 for intra. Q is the divisor used in the quantization process: $2^{20}/A(QP)$. Bits is the number of bits to code a nonzero coefficient. Notice that for a zero coefficient, RD_gain = 0.

Loop III

This loop scans through 2^{Double_ctr} combinations of quantization to find the one with most gain, that is lowest value. If all combinations of quantization result in positive RD_gain, all coefficients in the scan are set to 0 since this is the optimum solution. Notice that by limiting Double_ctr to 3, there are maximum 8 combinations of quantization to be checked.

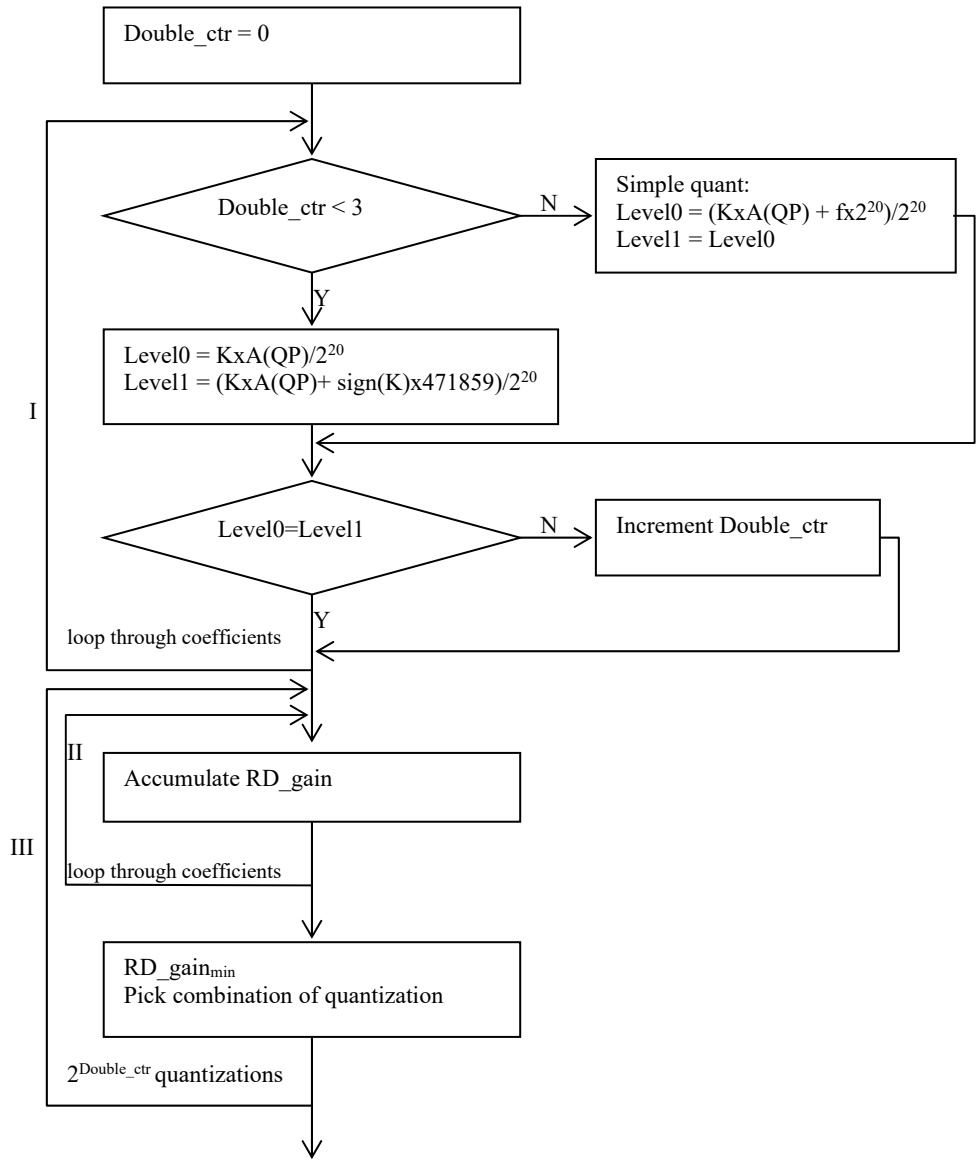


Figure 8 Block diagram of RD-quant

5.4 Elimination of single coefficients in inter macroblocks

With the small 4x4 blocks, it may happen that for instance a macroblock has only one nonzero coefficient with |Level| =1. This will probably be a very expensive coefficient and it could have been better to set it to zero. For that reason a procedure to check single coefficients have been implemented for inter luma blocks. During the quantization process, a parameter Single_ctr is accumulated depending on Run and Level according to the following rule:

If Level = 0 or (|Level| = 1 and Run > 5) nothing is added to Single_ctr.

If |Level| > 1, 9 is added to Single_ctr.

If |Level| = 1 and Run < 6, a value T(Run) is added to Single_ctr. where T(0:5) =(3,2,2,1,1,1)

If the accumulated Single_ctr for a 8x8 block is less than 4, all coefficients of that luma block are set to zero. Similarly, if the accumulated Single_ctr for the whole macroblock is less than 6, all coefficients of that luma macroblock are set to zero.

Appendix 3

ITU - Telecommunications Standardization Sector
STUDY GROUP 16 Question 6
Video Coding Experts Group (VCEG)

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Title: Terms of Reference for Joint Video Team Work

Purpose: Result of Management Discussions for Consideration and Approval

Status: Approved by VCEG, MPEG, and SG16

Terms of Reference for a Joint Project between ITU-T Q.6/SG16 and ISO/IEC JTC 1/SC 29/WG11 for the Development of new Video Coding Recommendation and International Standard

1.0 Goals, Scope and Intent of the Joint Project

These Terms of Reference (ToR) apply to the joint project of ITU-T Q.6/SG16 ("VCEG") and ISO/IEC JTC1/SC29/WG11 ("MPEG"). In the following the two organisations, or higher-level committees of VCEG (SG 16) and MPEG (SC 29), respectively, when required, will be called "parent bodies".

The goal of the joint project is to develop a new video coding standard satisfying the high-level requirements set forth in Annex 1 and according to the preliminary schedule set forth in Annex 2. The work will have as starting point the current draft ITU-T H.26L developed by VCEG that has proved to provide the most advanced results in the tests carried out by MPEG in June 2001.

The scope of the joint project will be the development of a new video coding standard and the assessment of its performance at the completion of the work using formal subjective testing procedures.

The intent is that the ITU-T Recommendation and ISO/IEC International Standard be technically aligned, fully interoperable with each other for all of the video codec's conformance points specified during the term of this joint work, and offer the best possible technical performance under the practical constraints of being implementable on various platforms and for various applications enabled by the relevant ITU-T Recommendations and ISO/IEC International Standards. Common text will not be used in the interest of minimising co-ordination overhead.

The scope of the project is the joint development or definition of:

- Requirements finalization using inputs from the parent bodies
- Video coding syntax
- Formatting of the video syntax for transport over a variety of networks, while keeping any aspects necessary for use with a specific transport system outside the scope of the joint video specification,
    - For example, it is within the scope to
        - define common aspects of a format appropriate to support bitstream-oriented use, e.g., in H.320 or in MPEG-2/MPEG-4 Systems
        - define common aspects of a format appropriate to support packet-oriented use (e.g., for encapsulation into RTP)
    - For example, it is not within the scope to specify any H.32x-specific carriage aspects (more appropriate for only an ITU Recommendation), any MPEG Systems specific aspects (more appropriate for only an ISO/IEC Standard), and any RTP encapsulation (more appropriate for only an IETF RFC).
- Interoperability conformance points (Profiles, and Levels)
- Development of conformance test data

The resulting text will be converted by the parent bodies and higher-level committees into the appropriate ITU-T Recommendation and ISO/IEC International Standard.

2.0 Joint Group

The work of the project will be conducted by a jointly-constituted experts group which will be known as the Joint Video Team ("JVT").

JVT will operate as a joint group under the ordinary policies and procedures of both organisations. In the event of differences between policies of ISO/IEC and ITU-T not covered by these ToR, the JVT Rapporteur|Chair will decide the issue, based on the consensus of the experts and if necessary in consultation with the parent bodies, in the best interests of standardization.

3.0 Deliverables of the Joint Project

The deliverables are a new video codec informally called the JVT codec, to be approved by ITU as an ITU-T Recommendation and by ISO/IEC as an International Standard. These deliverables will be developed with requirements as described.

4.0 Dissolution

The joint group will dissolve when the approval process for the new Recommendation and International Standard in both organisations is completed. The joint group may also be dissolved at the initiative of one or both the parent bodies if unexpected conditions materialise that require one or both of the parent bodies to take this action.

Potential new joint work beyond the duration of this project (e.g., extensions, corrigenda, amendments, etc.) will require the agreement of the two parent bodies. It is anticipated that such agreement would be reached in case the need for a corrigendum is discovered.

5.0 Meetings

JVT meeting venue and dates will be proposed by the JVT Rapporteur|Chair, and authorized by the parent bodies under the customary practices of both organisations.

JVT meetings will be held as an entity that is separate from the two parent bodies, and will operate under rules set forth in Annex 3 of this ToR.

The meeting dates and locations should be co-ordinated with those of meetings of the ITU-T SG16 and ISO/IEC JTC 1/SC 29/WG 11 (e.g. on an alternating basis if feasible for the progress of the project) in order to reduce the amount of travelling for participants and will be preferably co-located with a parent body meeting and held immediately before, during, or after the corresponding SG16 meetings or during the corresponding WG 11 meeting dates.

6.0 Management

The management of the JVT will consist of a jointly-appointed Rapporteur|Chair and two Associate Rapporteurs|Co-Chairs (one each as appointed from the parent bodies with joint consent), reporting to the parent bodies. Changes in the management team must be agreed by the two parent bodies.

7.0 Participation in JVT meetings

Meetings will be open to, and contributions accepted from, all parties qualified for participation in meetings according to the rules of either parent body. Experts may be invited by the Rapporteur|Chair, as permitted by ITU-T | ISO/IEC policies.

All contributions and all participants will have equal status in the technical work and will be considered on the same terms.

8.0 Documents and Contributions

JVT will maintain a document registry and electronic distribution archive. The registry and archive will be linked to both the ITU-T Q.6/SG16 and ISO/IEC JTC 1/SC 29/WG 11 web sites.

Any document from a participant in the meeting should be available to all the participants before the meeting through the use of electronic document handling. A registration and uploading deadline several days in advance of the start of the meeting will be announced for each meeting. A “late, unannounced” document hand-carried to the meeting should be accepted only with the consensus of the meeting participants. This policy will be stated in the invitation letter that is provided for every meeting to both organisations.

All documents and contributions will be in electronic form (preferably MS Word).

In order to facilitate cross-organisational communication, all input and output documents will be public unless the contributor of an input document indicates otherwise. In that circumstance, the document will be accessible only through a private, password-protected site accessible only to ITU/ISO/IEC members and invited experts regularly attending the JVT meetings. Invited experts not regularly attending JVT meetings may be given access to such documents upon approval of its author.

9.0 Working Methods

9.1 General Policies and Procedures

All group decisions will be made by the consensus of the JVT experts as determined by the JVT Chair|Rapporteur. All contributions related to the joint project must be addressed to JVT for the duration of the joint project, rather than to the individual parent bodies. Additionally, these may also

be submitted to any of the parent bodies (according to their specific document submission procedures), if the author of the contribution so determines.

The general rules for handling new proposals, and general polices are described in Annex 3.

9.2 Working relationship between JVT and the parent bodies

The parent bodies may like to provide inputs (either in the form of written documents or by holding meetings with the appropriate parent body sub-groups) on the work carried out by JVT. A non-exhaustive list includes:

1. Further details on the high-level requirements already given in Annex 1.
2. New requirements dictated by new applications that may be served by the new video coding
3. Complexity analysis of the solutions being adopted
4. Partitioning of the video coding tool space in profiles
5. Definition of levels
6. Requirements for the design of verification tests
7. Profiles to be tested in the verification tests.

JVT will consider the inclusion of these inputs in its work, also considering the impact of such inputs in the other parent body's requirements. JVT will report back to the originating organisation on the action taken.

9.3 Document Control

JVT will maintain a single master draft document and a single reference software codebase for the developing video coding standard, each under the control of a single editor, appointed by the JVT Chair|Rapporteur with the consensus of the experts. The document and codebase will contain the exact text to be submitted to the parent bodies for approval. For maintenance of the text, see Section 4 ("Dissolution").

10.0 Patent and Copyright Issues

The project and joint group will progress the project work in compliance with the Intellectual Property Rights ("IPR") policies and IPR reporting requirements and procedures of both organisations (http://www.itu.int/ITU-Databases/TSBPatent/ and http://www.itscj.ipsj.or.jp/sc29/29w7ipr.htm).

JVT will define a "baseline" profile. That profile should be royalty-free for all implementations. The performance of this profile will particularly be the subject of performance verification tests.

JVT's rules for the implementation of the IPR policy are contained in Annex 3.

11.0 Liaison Statements

The JVT will conduct liaison communications. All incoming liaison statements received by the parent bodies that have relevance to the JVT work will be forwarded to the JVT. The JVT may approve output written communications by a consensus of the JVT experts. All output liaison statements approved by the JVT will indicate the level of approval and be posted on the JVT FTP site, and provided to the experts. All outgoing liaison statements will undergo review and consent by both parent bodies (VCEG and MPEG, if necessary in consultation with higher-level committee management) before official transmittal to their addressee.

12.0 Meeting Reports

A meeting report will be provided by the JVT management shortly after the conclusion of each meeting and will be submitted to ITU TSB and ISO/IEC JTC 1/SC 29/WG 11, posted on the group's FTP sites, and distributed to the experts.

The report should include:

- Dates and venue
- Chairpersons/Rapporteurs of the meeting
- Attendance list with affiliation
- Agenda of the meeting
- List of documents considered with source
- Summary of results and an outline of any outstanding issues or resolutions
- Any outgoing liaison statements/communications sent to other organisations
- Future activities

13.0 Promotion and Public Relations Activities

Any public relations or promotional activities regarding the joint group, its project, and its results and deliverables will be approved by the JVT Chair|Rapporteur with the consensus of the experts. All promotion and public relations activities will undergo review and consent by both parent bodies (VCEG and MPEG, if necessary in consultation with higher-level committee management).

Annex 1: High-level requirements for Joint VCEG-MPEG Video Coding Project

- Simplification “back to basics” approach
  - adoption of a generally simple, straightforward design using well-known building blocks
  - for example, use of a minimal number of VLC tables for all parameters to be coded
  - for example, targeting a simplified design knowing that full backward/forward compatibility is not achievable
  - minimum number of conformance points
- High compression performance
  - having a capability goal of 50% or greater bit rate savings from H.263v2 (with Annexes DFIJ&T) or MPEG-4 Advanced Simple Profile at all bit rates
- Flexible application to delay constraints appropriate to a variety of services
  - low delay (e.g., no B pictures) for real-time conversational services
  - higher delay usage appropriate for storage or sever-based streaming application
- Network friendliness
  - ease of packetization
  - information priority control
  - application to video streaming services
- Error resilience
  - packet loss resilience
  - mobile channel corruption resilience
- Complexity scalability in encoder and decoder
  - asymmetry of encoder and decoder processing complexity
  - scalability between amount of encoder processing and achievable quality
- Full specification of decoding (no mismatch)
  - resolve mismatch problem (e.g., integer transform, VQ,…)
- High quality application
  - performance improvement in higher bitrate
  - applicability to entertainment-quality applications
- File storage support
  - simple stream exchange
  - http streaming service
  - random access
  - support of multiple streams with transitions

Annex 2: Preliminary Schedule for Joint VCEG-MPEG Video Coding Project

Approx Date	Auspices	Possible Location	Project Milestone
Dec, 2001	JTC1	Pattaya	JM1, JWD 1
Feb, 2002	ITU-T	Geneva	JM2, JWD 2
May, 2002	ITU-T & JTC1	Fairfax, VA	JM3, CD
Jul, 2002	JTC1	Klagenfurt	JM4, FCD
Oct, 2002	ITU-T	Geneva	JM5, AAP Consent
Dec, 2002	JTC1	TBD	JM6, FDIS & Rec.
Feb, 2003	<Ballot Result>	N/A	IS

The schedule for the definition of conformance tests is yet to be determined, but is expected to shortly follow the schedule for the text of the codec definition itself.

Annex 3: JVT Internal Operating Rules

1. Abstract

This annex defines rules the JVT will use for the future standardization process of the JVT video codec. Agreement of the two parent bodies (VCEG and MPEG, if necessary in consultation with higher-level committee management) is needed for modification of these rules.

These rules cover Intellectual Property Rights (IPR; patents and copyright) for the JVT codec, the Profile-Level framework, and submission and handling of technical proposals to JVT.

The ultimate purpose of the standardization effort is **not** to develop an official Recommendation/International Standard providing the highest possible theoretical performance, but to encourage **actual interoperation between implementations in the field,** at the highest practical level of performance. "Optional" modes which are unlikely to be commonly implemented do not enhance performance in the field, despite any theoretical advantages. This observation drives many of these rules.

The rules help to ensure maximal interoperability and simple capability negotiation of systems employing the JVT codec.

Note that all these rules apply only to the described types of proposals. These rules do not apply to informative or discussion contributions.

2. Definitions

The **Baseline** profile is the common set of features supported by all JVT decoder implementations, without exception. The Baseline profile supports video communication between all systems (although possibly requiring some non-transcoding gateway capability).

A **Profile** is defined by a set of feature capabilities supporting a particular tradeoff between performance and complexity within the encoder or decoder implementation. Applications which require similar tradeoffs between these parameters should use the same Profile.

A **Level** describes performance parameters within each Profile, which describe upper limits on decoder capability. Performance parameters may include maximum picture size, macroblocks per second, bitrate, and similar parameters. See the Joint Test Model (JM) document for a list of Levels.

3. IPR Policy & Guidelines

3.1 Basic IPR Principles

Regarding Intellectual Property Rights (IPR) for the JVT codec, JVT has agreed to the following basic principles:

- The JVT codec should have a simple royalty free "baseline" profile (both on the encoder and decoder) in order to promote the wide implementation and use of the JVT codec. All implementations should have such a common baseline profile core, in order to allow

minimal interoperability among all JVT codecs. The above requirement means that all technology applied in the baseline profile shall have no IPR, expired IPR, or valid but royalty-fee-free IPR (according to Box 2.1 or 2.2.1 of the JVT Patent Disclosure form, as shown below).

- Special, more advanced profiles of the JVT standard may contain patents per Box 2.2 of the JVT Patent Disclosure form (reasonable terms and conditions).

3.2 Collection of IPR information during the standardization process

According to the ITU-T and ISO/IEC IPR policy, members/experts are encouraged to disclose as soon as possible IPR information (of their own or of anyone else's) associated with any standardization proposal (of their own or anyone else's). Such information should be provided on a best effort basis.

For collecting such information, JVT has decided to use it's own Patent Declaration form – note that this is distinct from the *ITU ISO IEC Patent Statement and Licensing Declaration* that is to be submitted to the ISO Secretary General and ITU TSB Director when the contributed technology becomes part of the final standard.

Therefore, **JVT requires all technical (algorithmic) proposals include the following**:

> Attached at the end of each technical contribution, **a fully filled-out "JVT Patent Disclosure form"** (as shown below in this document). At the contribution stage, this form is for information only, and **may be signed by an expert or left unsigned**. The form **must be included in the contribution to JVT**,
>
> Additionally, **all submitted source code must include a written transfer of copyright** in the form described in section 5 below.

Note that the submission of the JVT Patent Disclosure form at the proposal stage does not have the same formal status as the final IPR declaration to the ITU TSB and ISO/IEC, which must be done in the approval process for the ITU-T Recommendation and ISO/IEC International Standard.

Such information provided to the Chair | Rapporteur will be tabulated in a "IPR status list" (e.g. a simple Word table) of the information received. Information not currently relevant (e.g. if a proposed method was not accepted) will be removed from the "IPR status list" as early as possible. The "IPR status list" is a living document of the JVT.

3.4 Outlook

It is hoped that the above implementation would facilitate to achieve the goals outlined under paragraph 3.1.

4. Rules for JVT itself

a) JVT shall ordinarily define each Level for a given Profile to require support of all lower-numbered Levels (L) for the same Profile (P). Therefore, when an endpoint signals Pa Lc, this indicates the ability to operate in any mode Profile a, Level (1..c).

For example, PZ L2 requires support for PZ L1, and PZ L2. It **does not** require support for PZ L3.

b) JVT shall not begin the formal approval process for the JVT Recommendation | Standard or any Annex(es) thereof, until the complete C-code for that technical content has been shown to work and test bitstreams have been generated and tested on the C-code model.

c) Contributed proposals which do not comply with the following rules will be considered by JVT only with the consensus of the group, and only if time is available after consideration of normal proposals. JVT may reach a tentative conclusion regarding such non-compliant proposals, but no proposal shall be formally accepted until the contributor supplies the required materials, and these are approved by JVT.

5. Rules for Technical (algorithmic) Proposals

All technical proposals for algorithms to be included in one or more Profile-Levels shall include:

a) The **results of a reference implementation relative to the official JM test model design**.

In the case of enhancements or evolutionary developments of algorithms already present in JM-n, the results must be based on the most recent JM-n. In the case of algorithms that address fundamentally new issues, it is sufficient that the software is relative to the earlier JM n-1. This requirement is distinct from the requirement of timely inclusion of the software implementation into JM n+1 in case of adoption (see below).

b) **A textual description** that fits into the current structure of the Joint Test Model, **and a change-bar version of JM n** including the new proposal, as a hint to the editor how the resulting JM n+1 may look like.

c) **A written transfer of copyright in the contributed C-code to the ITU and ISO/IEC.** As the JVT C-code model is a collaborative work by the JVT experts, copyright on the jointly-developed software code shall reside in the ITU and ISO/IEC, and contributors must agree to this condition.

Contributors of software code *retain the right to do whatever they wish with software they have contributed*. Contributors also *retain full patent rights in their contributed algorithms*, according to the ITU-T and ISO/IEC Patent Policies. The ITU and ISO/IEC will grant, free of charge, the right to use this software or variations on this software to anyone for purposes of implementation of the standard. JVT intends to include the final C-code version of encoder and decoder into the standard in the form of some normative or informative part of the standard (at the discretion of the group).

As a starting policy JVT members may use either the existing VCEG copyright license or the WG11 copyright license. In the interim software with the WG11 copyright license should be produced in a modularised way so as to store the source code with the WG11 copyright license in identified separate directories. JVT and its parent bodies will establish, as soon as possible, a copyright handling method for contributed software. The software should be developed and made publicly available in a manner that explicitly grants users of the

software the right to use the software for implementations of the Recommendation | Standard.

IMPLEMENTATION OF RULES (a), (b), (c)

Only for rules (a), (b) and (c) above, the contributor does not need to include these items in an initial contribution to JVT. In the case that JVT tentatively accepts the proposal, this will be noted in the JVT Meeting Report, and the contributor is then required to supply items (a), (b) and (c) before formal inclusion of the proposal. The JVT Document Editor and Source Code Coordinator have the discretion to accept items (a), (b), and (c) between JVT meetings. Such acceptance shall be notified to and reviewed by JVT at their next meeting.

d) An **intellectual property (patent) statement**. This shall be in the format given below.

e) **Performance and complexity analysis in a form to be established by the JVT**.

JVT will choose proposals that in the opinion of the experts, best meet the Requirements for the Profile-Level combination.

It is the policy of JVT that all technical results shall be confirmed by independent implementations tested under common conditions. At the discretion of JVT, technical results may be confirmed by submission of source code software to be tested under common conditions.

Note: In a later stage of the standardization process it may be desirable to have less strict rules for inclusion into the JM provided that syntax and semantics of the bitstream/packetstream remain unchanged.

JVT Patent Disclosure Form

International Telecommunication Union
Telecommunication Standardization Sector

International Organization for Standardization

International Electrotechnical Commission

Joint Video Coding Experts Group - *Patent Disclosure Form*

(Typically one per contribution and one per Standard | Recommendation)

Please send to:

JVT Rapporteur Gary Sullivan, Microsoft Corp., One Microsoft Way, Bldg. 9, Redmond WA 98052-6399, USA
Email (preferred): Gary.Sullivan@itu.int Fax: +1 425 706 7329 (+1 425 70MSFAX)

This form provides the ITU-T | ISO/IEC Joint Video Coding Experts Group (JVT) with information about the patent status of techniques used in or proposed for incorporation in a Recommendation | Standard. JVT requires that all technical contributions be accompanied with this form. *Anyone* with knowledge of any patent affecting the use of JVT work, of their own or of any other entity ("third parties"), is strongly encouraged to submit this form as well.

This information will be maintained in a "living list" by JVT during the progress of their work, on a best effort basis. If a given technical proposal is not incorporated in a Recommendation | Standard, the relevant patent information will be removed from the "living list". The intent is that the JVT experts should know in advance of any patent issues with particular proposals or techniques, so that these may be addressed well before final approval.

This is not a binding legal document; it is provided to JVT for information only, on a best effort, good faith basis. Please submit corrected or updated forms if your knowledge or situation changes.

This form is *not* a substitute for the *ITU ISO IEC Patent Statement and Licensing Declaration*, which should be submitted by Patent Holders to the ITU TSB Director and ISO Secretary General before final approval.

Submitting Organization or Person:

Organization name _____

Mailing address _____

Country _____

Contact person _____

Telephone _____

Fax _____

Email _____

Place and date of submission _____

Relevant Recommendation | Standard and, if applicable, Contribution:

Name (ex: "JVT") _____

Title _____

Contribution number _____

(Form continues on next page)

Disclosure information – Submitting Organization/Person (choose one box)

☐ 2.0 The submitter is not aware of having any granted, pending, or planned patents associated with the technical content of the Recommendation | Standard or Contribution.

or,

The submitter (Patent Holder) has granted, pending, or planned patents associated with the technical content of the Recommendation | Standard or Contribution. In which case,

☐ 2.1 The Patent Holder is prepared to grant – on the basis of reciprocity for the above Recommendation | Standard – a free license to an unrestricted number of applicants on a worldwide, non-discriminatory basis to manufacture, use and/or sell implementations of the above Recommendation | Standard.

☐ 2.2 The Patent Holder is prepared to grant – on the basis of reciprocity for the above Recommendation | Standard – a license to an unrestricted number of applicants on a worldwide, non-discriminatory basis and on reasonable terms and conditions to manufacture, use and/ or sell implementations of the above Recommendation | Standard.

Such negotiations are left to the parties concerned and are performed outside the ITU | ISO/IEC.

☐ 2.2.1 The same as box 2.2 above, but in addition the Patent Holder is prepared to grant a "royalty-free" license to anyone on condition that all other patent holders do the same.

☐ 2.3 The Patent Holder is unwilling to grant licenses according to the provisions of either 2.1, 2.2, or 2.2.1 above. In this case, the following information must be provided as part of this declaration:

- patent registration/application number;
- an indication of which portions of the Recommendation | Standard are affected.
- a description of the patent claims covering the Recommendation | Standard;

*In the case of any box **other than 2.0** above, please provide the following:*

Patent number(s)/status _____

Inventor(s)/Assignee(s) _____

Relevance to JVT _____

Any other remarks: _____

(please provide attachments if more space is needed)

(form continues on next page)

Third party patent information – fill in based on your best knowledge of relevant patents granted, pending, or planned by other people or by organizations other than your own.

Disclosure information – Third Party Patents (choose one box)

☐ 3.1 The submitter is not aware of any granted, pending, or planned patents *held by third parties* associated with the technical content of the Recommendation | Standard or Contribution.

☐ 3.2 The submitter believes third parties may have granted, pending, or planned patents associated with the technical content of the Recommendation | Standard or Contribution.

For box 3.2, please provide as much information as is known (provide attachments if more space needed) - JVT will attempt to contact third parties to obtain more information:

3rd party name(s) _____

Mailing address _____
Country _____
Contact person _____
Telephone _____
Fax _____
Email _____
Patent number/status _____
Inventor/Assignee _____
Relevance to JVT _____

Any other comments or remarks:

Appendix 4

Joint Video Team (JVT) of ISO/IEC MPEG and ITU-T VCEG Document **JVT-B118r2**
File: JVT-B118r2.doc
Geneva, Switzerland, January 29-February 1, 2002 Generated: 2002-03-15

Title: Working Draft Number 2, Revision 2 (WD-2)

Status: Approved Output Document

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Purpose: Information

This document presents the Working Draft Number 2 (***WD-2***) released by the Joint Video Team (JVT). The JVT is being formed by ITU-T SG16 Q.6 (VCEG) and ISO/IEC JTC 1/SC 29/WG 11 (MPEG). This document is a description of a reference coding method to be used for the development of a new video compression method called ***JVT Coding*** as ITU-T Recommendation (H.26L) and ISO/IEC JTC1 Standard (MPEG-4, Part 10).

The following changes are included relative to WD-1:

- Deblocking filter JVT-B011 (general usefulness)
- CACM+ CABAC JVT-B036 (general usefulness with CABAC)
- SI Frames JVT-B055 (use for streaming, random access, error recovery)
- Intra Prediction JVT-B080 (put in software as configurable feature, use it in common conditions, seek complexity analysis)
- Interlace frame/field switch at picture level from JVT-B071 (with field coding as the candidate baseline interlace-handling design)
- MB partition alteration VCEG-O17 (general usefulness)
- CABAC eff. improve JVT-B101 (general usefulness with CABAC)
- Normative picture number update behavior from JVT-B042 (error resilience)
- Enhanced GOP concept description in interim file format non-normative appendix JVT-B042
- Exp-Golomb VLC JVT-B029 (general usefulness without CABAC)
- Bitstream NAL structure with start code and emulation prevention part of JVT-B063 (use for bitstream environments)
- Transform JVT-B038 (general usefulness)
- Extension of quant range (general usefulness)

The following changes are adopted, but no text has been submitted to the editor for inclusion into this document. Please note that all adoptions are tentative unless being fully integrated into this document and the software.

- Encoding Motion Search Range JVT-B022 (lower complexity method not for common conditions testing)
- Robust reference frame selection JVT-B102

Additionally, the formula in the encoder test model for the determination of the Lagrange parameter was adapted by the editor to obtain a working description.

Non-editorial changes between JVT-B118r1 and JVT-B118r2:

- Another correction of TABLE 7
- Picture type (Ptype) extended for signaling S-frames

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1 Scope

This document is a description of a reference coding method to be used for the development of a new video compression ITU-T Recommendation (H.26L) and ISO Standard (MPEG-4, Part 10). The basic configuration of the algorithm is similar to H.263 and MPEG-4, Part 2.

2 Definitions

For the purposes of this Recommendation | International Standard, the following definitions apply.

AC coefficient:	Any transform coefficient for which the frequency in one or both dimensions is non-zero.
MH-field picture:	A field structure MH-Picture.
MH-frame picture:	A frame structure MH-Picture.
MH-picture:	A predictive-coded picture: A picture that is coded using up to two motion compensated prediction signals from past and/or future reference fields or frames.
backward compatibility:	A newer coding standard is backward compatible with an older coding standard if decoders designed to operate with the older coding standard are able to continue to operate by decoding all or part of a bitstream produced according to the newer coding standard.
backward motion vector:	A motion vector that is used for motion compensation from a reference frame or reference field at a later time in display order.
backward prediction:	Prediction from the future reference frame (field).
bitstream (stream):	An ordered series of bits that forms the coded representation of the data.
bitrate:	The rate at which the coded bitstream is delivered from the storage medium to the input of a decoder.
block:	An N-row by M-column matrix of samples, or NxM transform coefficients (source, quantised or dequantised).
bottom field:	One of two fields that comprise a frame. Each line of a bottom field is spatially located immediately below the corresponding line of the top field.
byte aligned:	A bit in a coded bitstream is byte-aligned if its position is a multiple of 8-bits from the first bit in the stream.
byte:	Sequence of 8-bits.
channel:	A digital medium that stores or transports a bitstream constructed according to this specification.
chrominance format:	Defines the number of chrominance blocks in a macroblock.
chrominance component:	A matrix, block or single sample representing one of the two colour difference signals related to the primary colours in the manner defined in the bitstream. The symbols used for the chrominance signals are Cr and Cb.
coded MH-frame:	A MH-frame picture or a pair of MH-field pictures.
coded frame:	A coded frame is a coded I-frame, a coded P-frame or a coded MH-frame.
coded I-frame:	An I-frame picture or a pair of field pictures, where the first field picture is an I-picture and the second field picture is an I-picture or a P-picture.
coded P-frame:	A P-frame picture or a pair of P-field pictures.
coded picture:	A coded picture is made of a picture header, the optional extensions immediately following it, and the following picture data. A coded picture may be a coded frame or a coded field.
coded video bitstream:	A coded representation of a series of one or more pictures as defined in this specification.
coded order:	The order in which the pictures are transmitted and decoded. This order is not necessarily the same as the display order.
coded representation:	A data element as represented in its encoded form.

coding parameters:	The set of user-definable parameters that characterise a coded video bitstream. Bitstreams are characterised by coding parameters. Decoders are characterised by the bitstreams that they are capable of decoding.
component:	A matrix, block or single sample from one of the three matrices (luminance and two chrominance) that make up a picture.
compression:	Reduction in the number of bits used to represent an item of data.
constant bitrate coded video:	A coded video bitstream with a constant average bitrate.
constant bitrate:	Operation where the bitrate is constant from start to finish of the coded bitstream.
data element:	An item of data as represented before encoding and after decoding.
data partitioning:	A method for dividing a bitstream into two separate bitstreams for error resilience purposes. The two bitstreams have to be recombined before decoding.
DC coefficient:	The transform coefficient for which the frequency is zero in both dimensions.
transform coefficient:	The amplitude of a specific basis function.
decoder input buffer:	The first-in first-out (FIFO) buffer specified in the video buffering verifier. 2
decoder:	An embodiment of a decoding process.
decoding (process):	The process defined in this specification that reads an input coded bitstream and produces decoded pictures or audio samples.
dequantisation:	The process of rescaling the quantised transform coefficients after their representation in the bitstream has been decoded and before they are presented to the inverse transform.
digital storage media (DSM):	A digital storage or transmission device or system.
transform:	Either the transform or the inverse discrete cosine transform. The transform is an invertible, discrete orthogonal transformation.
display aspect ratio:	The ratio height/width (in SI units) of the intended display.
display order:	The order in which the decoded pictures are displayed. Normally this is the same order in which they were presented at the input of the encoder.
display process:	The (non-normative) process by which reconstructed frames are displayed.
editing:	The process by which one or more coded bitstreams are manipulated to produce a new coded bitstream. Conforming edited bitstreams must meet the requirements defined in this specification.
encoder:	An embodiment of an encoding process.
encoding (process):	A process, not specified in this specification, that reads a stream of input pictures or audio samples and produces a valid coded bitstream as defined in this specification.
fast forward playback:	The process of displaying a sequence, or parts of a sequence, of pictures in display-order faster than real-time.
fast reverse playback:	The process of displaying the picture sequence in the reverse of display order faster than real-time.
field:	For an interlaced video signal, a “field” is the assembly of alternate lines of a frame. Therefore an interlaced frame is composed of two fields, a top field and a bottom field.
field-based prediction:	A prediction mode using only one field of the reference frame. The predicted block size is 16x16 luminance samples. Field-based prediction is not used in progressive frames.
field period:	The reciprocal of twice the frame rate.

field (structure) picture:	A field structure picture is a coded picture with picture_structure is equal to "Top field" or "Bottom field".
flag:	A variable which can take one of only the two values defined in this specification.
forbidden:	The term "forbidden" when used in the clauses defining the coded bitstream indicates that the value shall never be used. This is usually to avoid emulation of start codes.
forced updating:	The process by which macroblocks are intra-coded from time-to-time to ensure that mismatch errors between the inverse transform processes in encoders and decoders cannot build up excessively.
forward compatibility:	A newer coding standard is forward compatible with an older coding standard if decoders designed to operate with the newer coding standard are able to decode bitstreams of the older coding standard.
forward motion vector:	A motion vector that is used for motion compensation from a reference frame or reference field at an earlier time in display order.
forward prediction:	Prediction from the past reference frame (field).
frame:	A frame contains lines of spatial information of a video signal. For progressive video, these lines contain samples starting from one time instant and continuing through successive lines to the bottom of the frame. For interlaced video a frame consists of two fields, a top field and a bottom field. One of these fields will commence one field period later than the other.
frame-based prediction:	A prediction mode using both fields of the reference frame.
frame period:	The reciprocal of the frame rate.
frame (structure) picture:	A frame structure picture is a coded picture with picture_structure is equal to "Frame".
frame rate:	The rate at which frames are be output from the decoding process.
future reference frame (field):	A future reference frame(field) is a reference frame(field) that occurs at a later time than the current picture in display order.
frame reordering:	The process of reordering the reconstructed frames when the coded order is different from the display order. Frame reordering occurs when MH-frames are present in a bitstream. There is no frame reordering when decoding low delay bitstreams.
group of pictures:	tbd (to be defined :o)
header:	A block of data in the coded bitstream containing the coded representation of a number of data elements pertaining to the coded data that follow the header in the bitstream.
interlace:	The property of conventional television frames where alternating lines of the frame represent different instances in time. In an interlaced frame, one of the field is meant to be displayed first. This field is called the first field. The first field can be the top field or the bottom field of the frame.
I-field picture:	A field structure I-Picture.
I-frame picture:	A frame structure I-Picture.
I-picture, intra-coded picture:	A picture coded using information only from itself.
intra coding:	Coding of a macroblock or picture that uses information only from that macroblock or picture.
level :	A defined set of constraints on the values which may be taken by the parameters of this specification within a particular profile. A profile may contain one or more levels. In a different context, level is the absolute value of a non-zero coefficient (see “run”).
luminance component:	A matrix, block or single sample representing a monochrome representation of the signal and related to the primary colours in the manner defined in the bitstream. The

symbol used for luminance is Y.

Mbit: 1 000 000 bits

macroblock: The four 8 by 8 blocks of luminance data and the two (for 4:2:0 chrominance format), four (for 4:2:2 chrominance format) or eight (for 4:4:4 chrominance format) corresponding 8 by 8 blocks of chrominance data coming from a 16 by 16 section of the luminance component of the picture. Macroblock is sometimes used to refer to the sample data and sometimes to the coded representation of the sample values and other data elements defined in the macroblock header of the syntax defined in this part of this specification. The usage is clear from the context.

motion compensation: The use of motion vectors to improve the efficiency of the prediction of sample values. The prediction uses motion vectors to provide offsets into the past and/or future reference frames or reference fields containing previously decoded sample values that are used to form the prediction error.

motion estimation: The process of estimating motion vectors during the encoding process.

motion vector: A two-dimensional vector used for motion compensation that provides an offset from the coordinate position in the current picture or field to the coordinates in a reference frame or reference field.

non-intra coding: Coding of a macroblock or picture that uses information both from itself and from macroblocks and pictures occurring at other times.

opposite parity: The opposit parity of top is bottom, and vice versa.

P-field picture: A field structure P-Picture.

P-frame picture: A frame structure P-Picture.

P-picture, predictive-coded picture: A picture that is coded using motion compensated prediction from past reference fields or frame.

parameter: A variable within the syntax of this specification which may take one of a range of values. A variable which can take one of only two values is called a flag.

parity (of field): The parity of a field can be top or bottom.

past reference frame (field): A past reference frame(field) is a reference frame(field) that occurs at an earlier time than the current picture in display order.

picture: Source, coded or reconstructed image data. A source or reconstructed picture consists of three rectangular matrices of 8-bit numbers representing the luminance and two chrominance signals. A “coded picture” is defined in 3.21. For progressive video, a picture is identical to a frame, while for interlaced video, a picture can refer to a frame, or the top field or the bottom field of the frame depending on the context.

picture data: In the VBV operations, picture data is defined as all the bits of the coded picture, all the header(s) and user data immediately preceding it if any (including any stuffing between them) and all the stuffing following it, up to (but not including) the next start code, except in the case where the next start code is an end of sequence code, in which case it is included in the picture data.

prediction: The use of a predictor to provide an estimate of the sample value or data element currently being decoded.

prediction error: The difference between the actual value of a sample or data element and its predictor.

predictor: A linear combination of previously decoded sample values or data elements.

profile: A defined subset of the syntax of this specification.

progressive: The property of film frames where all the samples of the frame represent the same instances in time.

quantised transform coefficients: transform coefficients before dequantisation. A variable length coded representation of quantised transform coefficients is transmitted as part of the coded video bitstream.

quantiser scale:	A scale factor coded in the bitstream and used by the decoding process to scale the dequantisation.
random access:	The process of beginning to read and decode the coded bitstream at an arbitrary point.
reconstructed frame:	A reconstructed frame consists of three rectangular matrices of 8- bit numbers representing the luminance and two chrominance signals. A reconstructed frame is obtained by decoding a coded frame.
reconstructed picture:	A reconstructed picture is obtained by decoding a coded picture. A reconstructed picture is either a reconstructed frame (when decoding a frame picture), or one field of a reconstructed frame (when decoding a field picture). If the coded picture is a field picture, then the reconstructed picture is the top field or the bottom field of the reconstructed frame.
reference field:	A reference field is one field of a reconstructed frame. Reference fields are used for forward and backward prediction when P-pictures and MH-pictures are decoded. Note that when field P-pictures are decoded, prediction of the second field P- picture of a coded frame uses the first reconstructed field of the same coded frame as a reference field.
reference frame:	A reference frame is a reconstructed frame that was coded in the form of a coded I-frame or a coded P-frame. Reference frames are used for forward and backward prediction when P-pictures and MH-pictures are decoded.
reordering delay:	A delay in the decoding process that is caused by frame reordering.
reserved:	The term "reserved" when used in the clauses defining the coded bitstream indicates that the value may be used in the future for JVT defined extensions.
sample aspect ratio:	(abbreviated to SAR). This specifies the distance between samples. It is defined (for the purposes of this specification) as the vertical displacement of the lines of luminance samples in a frame divided by the horizontal displacement of the luminance samples. Thus its units are (metres per line) ÷ (metres per sample)
side information:	Information in the bitstream necessary for controlling the decoder. 16x8 prediction — A prediction mode similar to field-based prediction but where the predicted block size is 16x8 luminance samples.
run:	The number of zero coefficients preceding a non-zero coefficient, in the scan order. The absolute value of the non-zero coefficient is called “level”.
saturation:	Limiting a value that exceeds a defined range by setting its value to the maximum or minimum of the range as appropriate.
skipped macroblock:	A macroblock for which no data is encoded.
slice:	A series of macroblocks.
Source (input):	Term used to describe the video material or some of its attributes attributes before encoding.
spatial prediction:	prediction derived from the same decoded frame.
start codes [system and video]:	32-bit codes embedded in that coded bitstream that are unique. They are used for several purposes including identifying some of the structures in the coding syntax.
stuffing (bits, bytes):	Code-words that may be inserted into the coded bitstream that are discarded in the decoding process. Their purpose is to increase the bitrate of the stream which would otherwise be lower than the desired bitrate.
temporal prediction:	prediction derived from reference frames or fields other than those defined as spatial prediction
top field:	One of two fields that comprise a frame. Each line of a top field is spatially located immediately above the corresponding line of the bottom field.
variable bitrate:	Operation where the bitrate varies with time during the decoding of a coded bitstream.

variable length coding (VLC):	A reversible procedure for coding that assigns shorter code-words to frequent events and longer code-words to less frequent events.
video buffering verifier (VBV):	A hypothetical decoder that is conceptually connected to the output of the encoder. Its purpose is to provide a constraint on the variability of the data rate that an encoder or editing process may produce.
video complexity verifier (VCV):	Ok… just kidding.
video sequence:	The highest syntactic structure of coded video bitstreams. It contains a series of one or more coded frames.
XYZ profile decoder:	decoder able to decode bitstreams conforming to the specifications of the XYZ profile (with XYZ being any of the defined Profile names).
zig-zag scanning order:	A specific sequential ordering of the transform coefficients from (approximately) the lowest spatial frequency to the highest.

3 Source Coder

3.1 Picture formats

The image width and height of the source data are restricted to be multiples of 16. At the moment only colour sequences using 4:2:0 chrominance sub-sampling are supported.

This specification describes coding of video that contains either progressive or interlaced frames, which may be mixed together in the same sequence.

A frame of video contains two fields, the top field and the bottom field, which are interleaved. The first (i.e., top), third, fifth, etc. lines of a frame are the top field lines. The second, fourth, sixth, etc. lines of a frame are the bottom field lines. A top field picture consists of only the top field lines of a frame. A bottom field picture consists of only the bottom field lines of a frame.

The two fields of an interlaced frame are separated in time by a field period (which is half the time of a frame period). They may be coded separately as two field pictures or together as a frame picture. A progressive frame should always be coded as a single frame picture. However, a progressive frame is still considered to consist of two fields (at the same instant in time) so that other field pictures may reference the sub-fields of the frame.

The vertical and temporal sampling positions of samples in interlaced frames are shown in Figure 1. The vertical sampling positions of the chrominance samples in a top field of an interlaced frame are specified as shifted up by 1/4 luminance sample height relative to the field-sampling grid in order for these samples to align vertically to the usual position relative to the full-frame sampling grid. The vertical sampling positions of the chrominance samples in a bottom field of an interlaced frame are specified as shifted down by 1/4 luminance sample height relative to the field-sampling grid in order for these samples to align vertically to the usual position relative to the full-frame sampling grid. The horizontal sampling positions of the chrominance samples are specified as unaffected by the application of interlaced field coding.

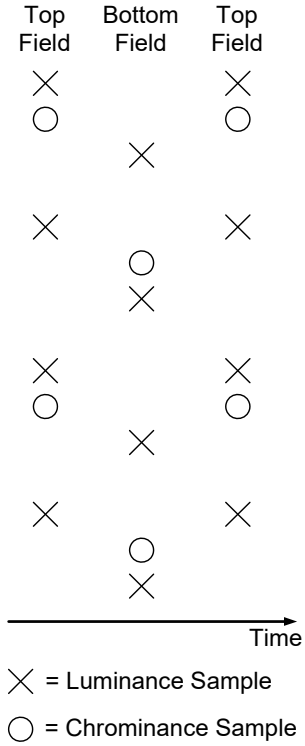


FIGURE 1

Vertical and temporal sampling positions of samples in interlaced frames

3.2 Subdivision of a picture into macroblocks

Pictures (both frame and field) are divided into macroblocks of 16x16 pixels. For instance, a QCIF picture is divided into 99 macroblocks as indicated in FIGURE 1. A number of consecutive macroblocks in coding order (see FIGURE 1) can be organized in slices. Slices represent independent coding units in a way that they can be decoded without referencing other slices of the same frame.

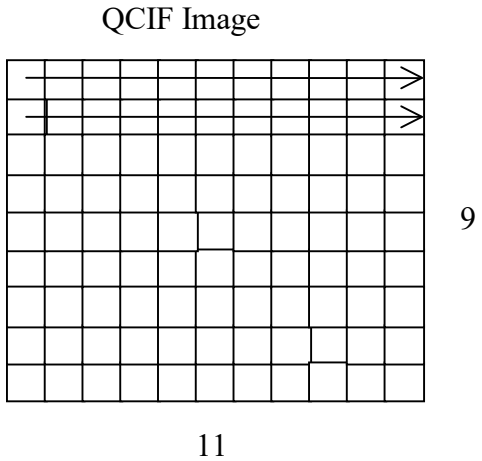


FIGURE 1

Subdivision of a QCIF picture into 16x16 macroblocks

3.3 Order of the bitstream within a macroblock

FIGURE 2 and FIGURE 3 indicate how a macroblock or 8x8 sub-block is divided and the order of the different syntax elements resulting from coding a macroblock.

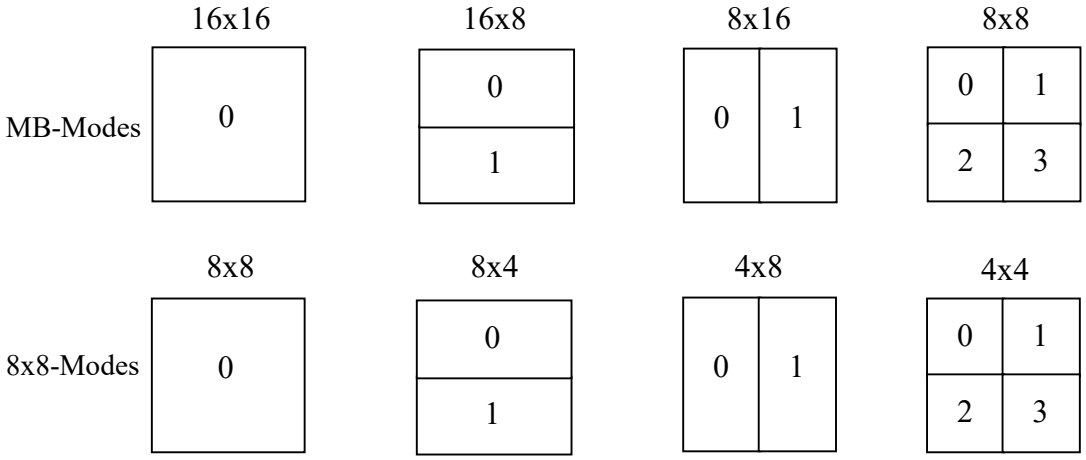


FIGURE 2

Numbering of the vectors for the different blocks depending on the inter mode. For each block the horizontal component comes first followed by the vertical component

CBPY 8x8 block order

0	1
2	3

Luma residual coding 4x4 block order

0	1	4	5
2	3	6	7
8	9	12	13
10	11	14	15

Chroma residual coding 4x4 block order

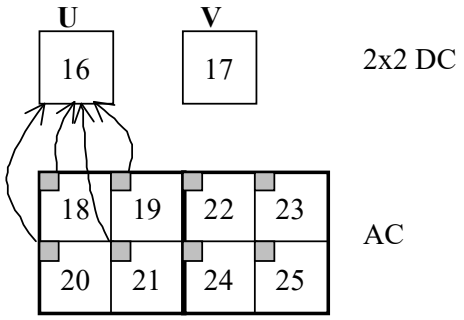


FIGURE 3

Ordering of blocks for CBPY and residual coding of 4x4 blocks

4 Syntax and Semantics

4.1 Organization of syntax elements (NAL concept)

The Video Coding Layer (VCL) is defined to efficiently represent the content of the video data, and the Network Adaptation Layer (NAL) is defined to format that data and provide header information in a manner appropriate for conveyance by the higher level system. The data is organized into data packets, each of which contains an integer number of bytes. These data packets are then transmitted in a manner defined by the NAL.

Any sequence of bits to be carried by an NAL can be formatted into a sequence of bytes in a manner defined as a Raw Byte Sequence Payload (RBSP), and any RBSP can be encapsulated in a manner that prevents emulation of byte stream start code prefixes in a manner defined defined as an encapsulated byte sequence payload (EBSP). These two formats are described below in this section.

4.1.1 Raw Byte Sequence Payload (RBSP)

A raw byte sequence payload (RBSP) is defined as an ordered sequence of bytes that contains a string of data bits (SODB). A SODB is defined as an ordered sequence of bits, in which the left-most bit is considered to be the first and most significant bit (MSB) and the right-most bit is considered to be the last and least significant bit (LSB). The RBSP contains the SODB in the following form:

1. If the SODB is null, the RBSP is also null.
2. Otherwise, the RBSP shall contain the SODB in the following form:
    a. The first byte of the RBSP shall contain the (most significant, left-most) eight bits of the SODB; the next byte of the RBSP shall contain the next eight bits of the SODB, etc.; until fewer than eight bits of the SODB remain.
    b. The final byte of the RBSP shall have the following form:
        i. The first (most significant, left-most) bits of the final RBSP byte shall contain the remaining bits of the SODB, if any,
        ii. The next bit of the final RBSP byte shall consist of a single packet stop bit (PSB) having the value one ('1'), and
        iii. Any remaining bits of the final RBSP byte, if any, shall consist of byte-alignment stuffing bits (BASB's) having the value zero ('0').

Note that the last byte of a RBSP can never have the zero (0x00).

If the boundaries of the RBSP are known, the decoder can extract the SODB from the RBSP by concatenating the bits of the bytes of the RBSP and discarding the last (least significant, right-most) bit having the value one ('1') and any following (less significant, farther to the right) bits that follow it having the value zero ('0').

The means for determining the boundaries of the RBSP depend on the NAL.

4.1.2 Encapsulated Byte Sequence Payload (EBSP)

A encapsulated byte sequence payload (EBSP) is defined as an ordered sequence of bytes that contains the raw byte sequence payload (RBSP) in the following form:

1. If the RBSP contains fewer than three bytes, the EBSP shall be the same as the RBSP.
2. Otherwise, the EBSP shall contain the RBSP in the following form:
    a. The first byte of the EBSP shall contain the first byte of the RBSP,
    b. The second byte of the EBSP shall contain the second byte of the RBSP,
    c. Corresponding to each subsequent byte of the RBSP, the EBSP shall contain one or two subsequent bytes as follows:
        i. If the last two previous bytes of the EBSP are both equal to zero (0x00) and if the next byte of the RBSP is either equal to one (0x01) or equal to 255 (0xFF), the EBSP shall contain two bytes of data that correspond to the next byte of the

RBSP. The first of these two bytes shall be an emulation prevention byte (EPB) equal to 255 (0xFF), and the second of these two bytes shall be equal to the next byte of the RBSP.

ii. Otherwise, the EBSP shall contain one next byte of data corresponding to the next byte of the RBSP. This byte shall be equal to the next byte of the RBSP.

The format of the EBSP prevents the three-byte start code prefix (SCP) equal to 0x00, 0x00, 0x01 from occurring within an EBSP. A decoder shall extract the RBSP from the EBSP by removing and discarding each byte having the value 255 (0xFF) which follows two bytes having the value zero (0x00) within an EBSP. The means for determining the boundaries of an EBSP is specified by the NAL.

Note that the effect of concatenating two or more RBSP's and then encapsulating them into an EBSP is the same as first encapsulating each individual RBPS and then concatenating the result (because the last byte of an RBSP is never zero). This allows the association of individual EBSP's to video data packets to depend on the NAL without affecting the content of the EBSP. For example, high-level header data can be placed in its own EBSP and this same EBSP content can be carried in several alternative ways, depending on the particular NAL design in use, including the possibilities of:

- Sending it within a low-level video packet with associated lower-level data for independent packet decoding, or
- Sending it in a separate higher-level header packet, or
- Sending it in an external "out-of-band" reliable channel.

4.1.3 Payload Type Indicator Byte (PTIB)

The type of data carried in a data packet is indicated by a payload type indicator byte (PTIB). The table below contains the values defined for the PTIB.

PTIB Value	Meaning
0x01	Sequence Data: Payload contains configuration information for sequence
0x02	Sequence SEI: Payload contains SEI for sequence
0x03	Random Access Point Data: Payload TBD
0x04	Random Access Point SEI: Payload contains SEI for random access point
0x05	Picture Data: Null payload
0x06	Picture SEI: Payload contains SEI for picture
0x07	Non-Partitioned Slice Data: Payload is one EBSP containing slice header data and non-data-partitioned video data for the slice
0x05	Slice Mode and MV Data: Payload is one EBSP containing slice header data and all other non-coefficient data for the slice
0x06	Slice Intra Coefficient Data: Payload is one EBSP containing slice header data and all intra coefficients for the slice
0x07	Slice Inter Coefficient Data: Payload is one EBSP containing slice header data and all non-intra coefficients for the slice
0x08	End of Sequence Data: Null payload
0x09	End of Sequence SEI: Payload contains SEI for end of sequence

[*Ed. Note:* Further work needed to finalize format of PTIB and define the types of data to follow.]

4.1.4 Slice Mode

Tbd.

4.1.5 Data Partitioning Mode

Data Partitioning re-arranges the symbols in a way that all symbols of one data type (e.g. DC coefficients, macroblock headers, motion vectors) that belong to a single slice are collected in one VLC coded bitstream that starts byte aligned. Decoders can process such a partitioned data streams by fetching symbols from the correct partition. The partition to fetch from is determined through the decoder's state machine, according to the syntax diagram discussed in section 4.4.

Data Partitioning is implemented by concatenating all VLC coded symbols of one data type and one slice (or full picture if slices are not used). At the moment, for a few partitions as indicated below contain data of more than one data type that are so closely related that a finer diversion seems to be fruitless. The following data types are currently defined:

0	TYPE_HEADER	Picture or Slice Headers (Note 1)
1	TYPE_MBHEADER	Macroblock header information (Note 2)
2	TYPE_MVD	Motion Vector Data
3	TYPE_CBP	Coded Block Patterm
4	TYPE_2x2DC	2x2 DC Coefficients
5	TYPE_COEFF_Y	Luminance AC Coefficients
6	TYPE_COEFF_C	Chrominance AC Coefficients
7	TYPE_EOS	End-of-Stream Symbol

Note 1: TYPE_HEADER encompasses all Picture/Slice header information

Note 2: TYPE_MBHEADER encompasses The MB-Type, Intra-Prediction mode and Reference Frame ID.

4.2 Syntax diagrams

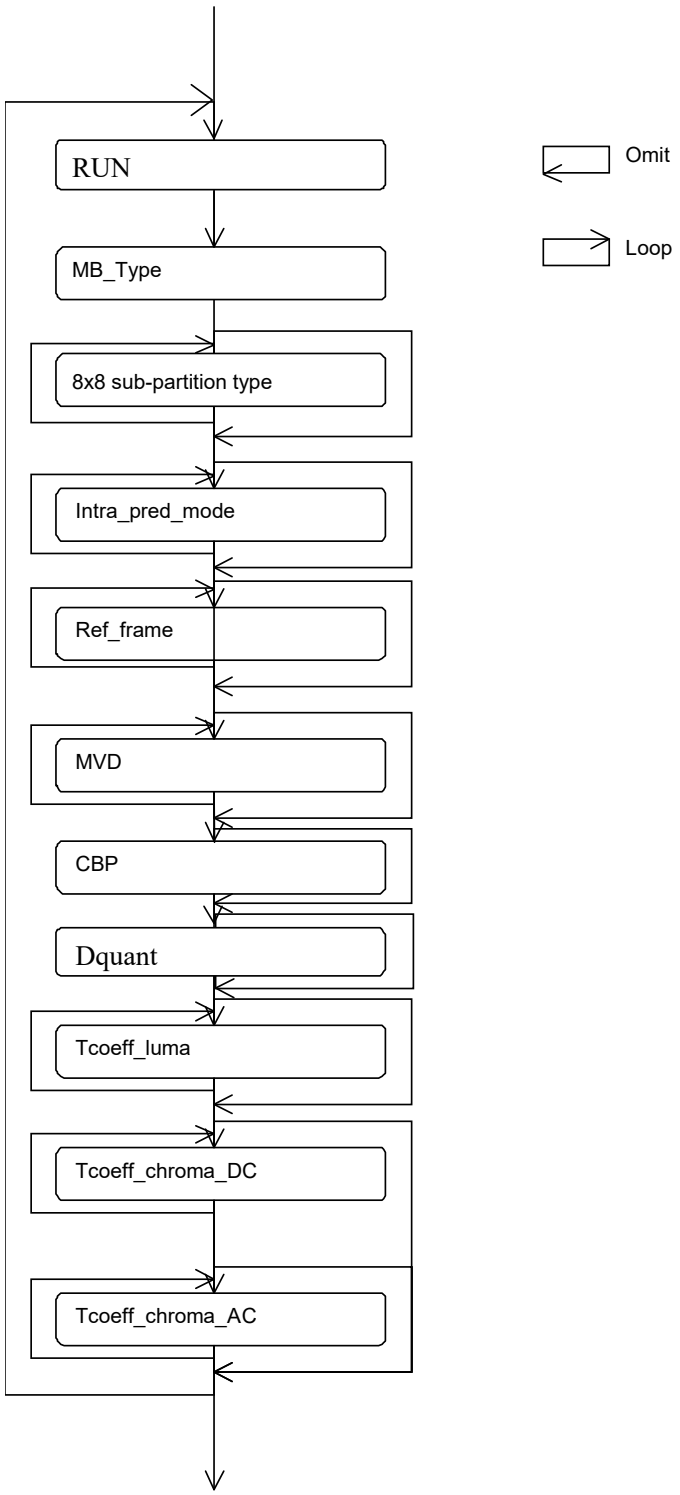


FIGURE 4

Syntax diagram for all the elements in the macroblock layer

4.3 Slice Layer

Editor: The slice layer needs a significant amount of work together with the NAL concept. The Picture sync and picture type codewords are present to ease the VCL development.

The information on the slice layer is coded depending on the NAL type. The coding, the order and even the presence of some fields may differ between the different NALs.

4.3.1 Slicesync

A slice sync may be inserted as the first codeword if it is needed by the NAL. If UVLC codes are used for the transmission of the slice level it should be a 31 bit long (L = 31) codeword with the INFO part set to zero.

4.3.2 Temporal reference (TRType/TR)

Two codewords. Temporal reference type (TRType) indicates how TR is transmitted

TRType = 0 Absoltue TR

TRType <> 0 Error

The value of TR is formed by incrementing its value in the temporally-previous reference picture header by one plus the number of skipped or non-reference pictures at the picture clock frequency since the previously transmitted one.

4.3.3 Picture type (Ptype)

Code_number =0: Inter picture with prediction from the most recent decoded picture only.

Code_number =1: Inter picture with possibility of prediction from more than one previous decoded picture. For this mode information reference picture for prediction must be signalled for each macroblock.

Code_number =2: Intra picture.

Code_number =3: B picture with prediction from the most recent previous decoded and subsequent decoded pictures only.

Code_number =4: B picture with possibility of prediction from more than one previous decoded picture and subsequent decoded picture. When using this mode, information reference frame for prediction must be signalled for each macroblock.

Code_number =5: SP picture with prediction from the most recent decoded picture only.

Code_number =6: SP picture with possibility of prediction from more than one previous decoded picture. For this mode information reference picture for prediction must be signalled for each macroblock.

Code_number =7: SI picture

4.3.4 Picture structure (PSTRUCT)

Code_number =0: Progressive frame picture.

Code_number =1: Top field picture.

Code_number =2: Bottom field picture.

Code_number =3: Interlaced frame picture, whose top field precedes its bottom field in time.

Code_number =4: Interlaced frame picture, whose bottom field precedes its top field in time.

Note that when top field and bottom field pictures are coded for a frame, the one that is decoded first is the one that occurs first in time.

4.3.5 Size information

A series of up to three codewords. The first codeword indicates a size change. If set to zero the size is unchaged otherwise (if set to one) it is followed by two codewords containing the new width and height.

4.3.6 Reference Picture ID

4.3.7 First MB in slice

The number of the first macroblock contained in this slice.

4.3.8 Slice QP (SQP)

Information about the quantizer QUANT to be used for luminance for the picture. (See under Quantization concerning QUANT for chrominance). The 6-bit representation is the natural binary representation of the value of QP+12, which range from 0 to 47 (QP ranges from -12 to +39). QP+12 is a pointer to the actual quantization parameter QUANT to be used. (See below under quantization). The range of quantization value is still about the same as for H.263, 1-31. An approximate relation between the QUANT in H.263 and QP is: $QUANT_{H.263}(QP) \approx QP0(QP) = 2QP/6$. QP0() will be used later for scaling purposes when selecting prediction modes. Negative values of QP correspond to even smaller step sizes, as described below under quantization.

4.3.9 SP Slice QP

For SP frames the SP slice QP is transmitted, using the same scale described above.

4.3.10 Number of macroblocks in slice

For CABAC entropy coding the number of macroblocks contained in the slice is transmitted.

4.3.11 Picture Number (PN)

PN shall be incremented by 1 for each coded and transmitted picture, in modulo MAX_PN operation, relative to the PN of the previous stored picture. For non-stored pictures, PN shall be incremented from the value in the most temporally recent stored picture, which precedes the non-stored picture in bitstream order.

The PN serves as a unique ID for each picture stored in the multi-picture buffer within MAX_PN coded and stored pictures. Therefore, a picture cannot be kept in the buffer after more than MAX_PN-1 subsequent coded and stored pictures unless it has been assigned a long-term picture index as specified below. The encoder shall ensure that the bitstream shall not specify retaining any short-term picture after more than MAX_PN-1 subsequent stored pictures. A decoder which encounters a picture number on a current picture having a value equal to the picture number of some other short-term stored picture in the multi-picture buffer should treat this condition as an error.

4.3.12 Reference Picture Selection Layer (RPSL)

RPSL can be signaled with the following values:

Code number 0: The RPS layer is not sent,

Code number 1: The RPS layer is sent.

If RPSL is not sent, the default buffer indexing order presented in the next subsection shall be applied. RPS layer information sent at the slice level does not affect the decoding process of any other slice.

If RPSL is sent, the buffer indexing used to decode the current slice and to manage the contents of the picture buffer is sent using the following code words.

4.3.13 Re-Mapping of Picture Numbers Indicator (RMPNI)

RMPNI is present in the RPS layer if the picture is a P or B picture. RMPNI indicates whether any default picture indices are to be re-mapped for motion compensation of the current slice – and how the re-mapping of the relative indices into the multi-picture buffer is to be specified if indicated. If RMPNI indicates the presence of an ADPN or LPIR field, an additional RMPNI field immediately follows the ADPN or LPIR field.

A picture reference parameter is a relative index into the ordered set of pictures. The RMPNI, ADPN, and LPIR fields allow the order of that relative indexing into the multi-picture buffer to be temporarily

altered from the default index order for the decoding of a particular slice. The default index order is for the short-term pictures (i.e., pictures which have not been given a long-term index) to precede the long-term pictures in the reference indexing order. Within the set of short-term pictures, the default order is for the pictures to be ordered starting with the most recent buffered reference picture and proceeding through to the oldest reference picture (i.e., in decreasing order of picture number in the absence of wrapping of the ten-bit picture number field). Within the set of long-term pictures, the default order is for the pictures to be ordered starting with the picture with the smallest long-term index and proceeding up to the picture with long-term index equal to the most recent value of MLIP1−1.

For example, if the buffer contains three short-term pictures with short-term picture numbers 300, 302, and 303 (which were transmitted in increasing picture-number order) and two long-term pictures with long-term picture indices 0 and 3, the default index order is:

default relative index 0 refers to the short-term picture with picture number 303,

default relative index 1 refers to the short-term picture with picture number 302,

default relative index 2 refers to the short-term picture with picture number 300,

default relative index 3 refers to the long-term picture with long-term picture index 0, and

default relative index 4 refers to the long-term picture with long-term picture index 3.

The first ADPN or LPIR field that is received (if any) moves a specified picture out of the default order to the relative index of zero. The second such field moves a specified picture to the relative index of one, etc. The set of remaining pictures not moved to the front of the relative indexing order in this manner shall retain their default order amongst themselves and shall follow the pictures that have been moved to the front of the buffer in relative indexing order.

If there is not more than one reference picture used, no more than one ADPN or LPIR field shall be present in the same RPS layer unless the current picture is a B picture. If the current picture is a B picture and more than one reference picture is used, no more than two ADPN or LPIR fields shall be present in the same RPS layer.

Any re-mapping of picture numbers specified for some slice shall not affect the decoding process for any other slice.

In a P picture an RMPNI "end loop" indication is followed by RPBT.

Within one RPS layer, RMPNI shall not specify the placement of any individual reference picture into more than one re-mapped position in relative index order.

TABLE 1

RMPNI operations for re-mapping of reference pictures

Code Number	Re-mapping Specified
0	ADPN field is present and corresponds to a negative difference to add to a picture number prediction value
1	ADPN field is present and corresponds to a positive difference to add to a picture number prediction value
2	LPIR field is present and specifies the long-term index for a reference picture
3	End loop for re-mapping of picture relative indexing default order

4.3.13.1 Absolute Difference of Picture Numbers (ADPN)

ADPN is present only if indicated by RMPNI. ADPN follows RMPNI when present. The code number of the UVLC corresponds to ADPN – 1. ADPN represents the absolute difference between the picture number of the currently re-mapped picture and the prediction value for that picture number. If no previous ADPN fields have been sent within the current RPS layer, the prediction value shall be the picture number

of the current picture. If some previous ADPN field has been sent, the prediction value shall be the picture number of the last picture that was re-mapped using ADPN.

If the picture number prediction is denoted PNP, and the picture number in question is denoted PNQ, the decoder shall determine PNQ from PNP and ADPN in a manner mathematically equivalent to the following:

```
if (RMPNI == '1') {   // a negative difference
  if (PNP - ADPN < 0)
    PNQ = PNP - ADPN + MAX_PN;
  else
    PNQ = PNP - ADPN;
}else{            // a positive difference
  if (PNP + ADPN > MAX_PN-1)
    PNQ  = PNP + ADPN - MAX_PN;
  else
    PNQ  = PNP + ADPN;
}
```

The encoder shall control RMPNI and ADPN such that the decoded value of ADPN shall not be greater than or equal to MAX_PN.

As an example implementation, the encoder may use the following process to determine values of ADPN and RMPNI to specify a re-mapped picture number in question, PNQ:

```
DELTA = PNQ - PNP;
if (DELTA < 0) {
  if (DELTA < -MAX_PN/2-1)
    MDELTA = DELTA + MAX_PN;
  else
    MDELTA = DELTA;
}else{
  if(DELTA > MAX_PN/2)
    MDELTA = DELTA - MAX_PN;
  else
    MDELTA = DELTA;
}

ADPN = abs(MDELTA);
```

where abs() indicates an absolute value operation. Note that the code number of the UVLC corresponds to the value of ADPN – 1, rather than the value of ADPN itself.

RMPNI would then be determined by the sign of MDELTA.

4.3.13.2 Long-term Picture Index for Re-Mapping (LPIR)

LPIR is present only if indicated by RMPNI. LPIR follows RMPNI when present. LPIR is transmitted using UVLC codewords. It represents the long-term picture index to be re-mapped. The prediction value used by any subsequent ADPN re-mappings is not affected by LPIR.

4.3.14 Reference Picture Buffering Type (RPBT)

RPBT specifies the buffering type of the currently decoded picture. It follows an RMPNI "end loop" indication when the picture is not an I picture. It is the first element of the RPS layer if the picture is an I picture. The values for RPBT are defined as follows:

Code number 0: Sliding Window,

Code number 1: Adaptive Memory Control.

In the "Sliding Window" buffering type, the current decoded picture shall be added to the buffer with default relative index 0, and any marking of pictures as "unused" in the buffer is performed automatically in a first-in-first-out fashion among the set of short-term pictures. In this case, if the buffer has sufficient "unused" capacity to store the current picture, no additional pictures shall be marked as "unused" in the buffer. If the buffer does not have sufficient "unused" capacity to store the current picture, the picture with the largest default relative index among the short-term pictures in the buffer shall be marked as "unused". In the sliding window buffering type, no additional information is transmitted to control the buffer contents.

In the "Adaptive Memory Control" buffering type, the encoder explicitly specifies any addition to the buffer or marking of data as "unused" in the buffer, and may also assign long-term indices to short-term pictures. The current picture and other pictures may be explicitly marked as "unused" in the buffer, as specified by the encoder. This buffering type requires further information that is controlled by memory management control operation (MMCO) parameters.

4.3.14.1 Memory Management Control Operation (MMCO)

MMCO is present only when RPBT indicates "Adaptive Memory Control", and may occur multiple times if present. It specifies a control operation to be applied to manage the multi-picture buffer memory. The MMCO parameter is followed by data necessary for the operation specified by the value of MMCO, and then an additional MMCO parameter follows – until the MMCO value indicates the end of the list of such operations. MMCO commands do not affect the buffer contents or the decoding process for the decoding of the current picture – rather, they specify the necessary buffer status for the decoding of subsequent pictures in the bitstream. The values and control operations associated with MMCO are defined in TABLE 2.

If MMCO is Reset, all pictures in the multi-picture buffer (but not the current picture unless specified separately) shall be marked "unused" (including both short-term and long-term pictures).

The picture height and width shall not change within the bitstream except within a picture containing a Reset MMCO command.

A "stored picture" does not contain an MMCO command in its RPS layer which marks that (entire) picture as "unused". If the current picture is not a stored picture, its RPS layer shall not contain any of the following types of MMCO commands:

- An Reset MMCO command,
- Any MMCO command which marks any other picture (other than the current picture) as "unused" that has not also been marked as "unused" in the ERPS layer of a prior stored picture, or
- Any MMCO command which assigns a long-term index to a picture that has not also been assigned the same long-term index in the ERPS layer of a prior stored picture

TABLE 2

Memory Management Control Operation (MMCO) Values

Code Number	Memory Management Control Operation	Associated Data Fields Following
0	End MMCO Loop	None (end of ERPS layer)
1	Mark a Short-Term Picture as "Unused"	DPN
2	Mark a Long-Term Picture as "Unused"	LPIN
3	Assign a Long-Term Index to a Picture	DPN and LPIN
4	Specify the Maximum Long-Term Picture Index	MLIP1
5	Reset	None

4.3.14.2 Difference of Picture Numbers (DPN)

DPN is present when indicated by MMCO. DPN follows MMCO if present. DPN is transmitted using UVLC codewords and is used to calculate the PN of a picture for a memory control operation. It is used in order to assign a long-term index to a picture, mark a short-term picture as "unused". If the current decoded picture number is PNC and the decoded UVLC code number is DPN, an operation mathematically equivalent to the following equations shall be used for calculation of PNQ, the specified picture number in question:

```
if (PNC – DPN < 0)
  PNQ = PNC – DPN + MAX_PN;
else
  PNQ = PNC – DPN;
```

Similarly, the encoder may compute the DPN value to encode using the following relation:

```
if (PNC – PNQ < 0)
  DPN = PNC – PNQ + MAX_PN;
else
  DPN = PNC – PNQ;
```

For example, if the decoded value of DPN is zero and MMCO indicates marking a short-term picture as "unused", the current decoded picture shall be marked as "unused" (thus indicating that the current picture is not a stored picture).

4.3.14.3 Long-term Picture Index (LPIN)

LPIN is present when indicated by MMCO. LPIN specifies the long-term picture index of a picture. It follows DPN if the operation is to assign a long-term index to a picture. It follows MMCO if the operation is to mark a long-term picture as "unused".

4.3.14.4 Maximum Long-Term Picture Index Plus 1 (MLIP1)

MLIP1 is present if indicated by MMCO. MLIP1 follows MMCO if present. If present, MLIP1 is used to determine the maximum index allowed for long-term reference pictures (until receipt of another value of MLIP1). The decoder shall initially assume MLIP1 is "0" until some other value has been received. Upon receiving an MLIP1 parameter, the decoder shall consider all long-term pictures having indices greater than the decoded value of MLIP1 – 1 as "unused" for referencing by the decoding process for subsequent pictures. For all other pictures in the multi-picture buffer, no change of status shall be indicated by MLIP1.

4.3.15 Supplemental Enhancement Information

Supplemental enhancement information (SEI) is encapsulated into chunks of data separate from coded slices, for example. It is up to the network adaptation layer to specify the means to transport SEI chunks. Each SEI chunck may contain one or more SEI messages. Each SEI message shall consist of a SEI header and SEI payload. The SEI header starts at a byte-aligned position from the first byte of a SEI chunk or from the first byte after the previous SEI message. The SEI header consists of two codewords, both of which consist of one or more bytes. The first codeword indicates the SEI payload type. Values from 00 to FE shall be reserved for particular payload types, whereas value FF is an escape code to extend the value range to yet another byte as follows:

```
payload_type = 0;
for (;;) {
  payload_type += *byte_ptr_to_sei;
  if (*byte_ptr_to_sei < 0xFF)
    break;
  byte_ptr_to_sei++;
}
```

The second codeword of the SEI header indicates the SEI payload size in bytes. SEI payload size shall be coded similarly to the SEI payload type.

The SEI payload may have a SEI payload header. For example, a payload header may indicate to which picture the particular data belongs. The payload header shall be defined for each payload type separately.

4.4 Macroblock layer

Following the syntax diagram for the macroblock elements, the various elements are described.

4.4.1 Number of Skipped Macroblocks (RUN)

A macroblock is called skipped if no information is sent. In that case the reconstruction of an inter macroblock is made by copying the collocated picture material from the last decoded frame.

If PSTRUCT indicates a frame, then the skipped macroblock is formed by copying the collocated picture material from the last decoded frame, which either was decoded from a frame picture or is the union of two decoded field pictures. If PSTRUCT indicates a field, then the skipped macroblock is formed by copying the collocated material from the last decoded field of the same parity (top or bottom), which was either decoded from a field picture or is part of the most recently decoded frame picture.

[Editor: this needs alignment with the RPS.]

For a B macroblock skip means direct mode without coefficients. RUN indicates the number of skipped macroblocks in an inter- or B-picture before a coded macroblock. If a picture or slice ends with one or more skipped macroblocks, they are represented by an additional RUN which counts the number of skipped macroblocks.

4.4.2 Macro block type (MB_Type)

Refer to TABLE 7. There are different MB-Type tables for Intra and Inter frames.

4.4.2.1 Intra Macroblock modes

Intra 4x4	Intra coding as defined in sections **Error! Reference source not found.** to **Error! Reference source not found.**.
Imode, nc, AC	See definition in section 0. These modes refer to 16x16 intra coding.

4.4.2.2 Inter Macroblock Modes

Skip	No further information about the macroblock is transmitted. A copy of the colocated macroblock in the most recent decoded picture is used as reconstruction for the present macroblock.
NxM (eg. 16x8)	The macroblock is predicted from a past picture with block size NxM. For the macroblock modes 16x16, 16x8, and 8x16, a motion vector is provided for each NxM block. If N=M=8, for each 8x8 sub-partition an additional codeword is transmitted which indicates in which mode the corresponding sub-partition is coded (see section 4.4.3). 8x8 sub-partitions can also be coded in intra 4x4 mode. Depending on N,M and the 8x8 sub-partition modes there may be 1 to 16 sets of motion vector data for a macroblock.
Intra 4x4	4x4 intra coding.

Code numbers from 6 and upwards represent 16x16 intra coding.

4.4.3 8x8 sub-partition modes

NxM (eg. 8x4)	The corresponding 8x8 sub-partition is predicted from a past picture with block size NxM. A motion vector is transmitted for each NxM block. Depending on N and M, up to 4 motion vectors are coded for an 8x8 sub-partition, and thus up to 16 motion vectors are transmitted for a macroblock.

Intra The 8x8 sub-partition is coded in intra 4x4 mode.

4.4.4 Intra Prediction Mode (Intra_pred_mode)

Even in Intra mode, prediction is always used for each sub block in a macroblock. A 4x4 block is to be coded (pixels labeled a to p below). The pixels A to Q from neighboring blocks may already be decoded and may be used for prediction. When pixels E-H are not available, whether because they have not yet been decoded, are outside the picture or outside the current independent slice, the pixel value of D is substituted for pixels E-H. When pixels M-P are not available, the pixel value of L is substituted for pixels M-P.

```
Q A B C D E F G H
I a b c d
J e f g h
K i j k l
L m n o p
M
N
O
P
```

FIGURE 5

Syntax diagram for the Picture header.

4.4.4.1.1 Prediction for Intra-4x4 mode for luminance blocks

For the luminance signal, there are 9 intra prediction modes labeled 0 to 8. Mode 0 is 'DC-prediction' (see below). The other modes represent directions of predictions as indicated below.

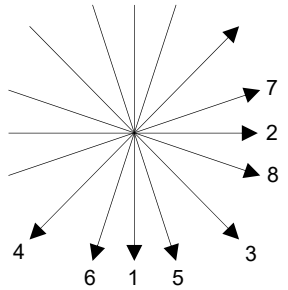


FIGURE 6

Syntax diagram for the Picture header.

<u>Mode 0: DC prediction</u>

Generally all pixels are predicted by (A+B+C+D+I+J+K+L)//8. If four of the pixels are outside the picture, the average of the remaining four is used for prediction. If all 8 pixels are outside the picture the prediction for all pixels in the block is 128. A block may therefore always be predicted in this mode.

<u>Mode 1: Vertical Prediction</u>

If A,B,C,D are inside the picture, a,e,i,m are predicted by A, b,f,j,n by B etc.

<u>Mode 2: Horizontal prediction</u>

If E,F,G,H are inside the picture, a,b,c,d are predicted by E, e,f,g,h by F etc.

<u>Mode 3: Diagonal Down/Right prediction</u>

This mode is used only if all A,B,C,D,I,J,K,L,Q are inside the picture. This is a 'diagonal' prediction.

m is predicted by:	(J + 2K + L + 2)/4
i,n are predicted by	(I + 2J + K + 2)/4
e,j,o are predicted by	(Q + 2I + J + 2)/4
a,f,k,p are predicted by	(A + 2Q + I + 2)/4
b,g,l are predicted by	(Q + 2A + B + 2)/4
c,h are predicted by	(A + 2B + C + 2)/4
d is predicted by	(B + 2C + D + 2)/4

Mode 4: Diagonal Down/Left prediction

This mode is used only if all A,B,C,D,I,J,K,L,Q are inside the picture. This is a 'diagonal' prediction.

a is predicted by	(A + 2B + C + I + 2J + K + 4) / 8;
b, e are predicted by	(B + 2C + D + J + 2K + L + 4) / 8;
c, f, i are predicted by	(C + 2D + E + K + 2L + M + 4) / 8;
d, g, j, m are predicted by	(D + 2E + F + L + 2M + N + 4) / 8;
h, k, n are predicted by	(E + 2F + G + M + 2N + O + 4) / 8;
l, o are predicted by	(F + 2G + H + N + 2O + P + 4) / 8;
p is predicted by	(G + H + O + P + 2) / 4;

Mode 5: Vertical-Left prediction

This mode is used only if all A,B,C,D,I,J,K,L,Q are inside the picture. This is a 'diagonal' prediction.

a, j are predicted by	(Q + A + 1) / 2;
b, k are predicted by	(A + B + 1) / 2;
c, l are predicted by	(B + C + 1) / 2;
d is predicted by	(C + D + 1) / 2;
e, n are predicted by	(I + 2Q + A + 2) / 4;
f, o are predicted by	(Q + 2A + B + 2) / 4;
g, p are predicted by	(A + 2B + C + 2) / 4;
h is predicted by	(B + 2C + D + 2) / 4;
i is predicted by	(Q + 2I + J + 2) / 4;
m is predicted by	(I + 2J + K + 2) / 4;

Mode 6: Vertical-Right prediction

This mode is used only if all A,B,C,D,I,J,K,L,Q are inside the picture. This is a 'diagonal' prediction.

a is predicted by	(2A + 2B + J + 2K + L + 4) / 8;
b, i are predicted by	(B + C + 1) / 2;
c, j are predicted by	(C + D + 1) / 2;
d, k are predicted by	(D + E + 1) / 2;
l is predicted by	(E + F + 1) / 2;
e is predicted by	(A + 2B + C + K + 2L + M + 4) / 8;
f, m are predicted by	(B + 2C + D + 2) / 4;
g, n are predicted by	(C + 2D + E + 2) / 4;
h, o are predicted by	(D + 2E + F + 2) / 4;
p is predicted by	(E + 2F + G + 2) / 4;

Mode 7: Horizontal-Up prediction

This mode is used only if all A,B,C,D,I,J,K,L,Q are inside the picture. This is a 'diagonal' prediction.

a is predicted by	(B + 2C + D + 2I + 2J + 4) / 8;
b is predicted by	(C + 2D + E + I + 2J + K + 4) / 8;
c, e are predicted by	(D + 2E + F + 2J + 2K + 4) / 8;
d, f are predicted by	(E + 2F + G + J + 2K + L + 4) / 8;
g, i are predicted by	(F + 2G + H + 2K + 2L + 4) / 8;
h, j are predicted by	(G + 3H + K + 3L + 4) / 8;
l, n are predicted by	(L + 2M + N + 2) / 4;
k, m are predicted by	(G + H + L + M + 2) / 4;
o is predicted by	(M + N + 1) / 2;
p is predicted by	(M + 2N + O + 2) / 4;

Mode 8: Horizontal-Down prediction

This mode is used only if all A,B,C,D,I,J,K,L,Q are inside the picture. This is a 'diagonal' prediction.

a, g are predicted by	(Q + I + 1) / 2;
b, h are predicted by	(I + 2Q + A+ 2) / 4;
c is predicted by	(Q + 2A + B+ 2) / 4;
d is predicted by	(A + 2B + C+ 2) / 4;
e, k are predicted by	(I + J + 1) / 2;
f, l are predicted by	(X + 2I + J+ 2) / 4;
I, o are predicted by	(J + K + 1) / 2;
j, p are predicted by	(I + 2J + K+ 2) / 4;
m is predicted by	(K + L + 1) / 2;
n is predicted by	(J + 2K + L + 2) / 4;

Coding of Intra 4x4 prediction modes

Since each of the 4x4 luminance blocks shall be assigned a prediction mode, this will require a considerable number of bits if coded directly. We have therefore tried to find more efficient ways of coding mode information. First of all we observe that the chosen prediction of a block is highly correlated with the prediction modes of adjacent blocks. This is illustrated in **Error! Reference source not found.**a. When the prediction modes of A and B are known (including the case that A or B or both are outside the picture) an ordering of the most probable, next most probable etc. of C is given. . When an adjacent block is coded by 16x16 intra mode, prediction mode is “mode 0: DC_prediction”; when it is coded in inter mode, prediction mode is “mode 0: DC_prediction” in the usual case and “outside” in the case of constrained intra update. This ordering is listed in **Error! Reference source not found.**.

For each prediction mode of A and B a list of 9 numbers is given. Example: Prediction mode for A and B is 2. The string 2 8 7 1 0 6 4 3 5 indicates that mode 2 is also the most probable mode for block C. Mode 8 is the next most probable one etc. In the bitstream there will for instance be information that Prob0 = 1 (see TABLE 8) indicating that the next most probable mode shall be used for block C. In our example this means Intra prediction mode 8. Use of '–' in the table indicates that this instance cannot occur because A or B or both are outside the picture.

For more efficient coding, information on intra prediction of two 4x4 luminance blocks are coded in one codeword (Prob0 and Prob1 in TABLE 8). The order of the resulting 8 codewords is indicated in **Error! Reference source not found.**b.

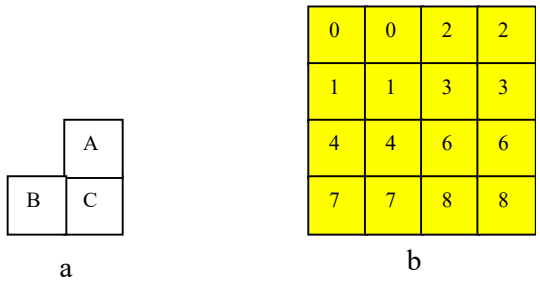


FIGURE 7

a) Prediction mode of block C shall be established. A and B are adjacent blocks. b) order of intra prediction information in the bitstream

TABLE 3

Prediction mode as a function of ordering signaled in the bitstream (see text)

B/A	Outside	0	1	2	3
Outside	0--------	01-------	10-------	---------	---------
0	02-------	021648573	125630487	021876543	021358647

1	---------	102654387	162530487	120657483	102536487
2	20-------	280174365	217683504	287106435	281035764
3	---------	201385476	125368470	208137546	325814670
4	---------	201467835	162045873	204178635	420615837
5	---------	015263847	152638407	201584673	531286407
6	---------	016247583	160245738	206147853	160245837
7	---------	270148635	217608543	278105463	270154863
8	---------	280173456	127834560	287104365	283510764

B/A	4	5	6	7	8
Outside	---------	---------	---------	---------	---------
0	206147583	512368047	162054378	204761853	208134657
1	162045378	156320487	165423078	612047583	120685734
2	287640153	215368740	216748530	278016435	287103654
3	421068357	531268470	216584307	240831765	832510476
4	426015783	162458037	641205783	427061853	204851763
5	125063478	513620847	165230487	210856743	210853647
6	640127538	165204378	614027538	264170583	216084573
7	274601853	271650834	274615083	274086153	278406153
8	287461350	251368407	216847350	287410365	283074165

4.4.4.1.2 Prediction for Intra-16x16 mode for luminance

Assume that the block to be predicted has pixel locations 0 to 15 horizontally and 0 to 15 vertically. We use the notation P(i,j) where i,j = 0..15. P(i,-1), i=0..15 are the neighboring pixels above the block and P(-1,j), j=0..15 are the neighboring pixels to the left of the block. Pred(i,j) i,j = 0..15 is the prediction for the whole Luminance macroblock. We have 4 different prediction modes:

<u>Mode 0 (vertical)</u>

Pred(i,j) = P(i,-1), i,j=0..15

<u>Mode 1 (horizontal)</u>

Pred(i,j) = P(-1,j), i,j=0..15

<u>Mode 2 (DC prediction)</u>

Pred(i,j) = $(\sum_{i=0}^{15}(P(-1,i)+P(i,-1)))/32$ i,j=0..15,

where only the average of 16 pixels are used when the other 16 pixels are outside the picture or slice. If all 32 pixels are outside the picture, the prediction for all pixels in the block is 128.

<u>Mode 3 (Plane prediction)</u>

Pred(i,j) = max(0, min(255, (a + bx(i-7) + cx(j-7) +16)/32)),

where:

a = 16x(P(-1,15) + P(15,-1))

b = 5x(H/4)/16

c = 5x(V/4)/16

$$H = \sum_{i=1}^{8} ix(P(7+i,-1) - P(7-i,-1))$$

$$V = \sum_{j=1}^{8} jx(P(-1,7+j) - P(-1,7-j))$$

<u>Residual coding</u>

The residual coding is based on 4x4 transform. But similar to coding of chrominance coefficients, another 4x4 transform to the 16 DC coefficients in the macroblock are added. In that way we end up with an overall DC for the whole MB which works well in flat areas.

Since we use the same integer transform to DC coefficients, we have to perform additional normalization to those coefficients, which implies a division by 676. To avoid the division we performed normalization by $49/2^{15}$ on the encoder side and $48/2^{15}$ on the decoder side, which gives sufficient accuracy.

Only single scan is used for 16x16 intra coding.

To produce the bitstream, we first scan through the 16 'DC transform' coefficients. There is no 'CBP' information to indicate no coefficients on this level. If AC = 1 (see below) ac coefficients of the 16 4x4 blocks are scanned. There are 15 coefficients in each block since the DC coefficients are included in the level above.

Coding of mode information for Intra-16x16 mode

See TABLE 7. Three parameters have to be signaled. They are all included in MB-type.

Imode:	0,1,2,3
AC:	0 means there are no ac coefficients in the 16x16 block. 1 means that there is at least one ac coefficient and all 16 blocks are scanned.
nc:	CBP for chrominance (see 4.4.7)

4.4.4.1.3 Prediction in intra coding of chrominance blocks

For chrominance prediction there is only one mode. No information is therefore needed to be transmitted. The prediction is indicated in the figure below. The 8x8 chrominance block consists of 4 4x4 blocks A,B,C,D. S0,1,2,3 are the sums of 4 neighbouring pixels.

If S0, S1, S2, S3 are all inside the frame:

A = (S0 + S2 + 4)/8

B = (S1 + 2)/4

C = (S3 + 2)/4

D = (S1 + S3 + 4)/8

If only S0 and S1 are inside the frame:

A = (S0 + 2)/4

B = (S1 + 2)/4

C = (S0 + 2)/4

D = (S1 + 2)/4

If only S2 and S3 are inside the frame:

A = (S2 + 2)/4

B = (S2 + 2)/4

C = (S3 + 2)/4

D = (S3 + 2)/4

If S0, S1, S2, S3 are all outside the frame: A = B = C = D = 128

(Note: This prediction should be considered changed)

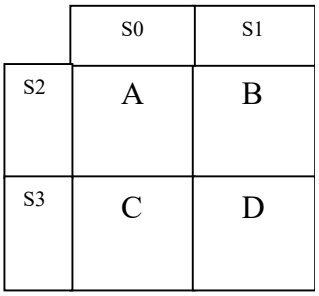


FIGURE 8

Prediction of Chrominance blocks.

4.4.5 Reference picture (Ref_picture)

If PTYPE indicates possibility of prediction from more than one previous decoded picture, the exact picture to be used must be signalled. This is done according to the following tables. If PSTRUCT indicates that the current picture is a frame picture, then the reference picture is a previous frame in the reference buffer that was either encoded as a single frame picture or a frame that was encoded as two field pictures and have been re-constructed as a frame. Thus for frames the following table gives the reference frame:

Code_number	Reference frame
0	The last decoded previous frame (1 frame back)
1	2 frames back
2	3 frames back
..	..

The reference parameter is transmitted for each 16x16, 16x8, or 8x16 block. If the macroblock is coded in 8x8 mode, the reference frame parameter is coded once for each 8x8 sub-partition unless the 8x8 sub-partition is transmitted in intra mode. If the UVLC is used for entropy coding and the macroblock type is indicated by codeword 4 (8x8, ref=0), no reference frame parameters are transmitted for the whole macroblock.

If PSTRUCT indicates that the current picture is a field picture, then the reference picture is either a previous field in the reference buffer that was separately encoded as a field picture or a previous field that is half of a frame that was encoded as a frame picture. Note that for a P field picture, forward prediction from field 1 to field 2 in the same frame is allowed. For the purpose of determining REF_picture, a unique reference field number is assigned to each reference field in the reference field (frame) buffer according to its distance from the current field, as shown in Figures 3a and 3b, modified by the fact that smaller code numbers are given to the fields of the same field parity as the current field. Thus for fields the following table gives the reference field:

Code_number	Reference field
0	the last decoded previous field of the same parity (2 fields back)
1	the last decoded previous field of the opposite parity (1 field back)
2	same parity field 4 fields back
3	opposite parity field 3 fields back
..	..

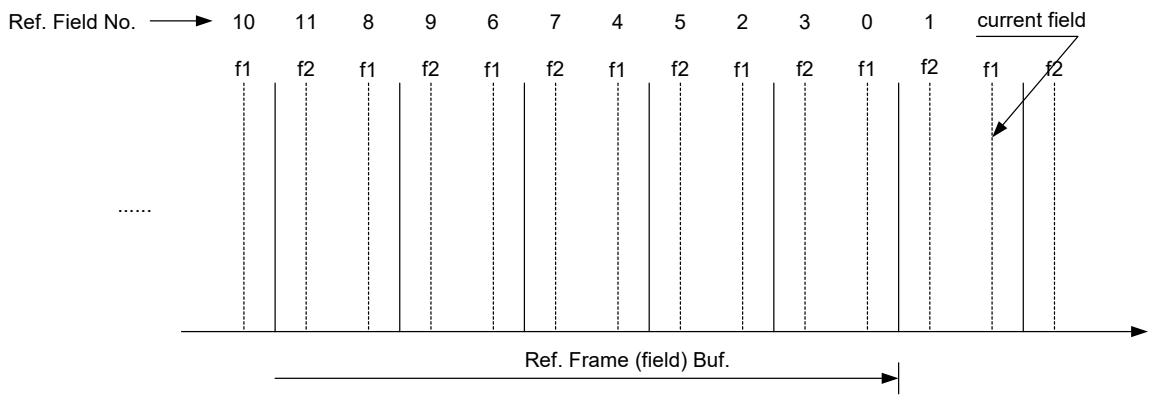


FIGURE 3a

Reference picture number assignment when the current picture is the *first* field coded in a frame. Solid-line is for frames and dotted-line for fields. f1 stands for field 1 and f2 for field 2.

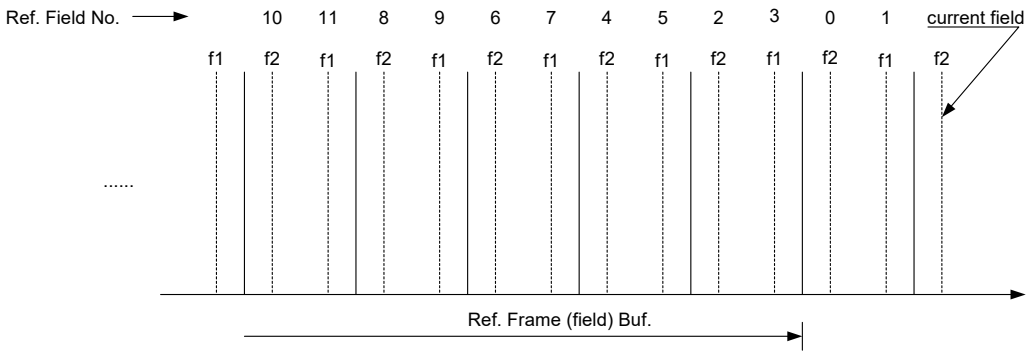


FIGURE 3b

Reference picture number assignment when the current picture is the *second* field coded in a frame. Solid-line is for frames and dotted-line for fields. f1 stands for field 1 and f2 for field 2.

4.4.6 Motion Vector Data (MVD)

If so indicated by MB_type, vector data for 1-16 blocks are transmitted. For every block a prediction is formed for the horizontal and vertical components of the motion vector. MVD signals the difference between the vector component to be used and this prediction. The order in which vector data is sent is indicated in FIGURE 2. Motion vectors are allowed to point to pixels outside the reference frame. If a pixel outside the reference frame is referred to in the prediction process, the nearest pixel belonging to the frame (an edge or corner pixel) shall be used. All fractional pixel positions shall be interpolated as described below. If a pixel referred in the interpolation process (necessarily integer accuracy) is outside of the reference frame it shall be replaced by the nearest pixel belonging to the frame (an edge or corner pixel). Reconstructed motion vectors shall be clipped to +-19 integer pixels outside of the frame.

4.4.6.1 Prediction of vector components

With exception of the 16x8 and 8x16 block shapes, "median prediction" (see 4.4.6.1.1) is used. In case the macroblock may be classified to have directional segmentation the prediction is defined in 4.4.6.1.2.

4.4.6.1.1 Median prediction

In the figure below the vector component E of the indicated block shall be predicted. The prediction is normally formed as the median of A, B and C. However, the prediction may be modified as described below. Notice that it is still referred to as "median prediction"

A The component applying to the pixel to the left of the upper left pixel in E

B The component applying to the pixel just above the upper left pixel in E

C The component applying to the pixel above and to the right of the upper right pixel in E

D The component applying to the pixel above and to the left of the upper left pixel in E

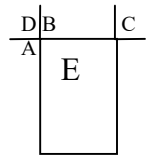


FIGURE 9

Median prediction of motion vectors.

A, B, C, D and E may represent motion vectors from different reference pictures. As an example we may be seeking prediction for a motion vector for E from the last decoded picture. A, B, C and D may represent vectors from 2, 3, 4 and 5 pictures back. The following substitutions may be made prior to median filtering.

- If A and D are outside the picture, their values are assumed to be zero and they are considered to have "different reference picture than E".
- If D, B, C are outside the picture, the prediction is equal to A (equivalent to replacing B and C with A before median filtering).
- If C is outside the picture or still not available due to the order of vector data (see FIGURE 2), C is replaced by D.

If any of the blocks A, B, C, D are intra coded they count as having "different reference frame. If one and only one of the vector components used in the median calculation (A, B, C) refer to the same reference picture as the vector component E, this one vector component is used to predict E.

4.4.6.1.2 Directional segmentation prediction

If the macroblock where the block to be predicted is coded in 16x8 or 8x16 mode, the prediction is generated as follows (refer to figure below and the definitions of A, B, C, E above):

Vector block size 8x16:

Left block: A is used as prediction if it has the same reference picture as E, otherwise "Median prediction" is used

Right block: C is used as prediction if it has the same reference picture as E, otherwise "Median prediction" is used

Vector block size 16x8:

Upper block: B is used as prediction if it has the same reference picture as E, otherwise "Median prediction" is used

Lower block: A is used as prediction if it has the same reference picture as E, otherwise "Median prediction" is used

If the indicated prediction block is outside the picture, the same substitution rules are applied as in the case of median prediction.

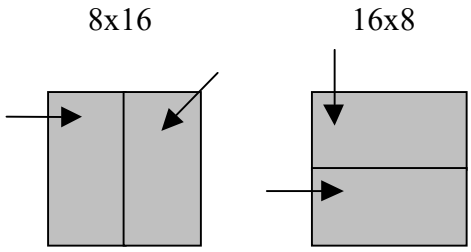


FIGURE 10

Directional segmentation prediction

4.4.6.2 Chrominance vectors

Chrominance vectors are derived from the Luminance vectors. Since chrominance has half resolution compared to luminance, the chrominance vectors are obtained by a division of two:

Croma_vector = Luma_vector/2 - which means that the chrominance vectors have a resolution of 1/8 pixel.

Due to the half resolution, a chrominance vector applies to 1/4 as many pixels as the Luminance vector. For example if the Luminance vector applies to 8x16 Luminance pixels, the corresponding chrominance vector applies to 4x8 chrominance pixels and if the Luminance vector applies to 4x4 Luminance pixels, the corresponding chrominance vector applies to 2x2 chrominance pixel.

For fractional pixel interpolation for chrominance prediction, bilinear interpolation is used. The result is rounded to the nearest integer.

4.4.7 Coded Block Pattern (CBP)

The CBP contains information of which 8x8 blocks - Luminance and chrominance - contain transform coefficients. Notice that an 8x8 block contains 4 4x4 blocks meaning that the statement '8x8 block contains coefficients' means that 'one or more of the 4 4x4 blocks contain coefficients'. The 4 least significant bits of CBP contain information on which of 4 8x8 luminance blocks in a macroblock contains nonzero coefficients. Let us call these 4 bits CBPY. The ordering of 8x8 blocks is indicated in FIGURE 3. A 0 in position n of CBP (binary representation) means that the corresponding 8x8 block has no coefficients whereas a 1 means that the 8x8 block has one or more non-zero coefficients.

For chrominance we define 3 possibilities:

nc=0:	no chrominance coefficients at all.
nc=1	There are nonzero 2x2 transform coefficients. All chrominance AC coefficients = 0. Therefore we do not send any EOB for chrominance AC coefficients.
nc=2	There may be 2x2 nonzero coefficients and there is at least one nonzero chrominance AC coefficient present. In this case we need to send 10 EOBs (2 for DC coefficients and 2x4=8 for the 8 4x4 blocks) for chrominance in a macroblock.

The total CBP for a macroblock is: **CBP = CBPY + 16xnc**

The CBP is signalled with a different codeword for Inter macroblocks and Intra macroblocks since the statistics of CBP values are different in the two cases.

4.4.8 Change of Quantizer Value (Dquant)

Dquant contains the possibility of changing QUANT on the macroblock level. It does not need to be present for macroblocks without nonzero transform coefficients. More specifically Dquant is present for non-skipped macroblocks:

- If CBP indicates that there are nonzero transform coefficients in the MB **or**
- If the MB is 16x16 based intra coded

The value of Dquant may range from -26 to +26, which enables the QP to be changed to any value in the range [-12..39].

$QUANT_{new} = -12 + modulo_{52}(QUANT_{old} + Dquant + 64)$ (also known as "arithmetic wrap")

5 Decoding Process

5.1 Slice Decoding

5.1.1 Multi-Picture Decoder Process

The decoder stores the reference pictures for inter-picture decoding in a multi-picture buffer. The decoder replicates the multi-picture buffer of the encoder according to the reference picture buffering type and any memory management control operations specified in the bitstream. The buffering scheme may also be operated when partially erroneous pictures are decoded.

Each transmitted and stored picture is assigned a Picture Number (PN) which is stored with the picture in the multi-picture buffer. PN represents a sequential picture counting identifier for stored pictures. PN is constrained, using modulo MAX_PN arithmetic operation. For the first transmitted picture, PN should be "0". For each and every other transmitted and stored picture, PN shall be increased by 1. If the difference (modulo MAX_PN) of the PNs of two consecutively received and stored pictures is not 1, the decoder should infer a loss of pictures or corruption of data. In such a case, a back-channel message indicating the loss of pictures may be sent to the encoder.

Besides the PN, each picture stored in the multi-picture buffer has an associated index, called the default relative index. When a picture is first added to the multi-picture buffer it is given default relative index 0 – unless it is assigned to a long-term index. The default relative indices of pictures in the multi-picture buffer are modified when pictures are added to or removed from the multi-picture buffer, or when short-term pictures are assigned to long-term indices.

The pictures stored in the multi-picture buffers can also be divided into two categories: long-term pictures and short-term pictures. A long-term picture can stay in the multi-picture buffer for a long time (more than MAX_PN-1 coded and stored picture intervals). The current picture is initially considered a short-term picture. Any short-term picture can be changed to a long-term picture by assigning it a long-term index according to information in the bitstream. The PN is the unique ID for all short-term pictures in the multi-picture buffer. When a short-term picture is changed to a long-term picture, it is also assigned a long-term picture index (LPIN). A long-term picture index is assigned to a picture by associating its PN to an LPIN. Once a long-term picture index has been assigned to a picture, the only potential subsequent use of the long-term picture's PN within the bitstream shall be in a repetition of the long-term index assignment. The PNs of the long-term pictures are unique within MAX_PN transmitted and stored pictures. Therefore, the PN of a long-term picture cannot be used for assignment of a long-term index after MAX_PN-1 transmitted subsequent stored pictures. LPIN becomes the unique ID for the life of a long-term picture.

PN (for a short-term picture) or LPIN (for a long-term picture) can be used to re-map the pictures into re-mapped relative indices for efficient reference picture addressing.

5.1.1.1 Decoder Process for Short/Long-term Picture Management

The decoder may have both long-term pictures and short-term pictures in its multi-picture buffer. The MLIP1 field is used to indicate the maximum long-term picture index allowed in the buffer. If no prior value of MLIP1 has been sent, no long-term pictures shall be in use, i.e. MLIP1 shall initially have an implied value of "0". Upon receiving an MLIP1 parameter, a new MLIP1 shall take effect until another value of MLIP1 is received. Upon receiving a new MLIP1 parameter in the bitstream, all long-term pictures with associated long-term indices greater than or equal to MLIP1 shall be considered marked "unused". The frequency of transmitting MLIP1 is out of the scope of this Recommendation. However, the encoder should send an MLIP1 parameter upon receiving an error message, such as an Intra request message.

A short-term picture can be changed to a long-term picture by using an MMCO command with an associated DPN and LPIN. The short-term picture number is derived from DPN and the long-term picture index is LPIN. Upon receiving such an MMCO command, the decoder shall change the short-term picture with PN indicated by DPN to a long-term picture and shall assign it to the long-term index indicated by LPIN. If a long-term picture with the same long-term index already exists in the buffer, the previously-

existing long-term picture shall be marked "unused". An encoder shall not assign a long-term index greater than MLIP1–1 to any picture. If LPIN is greater than MLIP1–1, this condition should be treated by the decoder as an error. For error resilience, the encoder may send the same long-term index assignment operation or MLIP1 specification message repeatedly. If the picture specified in a long-term assignment operation is already associated with the required LPIN, no action shall be taken by the decoder. An encoder shall not assign the same picture to more than one long term index value. If the picture specified in a long-term index assignment operation is already associated with a different long-term index, this condition should be treated as an error. An encoder shall only change a short-term picture to a long-term picture within MAX_PN transmitted consecutive stored pictures. In other words, a short-term picture shall not stay in the short-term buffer after more than MAX_PN-1 subsequent stored pictures have been transmitted. An encoder shall not assign a long-term index to a short-term picture that has been marked as "unused" by the decoding process prior to the first such assignment message in the bitstream. An encoder shall not assign a long-term index to a picture number that has not been sent.

5.1.1.2 Decoder Process for Reference Picture Buffer Mapping

The decoder employs indices when referencing a picture for motion compensation on the macroblock layer. In pictures other than B pictures, these indices are the default relative indices of pictures in the multi-picture buffer when the fields ADPN and LPIR are not present in the current slice layer as applicable, and are re-mapped relative indices when these fields are present. In B pictures, the first one or two pictures (depending on BTPSM) in relative index order are used for backward prediction, and the forward picture reference parameters specify a relative index into the remaining pictures for use in forward prediction. (needs to be changed)

The indices of pictures in the multi-picture buffer can be re-mapped onto newly specified indices by transmitting the RMPNI, ADPN, and LPIR fields. RMPNI indicates whether ADPN or LPIR is present. If ADPN is present, RMPNI specifies the sign of the difference to be added to a picture number prediction value. The ADPN value corresponds to the absolute difference between the PN of the picture to be re-mapped and a prediction of that PN value. The first transmitted ADPN is computed as the absolute difference between the PN of the current picture and the PN of the picture to be re-mapped. The next transmitted ADPN field represents the difference between the PN of the previous picture that was re-mapped using ADPN and that of another picture to be re-mapped. The process continues until all necessary re-mapping is complete. The presence of re-mappings specified using LPIR does not affect the prediction value for subsequent re-mappings using ADPN. If RMPNI indicates the presence of an LPIR field, the re-mapped picture corresponds to a long-term picture with a long-term index of LPIR. If any pictures are not re-mapped to a specific order by RMPNI, these remaining pictures shall follow after any pictures having a re-mapped order in the indexing scheme, following the default order amongst these non-re-mapped pictures.

If the indicated parameter set in the latest received slice or data partition signals the required picture number update behavior, the decoder shall operate as follows. The default picture index order shall be updated as if pictures corresponding to missing picture numbers were inserted to the multi-picture buffer using the "Sliding Window" buffering type. An index corresponding to a missing picture number is called an "invalid" index. The decoder should infer an unintentional picture loss if any "invalid" index is referred to in motion compensation or if an "invalid" index is re-mapped.

If the indicated parameter set in the latest received slice or data partition does not signal the required picture number update behavior, the decoder should infer an unintentional picture loss if one or several picture numbers are missing or if a picture not stored in the multi-picture buffer is indicated in a transmitted ADPN or LPIR.

In case of an unintentional picture loss, the decoder may invoke some concealment process. If the required picture number update behavior was indicated, the decoder may replace the picture corresponding to an "invalid" index with an error-concealed one and remove the "invalid" indication. If the required picture number update behavior was not indicated, the decoder may insert an error-concealed picture into the multi-picture buffer assuming the "Sliding Window" buffering type. Concealment may be conducted by copying the closest temporally preceding picture that is available in the multi-picture buffer into the position of the missing picture. The temporal order of the short-term pictures in the multi-picture buffer can be inferred from their default relative index order and PN fields. In addition or instead, the

decoder may send a forced INTRA update signal to the encoder by external means (for example, Recommendation H.245), or the decoder may use external means or back-channel messages (for example, Recommendation H.245) to indicate the loss of pictures to the encoder.

5.1.1.3 Decoder Process for Multi-Picture Motion Compensation

Multi-picture motion compensation is applied if the use of more than one reference picture is indicated. For multi-picture motion compensation, the decoder chooses a reference picture as indicated using the reference frame fields on the macroblock layer. Once, the reference picture is specified, the decoding process for motion compensation proceeds.

5.1.1.4 Decoder Process for Reference Picture Buffering

The buffering of the currently decoded picture can be specified using the reference picture buffering type (RPBT). The buffering may follow a first-in, first-out ("Sliding Window") mode. Alternatively, the buffering may follow a customized adaptive buffering ("Adaptive Memory Control") operation that is specified by the encoder in the forward channel.

The "Sliding Window" buffering type operates as follows. First, the decoder determines whether the picture can be stored into “unused” buffer capacity. If there is insufficient “unused” buffer capacity, the short-term picture with the largest default relative index (i.e. the oldest short-term picture in the buffer) shall be marked as “unused”. The current picture is stored in the buffer and assigned a default relative index of zero. The default relative index of all other short-term pictures is incremented by one. The default relative indices of all long-term pictures are incremented by one minus the number of short-term pictures removed.

In the "Adaptive Memory Control" buffering type, specified pictures may be removed from the multi-picture buffer explicitly. The currently decoded picture, which is initially considered a short-term picture, may be inserted into the buffer with default relative index 0, may be assigned to a long-term index, or may be marked as “unused” by the encoder. Other short-term pictures may also be assigned to long-term indices. The buffering process shall operate in a manner functionally equivalent to the following: First, the current picture is added to the multi-picture buffer with default relative index 0, and the default relative indices of all other pictures are incremented by one. Then, the MMCO commands are processed:

If MMCO indicates a reset of the buffer contents , all pictures in the buffer are marked as “unused” except the current picture (which will be the picture with default relative index 0).

If MMCO indicates a maximum long-term index using MLIP1, all long-term pictures having long-term indices greater than or equal to MLIP1 are marked as “unused” and the default relative index order of the remaining pictures are not affected.

If MMCO indicates that a picture is to be marked as “unused” in the multi-picture buffer and if that picture has not already been marked as “unused”, the specified picture is marked as “unused” in the multi-picture buffer and the default relative indices of all subsequent pictures in default order are decremented by one.

If MMCO indicates the assignment of a long-term index to a specified short-term picture and if the specified long-term index has not already been assigned to the specified short-term picture, the specified short-term picture is marked in the buffer as a long-term picture with the specified long-term index. If another picture is already present in the buffer with the same long-term index as the specified long-term index, the other picture is marked as “unused”. All short-term pictures that were subsequent to the specified short-term picture in default relative index order and all long-term pictures having a long-term index less than the specified long-term index have their associated default relative indices decremented by one. The specified picture is assigned to a default relative index of one plus the highest of the incremented default relative indices, or zero if there are no such incremented indices.

5.2 Motion Compensation

5.2.1 Fractional pixel accuracy

Note that when PSTRUCT indicates a field picture, then all of the interplations for sub-pel motion are based solely on pixels from just the reference field indicated by REF_picture; the pixels from the other field of the containing frame play no role at all.

5.2.1.1 1/4 luminance sample interpolation

The pixels labeled as 'A' represent original pixels at integer positions and other symbols represent the pixels to be interpolated

A	d	**b**	d	**A**
e	h	f	h	
b	g	**c**	g	**b**
e	h	f	i	
A		**b**		**A**

The interpolation proceeds as follows

1 The 1/2 sample positions labeled as ‘b’ are obtained by first applying 6-tap filter (1,-5,20,20,-5,1) to nearest pixels at integer locations in horizontal or vertical direction. The resulting intermediate value *b* is divided by 32, rounded to the nearest integer and clipped to lie in the range [0, 255].

2 The 1/2 sample position labeled as ‘c’ is obtained using 6-tap filtering (1,-5,20,20,-5,1) of intermediate the values *b* of the closest 1/2 sample positions in vertical or horizontal direction. The obtained value is divided by 1024, rounded to the nearest integer and clipped to lie in the range [0, 255].

3 The 1/4 sample positions labeled as ‘d’, ‘g’, ‘e’ and ‘f’ are obtained by averaging (with truncation to the nearest integer) the two nearest samples at integer or 1/2 sample position using d=(A+b)/2, g=(b+c)/2, e=(A+b)/2, f=(b+c)/2.

4 The 1/4 sample positions labeled as 'h' are obtained by averaging (with truncation to nearest integer) the two nearest pixels ‘b’ in diagonal direction.

5 The pixel labeled 'i' (the "funny" position) is computed as $(A_1+A_2+A_3+A_4+2)/4$ using the four nearest original pixels.

5.2.1.2 1/8 Pel Luminance Samples Interpolation

The pixels labeled as 'A' represent original pixels at integer positions and other symbols represent 1/2, 1/4 and 1/8 pixels to be interpolated.

A	d	$\mathbf{b^1}$	d	$\mathbf{b^2}$	d	$\mathbf{b^3}$	d	**A**
d	e	d	f	d	f	d	e	
$\mathbf{b^1}$	d	$\mathbf{c^{11}}$	d	$\mathbf{c^{12}}$	d	$\mathbf{c^{13}}$	d	
d	f	d	g	d	g	d	f	
$\mathbf{b^2}$	d	$\mathbf{c^{21}}$	d	$\mathbf{c^{22}}$	d	$\mathbf{c^{23}}$	d	
d	f	d	g	d	g	d	e	
$\mathbf{b^3}$	d	$\mathbf{c^{31}}$	d	$\mathbf{c^{32}}$	d	$\mathbf{c^{33}}$	d	
d	e	d	f	d	f	d	e	
A								**A**

The interpolation proceeds as follows

1 The 1/2 and 1/4 sample positions labeled as 'b' are obtained by first calculating intermediate values ‘*b*’ using 8 tap filtering of nearest pixels at integer locations in horizontal or vertical direction. The final value of 'b' is calculated as (*b*+128)/256 and clipped to lie in the range [0, 255]. The 1/2 and 1/4 sample positions labeled as 'c' are obtained by 8 tap filtering of intermediate values *b* in horizontal or vertical direction, dividing the result of filtering by 65536, rounding it to the nearest

integer and clipping it to lie in the range [0, 255]. The filter tap values depend on pixel position and are listed below:

'b', 'c' position	filter tabs
1/4	(-3, 12, -37, 229, 71, -21, 6, -1)
2/4	(-3, 12, -39, 158, 158, -39, 12, -3)
3/4	(-1, 6, -21, 71, 229, -37, 12, -3)

2 The 1/8 sample positions labeled as 'd' are calculated as the average (with truncation to the nearest integer) of the two closest 'A', 'b' or 'c' values in the horizontal or vertical direction.

3 The 1/8 sample positions labeled as 'e' are calculated by averaging with truncation of two 1/4 pixels labeled as 'b^1', which are the closest in the diagonal direction *[Editor: what about the e-position column 8, row 6 ?]*. The 1/8 sample positions labeled as 'g' are calculated via $(A+3c^{22}+2)/4$ and the 1/8 sample positions marked as 'f' are calculated via $(3b^1+ b^1+2)/4$ (pixel 'b^2' closer to 'f' is multiplied by 3).

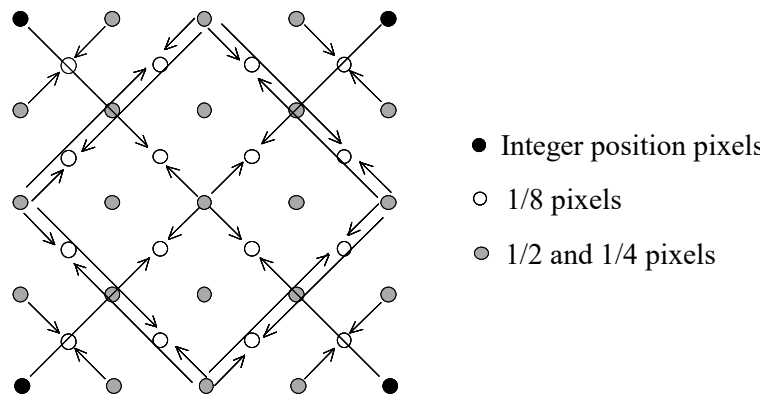


FIGURE 11

Diagonal interpolation for 1/8 pel interpolation.

5.3 Transform Coefficient Decoding

This section defines all elements related to transform coding and decoding. It is therefore relevant to all the syntax elements 'Tcoeff' in the syntax diagram.

5.3.1 Transform for Blocks of Size 4x4 Samples

Instead of a discrete cosine transform (DCT), an integer transform with a similar coding gain as a 4x4 DCT is used. The transformation of input pixels $X=\{x_{00} \ldots x_{33}\}$ to output coefficients Y is defined by:

$$Y = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 1 & -2 & 2 & -1 \end{bmatrix} \begin{bmatrix} x_{00} & x_{01} & x_{02} & x_{03} \\ x_{10} & x_{11} & x_{12} & x_{13} \\ x_{20} & x_{21} & x_{22} & x_{23} \\ x_{30} & x_{31} & x_{32} & x_{33} \end{bmatrix} \begin{bmatrix} 1 & 2 & 1 & 1 \\ 1 & 1 & -1 & -2 \\ 1 & -1 & -1 & 2 \\ 1 & -2 & 1 & -1 \end{bmatrix}$$

Multiplication by two can be performed either through additions or through left shifts, so that no actual multiplication operations are necessary. Thus, we say that the transform is multiplier-free.

For input pixels with 9-bit dynamic range (because they are residuals from 8-bit pixel data), the transform coefficients are guaranteed to fit within 16 bits, even when the second transform for DC coefficients is used. Thus, all transform operations can be computed in 16-bit arithmetic. In fact, the maximum dynamic range of the transforms coefficients fills a range of only 15.2 bits; this small headroom can be used to support a variety of different quantization strategies (which are outside the scope of this specification).

The inverse transformation of normalized coefficients $Y'=\{y'_{00} \ldots y'_{33}\}$ to output pixels X' is defined by:

$$X' = \begin{bmatrix} 1 & 1 & 1 & \frac{1}{2} \\ 1 & \frac{1}{2} & -1 & -1 \\ 1 & -\frac{1}{2} & -1 & 1 \\ 1 & -1 & 1 & -\frac{1}{2} \end{bmatrix} \begin{bmatrix} y'_{00} & y'_{01} & y'_{02} & y'_{03} \\ y'_{10} & y'_{11} & y'_{12} & y'_{13} \\ y'_{20} & y'_{21} & y'_{22} & y'_{23} \\ y'_{30} & y'_{31} & y'_{32} & y'_{33} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & \frac{1}{2} & -\frac{1}{2} & -1 \\ 1 & -1 & -1 & 1 \\ \frac{1}{2} & -1 & 1 & -\frac{1}{2} \end{bmatrix}$$

Multiplications by ½ are actually performed via right shifts, so that the inverse transform is also multiplier-free. The small errors introduced by the right shifts are compensated by a larger dynamic range for the data at the input of the inverse transform.

The transform and inverse transform matrices above have orthogonal basis functions. Unlike the DCT, though, the basis functions don't have the same norm. Therefore, for the inverse transform to recover the original pixels, appropriate normalization factors must be applied to the transform coefficients before quantization and after dequantization. Such factors are absorbed by the quantization and dequantization scaling factors described below.

By the above exact definition of the inverse transform, the same operations will be performed on coder and decoder side. Thus we avoid the usual problem of "inverse transform mismatch".

5.3.1.1 Transform for Blocks of Size 4x4 Samples Containing DC vales for Luminance

To minimize the dynamic range expansion due to transformations (and thus minimize rounding errors in the quantization scale factors), a simple scaled Hadamard transform is used. The direct transform is defined by:

$$Y_D = \left(\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \begin{bmatrix} x_{D00} & x_{D01} & x_{D02} & x_{D03} \\ x_{D10} & x_{D11} & x_{D12} & x_{D13} \\ x_{D20} & x_{D21} & x_{D22} & x_{D23} \\ x_{D30} & x_{D31} & x_{D32} & x_{D33} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \right) // 2$$

where the symbol // denotes division with rounding to the nearest integer:

$$a // 2^b = \text{sign}(a) \times \left[\left(\text{abs}(a) + 2^{b-1} \right) >> b \right]$$

The inverse transform for the 4x4 luminance DC coefficients is defined by:

$$X_{QD} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \begin{bmatrix} y_{QD00} & y_{QD01} & y_{QD02} & y_{QD03} \\ y_{QD10} & y_{QD11} & y_{QD12} & y_{QD13} \\ y_{QD20} & y_{QD21} & y_{QD22} & y_{QD23} \\ y_{QD30} & y_{QD31} & y_{QD32} & y_{QD33} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix}$$

5.3.2 Transform for Blocks of Size 2x2 Samples (DC vales for Chrominance)

With the low resolution of chrominance it seems to be preferable to have larger blocksize than 4x4. Specifically the 8x8 DC coefficient seems very useful for better definition of low resolution chrominance. The 2 dimensional 2x2 transform procedure is illustrated below. DC0,1,2,3 are the DC coefficients of 2x2 chrominance blocks.

DC0	DC1	Two dimensional 2x2 transform	⇒	DDC(0,0)	DDC(1,0)
DC2	DC3			DDC(0,1)	DDC(1,1)

Definition of transform:

DCC(0,0) = (DC0+DC1+DC2+DC3)

DCC(1,0) = (DC0-DC1+DC2-DC3)

DCC(0,1) = (DC0+DC1-DC2-DC3)

DCC(1,1) = (DC0-DC1-DC2+DC3)

Definition of inverse transform:

DC0 = (DCC(0,0)+ DCC(1,0)+ DCC(0,1)+ DCC(1,1))

DC1 = (DCC(0,0)- DCC(1,0)+ DCC(0,1)- DCC(1,1))

DC2 = (DCC(0,0)+ DCC(1,0)- DCC(0,1)- DCC(1,1))

DC3 = (DCC(0,0)- DCC(1,0)- DCC(0,1)+ DCC(1,1))

5.3.3 Zig-zag Scanning and Quantization

5.3.3.1 Simple Zig-Zag Scan

Except for Intra coding of luminance with QP<24, simple scan is used. This is basically zig-zag scanning similar to the one used in H.263. The scanning pattern is:

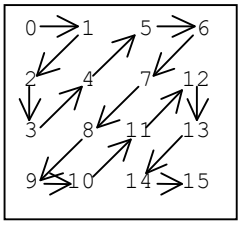


FIGURE 12

Simple zig-zag scan.

5.3.3.2 Double Zig-Zag Scan

When using the VLC defined above, we use a one bit code for EOB. For Inter blocks and Intra with high QP the probability of EOB is typically 50%, which is well matched with the VLC. In other words this means that we on average have one non-zero coefficient per 4x4 block in addition to the EOB code (remember that a lot of 4x4 blocks only have EOB). On the other hand, for Intra coding we typically have more than one non-zero coefficient per 4x4 block. This means that the 1 bit EOB becomes inefficient. To improve on this the 4x4 block is subdivided into two parts that are scanned separately and with one EOB each. The two scanning parts are shown below – one of them in bold.

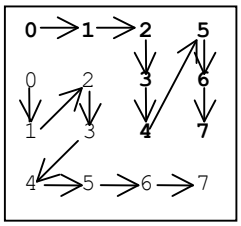


FIGURE 13

Double zig-zag scan.

5.3.3.3 Quantization

The quantization and dequantization processes shall perform usual quantization and dequantization, as well as take care of the necessary normalization of transform coefficients. As specified in sub-subsection 4.4.8, 52 different QP values are used, from -12 to +39. The quantization and dequantization equations are defined such that the equivalent step size doubles for every increment of 6 in QP. Thus, there is an increase in step size of about 12% from one QP to the next. There is no “dead zone” in the quantization process. For the QP in the range [0…31] the corresponding step size range is about the same as that for H.263. With the range [-12…39], the smallest step size is about four times smaller than in H.263, allowing for very high fidelity reconstruction, and the largest is about 60% larger than in H.263, allowing for more rate control flexibility.

The QP signaled in the bitstream applies for luminance quantization/dequantization. This could be called QPluma. For chrominance quantization/dequantization a different value - QPchroma - is used. The relation between the two is:

QPluma:	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
QPchroma:	17	17	18	19	20	20	21	22	22	23	23	24	24	25	25	25	26	26	26	27	27	27	27

with QPchroma = QPluma if QPluma < 17.

5.3.3.3.1 Quantization of 4x4 luminance or chrominance coefficients

Since the step size doubles for every increment of 6 in QP, a periodic quantization table is used. Thus, our indices into quantization coefficient tables depend only on (QP+12)%6 = QP%6 (where the % symbol means the modulus operator), and the quantization and de-quantization formulas depend both on QP%6 and (QP+12)/6. In that way, the table size is minimized.

Quantization is performed according to the following equation:

$$Y_Q(i,j) = \left[Y(i,j) \cdot Q((QP+12)\%6, i, j) + f \right] / 2^{15+(QP+12)/6}, \quad i,j = 0,\ldots,3$$

where Y are the transformed coefficients, Y_Q are the corresponding quantized values, Q(m,i,j) are the quantization coefficients listed below, and |f| is in the range 0 to $2^{14+(QP+12)/6}/2$, with f having the same sign as the coefficient that is being quantized. Recall that QP+12 is the value signaled to the decoder, as discussed in Subsection **Error! Reference source not found.**. Note that while the intermediate value inside square brackets in the equation above has a 32-bit range, the final value Y_Q is guaranteed to fit in 16 bits.

5.3.3.3.2 Dequantization of 4x4 luminance or chrominance coefficients

Dequantization is performed according to the following equation:

$$Y'(i,j) = Y_Q(i,j) \cdot R((QP+12)\%6, i, j) << (QP+12)/6, \quad i,j = 0,\ldots,3$$

where the R(m,i,j) are the dequantization coefficients listed below. After dequantization, the inverse transform specified above is applied. Then the final results are normalized by:

$$X(i,j) = \left(X'(i,j) + 2^5 \right) >> 6$$

The dequantization formula can be performed in 16-bit arithmetic, because the coefficients R(m,i,j) are small enough. Furthermore, the de-quantized coefficients have the maximum dynamic range that still allows for the inverse transform to be performed in 16-bit arithmetic. Thus, the decoder needs only 16-bit arithmetic for dequantization and inverse transform.

5.3.3.3.3 Quantization of 4x4 luminance DC coefficients

Quantization is performed according to the following equation:

$$Y_Q(i,j) = \left[Y(i,j) \cdot Q((QP+12)\%6, i, j) + f \right] / 2^{16+(QP+12)/6}, \quad i,j = 0,\ldots,3$$

5.3.3.3.4 Dequantization of 4x4 luminance DC coefficients

The order of inverse transform and de-quantization of DC coefficients is changed, that is, the inverse transform is performed first, then dequantization. This achieves the best possible dynamic range during inverse transform computations.

After the inverse transform, dequantization is performed according to the following equation:

$$X_D(i,j) = \left[X_{QD}(i,j) \cdot R((QP+12)\%6, 0, 0) \right] / 2^{4-(QP+12)/6}, \quad i,j = 0,\ldots,3$$

5.3.3.3.5 Quantization of 2x2 chrominance DC coefficients

Quantization is performed according to the following equation:

$$Y_Q(i,j) = \left[Y(i,j) \cdot Q((QP+12)\%6, i, j) + 2f \right] / 2^{16+(QP+12)/6}, \quad i,j = 0,\ldots,3$$

5.3.3.3.6 Dequantization of 2x2 chrominance DC coefficients

Again the order of inverse transform and de-quantization of DC coefficients is changed, that is, the inverse transform is performed first, then dequantization. This achieves the best possible dynamic range during inverse transform computations.

After the inverse transform, dequantization is performed according to the following equation:

$$X_D(i,j) = \left[X_{QD}(i,j) \cdot R\left((QP+12)\%6, 0, 0\right) \right] / 2^{3-(QP+12)/6}, \quad i,j = 0,\ldots,3$$

5.3.3.3.7 Quantization and dequantization coefficient tables

The coefficients Q(m,i,j) and R(m,i,j), used in the formulas above, are defined in pseudo code by:

```
Q[m][i][j] = quantMat[m][0] for (i,j) = {(0,0),(0,2),(2,0),(2,2)},
Q[m][i][j] = quantMat[m][1] for (i,j) = {(1,1),(1,3),(3,1),(3,3)},
Q[m][i][j] = quantMat[m][2] otherwise.

R[m][i][j] = dequantMat[m][0] for (i,j) = {(0,0),(0,2),(2,0),(2,2)},
R[m][i][j] = dequantMat[m][1] for (i,j) = {(1,1),(1,3),(3,1),(3,3)},
R[m][i][j] = dequantMat[m][2] otherwise.

quantMat[6][3] = {{13107, 5243, 8066}, {11916, 4660, 7490}, {10082, 4194, 6554},
{9362, 3647, 5825}, {8192, 3355, 5243}, {7282, 2893 , 4559}};

dequantMat[6][3] = {{10, 16, 13}, {11, 18, 14}, {13, 20, 16}, {14, 23, 18}, {16, 25,
20}, {18, 29, 23}};
```

5.3.3.4 Scanning and Quantization of 2x2 chrominance DC coefficients

DDC() is quantized (and dequantized) separately resulting in LEVEL, RUN and EOB. The scanning order is: DCC(0,0), DCC(1,0), DCC(0,1), DCC(1,1). Inverse 2x2 transform as defined above is then performed after dequantization resulting in dequantized 4x4 DC coefficients: DC0' DC1' DC2' DC3'.

Chrominance AC coefficients (4x4 based) are then quantized similarly to before. Notice that there are only 15 AC coefficients. The maximum size of RUN is therefore 14. However, for simplicity we use the same relation between LEVEL, RUN and Code no. as defined for 'Simple scan' in TABLE 7.

5.3.4 Use of 2-dimensional model for coefficient coding.

In the 3D model for coefficient coding (see H.263) there is no good use of a short codeword of 1 bit. On the other hand, with the use of 2D VLC plus End Of Block (EOB) (as used in H.261, H.262) and with the small block size, 1 bit for EOB is usually well matched to the VLC.

Furthermore, with the fewer non-zero coefficients per block, the advantage of using 3D VLC is reduced.

As a result we use a 2D model plus End Of Block (EOB) in the present model. This means that an event to be coded (RUN, LEVEL) consists of:

RUN	which is the number of zero coefficients since the last nonzero coefficient.
LEVEL	the size of the nonzero coefficient
EOB	signals that there are no more nonzero coefficients in the block

5.4 Deblocking Filter

After the reconstruction of a macroblock a conditional filtering of this macroblock is taking place, that effects the boundaries of the 4x4 block structure. Filtering is done on a macroblock level. In a first step the 16 pel of the 4 vertical edges (horizontal filtering) of the 4x4 raster are filtered. After that, the 4 horizontal edges (vertical filtering) follow. This process also affects the boundaries of the already reconstructed macroblocks above and to the right of the current macroblock. Frame edges are not filtered. Note, that intra prediction of the current macro block takes place on the unfiltered content of the already decoded neighbouring macroblocks. Depending on the implementation, these values have to be stored before filtering.

Note that when PSTRUCT indicates a field picture, then all calculations for the deblocking filter are based solely on pixels from just the current field; the pixels from the other field of the containing frame play no role at all.

5.4.1 Content Dependent thresholds

For the purpose of filtering each 4x4 block edge in a reconstructed macroblock a filtering **Boundary Strength Bs** is assigned for luma:

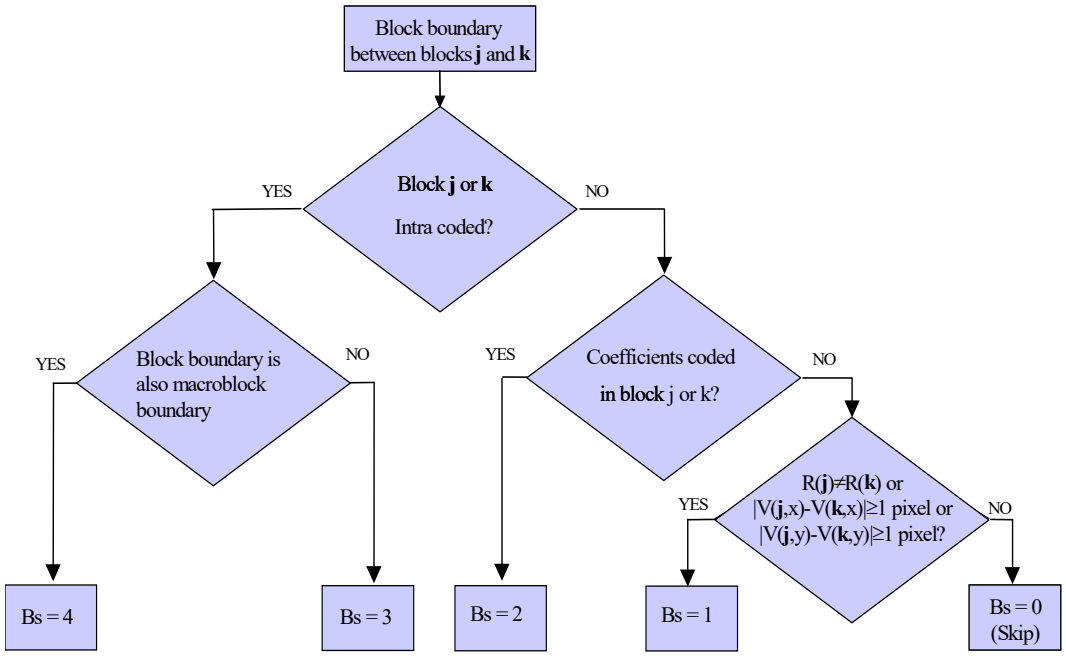


FIGURE 14

Flow chart for determining boundary strength (Bs), for the block boundary between two neighbouring blocks j and k.

Block boundaries of chroma blocks always correspond to a block boundary of luma blocks. Therefore the corresponding **Bs** for luma is also used for chroma boundaries.

The set of eight pixels across a 4x4 block horizontal or vertical boundary is denoted as

$$p_4, p_3, p_2, p_1 \mid q_1, q_2, q_3, q_4$$

with the actual boundary between p1 and q1. In the default mode up to two pixels can be updated as a result of the filtering process on both sides of the boundary (that is at most p2, p1, q1, q2). Filtering across a certain 4x4 block boundary is skipped all together if the corresponding Bs is equal to zero. Sets of pixels across this edge are only filtered if the condition

$$Bs \neq 0 \quad \textbf{AND} \quad |p_1 - q_1| < \alpha \quad \textbf{AND} \quad |p_2 - p_1| < \beta \quad \textbf{AND} \quad |q_2 - q_1| < \beta$$

is true. The QP dependant thresholds α and β can be found in table 5.

QP	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
α	3	3	3	3	3	3	3	3	3	3	4	4	5	6	8	10	13	17	21	26	30	35	43	48	55	64	77	96	128	128	192	192
β	0	0	0	0	0	0	0	0	4	4	4	5	5	5	7	7	7	8	9	9	10	10	11	11	12	12	13	13	14	14	15	15

TABLE 4

QP dependent threshold parameters α and β.

5.4.2 The Filtering Process

Two sorts of filter are defined. In the default case the following filter will be used for p_1 and q_1

$\Delta = Clip(-C, C, ((q_1 - p_1) << 2 + (p_2 - q_2) + 4) >> 3)$

$P_1 = Clip(0, 255, (p_1+\Delta))$

$Q_1 = Clip(0, 255, (q_1-\Delta))$

The two intermediate threshold variables

$a_p = |p3 - p1|$

$a_q = |q3 - q1|$

are used to decide whether p_2 and q_2 are filtered. These pixels are only processed for luminance.

If (Luma && $a_p < \beta$) p_2 is filtered by:

$P_2 = p_2 + Clip(-C0, C0, (p_3+P_1 - p_2<<1) >> 1)$

If (Luma && $a_q < \beta$) q_2 is filtered by:

$Q_2 = q_2 + Clip(-C0, C0, (q_3+Q_1 - q_2<<1) >> 1)$

where Clip() denotes a clipping function with the parameters Clip(Min, Max, Value) and the clipping thesholds:

$C0 = ClipTable[QP, Bs]$ *(see TABLE 5)*

C is set to *C0* and than incremented by one if p_2 will be filtered and again by one if q_2 will be filtered.

TABLE 5

QP and Bs dependent Clipping thresholds

QP	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
ClipTable[QP,1]	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	4	4
ClipTable[QP,2]	0	0	0	0	0	0	0	0	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	4	5	5	6	6
ClipTable[QP,3]	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	5	5	6	6	6	8	8	9	10
ClipTable[QP,4]	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	3	3	3	3	4	4	4	5	5	6	6	6	8	8	9	10

5.4.3 Stronger filtering for intra coded blocks

In case of intra coding and areas in the picture with little texture the subjective quality can be improved by stronger filtering across block boundaries (that is: *not* 4x4 block boundaries). This stronger filtering is performed if:

$(Bs == 4)$ **AND** $(a_p < \beta)$ **AND** $(a_q < \beta)$ **AND** $(1 < |p_1-q_1| < QP / 4)$

In this case filtering is performed with the equations shown below.

$$P_1 = (p_3 + 2*p_2 + 2*p_1 + 2*q_1 + q_2 + 4) / 8$$
$$P_2 = (p_4 + 2*p_3 + 2*p_2 + 2*p_1 + q_1 + 4) / 8$$
$$Q_1 = (p_2 + 2*p_1 + 2*q_1 + 2*q_2 + q_3 + 4) / 8$$
$$Q_2 = (p_1 + 2*q_1 + 2*q_2 + 2*q_3 + q_4 + 4) / 8$$

Only for luma p3 and q3 are filtered:

$$P_3 = (2*p_4 + 3*p_3 + 2*p_2 + p_1 + 4) / 8$$
$$Q_3 = (2*q_4 + 3*q_3 + 2*q_2 + q_1 + 4) / 8$$

5.5 Entropy Coding

In the default entropy coding mode, a universal VLC is used to code all syntax. The table of codewords are written in the following compressed form.

```
1
0 1 x0
0 0 1 x1 x0
```

```
0 0 0 1 x2 x1 x0
0 0 0 0 1 x3 x2 x1 x0
. . . . . . . . . . . . . . . . .
```

where xn take values 0 or 1. We will sometimes refer to a codeword with its length in bits (L = 2n-1) and INFO = xn,…x1, x0. Notice that the number of bits in INFO is n-1 bits. The codewords are numbered from 0 and upwards. The definition of the numbering is:

Code_number = 2^L/2 + INFO -1 (L/2 use division with truncation. INFO = 0 when L = 1) Some of the first code numbers and codewords are written explicitly in the table below. As an example, for the code number 5, L = 5 and INFO = 10 (binary) = 2 (decimal)

TABLE 6

Code number and Codewords in explicit form

Code_number	Code word
0	1
1	0 1 0
2	0 1 1
3	0 0 1 0 0
4	0 0 1 0 1
5	0 0 1 1 0
6	0 0 1 1 1
7	0 0 0 1 0 0 0
8	0 0 0 1 0 0 1
9	0 0 0 1 0 1 0
10	0 0 0 1 0 1 1
. . . . .	. . . . .

When L (L = 2N-1) and INFO is known, the regular structure of the table makes it easy to create a codeword. Similarly, a decoder may easily decode a codeword by reading in N bit prefix followed by N-1 INFO. L and INFO is then readily available. For each parameter to be coded, there is a conversion rule from the parameter value to the code number (or L and INFO). TABLE 7 lists the connection between code number and most of the parameters used in the present coding method.

TABLE 7

Connection between codeword number and parameter values.

Code_ number	RUN	MB_Type		8x8 mode	MVD D-QUANT	CBP		Tcoeff_chroma_DC[1]		Tcoeff_chroma_AC[1] Tcoeff_luma[1] Simple scan		Tcoeff_luma[1] Double scan	
		Intra	Inter			Intra	Inter	Level	Run	Level	Run	Level	Run
0	0	Intra4x4	16x16	8x8	0	47	0	EOB	-	EOB	-	EOB	-
1	1	0,0,0[2]	16x8	8x4	1	31	16	1	0	1	0	1	0
2	2	1,0,0	8x16	4x8	-1	15	1	-1	0	-1	0	-1	0
3	3	2,0,0	8x8	4x4	2	0	2	2	0	1	1	1	1
4	4	3,0,0	~~8x4~~8x8 (ref=0)	Intra	-2	23	4	-2	0	-1	1	-1	1
5	5	0,1,0	Intra4x4 ~~4x8~~		3	27	8	1	1	1	2	2	0
6	6	1,1,0	0,0,0[2]~~4x4~~		-3	29	32	-1	1	-1	2	-2	0
7	7	2,1,0	1,0,0~~Intra4x4~~		4	30	3	3	0	2	0	1	2
8	8	3,1,0	2,0,0~~0,0,0~~[3]		-4	7	5	-3	0	-2	0	-1	2
9	9	0,2,0	3,0,0~~1,0,0~~		5	11	10	2	1	1	3	3	0
10	10	1,2,0	0,1,0~~2,0,0~~		-5	13	12	-2	1	-1	3	-3	0
11	11	2,2,0	1,1,0~~3,0,0~~		6	14	15	1	2	1	4	4	0
12	12	3,2,0	2,1,0~~0,1,0~~		-6	39	47	-1	2	-1	4	-4	0
13	13	0,0,1	3,1,0~~1,1,0~~		7	43	7	1	3	1	5	5	0
14	14	1,0,1	0,2,0~~2,1,0~~		-7	45	11	-1	3	-1	5	-5	0
15	15	2,0,1	1,2,0~~3,1,0~~		8	46	13	4	0	3	0	1	3
16	16	3,0,1	2,2,0~~0,2,0~~		-8	16	14	-4	0	-3	0	-1	3
17	17	0,1,1	3,2,0~~1,2,0~~		9	3	6	3	1	2	1	1	4
18	18	1,1,1	0,0,1~~2,2,0~~		-9	5	9	-3	1	-2	1	-1	4
19	19	2,1,1	1,0,1~~3,2,0~~		10	10	31	2	2	2	2	2	1
20	20	3,1,1	2,0,1~~0,0,1~~		-10	12	35	-2	2	-2	2	-2	1
21	21	0,2,1	3,0,1~~1,0,1~~		11	19	37	2	3	1	6	3	1
22	22	1,2,1	0,1,1~~2,0,1~~		-11	21	42	-2	3	-1	6	-3	1
23	23	2,2,1	1,1,1~~3,0,1~~		12	26	44	5	0	1	7	6	0
24	24	3,2,1	2,1,1~~0,1,1~~		-12	28	33	-5	0	-1	7	-6	0
25	25		3,1,1~~1,1,1~~		13	35	34	4	1	1	8	7	0
26	26		0,2,1~~2,1,1~~		-13	37	36	-4	1	-1	8	-7	0
27	27		1,2,1~~3,1,1~~		14	42	40	3	2	1	9	8	0
28	28		2,2,1~~0,2,1~~		-14	44	39	-3	2	-1	9	-8	0
29	29		3,2,1~~1,2,1~~		15	1	43	3	3	4	0	9	0
30	30		~~2,2,1~~		-15	2	45	-3	3	-4	0	-9	0
31	31		~~3,2,1~~		16	4	46	6	0	5	0	10	0
32	32				-16	8	17	-6	0	-5	0	-10	0
33	33				17	17	18	5	1	3	1	4	1
34	34				-17	18	20	-5	1	-3	1	-4	1
35	35				18	20	24	4	2	3	2	2	2

36	36				-18	24	19	-4	2	-3	2	-2	2
37	37				19	6	21	4	3	2	3	2	3
38	38				-19	9	26	-4	3	-2	3	-2	3
39	39				20	22	28	7	0	2	4	2	4
40	40				-20	25	23	-7	0	-2	4	-2	4
41	41				21	32	27	6	1	2	5	2	5
42	42				-21	33	29	-6	1	-2	5	-2	5
43	43				22	34	30	5	2	2	6	2	6
44	44				-22	36	22	-5	2	-2	6	-2	6
45	45				23	40	25	5	3	2	7	2	7
46	46				-23	38	38	-5	3	-2	7	-2	7
47	47				24	41	41	8	0	2	8	11	0
	..				..			..	..	..	..	..	..

[1]For the entries above the horizontal line, the table is needed for relation between code number and Level/Run/EOB. For the remaining Level/Run combination there is a simple rule. The Level/Run combinations are assigned a code number according to the following priority: 1) sign of Level (+ -) 2) Run (ascending) 3) absolute value of Level (ascending).

[2]16x16 based intra mode. The 3 numbers refer to values for (Imode,AC,nc) - see 0.

TABLE 8

Connection between codeword number and Intra Prediction Mode Probability

Code_ number	Prob0, Prob1[3]	Code_ number	Prob0, Prob1[3]	Code_ number	Prob0, Prob1[3]	Code_ number	Prob0, Prob1[3]
0	0,0	21	2,3	41	2,6	61	6,5
1	0,1	22	3,2	42	6,2	62	4,7
2	1,0	23	1,5	43	3,5	63	7,4
3	1,1	24	5,1	44	5,3	64	3,8
4	0,2	25	2,4	45	1,8	65	8,3
5	2,0	26	4,2	46	8,1	66	4,8
6	0,3	27	3,3	47	2,7	67	8,4
7	3,0	28	0,7	48	7,2	68	5,7
8	1,2	29	7,0	49	4,5	69	7,5
9	2,1	30	1,6	50	5,4	70	6,6
10	0,4	31	6,1	51	3,6	71	6,7
11	4,0	32	2,5	52	6,3	72	6,7
12	3,1	33	5,2	53	2,8	73	5,8
13	1,3	34	3,4	54	8,2	74	8,5
14	0,5	35	4,3	55	4,6	75	6,8
15	5,0	36	0,8	56	6,4	76	8,6
16	2,2	37	8,0	57	5,5	77	7,7
17	1,4	38	1,7	58	3,7	78	7,8
18	4,1	39	7,1	59	7,3	79	8,7
19	0,6	40	4,4	60	5,6	80	8,8
20	6,0						

[3] Prob0 and Prob1 defines the Intra prediction modes of two blocks relative to the prediction of prediction modes (see details in the section for Intra coding).

6 Context-based Adaptive Binary Arithmetic Coding (CABAC)

6.1 Overview

The entropy coding method of context-based adaptive binary arithmetic coding (CABAC) has three distinct elements compared to the default entropy coding method using a fixed, universal table of variable length codes (UVLC):

- *Context modeling* provides estimates of conditional probabilities of the coding symbols. Utilizing suitable context models, given inter-symbol redundancy can be exploited by switching between different probability models according to already coded symbols in the neighborhood of the current symbol to encode.
- *Arithmetic codes* permit non-integer number of bits to be assigned to each symbol of the alphabet. Thus the symbols can be coded almost at their entropy rate. This is extremely beneficial for symbol probabilities much greater than 0.5, which often occur with efficient context modeling. In this case, a variable length code has to spend at least one bit in contrast to arithmetic codes, which may use a fraction of one bit.
- *Adaptive* arithmetic codes permit the entropy coder to adapt itself to non-stationary symbol statistics. For instance, the statistics of motion vector magnitudes vary over space and time as well as for different sequences and bit-rates. Hence, an adaptive model taking into account the cumulative probabilities of already coded motion vectors leads to a better fit of the arithmetic codes to the current symbol statistics.

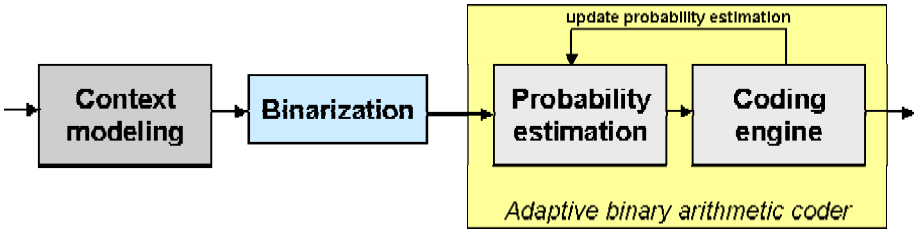


FIGURE 15

Generic block diagram of CABAC entropy coding scheme

Next we give a short overview of the main coding elements of the CABAC entropy coding scheme as depicted in FIGURE 15. Suppose a symbol related to an arbitrary syntax element is given, then, in a first step, a suitable model is chosen according to a set of past observations. This process of constructing a model conditioned on neighboring symbols is commonly referred to as *context modeling* and is the first step in the entropy coding scheme. The particular context models that are designed for each given syntax model are described in detail in Section 6.2 and Section 6.3. If a given symbol is non-binary valued, it will be mapped onto a sequence of binary decisions, so-called *bins*, in a second step. The actual *binarization* is done according to a given binary tree, as specified in Section 6.6. Finally, each binary decision is encoded with the *adaptive binary arithmetic coding* (AC) engine using the *probability estimates*, which have been provided either by the context modeling stage or by the binarization process itself. The provided models serve as a probability estimation of the related bins. After encoding of each bin, the related model will be updated with the encoded binary symbol. Hence, the model keeps track of the actual statistics.

6.2 Context Modeling for Coding of Motion and Mode Information

In this section we describe in detail the context modeling of our adaptive coding method for the syntax elements macroblock type (MB_type), motion vector data (MVD) and reference frame parameter (Ref_frame).

6.2.1 Context Models for Macroblock Type

We distinguish between MB_type for intra and inter frames. In the following, we give a description of the context models which have been designed for coding of the MB_type information in both cases. The subsequent process of mapping a non-binary valued MB_type symbol to a binary sequence in the case of inter frames will be given in detail in section 6.6.

6.2.1.1 Intra Pictures

For intra pictures, there are two possible modes for each macroblock, i.e. Intra4x4 and Intra16x16, so that signalling the mode information is reduced to transmitting a binary decision. Coding of this binary decision for a given macroblock is performed by means of context-based arithmetic coding, where the context of a current MB_type C is build by using the MB_types A and B[1] of neighboring macroblocks (as depicted in FIGURE 16) which are located in the causal past of the current coding event C. Since A and B are binary decisions, we define the actual context number *ctx_mb_type_intra(C)* of C by *ctx_mb_type_intra(C) = A + B*, which results in three different contexts according to the 4 possible combinations of MB_type states for A and B.

In the case of MB_type Intra16x16, there are three additional parameters related to the chosen intra prediction mode, the occurrence of significant AC-coefficients and the coded block pattern for the chrominance coefficients, which have to be signalled. In contrast to the current test model, this information is not included in the mode information, but is coded separately by using distinct models as described in Section 6.6.

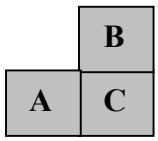


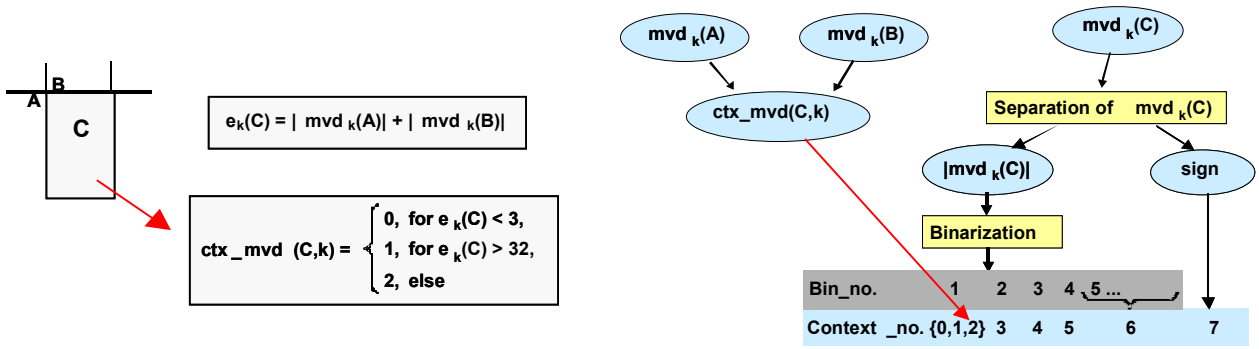
FIGURE 16

Neighboring symbols A and B used for conditional coding of a current symbol C.

6.2.1.2 P- and B-Pictures

Currently there a 10 different macroblock types for P-frames and 18 different macroblock types for B-frames, provided that the additional information of the 16x16 Intra mode is not considered as part of the mode information. Coding of a given MB_type information C is done similar to the case of intra frames by using a context model which involves the MB_type information A and B of previously encoded (or decoded) macroblocks (see FIGURE 16). However, here we only use the information whether the neighboring macroblocks of the given macroblock are of type Skip (P-frame) or Direct (B-frame), such that the actual context number *ctx_mb_type_inter(C)* is given in C-style notation for P-frame coding by *ctx_mb_type_inter(C) = ((A==Skip)?0:1) + ((B==Skip)?0:1)* and by *ctx_mb_type_inter(C) = ((A==Direct)?0:1) + ((B==Direct)?0:1)* for B-frame coding. Thus, we obtain 3 different contexts, which, however, are only used for coding of the first bin of the binarization ***b****(C)* of C, where the actual binarization of C will be performed as outlined in Section 6.6. For coding the second bin, a separate model is provided and for all remaining bins of ***b****(C)* two additional models are used as further explained in Section 6.6. Thus, a total number of 6 different models are supplied for coding of macroblock type information relating to P-and B-frames.

1 For mathematical convenience the meaning of the variables A, B and C is context dependent.



(a) (b)

FIGURE 17

Illustration of the encoding process for a given residual motion vector component $mvd_k(C)$ of a block C: (a) Context selection rule. (b) Separation of $mvd_k(C)$ into sign and magnitude, binarization of the magnitude and assignment of context models to bin_nos.

6.2.2 Context Models for Motion Vector Data

Motion vector data consists of residual vectors obtained by applying motion vector prediction. Thus, it is a reasonable approach to build a model conditioned on the local prediction error. A simple measure of the local prediction error at a given block C is given by evaluating the L1-norm $e_k(A,B) = |mvd_k(A)| + |mvd_k(B)|$ of two neighboring motion vector prediction residues $mvd_k(A)$ and $mvd_k(B)$ for each component of a motion vector residue $mvd_k(C)$ of a given block, where A and B are neighboring blocks of block C, as shown in FIGURE 17(a). If one of the neighboring blocks belongs to an adjacent macroblock, we take the residual vector component of the leftmost neighboring block in the case of the upper block B, and in the case of the left neighboring block A we use the topmost neighboring block. If one of the neighboring blocks is not available, because, for instance, the current block is at the picture boundary, we discard the corresponding part of e_k. By using e_k, we now define a context model *ctx_mvd(C,k)* for the residual motion vector component $mvd_k(C)$ consisting of three different context models:

$$ctx_mvd(C,k) = \begin{cases} 0, e_k(C) < 3, \\ 1, e_k(C) > 32, \\ 2, else. \end{cases}$$

For the actual coding process, we separate $mvd_k(C)$ in sign and modulus, where only the first bin of the binarization of the modulus $|mvd_k(C)|$ is coded using the context models *ctx_mvd(C,k)*. For the remaining bins of the modulus, we have 4 additional models: one for the second, one for the third bin, one for the fourth, and one model for all remaining bins. In addition, the sign coding routine is provided with a separate model. This results in a total sum of 8 different models for each vector component.

In the case of B-frame coding, an additional syntax element has to be signaled when the bi-directional mode is chosen. This element represents the block size (Blk_size), which is chosen for forward or backward motion prediction. The related code number value ranges between 0 and 6 according to the 7 possible block shapes in FIGURE 2. Coding of Blk_size is done by using the binarization of the P_MB_type as described in Section 6.6.

6.2.3 Context Models for Reference Frame Parameter

If the option of temporal prediction from more than one reference frame is enabled, the chosen reference frame for each macroblock must be signaled. Given a macroblock and its reference frame parameter as a symbol C according to the definition in Section 4.4, a context model is built by using symbols A and B of the reference frame parameter belonging to the two neighboring macroblocks (see FIGURE 16). The actual context number of C is then defined by *ctx_ref_frame(C) = ((A==0)?0:1) + 2*((B==0)?0:1)*, such that *ctx_ref_frame(C)* indicates one of four models used for coding of the first bin of the binary

equivalent ***b(C)*** of C. Two additional models are given for the second bin and all remaining bins of ***b(C)***, which sums up to a total number of six different models for the reference frame information.

6.3 Context Modeling for Coding of Texture Information

This section provides detailed information about the context models used for the syntax elements of coded block pattern (CBP), intra prediction mode (IPRED) and (RUN, LEVEL) information.

6.3.1 Context Models for Coded Block Pattern

Except for MB_type Intra16x16, the context modeling for the coded block pattern is treated as follows. There are 4 luminance CBP bits belonging to 4 8x8 blocks in a given macroblock. Let C denote such a Y-CBP bit, then we define *ctx_cbp_luma(C) = A + 2*B,* where A and B are Y-CBP bits of the neighboring 8x8 blocks, as depicted in FIGURE 16. The remaining 2 bits of CBP are related to the chrominance coefficients. In our coding approach, these bits are translated into two dependant binary decisions, such that, in a first step, we send a bit *cbp_chroma_sig* which signals whether there are significant chrominance coefficients at all. The related context model is of the same kind as that of the Y-CBP bits, i.e. *ctx_cbp_chroma_sig(C) = A + 2*B,* where A and B are now notations for the corresponding *cbp_chroma_sig* bits of neighboring macroblocks. If *cbp_chroma_sig = 1* (non-zero chroma coefficients exist), a second bit *cbp_chroma_ac* related to the significance of AC chrominance coefficients has to be signalled. This is done by using a context model conditioned on the *cbp_chroma_ac* decisions A and B of neighboring macroblocks, such that *ctx_cbp_chroma_AC(C) = A + 2*B.* Note, that due to the different statistics there are different models for Intra and Inter macroblocks, so that the total number of different models for CBP amounts to 2*3*4=24. For the case of MB_type Intra16x16, there are three additional models, one for the binary AC decision and two models for each of the two chrominance CBP bits.

6.3.2 Context Models for Intra Prediction Mode

In Intra4x4 mode, coding of the intra prediction mode C of a given block is conditioned on the intra prediction mode of the previous block A to the left of C (see FIGURE 16). In fact, it is not the prediction mode number itself which is signaled and which is used for conditioning but rather its predicted order similar as it is described in Section 4.4.4. There are 6 different prediction modes and for each mode, two different models are supplied: one for the first bin of the binary equivalent of C and the other for all remaining bins. Together with two additional models for the two bits of the prediction modes of MB_type Intra16x16 (in binary representation), a total number of 14 different models for coding of intra prediction modes is given.

6.3.3 Context Models for Run/Level and Coeff_count

Coding of RUN and LEVEL is conditioned primarily on the scanning mode, the DC/AC block type, the luminance/chrominance, and the intra/inter macroblock decision. Thus, a total number of 8 different block types are given according to TABLE 9. In contrast to the UVLC coding mode, RUN and LEVEL are coded separately in the CABAC mode, and furthermore an additional coding element called COEFF_COUNT is introduced, which denotes the number of non-zero coefficients in a given block. The coefficients corresponding to a scanning mode are processed in the following way: First, the number of non-zero coefficients COEFF_COUNT is encoded. Then, in a second step, RUN, LEVEL and SIGN of all non-zero coefficients are encoded. FIGURE 18 illustrates this encoding scheme that is described in more detail in the following sections.

TABLE 9

Numbering of the different block types used for coding of RUN, LEVEL and COEFF_COUNT

Ctx_run_level_coeff_count	Block Type
0	Double Scan (Intra Luma only)
1	Single Scan (Inter Luma only)
2	Intra Luma 16x16, DC

3	Intra Luma 16x16, AC
4	Inter Chroma, DC
5	Intra Chroma, DC
6	Inter Chroma, AC
7	Intra Chroma, AC

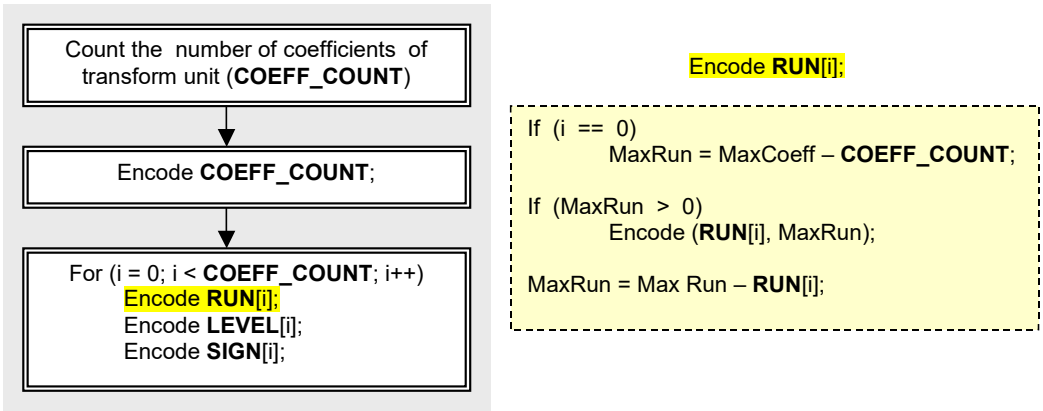


FIGURE 18

Coding scheme for transform coefficients

6.3.3.1 Context-based Coding of COEFF_COUNT Information

For capturing the correlations between COEFF_COUNTs of neighboring blocks appropriate context models are designed, which are only applied to the first binary decision (*bin*) in the unary binarization tree. More specifically, first the COEFF_COUNT is classified according the block type and then a local context for the first bin is built according to the rules specified in TABLE 10. The remaining bins are coded with two separate models; one for the second and the other for all remaining bins.

TABLE 10

Description of the context formation for the first bin for coding of COEFF_COUNT (CC denotes the COEFF_COUNT of the corresponding blocks)

Block Type	*Number of ctx's*	*Description of the context formation for the first bin*	*Comments*
0	3	ctx_coeff_count(A) =0; ctx_coeff_count(B) = (CC(A)==0) ? 1 : 2;	A: upper scan path; B: lower scan path
1	4	ctx_coeff_count(C) = ((CC(A)==0)?0:1) + 2*((CC(B)==0)?0:1);	A,B,C as in **Error! Reference source not found.**
2	1	Only one ctx	
3	3	ctx_coeff_count(0) =0; ctx_coeff_count(i) = (CC(i-1)==0) ? 1 : 2; i={1,..,15}	i denotes the number of the 4x4 block as in **FIGURE 3**
4,5,6,7	2	ctx_coeff_count(U) == 0; ctx_coeff_count(V) == 1;	U, V : the different chroma parts

6.3.3.2 Context-based Coding of RUN Information

For encoding the RUN, the information of the initially encoded COEFF_COUNT and all previously encoded RUN elements is exploited, as shown in the pseudo-C code of FIGURE 18. Here, we make use of the fact that, if the maximum number of a RUN range is known in advance, the binarization can be restricted to a truncated code tree, which is explained in section 4.5.2.3.5. However, by using the information given by previously encoded RUNs the *MaxRun* counter can further be adapted on the fly, which may lead to potentially shorter binarized codewords of subsequent RUN elements to encode. In some cases, where, for instance, coefficients are aggregated at the end of the scan path, signaling of zero-valued RUN elements is completely omitted.

Context models for coding of RUN information depend on a threshold decision involving mostly the coefficient counter, *e.g.* in 4x4 single scan inter coding mode, the context model *ctx_run* for luma is given by *ctx_run = ((COEFF_COUNT) >= 4) ? 1 : 0.* For a more detailed description refer to Table 11. The idea behind this context design is that the COEFF_COUNT represents the activity of the given block, and that the probability distribution of the RUN symbol somehow depends on the activity of the block. First, the RUN is classified according the given block type, then a context *ctx_run* is chosen according to Table 11. For each context *ctx_run* two separate models are provided for the coding of RUN; one model for the first bin and the second model for all remaining bins of the binary codeword related to RUN.

Table 11

Description of the context formation for RUNs
(the variable i denotes the coefficient counter (i ∈ {0,..,(COEFF_COUNT-1)}

Block Type	***Description of the context formation for the runs)***
0,3,6,7	ctx_run = ((COEFF_COUNT-i) >= 3) ? 1 : 0;
1	ctx_run = (COEFF_COUNT >= 4) ? 1 : 0;
2	ctx_run = ((COEFF_COUNT-i) >= 4) ? 1 : 0;
4,5	ctx_run = ((COEFF_COUNT-i) >= 2) ? 1 : 0;

6.3.3.3 Context-based Coding of LEVEL Information

LEVEL information is first separated into sign and magnitude. Then the magnitude and sign of LEVEL, are first classified based on the block type. For coding of *ABS_LEVEL=abs(LEVEL)* context models depending on the previously encoded or decoded *ABS_LEVEL* within a given block are applied. More specifically, the following context model is defined for bins of the magnitude *ABS_LEVEL:*

Context Model for ABS_LEVEL

```
if (bin_nr>3)
        bin_nr=3;
end
if (Prev_level>MAX_LEVEL)
        Prev_level=MAX_LEVEL;
end
context_nr = (bin_nr-1)*MAX_LEVEL+Prev_level,
```

where *MAX_LEVEL=3,* and where the *Prev_level* is initialized to zero at the beginning of each block and updated after each en-/decoding step by the most recently en-/decoded ABS_LEVEL value. Note that for double-scan, *Prev_level* is initialized at the beginning of each scan, i.e., twice per block.

6.4 Double Scan Always for CABAC Intra Mode

In the UVLC mode, the scan mode for intra coding depends on the QP value: for QP < 24 the double scan is used, whereas for QP≥24 the single scan mode is employed. In the contrast to that, CABAC entropy coding always uses the double scan mode, independently of the given QP value.

6.5 Context Modeling for Coding of Dquant

For a given macroblock, the value of Dquant is first mapped to a positive value using the arithmetic wrap as described in section 4.4.8. This wrapped value *C* is then coded conditioned on the corresponding Dquant *A* of the left neighboring macroblock, such that that *ctx_dquant(C)=(A !=0);* This results in 2 context models for the first bin. Two additional models are used for the second and all remaining bins of the binarized value *C*. Thus, a total sum of four context models are used for Dquant.

TABLE 11

Binarization by means of the unary code tree

Code symbol	Binarization							
0	1							
1	0	1						
2	0	0	1					
3	0	0	0	1				
4	0	0	0	0	1			
5	0	0	0	0	0	1		
6	0	0	0	0	0	0	1	
. . .	.	.	.	.	.	.	.	.
Bin_no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	. .

6.6 Binarization of Non-Binary Valued Symbols

A non-binary valued symbol will be decomposed into a sequence of binary decisions. Except for the MB_type syntax element we use the binarization given by the unary code tree in Table 12.

TABLE 12

(a) Binarization for P-frame MB_type and (b) for B-frame MB_type

P_MB_type	Binarization
0	0
1	1 0 0
2	1 0 1
3	1 1 0 0 0
4	1 1 0 0 1
5	1 1 0 1 0
6	1 1 0 1 1
7	1 1 1 0 0
8	1 1 1 0 1
9	1 1 1 1 0
Bin_no	**1 2 3 4 5**

B_MB_type	Binarization
0	0
1	1 0 0
2	1 0 1
3	1 1 0 0 0
4	1 1 0 0 1
5	1 1 0 1 0
6	1 1 0 1 1
7	1 1 1 0 0 0 0
.	.
17	1 1 1 1 0 1 0
Bin_no	**1 2 3 4 5 6 7**

For the binary decomposition of the MB_type symbols of P- or B-frames, which are of limited range (0 … 9) or (0 … 17) respectively, an alternative binarization is used, which is shown in TABLE 14.

6.6.1 Truncated Binarization for RUN, COEFF_COUNT and Intra Prediction Mode

If the maximum number of a given syntax element is known in advance, the binarization can be restricted to a truncated code tree. Suppose the alphabet size of a specific syntax element is fixed, then for the unary binarization of the maximum value of this syntax element the terminating "1" can be omitted. This mechanism applies for RUN, COEFF_COUNT and Intra Prediction Mode.

6.7 Adaptive Binary Arithmetic Coding

At the beginning of the overall encoding of a given frame the probability models associated with all 126 different contexts are initialized with a pre-computed start distribution. For each symbol to encode the frequency count of the related binary decision is updated, thus providing a new probability estimate for the next coding decision. However, when the total number of occurrences of a given model exceeds a pre-defined threshold, the frequency counts will be scaled down. This periodical rescaling exponentially weighs down past observations and helps to adapt to the non-stationarity of a source.

The binary arithmetic coding engine used in our presented approach is a straightforward implementation similar to that given in "Arithmetic Coding Revisited", Moffat, Neal, Witten. ACM Transactions on Information Systems, 16(3):256-294, July 1998.

[Editor: This must be improved by the area assistant editor.]

7 B-pictures

7.1 Introduction

Temporal scalability is achieved using bi-directionally predicted pictures, or B pictures. The use of B pictures is indicated in PTYPE. The B pictures are predicted from either or both the previous and subsequent reconstructed pictures to achieve improved coding efficiency as compared to that of P pictures. FIGURE 19 illustrates the predictive structure with two B pictures inserted between I/P pictures.

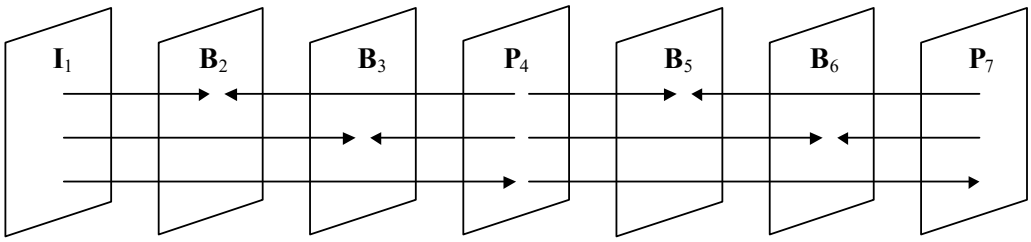


FIGURE 19

Illustration of B picture concept.

The location of B pictures in the bitstream is in a data-dependence order rather than in temporal order. Pictures that are dependent on other pictures shall be located in the bitstream after the pictures on which they depend. For example, as illustrated in Figure A.1, B_2 and B_3 are dependent on I_1 and P_4, and B_5 and B_6 are dependent on P_4 and P_7. Therefore the bitstream syntax order of the encoded pictures would be I_1, P_4, B_2, B_3, P_7, B_5, B_6, … However, the display order of the decoded pictures should be I_1, B_2, B_3, P_4, B_5, B_6, P_7, … The difference between the bitstream order of encoded pictures and the display order of decoded pictures will increase latency and memory to buffer the P pictures.

There is no limit to the number of B pictures that may be inserted between each I/P picture pair. The maximum number of such pictures may be signaled by external means (for example Recommendation H.245). The picture height, width, and pixel aspect ratio of a B picture shall always be equal to those of its temporally subsequent reference picture.

The B pictures support multiple reference frame prediction. The maximum number of previous reference frames that may be used for prediction in B pictures must be less than or equal to the number of reference frames used in the immediately following P frame, and it may be signaled by external means (for example Recommendation H.245). The use of this mode is indicated by PTYPE.

7.2 Macroblock modes and 8x8 sub-partition modes

There are five different prediction types supported by B pictures. They are direct, forward, backward, bi-directional and the intra prediction modes. Both direct mode and bi-directional mode are bi-directional prediction. The only difference is that the bi-directional mode uses separate motion vectors for forward and backward prediction, whereas the forward and backward motion vectors of the direct mode are derived from the motion vectors used in the corresponding macroblocks of the subsequent reference frame. In the direct mode, the same number of motion vectors as in the co-located macroblock of the temporal following reference picture is used. To calculate prediction blocks for the direct and bi-directional prediction mode, the forward and backward motion vectors are used to obtain appropriate blocks from reference frames and then these blocks are averaged by dividing the sum of the two prediction blocks by two.

Forward prediction means prediction from a previous reference picture, and backward prediction means prediction from a temporally subsequent reference picture.

The intra prediction means to encode the macroblock by using intra coding.

For B-frames, a similar tree-structured macroblock partitioning as in P-pictures is used. As in P-frames, one reference frame parameter is transmitted for each 16x16, 16x8, and 8x16 block as well as for each 8x8 sub-partition. Additionally, for each 16x16, 16x8, 8x16 block, and each 8x8 sub-partition, the prediction direction (forward, backward, bi-directional) can be chosen separately. For avoiding a separate code word to specify the prediction direction, the indication of the prediction direction is incorporated into the codewords for macroblock modes and 8x8 partitioning modes, respectively, as shown in the table Table 12 and Table 13. Moreover, an 8x8 sub-partition of a B-frame macroblock can also be coded in Direct mode.

Table 12: Macroblock modes for B-frames

Code number	Macroblock mode	1. block	2. block
0	Direct		
1	16x16	Forw.	
2	16x16	Backw.	
3	16x16	Bidirect.	
4	16x8	Forw.	Forw.
5	8x16	Forw.	Forw.
6	16x8	Backw.	Backw.
7	8x16	Backw.	Backw.
8	16x8	Forw.	Backw.
9	8x16	Forw.	Backw.
10	16x8	Backw.	Forw.
11	8x16	Backw.	Forw.
12	16x8	Forw.	Bidirect.
13	8x16	Forw.	Bidirect.
14	16x8	Backw.	Bidirect.
15	8x16	Backw.	Bidirect.
16	16x8	Bidirect.	Forw.
17	8x16	Bidirect.	Forw.
18	16x8	Bidirect.	Backw.
19	8x16	Bidirect.	Backw.
20	16x8	Bidirect.	Bidirect.
21	8x16	Bidirect.	Bidirect.
22	8x8(split)		
23	Intra4x4		
24 …	Intra16x16		

Table 13: Modes for 8x8 sub-partitions in B-frames

Code number	8x8 partition mode	Prediction
0	Direct	
1	8x8	Forw.
2	8x8	Backw.
3	8x8	Bidirect.
4	8x4	Forw.
5	4x8	Forw.
6	8x4	Backw.
7	4x8	Backw.
8	8x4	Bidirect.
9	4x8	Bidirect.
10	4x4	Forw.
11	4x4	Backw.

12	4x4	Bidirect.
13	Intra	

7.3 Syntax

Some additional syntax elements are needed for B pictures. The structure of B picture related fields is shown in FIGURE 20. On the Ptype, two picture types shall be added to include B pictures with and without multiple reference frame prediction. On the MB_type, different macroblock types are defined to indicate the different prediction types for B pictures. The fields of MVDFW, and MVDBW are inserted to enable bi-directional prediction. These fields replace the syntax element MVD.

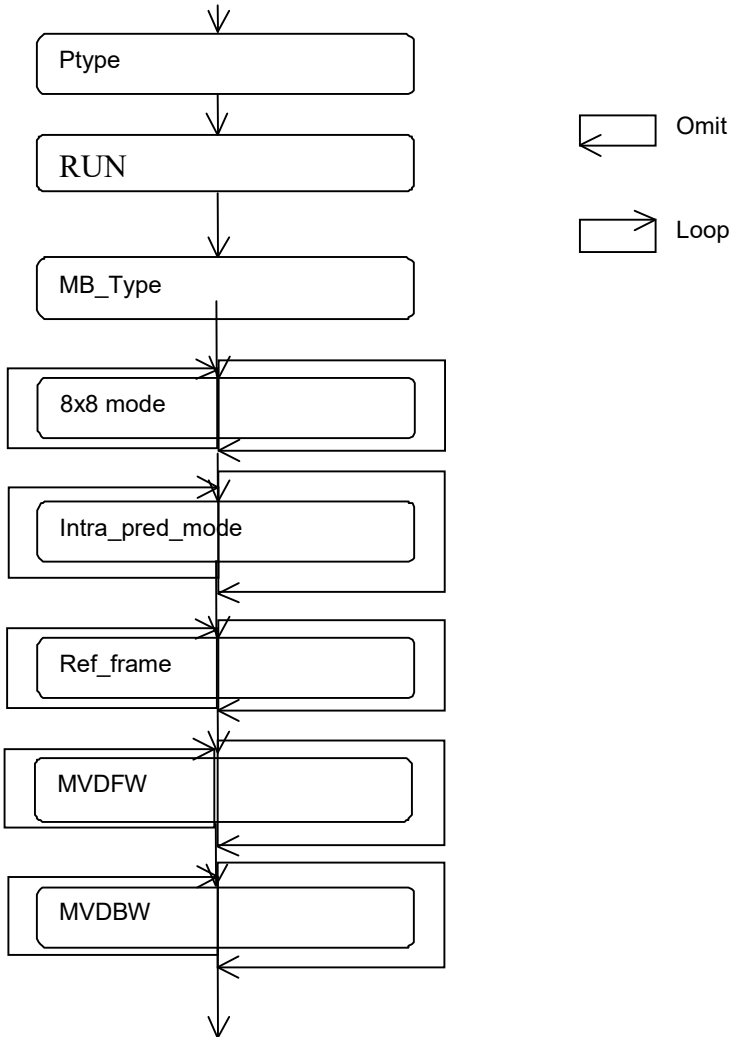


FIGURE 20

Syntax diagram for B pictures.*[Editor: Add PSTRUCT]*

7.3.1 Picture type (Ptype)), Picture Structure (PSTRUCT) and RUN

See section 3.1 for definition.

7.3.2 Macro block type (MB_type) and 8x8 sub-partition type

Table 12shows the macroblock modes for B pictures.

In "Direct" prediction type, no motion vector data is transmitted.

In NxM mode, each NxM block of a macroblock is predicted by using different motion vectors, reference frames, and prediction directions. As indicated in Table 12, three different macroblock modes that differ

in their prediction directions exist for the 16x16 mode. For the 16x8 and 8x16 macroblock modi, 9 different combinations of the prediction directions are possible. If a macroblock is transmitted in 8x8 mode, an additional codeword for each 8x8 sub-partition indicates the decomposition of the 8x8 block as well as the chosen prediction direction (see Table 13).

.

The "Intra_4x4" and "Intra_16x16" prediction type indicates that the macroblock is encoded by intra coding with different intra prediction modes which are defined in the same manner as in section 4.4.4 and TABLE 7. No motion vector data is transmitted for the intra macroblocks or 8x8 sub-partition coded in intra mode.

7.3.3 Intra prediction mode (Intra_pred_mode)

As present, Intra_pred_mode indicates which intra prediction mode is used. Intra_pred_mode is present when Intra_4x4 prediction type is indicated in the MB_type or the 8x8 sub-partition type. The code_number is same as that described in the Intra_pred_mode entry of TABLE 7.

7.3.4 Reference Picture (Ref_picture)

At present, Ref_picture indicates the position of the reference picture in the reference picture buffer to be used for forward motion-compensated for current macroblock. The reference frame parameter is transmitted for each 16x16, 16x8, 8x16 block, and each 8x8 sub-partition if forward or bi-directional prediction is used. Ref_picture is present only when the Ptype signals the use of multiple reference frames. Decoded I/P pictures are stored in the reference picture buffer in first-in-first-out manner and the most recently decoded I/P picture is always stored at position 0 in the reference frame buffer. The code_number and interpretation for Ref_picture differs for PSTRUCT indicating field picture or frame picture and is the same as the definition for REF_picture in section 3.4.4.

Note that whenever PSTRUCT indicates that the current picture is a field picture and when the present MB_type indicates Backward_NxM or Bi-directional prediction type, the backward reference is the immediately following I or P field of the same field parity (in display order). If PSTRUCT indicates a frame, then the backward reference is the immediately following I or P frame (in display order).

TABLE 14

Code_number for ref_frame

Code_number	Reference frame
0	The most recent previous frame (1 frame back)
1	2 frames back
2	3 frames back
…	…

7.3.5 Motion vector data (MVDFW, MVDBW)

MVDFW is the motion vector data for the forward vector, if present. MVDBW is the motion vector data for the backward vector, if present. If so indicated by MB_type and/or 8x8 sub-partition type, vector data for 1-16 blocks are transmitted. The order of transmitted motion vector data is the same as thatindicated in FIGURE 2. For the code_number of motion vector data, please refer to TABLE 7.

7.4 Decoder Process for motion vector

7.4.1 Differential motion vectors

Motion vectors for forward, backward, or bi-directionally predicted blocks are differentially encoded. A prediction has to be added to the motion vector differences to get the motion vectors for the macroblock.

The predictions are formed in way similar to that described in section 4.4.6. The only difference is that forward motion vectors are predicted only from forward motion vectors in surrounding macroblocks, and backward motion vectors are predicted only from backward motion vectors in surrounding macroblocks.

If a neighboring macroblock does not have a motion vector of the same type, the candidate predictor for that macroblock is set to zero for that motion vector type.

7.4.2 Motion vectors in direct mode

In direct mode the same block structure as for the co-located macroblock in the temporally subsequent picture is used. For each of the sub-blocks the forward and backward motion vectors are computed as scaled versions of the corresponding vector components of the co-located macroblock in the temporally subsequent picture as described below.

If the multiple reference frame prediction is used, the forward reference frame for the direct mode is the same as the one used for the corresponding macroblock in the temporally subsequent reference picture. The forward and backward motion vectors for direct mode macroblocks are calculated differently depending on whether PSTRUCT and the reference are fields or frames. Also note that if the subsequent reference picture is an intra-coded frame or the reference macroblock is an intra-coded block, the motion vectors are set to zero. With possible adaptive switch of frame/field coding at picture level, a B-frame or its future reference frame can be coded in either frame structure or field structure. Hence, there can be four different combinations of frame or field coding for a pair of a MB in B and its collocated MB in the future reference. Calculations of the two MVs in direct mode are slightly different for the four cases.

Case 1: Both the current MB and its collocated are in frame mode

Both the current B and its future reference are in frame structure, as shown in Fig. 4. The forward reference is the frame pointed by the forward MV of the collocated MB and the backward reference is the immediate future reference frame of I or P. Two MVs (MV_F, MV_B) are calculated by (see Fig. 4)

$$MV_F = TR_B \cdot MV / TR_D$$
$$MV_B = (TR_B - TR_D) \cdot MV / TR_D$$

where TR_B is the temporal distance between the current B frame and the reference frame pointed by the forward MV of the collocated MB, and TR_D is the temporal distance between the future reference frame and the reference frame pointed by the forward MV of the collocated MB.

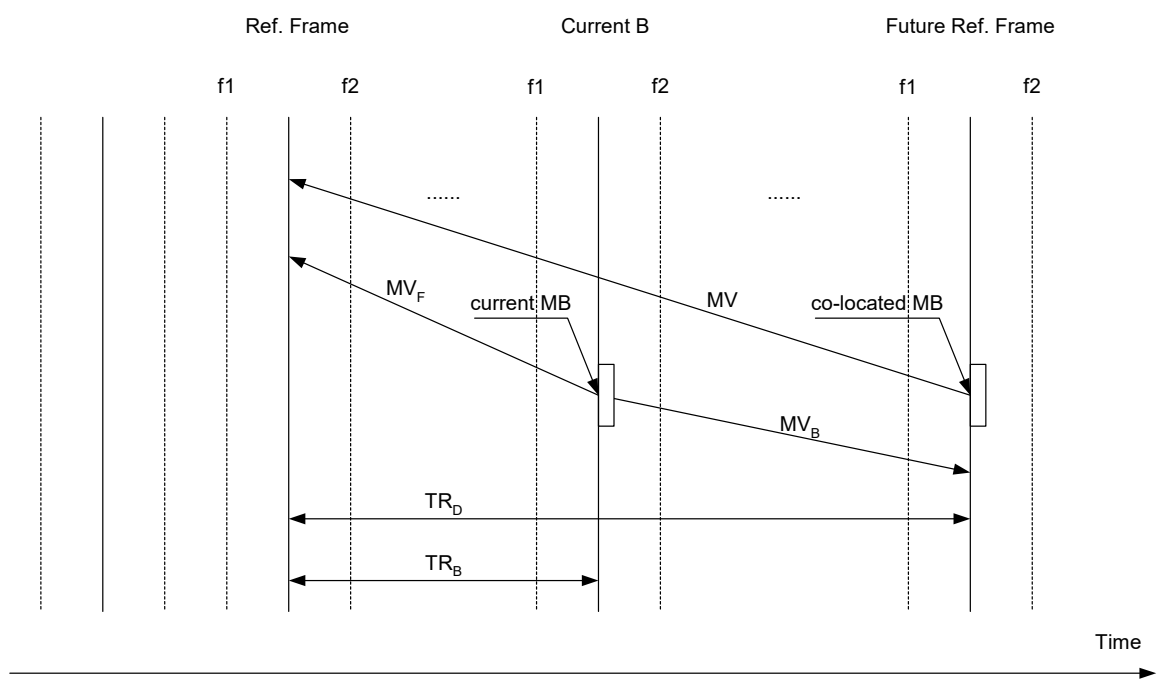


FIGURE 21

Both the current MB in B and its collocated MB in the future reference of I or P are in frame mode. Solid-line is for frames and dot-line for fields. f1 stands for field 1 and f2 for field 2.

Case 2: Both the current MB and its collocated MB are in field mode

Both the current B frame and its future reference are in field structure. Two MVs of direct mode MB in B field are calculated from the forward MV of the collocated MB in the future reference field of the same parity. For field 1, the forward MV of the collocated MB will always point to one of the previously coded I or P fields, as shown in Fig. 5. The forward reference field for the direct mode MB will be the same as pointed by the forward MV of the collocated MB, and the backward reference field will be field 1 of the future reference frame. The forward and backward MVs $(MV_{F,i}, MV_{B,i})$ for the direct mode MB are calculated as follows,

$$MV_{F,i} = TR_{B,i} \cdot MV_i / TR_{D,i}$$
$$MV_{B,i} = (TR_{B,i} - TR_{D,i}) \cdot MV_i / TR_{D,i}$$

where the subscript, i, is the field index (1 for the 1st field and 2 for the 2nd field), and MV_i is the forward MV of the collocated MB in field i of the future reference frame. $TR_{B,i}$ is the temporal distance between the current B field (i) and the reference field pointed by the forward MV of the collocated MB in field interval, $TR_{D,i}$ is the temporal distance between the future reference field (i) and the reference field pointed by the forward MV of the collocated MB in field interval.

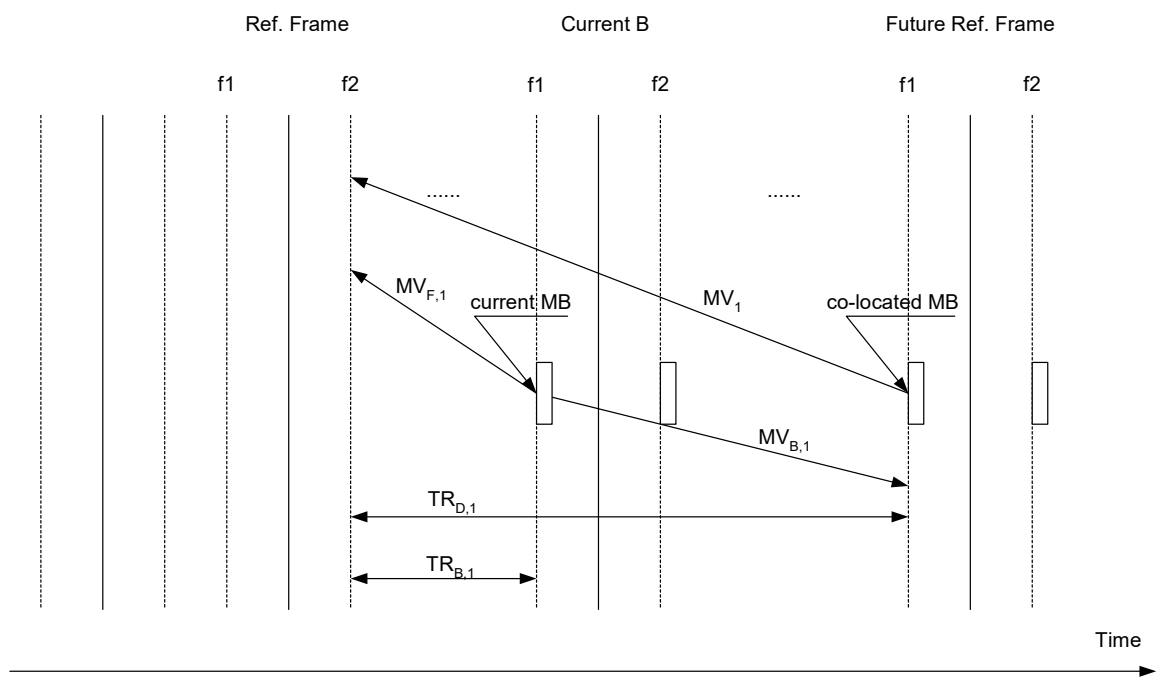


FIGURE 22

Both the current MB in B and its collocated MB in the future reference of I or P are in field mode. Solid-line is for frames and dot-line for fields. f1 stands for field 1 and f2 for field 2. The forward MV of the collocated MB in field 1 of the future reference always points to one of the previously coded I or P fields.

For field 2, the forward MV of the collocated MB may point to one of the previously coded I or P fields. Calculation of the forward and backward MVs therefore follows the same equation (2) above. However, it is also possible that the forward MV of the collocated MB in field 2 of the future reference frame points to field 1 of the same frame, as shown in Fig. 6. In this case, the two MVs $(MV_{F,2}, MV_{B,2})$ of the direct mode MB are calculated as follows:

$$MV_{F,2} = -TR_{B,2} \cdot MV_2 / TR_{D,2}$$
$$MV_{B,2} = -(TR_{B,2} + TR_{D,2}) \cdot MV_2 / TR_{D,2}$$

Note that both MVs $(MV_{F,2}, MV_{B,2})$ are now backward MVs, pointing to field 1 and field 2 of the future reference frame respectively.

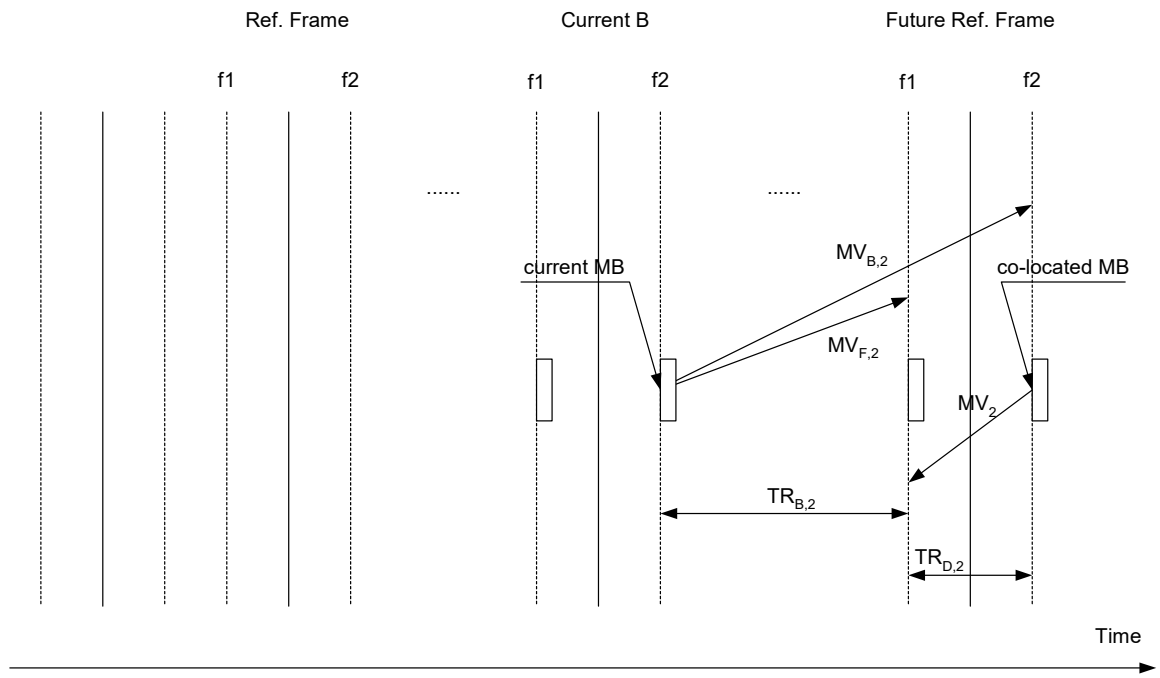


FIGURE 23

Both the current MB in B and its collocated MB in the future reference of I or P are in field mode. Solid-line is for frames and dot-line for fields. f1 stands for field 1 and f2 for field 2. The forward MV of the collocated MB in field 2 of the future reference frame may point to field 1 of the same frame.

Case 3:The current MB is field mode and its collocated MB in frame mode

The current B is in field structure while its future reference is in frame structure, as shown in Fig. 7. Let $y_{current_MB}$ and $y_{collocated_MB}$ be the notations of the vertical indexes of the current MB and its collocated MB respectively. Then, $y_{collocated_MB} = 2y_{current_MB}$. Two MVs of direct mode MB are calculated from the forward MV of the collocated MB in the future reference frame as follows

$$MV_{F,i} = TR_{B,i} \cdot MV / TR_D$$
$$MV_{B,i} = (TR_{B,i} - TR_D) \cdot MV / TR_D$$

Since the collocated MB is frame coded, MV in (4) is derived by dividing the associated frame-based MV by 2 in vertical direction. Forward reference field of direct mode MB is the same parity field in the reference frame used by its collocated MB. Backward reference field is the same parity field of the future reference frame.

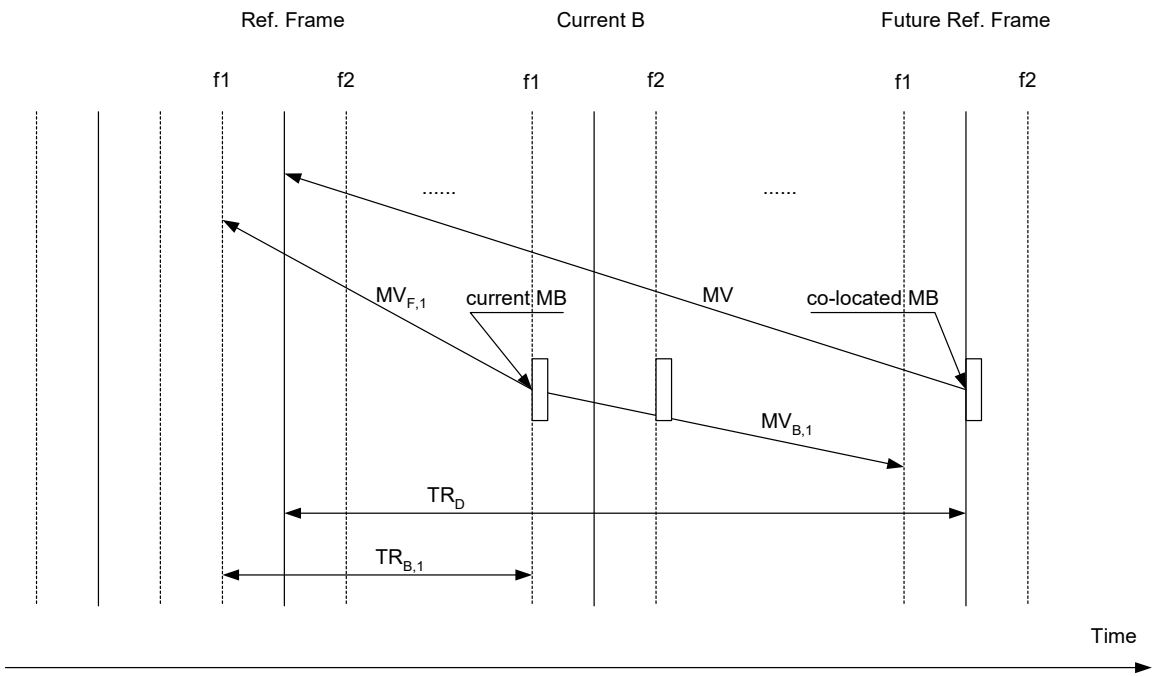


FIGURE 24

The current MB in B is in field mode while its collocated MB in the future reference of I or P in frame mode. Solid-line is for frames and dot-line for fields. f1 stands for field 1 and f2 for field 2.

Case 4: The current MB is in frame mode while its collocated MB in fieldmode

The current B is in frame structure while its future reference is in field structure, as shown in Fig. 8. Let $y_{current_MB}$ and $y_{collocated_MB}$ be the notations of the vertical indexes of the current MB and its collocated MB respectively. Then, $y_{collocated_MB} = y_{current_MB}/2$. The two fields of the collocated MB in the future reference may be coded in different modes. Since field 1 of the future reference is temporally close to the current B, the collocated MB in field 1 of the future reference provides certain basis for the current MB. Hence, the collocated MB in field 1 of the future reference is used in calculating the MVs and determining the references for direct mode. Two frame-based MVs (MV_F, MV_B) of direct mode MB are calculated as follows

$$MV_F = TR_B \cdot MV_1 / TR_{D,1}$$
$$MV_B = (TR_B - TR_{D,1}) \cdot MV_1 / TR_{D,1}$$

where MV_1 is derived by doubling the field-based MV of the collocated MB in field 1 of the future reference in vertical direction, TR_B is the temporal distance between the reference frame of one of whose fields is pointed by the forward MV of the collocated MB in field 1 of the future reference and the current B frame in field interval, and $TR_{D,1}$ is the temporal distance between field 1 of the future reference and the reference field pointed by the forward MV of the collocated MB in field 1 of future reference. Forward reference frame of the direct mode MB is the frame of one of whose fields is pointed by the forward field MV of the collocated MB in field 1 of the future reference frame. Backward reference frame is the future reference frame.

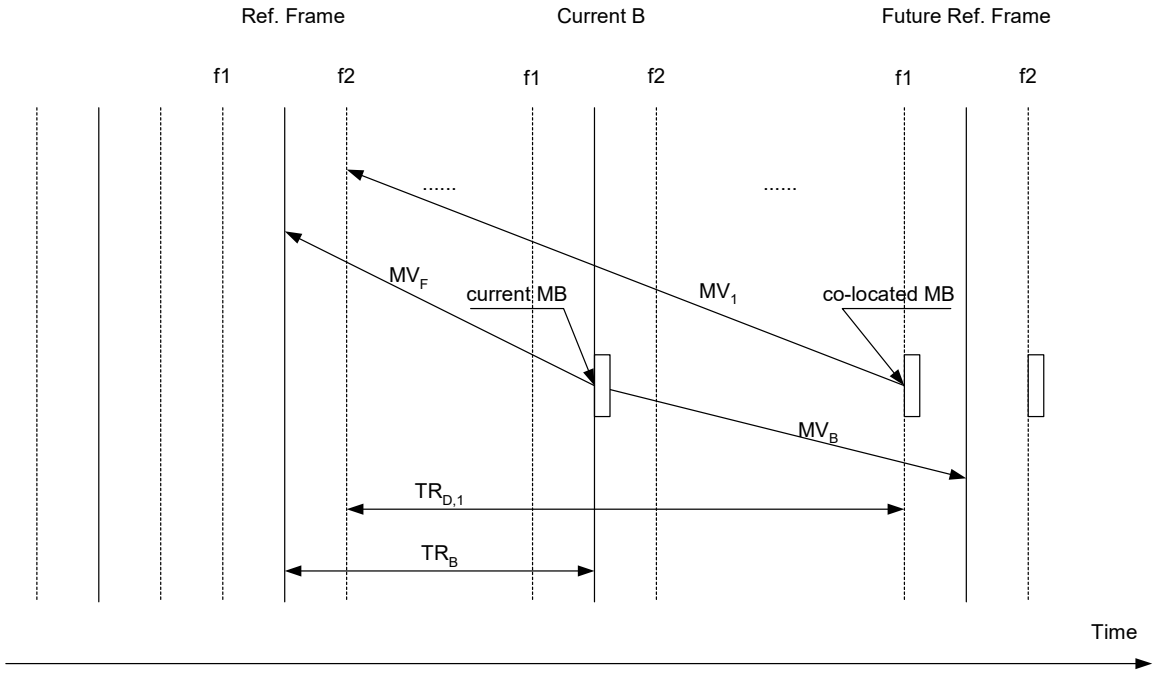


FIGURE 25

The current MB in B is in frame mode while its collocated MB in the future reference of I or P is in field mode. Solid-line is for frames and dot-line for fields. f1 stands for field 1 and f2 for field 2.

8 SP-pictures

There are two types of S-pictures, namely SP-pictures and SI-pictures. SP-pictures make use of motion-compensated predictive coding to exploit temporal redundancy in the sequence similar to P-pictures and SI-pictures make use of spatial prediction similar to I-pictures. Unlike P-pictures, however, SP-picture coding allows identical reconstruction of a frame even when different reference frames are being used. SI-picture, on the other hand, can identically reconstruct a corresponding SP-picture. These properties of S-pictures provide functionalities for bitstream switching, splicing, random access, VCR functionalities such as fast-forward and error resilience/recovery.

8.1 Syntax

The use of S-pictures is indicated by PTYPE. If PTYPE indicates an S-picture, quantization parameter PQP is followed by an additional quantization parameter SPQP in the slice header, see Section **Error! Reference source not found.**. The rest of the syntax elements for SP-pictures are the same as those in Inter-frames. Similarly, the rest of the syntax elements for SI-pictures are the same as those in I-pictures.

8.1.1 Picture type (Ptype) and RUN

See Section **Error! Reference source not found.** for definition.

8.1.2 Macro block type (MB_Type)

MB_Type indicates the prediction mode and the block size used to encode each macroblock. There are different MB types for SP and SI-pictures.

8.1.3 Macroblock modes for SI-pictures

The MB types for SI-pictures are similar to those of I-pictures with an additional MB type, called SIntra 4x4. TABLE 15 depicts the relationship between the code numbers and MB_Type for SI-pictures.

SIntra 4x4	SI Mode.
Intra 4x4	4x4 Intra coding.
Imode, nc, AC	See definition in Section **Error! Reference source not found.**. These modes refer to 16x16 intra coding.

TABLE 15

MB Type for SI-Pictures

Code_ number	MB_Type (SI-pictures)
0	SIntra 4x4
1	Intra 4x4
2	0,0,0[1]
3	1,0,0
4	2,0,0
5	3,0,0
6	0,1,0
7	1,1,0
8	2,1,0
9	3,1,0
10	0,2,0
11	1,2,0
12	2,2,0
13	3,2,0
14	0,0,1
15	1,0,1
16	2,0,1
17	3,0,1
18	0,1,1
19	1,1,1
20	2,1,1
21	3,1,1
22	0,2,1

23	1,2,1
24	2,2,1
25	3,2,1

[1] 16x16 based intra mode. The 3 numbers refer to values for (Imode,AC,nc) - see **Error! Reference source not found.**.

8.1.4 Macroblock Modes for SP-pictures

The MB types for SP-pictures are identical to those of P-pictures, see Section **Error! Reference source not found.** and TABLE 7. However, all of the inter mode macroblocks, i.e., Skip and NxM, in SP frames refer to SP mode.

8.1.5 Intra Prediction Mode (Intra_pred_mode)

Intra_pred_mode is present when Intra 4x4 or SIntra 4x4 prediction types are indicated by the MB_Type. Intra_pred_mode indicates which intra prediction mode is used for a 4x4 block in the macroblock. The code_number for SIntra 4x4 is the same as that described in the Intra_pred_mode entry of TABLE 7.

Coding of Intra 4x4 prediction modes

Coding of the intra prediction modes for SIntra 4x4 blocks in SI-pictures is identical to that in I-pictures, i.e., the intra prediction modes of the neighboring blocks are taken into account as described in Section 3.4.3.1.1. Coding of the intra prediction modes for Intra 4x4 blocks in SI-pictures differs from I-picture coding if the neighboring block is coded in SIntra 4x4 mode. In this case the prediction mode of the neighboring Sintra 4x4 block is treated to be “mode 0: DC_prediction”.

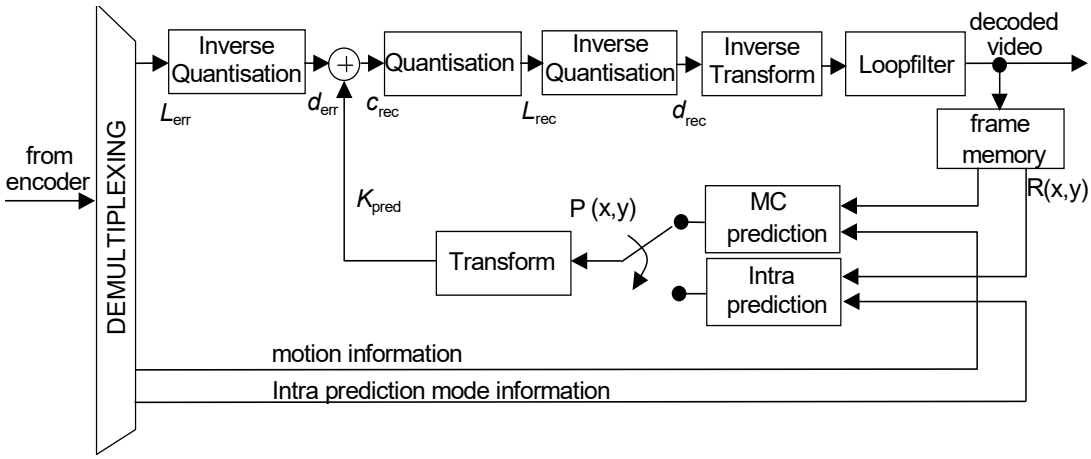


FIGURE 26

A generic block diagram of S-picture decoder

8.2 S-frame decoding

A video frame in SP-picture format consists of blocks encoded in either Intra mode (Intra 4x4, Intra 8x8 or Intra 16x16 Modes) or in SP mode (Skip or NxM). Similarly, SI-pictures consist of macroblocks encoded in either Intra mode or in SI mode (SIntra 4x4). Intra macroblocks are decoded identically to those in I- and P-pictures. FIGURE 26 depicts a generic S-picture decoding for SI and SP modes. In SP mode, the prediction P(x,y) for the current macroblock of the frame being decoded is formed by the motion compensated prediction block in the identical way to that used in P-picture decoding. In SI mode, the prediction P(x,y) is formed by intra prediction block in the identical way to that used in I-picture decoding. After forming the predicted block P(x,y), the decoding of SI and SP-macroblocks follows the same steps. Firstly, the received prediction error coefficients denoted by L_{err} are dequantized using quantization parameter PQP and the results are added to the transform coefficients K_{pred} of predicted block which are found by applying forward transform, see Section **Error! Reference source not found.**, to the predicted block. The resulting sum is quantized with the quantization parameter SPQP. These steps are combined in a single step as follows:

$$Y_{QREC}(i,j) = \frac{Y_{PRED}(i,j) \cdot Q((QP2+12)\%6,i,j) + Y_{QERR}(i,j) \cdot F(QP1,QP2,i,j) + f}{2^{15+(QP2+12)/6}}, \quad i,j = 0,\ldots,3$$

where

$$F(QP1,QP2,i,j) = \frac{Q((QP2+12)\%6,i,j) \cdot 2^{15+(QP2+12)/6} + Q((QP1+12)\%6,i,j)/2}{Q((QP1+12)\%6,i,j)}$$

and the values of f and the coefficients Q(m,i,j) are defined in Subsection 5.3.3.3. Here QP_1 is signaled by PQP value and the QP_2 is signaled by the additional QP parameter SPQP. Notice that when QP1=QP2, then the calculation of Y_{QREC} reduces simply to the sum of the received level and the level found by quantizing the predicted block coefficient. The coefficients Y_{QREC} are then dequantized using $QP=QP_2$ and inverse transform is performed for these dequantized levels, as defined in Subsections 0 and 5.3.1, respectively. Finally, after the reconstruction of a macroblock, filtering of this macroblock takes place as described in Section 8.2.2.

8.2.1 Decoding of DC values of Chrominance

The decoding of chrominance components for SP- and SI-macroblocks is similar to the decoding of luminance components described in Section 8.2. AC coefficients of the chrominance blocks are decoded following the steps described in the earlier section 8.2 where the quantization parameters PQP and SPQP are changed according to the relation between the quantization values of luminance and chrominance, as specified in Section **Error! Reference source not found.**. As described in Section **Error! Reference source not found.**, the coding of DC coefficients of chrominance components includes an additional 2x2 transform. Similarly, for SP and SI-macroblocks, an additional 2x2 transform is applied to the DC coefficients of the predicted 4x4 chrominance blocks and the steps described in Section 8.2 are applied to the 2x2 transform coefficients.

8.2.2 Deblocking Filter

When applying deblocking filter for macroblocks in S-frames, all macroblocks are treated as Intra macroblocks as described in Section **Error! Reference source not found.**.

9 Hypothetical Reference Decoder

9.1 Purpose

The hypothetical reference decoder (HRD) is a mathematical model for the decoder, its input buffer, and the channel. The HRD is characterized by the channel's peak rate R (in bits per second), the buffer size B (in bits), and the initial decoder buffer fullness F (in bits). These parameters represent levels of resources (transmission capacity, buffer capacity, and delay) used to decode a bit stream.

A closely related object is the leaky bucket (LB), which is a mathematical constraint on a bit stream. A leaky bucket is characterized by the bucket's leak rate R_1 (in bits per second), the bucket size B_1 (in bits), and the initial bucket fullness $B_1 - F_1$ (in bits). A given bit stream may be constrained by any number of leaky buckets $(R_1,B_1,F_1),\ldots,(R_N,B_N,F_N)$, $N \geq 1$. The LB parameters for a bit stream, which are encoded in the bit stream header, precisely describe the minimum levels of the resources R, B, and F that are sufficient to guarantee that the bit stream can be decoded.

9.2 Operation of the HRD

The HRD input buffer has capacity B bits. Initially, the buffer begins empty. At time t_{start} it begins to receive bits, such that it receives $S(t)$ bits through time t. $S(t)$ can be regarded as the integral of the instantaneous bit rate through time t. The instant at which $S(t)$ reaches the initial decoder buffer fullness F is identified as the decoding time t_0 of the first picture in the bit stream. Decoding times t_1, t_2, t_3, …, for subsequent pictures (in bit stream order) are identified relative to t_0, per Section 9.3. At each decoding time t_i, the HRD instantaneously removes and decodes all d_i bits associated with picture i, thereby reducing the decoder buffer fullness from b_i bits to $b_i - d_i$ bits. Between time t_i and t_{i+1}, the decoder buffer fullness increases from $b_i - d_i$ bits to $b_i - d_i + [S(t_{i+1}) - S(t_i)]$ bits. That is, for $i \geq 0$,

$$b_0 = F$$

$$b_{i+1} = b_i - d_i + [S(t_{i+1}) - S(t_i)].$$

The channel connected to the HRD buffer has peak rate R. This means that unless the channel is idle (whereupon the instantaneous rate is zero), the channel delivers bits into the HRD buffer at instantaneous rate R bits per second.

9.3 Decoding Time of a Picture

The decoding time t_i of picture i is equal to its presentation time τ_i, if there are no B pictures in the sequence. If there are B pictures in the sequence, then $t_i = \tau_i - m_i$, where $m_i = 0$ if picture i is a B picture; otherwise m_i equals $\tau_i - \tau_i'$, where τ_i' is the presentation time of the I or P picture that immediately precedes picture i (in presentation order). If there is no preceding I or P picture (i.e., if $i = 0$), then $m_i = m_0 = t_1 - t_0$. The presentation time of a picture is determinable from its temporal reference and the frame rate.

9.4 Schedule of a Bit Stream

The sequence (t_0,d_0), (t_1,d_1), (t_2,d_2), … is called the schedule of a bit stream. The schedule of a bit stream is intrinsic to the bit stream, and completely characterizes the instantaneous coding rate of the bit stream over its lifetime. A bit stream may be pre-encoded, stored to a file, and later transmitted over channels with different peak bit rates to decoders with different buffer sizes. The schedule of the bit stream is invariant over such transmissions.

9.5 Containment in a Leaky Bucket

A leaky bucket with leak rate R_1, bucket size B_1, and initial bucket fullness $B_1 - F_1$ is said to contain a bit stream with schedule (t_0,d_0), (t_1,d_1), (t_2,d_2), … if the bucket does not overflow under the following conditions. At time t_0, d_0 bits are inserted into the leaky bucket on top of the $B_1 - F_1$ bits already in the bucket, and the bucket begins to drain at rate R_1 bits per second. If the bucket empties, it remains empty until the next insertion. At time t_i, $i \geq 1$, d_i, bits are inserted into the bucket, and the bucket continues to drain at rate R_1 bits per second. In other words, for $i \geq 0$, the state of the bucket just prior to time t_i is

$b_0 = B_1 – F_1$

$b_{i+1} = \max\{0, b_i + d_i – R_1(t_{i+1}–t_i)\}$.

The leaky bucket does not overflow if $b_i + d_i \le B_1$ for all $i \ge 0$.

Equivalently, the leaky bucket contains the bit stream if the graph of the schedule of the bit stream lies between two parallel lines with slope R_1, separated vertically by B_1 bits, possibly sheared horizontally, such that the upper line begins at F_1 at time t_0, as illustrated in the figure below. Note from the figure that the same bit stream is containable in more than one leaky bucket. Indeed, a bit stream is containable in an infinite number of leaky buckets.

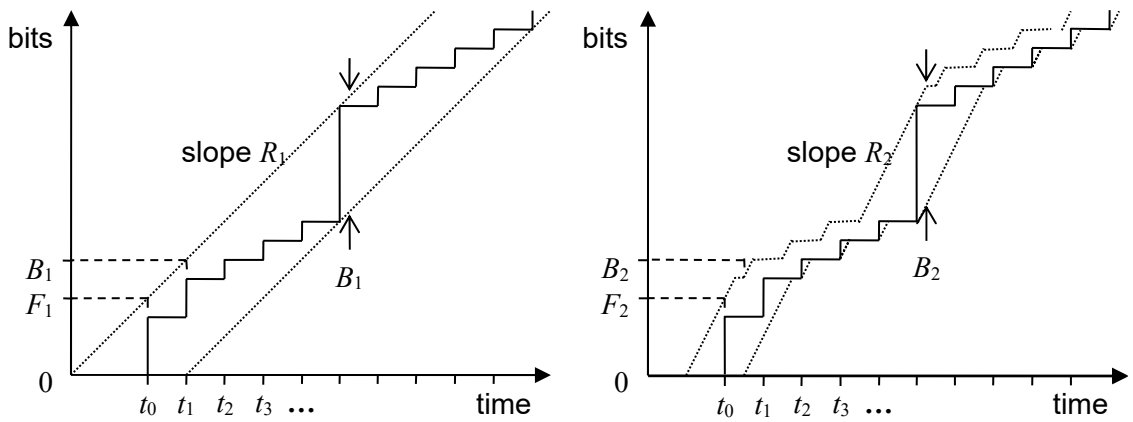


FIGURE 27

Illustration of the leaky bucket concept.

If a bit stream is contained in a leaky bucket with parameters (R_1,B_1,F_1), then when it is communicated over a channel with peak rate R_1 to a hypothetical reference decoder with parameters $R=R_1$, $B=B_1$, and $F=F_1$, then the HRD buffer does not overflow or underflow.

9.6 Bit Stream Syntax

The header of each bit stream shall specify the parameters of a set of $N \ge 1$ leaky buckets, $(R_1,B_1,F_1),\ldots,(R_N,B_N,F_N)$, each of which contains the bit stream. In the current Test Model, these parameters are specified in the first $1+3N$ 32-bit integers of the Interim File Format, in network (big-endian) byte order:

$N, R_1, B_1, F_1, \ldots, R_N, B_N, F_N$.

The R_n shall be in strictly increasing order, and both B_n and F_n shall be in strictly decreasing order.

These parameters shall not exceed the capability limits for particular profiles and levels, which are yet to be defined.

9.7 Minimum Buffer Size and Minimum Peak Rate

If a bit stream is contained in a set of leaky buckets with parameters $(R_1,B_1,F_1), \ldots, (R_N,B_N,F_N)$, then when it is communicated over a channel with peak rate R, it is decodable (i.e., the HRD buffer does not overflow or underflow) provided $B \ge B_{min}(R)$ and $F \ge F_{min}(R)$, where for $R_n \le R \le R_{n+1}$,

$B_{min}(R) = \alpha B_n + (1 – \alpha)B_{n+1}$

$F_{min}(R) = \alpha F_n + (1 – \alpha)F_{n+1}$

$\alpha = (R_{n+1} – R) / (R_{n+1} – R_n)$.

For $R \le R_1$,

$B_{min}(R) = B_1 + (R_1 – R)T$

$F_{min}(R) = F_1$,

where $T = t_{L-1} - t_0$ is the duration of the bit stream (i.e., the difference between the decoding times for the first and last pictures in the bit stream). And for $R \geq R_N$,

$$B_{min}(R) = B_N$$

$$F_{min}(R) = F_N .$$

Thus, the leaky bucket parameters can be linearly interpolated and extrapolated.

Alternatively, when the bit stream is communicated to a decoder with buffer size B, it is decodable provided $R \geq R_{min}(B)$ and $F \geq F_{min}(B)$, where for $B_n \geq B \geq B_{n+1}$,

$$R_{min}(B) = \alpha R_n + (1 - \alpha)R_{n+1}$$

$$F_{min}(B) = \alpha F_n + (1 - \alpha)F_{n+1}$$

$$\alpha = (B - B_{n+1}) / (B_n - B_{n+1}).$$

For $B \geq B_1$,

$$R_{min}(B) = R_1 - (B - B_1)/T$$

$$F_{min}(B) = F_1.$$

For $B \leq B_N$, the stream may not be decodable.

In summary, the bit stream is guaranteed to be decodable in the sense that the HRD buffer does not overflow or underflow, provided that the point (R,B) lies on or above the lower convex hull of the set of points $(0,B_1+R_1T)$, (R_1,B_1), …, (R_N,B_N), as illustrated in the figure below. The minimum start-up delay necessary to maintain this guarantee is $F_{min}(R) / R$.

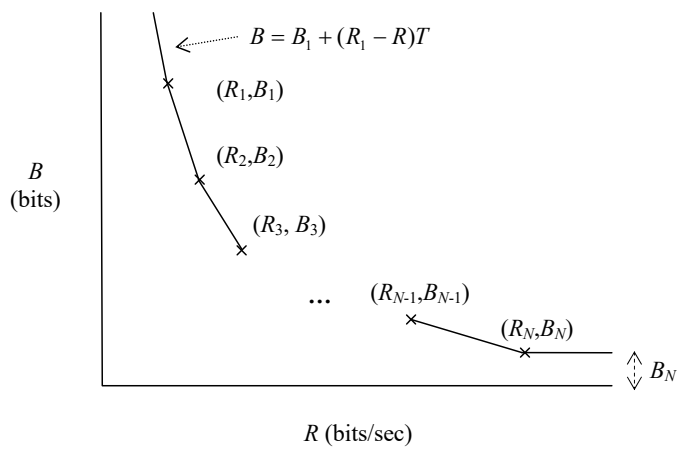


FIGURE 28

Illustration of the leaky bucket concept.

A compliant decoder with buffer size B and initial decoder buffer fullness F that is served by a channel with peak rate R shall perform the tests $B \geq B_{min}(R)$ and $F \geq F_{min}(R)$, as defined above, for any compliant bit stream with LB parameters $(R_1,B_1,F_1),\ldots,(R_N,B_N,F_N)$, and shall decode the bit stream provided that $B \geq B_{min}(R)$ and $F \geq F_{min}(R)$.

9.8 Encoder Considerations (informative)

The encoder can create a bit stream that is contained by some given N leaky buckets, or it can simply compute N sets of leaky bucket parameters after the bit stream is generated, or a combination of these. In the former, the encoder enforces the N leaky bucket constraints during rate control. Conventional rate control algorithms enforce only a single leaky bucket constraint. A rate control algorithm that simultaneously enforces N leaky bucket constraints can be obtained by running a conventional rate control algorithm for each of the N leaky bucket constraints, and using as the current quantization parameter (QP) the maximum of the QPs recommended by the N rate control algorithms.

Additional sets of leaky bucket parameters can always be computed after the fact (whether rate controlled or not), from the bit stream schedule for any given Rn, from the iteration specified in Section 9.5.

Appendix I Non-normative Encoder Recommendation

I.1 Motion Estimation and Mode Decision

I.1.1 Low-complexity mode

I.1.1.1 Finding optimum prediction mode

Both for intra prediction and motion compensated prediction, a similar loop as indicated in **Error! Reference source not found.** is run through. The different elements will be described below.

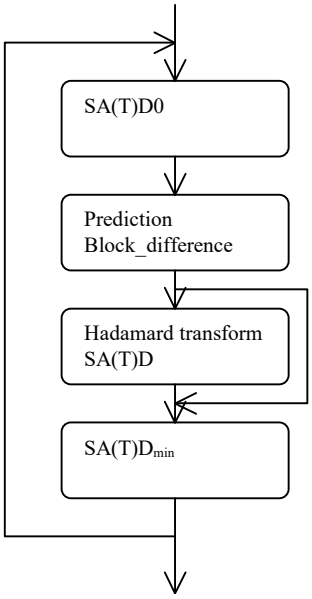


FIGURE 29

Loop for prediction mode decision

I.1.1.1.1 SA(T)D0

The SA(T)D to be minimised is given a 'bias' value SA(T)D0 initially in order to favour prediction modes that need few bits to be signalled. This bias is basically a parameter representing bit usage times $QP_0(QP)$

Intra mode decision: SA(T)D0 = $QP_0(QP)$xOrder_of_prediction_mode (see above)

Motion vector search: SA(T)D0 = $QP_0(QP)$x(Bits_to_code_vector + 2xcode_number_of_ref_frame)

In addition there are two special cases:

- For motion prediction of a 16x16 block with 0 vector components, 16x$QP_0(QP)$ is subtracted from SA(T)D to favour the skip mode.
- For the whole intra 4x4 macroblock, 24x$QP_0(QP)$ is added to the SA(T)D before comparison with the best SA(T)D for inter prediction. This is an empirical value to prevent using too many intra blocks.

For flat regions having zero motion, B pictures basically fail to make effective use of zero motion and instead are penalized in performance by selecting 16x16 intra mode. Therefore, in order to prevent assigning 16x16 intra mode to a region with little details and zero motion, SA(T)D of direct mode is subtracted by 16x$QP_0(QP)$ to bias the decision toward selecting the direct mode.

The calculation of SA(T)D0 at each mode is as follows.

- Forward prediction mode :
  SA(T)D0 = $QP_0(QP)$ x (2xcode_number_of_Ref_frame + Bits_to_code_MVDFW)
- Backward prediction mode :
  SA(T)D0 = $QP_0(QP)$ x Bits_to_code_MVDBW

- Bi-directional prediction mode :
  SA(T)D0 = QP_0(QP) x (2xcode_number_of_Ref_frame + Bits_to_code_forward_Blk_size + Bits_to_code_backward_Blk_size + Bits_to_code_MVDFW + Bits_to_code_MVDBW)
- Direct prediction mode :
  SA(T)D0 = – 16 x QP_0(QP)
- Intra 4x4 mode :
  SA(T)D0 = 24 x QP_0(QP)
- Intra 16x16 mode :
  SA(T)D0 = 0

I.1.1.1.2 Block_difference

For the whole block the difference between the original and prediction is produced

Diff(i,j) = Original(i,j) - Prediction(i,j)

I.1.1.1.3 Hadamard transform

For integer pixel search (see below) we use SAD based on Diff(i,j) for decision. Hence no Hadamard is done and we use SAD instead of SATD.

$$SAD = \sum_{i,j} \left| Diff(i,j) \right|$$

However, since we will do a transform of Diff(i,j) before transmission, we will do a better optimisation if a transform is done before producing SAD. Therefore a two dimensional transform is performed in the decision loop for selecting intra modes and for fractional pixel search (see below). To simplify implementation, the Hadamard transform is chosen in this mode decision loop. The relation between pixels and basis vectors (BV) in a 4 point Hadamard transform is illustrated below (not normalized):

```
     Pixels →
B    1    1   1   1
V    1    1  -1  -1
↓    1   -1  -1   1
     1   -1   1  -1
```

This transformation is performed horizontally and vertically and result in DiffT(i,j). Finally SATD for the block and for the present prediction mode is produced.

$$SATD = (\sum_{i,j} \left| DiffT(i,j) \right|) / 2$$

I.1.1.1.4 Mode decision

Choose the prediction mode that results in the minimum value SA(T)D_{min} = min(SA(T)D+SA(T)D0).

I.1.1.2 Encoding on macroblock level

I.1.1.2.1 Intra coding

When starting to code a macroblock, intra mode is checked first. For each 4x4 block, full coding indicated in **Error! Reference source not found.** is performed. At the end of this loop the complete macroblock is intra coded and a $SATD_{intra}$ is calculated.

I.1.1.2.2 Table for intra prediction modes to be used at the encoder side

Error! Reference source not found. gives the table of intra prediction modes according to probability of each mode to be used on the decoder side. On the encoder side we need a sort of inverse table. Prediction modes for A and B are known as in **Error! Reference source not found.**. For the encoder we have found a Mode that we want to signal with an ordering number in the bitstream (whereas on the

decoder we receive the order in the bitstream and want to convert this to a mode). **Error! Reference source not found.** is therefore the relevant table for the encoder. Example: Prediction mode for A and B is 2. The string in **Error! Reference source not found.** is 2 1 0 3 4 5. This indicates that prediction mode 0 has order 2 (third most probable). Prediction mode 1 is second most probable and prediction mode 2 has order 0 (most probable) etc. As in **Error! Reference source not found.** '–' indicates that this instance can not occur because A or B or both are outside the picture.

TABLE 16

Prediction ordering to be used in the bitstream as a function of prediction mode (see text).

B\A	outside	0	1	2	3	4	5
outside	0-----	021---	102---	120---	012---	012---	012---
0	0---12	025314	104325	240135	143025	035214	045213
1	0---12	014325	102435	130245	032145	024315	015324
2	0---12	012345	102345	210345	132045	032415	013245
3	0---12	135024	214035	320154	143025	145203	145032
4	1---02	145203	125403	250314	245103	145203	145302
5	1---20	245310	015432	120534	245130	245301	135420

I.1.1.2.3 Inter mode selection

Next motion vector search is performed for motion compensated prediction. A search is made for all 7 possible block structures for prediction as well as from the 5 past decoded pictures. This result in 35 combinations of blocksizes and reference frames. For B-frames, the motion search is also conducted for the temporal following reference picture to obtain backward motion vectors.

I.1.1.2.4 Integer pixel search

The search positions are organised in a 'spiral' structure around the <u>predicted</u> vector (see vector prediction). The numbering from 0 and upwards for the first positions are listed below:

```
.  .  .  .  .  .
. 15  9 11 13 16
. 17  3  1  4 18
. 19  5  0  6 20
. 21  7  2  8 22
. 23 10 12 14 24
```

A parameter MC_range is used as input for each sequence. To speed up the search process, the search range is further reduced:

- Search range is reduced to: Range = MC_range/2 for all block sizes except 16x16 in prediction from the most recent decoded picture.
- The range is further reduced to: Range = Range/2 for search relative to all older pictures.

After Range has been found, the centre for the spiral search is adjusted so that the (0,0) vector position is within the search range. This is done by clipping the horizontal and vertical positions of the search centre to ±Range.

I.1.1.2.5 Fractional pixel search

Fractional pixel search is performed in two steps. This is illustrated below where capital letters represent integer positions, numbers represent ½ pixel positions and lower case letters represent ¼ pixel positions.

```
A       B       C
    1   2   3
D   4   E   5   F
      a b c
```

```
        6 d 7 e 8
          f g h
   G        H        I
```

Assume that the integer search points to position E. Then ½ pixel positions 1,2,3,4,5,6,7,8 are searched. Assume that 7 is the best position. Then the ¼ pixel positions a,b,c,d,e,f,g,h are searched. (Notice that by this procedure a position with 'more low pass filtering' – see 5.2.1 - is automatically checked). If motion compensation with 1/8 pixel accuracy is used, an additional sub-pixel refinement step is performed in the described way. After fractional pixel search has been performed for the complete macroblock, the SATD for the whole macroblock is computed: $SATD_{inter}$.

I.1.1.2.6 Decision between intra and inter

If $SATD_{intra} < SATD_{inter}$ intra coding is used. Otherwise inter coding is used.

I.1.2 High-complexity mode

I.1.2.1 Motion Estimation

For each block or macroblock the motion vector is determined by full search on integer-pixel positions followed by sub-pixel refinement.

I.1.2.1.1 Integer-pixel search

As in low-complexity mode, the search positions are organized in a spiral structure around a prediction vector. The full search range given by MC_range is used for all INTER-modes and reference frames. To speed up the search process , the prediction vector of the 16x16 block is used as center of the spiral search for all INTER-modes. Thus the SAD values for 4x4 blocks can be pre-calculated for all motion vectors of the search range and than used for fast SAD calculation of all larger blocks. The search range is not forced to contain the (0,0)-vector.

I.1.2.1.2 Fractional pixel search

The fractional pixel search is performed as in the low-complexity case.

I.1.2.1.3 Finding the best motion vector

The integer-pixel motion search as well as the sub-pixel refinement returns the motion vector that minimizes

$$J(\mathbf{m}, \lambda_{MOTION}) = SA(T)D(s, c(\mathbf{m})) + \lambda_{MOTION} \cdot R(\mathbf{m} - \mathbf{p})$$

with $\mathbf{m} = (m_x, m_y)^T$ being the motion vector, $\mathbf{p} = (p_x, p_y)^T$ being the prediction for the motion vector, and λ_{MOTION} being the Lagrange multiplier. The rate term $R(\mathbf{m} - \mathbf{p})$ represents the motion information only and is computed by a table-lookup. The rate is estimated by using the universal variable length code (UVLC) table, even if CABAC is used as entropy coding method. For integer-pixel search, SAD is used as distortion measure. It is computed as

$$SAD(s,\ c(\mathbf{m})) = \sum_{x=1,\ y=1}^{B,\ B} \left| s[x, y] - c[x - m_x, y - m_y] \right|, \qquad B = 16, 8 \ or\ 4\ .$$

with s being the original video signal and c being the coded video signal. In the sub-pixel refinement search, the distortion measure SATD is calculated after a Hadamard transform (see section **Error! Reference source not found.**). The Lagrangian multiplier λ_{MOTION} is given by

$$\lambda_{MODE,P} = \sqrt{0.85 \cdot 2^{QP/3}}$$

for I- and P-frames and

$$\lambda_{MODE,B} = \sqrt{4 \cdot 0.85 \cdot 2^{QP/3}}$$

for B-frames, where QP is the macroblock quantization parameter.

I.1.2.1.4 Finding the best reference frame

The determination of the reference frame *REF* and the associated motion vectors for the *NxM* inter modes is done after motion estimation by minimizing

$$J(REF \mid \lambda_{MOTION}) = SATD(s, c(REF, \mathbf{m}(REF))) + \lambda_{MOTION} \cdot (R(\mathbf{m}(REF) - \mathbf{p}(REF)) + R(REF)).$$

The rate term $R(REF)$ represents the number of bits associated with choosing REF and is computed by table-lookup using UVLC.

I.1.2.1.5 Finding the best prediction direction for B-frames

The determination of the prediction direction *PDIR* for the *NxM* inter modes in B-frames is done after motion estimation and reference frame decision by minimizing

$$J(PDIR \mid \lambda_{MOTION}) = SATD(s, c(PDIR, \mathbf{m}(PDIR))) + \lambda_{MOTION} \cdot (R(\mathbf{m}(PDIR) - \mathbf{p}(PDIR)) + R(REF(PDIR)))$$

I.1.2.2 Mode decision

I.1.2.2.1 Macroblock mode decision

The macroblock mode decision is done by minimizing the Lagrangian functional

$$J(s, c, MODE \mid QP, \lambda_{MODE}) = SSD(s, c, MODE \mid QP) + \lambda_{MODE} \cdot R(s, c, MODE \mid QP)$$

where QP is the macroblock quantizer, λ_{MODE} is the Lagrange multiplier for mode decision, and $MODE$ indicates a mode chosen from the set of potential prediction modes:

I-frame: $MODE \in \{INTRA4x4,\ INTRA16x16\}$,

P-frame: $MODE \in \left\{ \begin{matrix} INTRA4x4,\ INTRA16x16,\ SKIP, \\ 16x16,\ 16x8,\ 8x16,\ 8x8 \end{matrix} \right\}$,

B-frame: $MODE \in \left\{ \begin{matrix} INTRA4x4,\ INTRA16x16,\ DIRECT, \\ 16x16,\ 16x8,\ 8x16,\ 8x8 \end{matrix} \right\}$.

Note that the $SKIP$ mode refers to the 16x16 mode where no motion and residual information is encoded. SSD is the sum of the squared differences between the original block s and its reconstruction c given as

$$SSD(s, c, MODE \mid QP) = \sum_{x=1,y=1}^{16,16} \left(s_Y[x,y] - c_Y[x,y,MODE \mid QP]\right)^2 + \sum_{x=1,y=1}^{8,8} \left(s_U[x,y] - c_U[x,y,MODE \mid QP]\right)^2 + \sum_{x=1,y=1}^{8,8} \left(s_V[x,y] - c_V[x,y,MODE \mid QP]\right)^2,$$

and $R(s, c, MODE \mid QP)$ is the number of bits associated with choosing $MODE$ and QP including the bits for the macroblock header, the motion, and all DCT blocks. $c_Y[x, y, MODE \mid QP]$ and $s_Y[x, y]$ represent the reconstructed and original luminance values; c_U, c_V and s_U, s_V the corresponding chrominance values.

The Lagrangian multiplier λ_{MODE} is given by

$$\lambda_{MODE,P} = 0.85 \cdot 2^{QP/3}$$

for I- and P-frames and

$$\lambda_{MODE,B} = 4 \cdot 0.85 \cdot 2^{QP/3}$$

for B-frames, where QP is the macroblock quantization parameter.

I.1.2.2.2 8x8 mode decision

The mode decision for 8x8 sub-partitions is done similar to the macroblock mode decision by minimizing the Lagrangian functional

$$J(s,c,MODE \mid QP,\lambda_{MODE}) = SSD(s,c,MODE \mid QP) + \lambda_{MODE} \cdot R(s,c,MODE \mid QP)$$

where QP is the macroblock quantizer, λ_{MODE} is the Lagrange multiplier for mode decision, and $MODE$ indicates a mode chosen from the set of potential prediction modes:

P-frame: $$MODE \in \begin{Bmatrix} INTRA\,4x4, \\ 8x8,\ 8x4,\ 4x8,\ 4x4 \end{Bmatrix}$$

B-frame: $$MODE \in \begin{Bmatrix} INTRA\,4x4,\ DIRECT, \\ 8x8,\ 8x4,\ 4x8,\ 4x4 \end{Bmatrix}.$$

I.1.2.2.3 INTER 16x16 mode decision

The *INTER16x16* mode decision is performed by choosing the INTER16x16 mode which results in the minimum SATD value.

I.1.2.2.4 INTER 4x4 mode decision

For the *INTRA4x4* prediction, the mode decision for each 4x4 block is performed similar to the macroblock mode decision by minimizing

$$J(s,c,IMODE \mid QP,\lambda_{MODE}) = SSD(s,c,IMODE \mid QP) + \lambda_{MODE} \cdot R(s,c,IMODE \mid QP)$$

where QP is the macroblock quantizer, λ_{MODE} is the Lagrange multiplier for mode decision, and $IMODE$ indicates an intra prediction mode:

$$IMODE \in \{DC,\ HOR,\ VERT,\ DIAG,\ DIAG_RL,\ DIAG_LR\}.$$

SSD is the sum of the squared differences between the original 4x4 block luminance signal s and its reconstruction *c,* and $R(s,c,IMODE \mid QP)$ represents the number of bits associated with choosing *IMODE.* It includes the bits for the intra prediction mode and the DCT-coefficients for the 4x4 luminance block. The rate term is computed using the UVLC entropy coding, even if CABAC is used for entropy coding.

I.1.2.3 Algorithm for motion estimation and mode decision

The procedure to encode one macroblock s in a I-, P- or B-frame in the high-complexity mode is summarized as follows.

1. Given the last decoded frames, λ_{MODE}, λ_{MOTION}, and the macroblock quantizer QP
2. Choose intra prediction modes for the *INTRA 4x4* macroblock mode by minimizing
   $J(s,c,IMODE \mid QP,\lambda_{MODE}) = SSD(s,c,IMODE \mid QP) + \lambda_{MODE} \cdot R(s,c,IMODE \mid QP)$
   with $IMODE \in \{DC,\ HOR,\ VERT,\ DIAG,\ DIAG_RL,\ DIAG_LR\}$.
3. Determine the best $INTRA16x16$ prediction mode by choosing the mode that results in the minimum SATD.
4. For each 8x8 sub-partition

Perform motion estimation and reference frame selection by minimizing

SSD + λ Rate(MV, REF)

B-frames: Choose prediction direction by minimizing

SSD + λ Rate(MV(PDIR), REF(PDIR))

Determine the coding mode of the 8x8 sub-partition using the rate-constrained mode decision, i.e. minimize

SSD + λ Rate(MV, REF, Luma-Coeff, block 8x8 mode)

Here the SSD calculation is based on the reconstructed signal after DCT, quantization, and IDCT.

5. Perform motion estimation and reference frame selection for 16x16, 16x8, and 8x16 modes by minimizing
$J(REF, \mathbf{m}(REF) \mid \lambda_{MOTION}) = SA(T)D(s, c(REF, \mathbf{m}(REF))) + \lambda_{MOTION} \cdot (R(\mathbf{m}(REF) - \mathbf{p}(REF)) + R(REF))$
for each reference frame and motion vector of a possible macroblock mode.
6. B-frames: Determine prediction direction by minimizing
$J(PDIR \mid \lambda_{MOTION}) = SATD(s, c(PDIR, \mathbf{m}(PDIR))) + \lambda_{MOTION} \cdot (R(\mathbf{m}(PDIR) - \mathbf{p}(PDIR)) + R(REF(PDIR)))$

7. Choose the macroblock prediction mode by minimizing
$J(s, c, MODE \mid QP, \lambda_{MODE}) = SSD(s, c, MODE \mid QP) + \lambda_{MODE} \cdot R(s, c, MODE \mid QP)$,
given QP and λ_{MODE} when varying $MODE$. $MODE$ indicates a mode out of the set of potential macroblock modes:

I-frame: $MODE \in \{INTRA4x4, INTRA16x16\}$,

P-frame: $MODE \in \begin{Bmatrix} INTRA4x4, INTRA16x16, SKIP, \\ 16x16, 16x8, 8x16, 8x8 \end{Bmatrix}$,

B-frame: $MODE \in \begin{Bmatrix} INTRA4x4, INTRA16x16, DIRECT, \\ 16x16, 16x8, 8x16, 8x8 \end{Bmatrix}$.

The computation of $J(s, c, SKIP \mid QP, \lambda_{MODE})$ and $J(s, c, DIRECT \mid QP, \lambda_{MODE})$ is simple. The costs for the other macroblock modes are computed using the intra prediction modes or motion vectors and reference frames, which have been estimated in the previous steps.

I.2 Quantization

$$Y_Q(i,j) = \left[Y(i,j) \cdot Q((QP+12)\%6, i, j) + f \right] / 2^{15+(QP+12)/6}$$

I.3 Elimination of single coefficients in inter macroblocks

I.3.1 Luminance

With the small 4x4 blocks, it may happen that for instance a macroblock has only one nonzero coefficient with |Level| =1. This will probably be a very expensive coefficient and it could have been better to set it to zero. For that reason a procedure to check single coefficients have been implemented for inter luma blocks. During the quantization process, a parameter **Single_ctr** is accumulated depending on Run and Level according to the following rule:

- If Level = 0 or (|Level| = 1 and Run > 5) nothing is added to Single_ctr.

- If |Level| > 1, 9 is added to Single_ctr.
- If |Level| = 1 and Run < 6, a value T(Run) is added to Single_ctr. where T(0:5) =(3,2,2,1,1,1)
- If the accumulated Single_ctr for a 8x8 block is less than 4, all coefficients of that luma block are set to zero. Similarly, if the accumulated Single_ctr for the whole macroblock is less than 6, all coefficients of that luma macroblock are set to zero.

I.3.2 Chrominance

A similar method to the one for luma is used. **Single_ctr** is calculated similarly for each chroma component, but for AC coefficients only and for the whole macroblock.

If the accumulated **Single_ctr** for each chroma component of a macroblock is less than 7, all the AC chroma coefficients of that component for the whole macroblock are set to zero.

I.4 S-Pictures

I.4.1 Encoding of secondary SP-pictures

This section suggests an algorithm that can be used to create a secondary SP-picture with identical pixel values to another SP-picture (called the target SP-picture). The secondary SP-picture is typically used for switching from one bitstream to another and thus has different reference frames for motion compensation than the target SP-picture.

Intra-type macroblocks from the target SP-picture are copied into the secondary SP-picture without alteration. SP-macroblocks from the target SP-pictures will be replaced by the following procedure: Let L_{rec} be the quantized coefficients, see Section 8.2, that are used to reconstruct the SP-block. Define the difference levels L_{err} by:

$$L_{err} = L_{rec} - L_P$$

where L_P is the quantized transform coefficients of the predicted block from any of the SP coding modes. Then a search over all the possible SP modes is performed and the mode resulting in the minimum number of bits is selected.

I.4.2 Encoding of SI-pictures

The following algorithm is suggested to encode an SI-picture such that the reconstruction of it is identical to that of an SP-picture. SP-pictures consist of intra and SP-macroblocks. Intra-type macroblocks from SP-pictures are copied into SI-pictures with minor alteration. Specifically, the MB_Type is altered to reflect Intra Modes in SI-pictures, i.e., MB_Type is incremented by one, See TABLE 15. The SP-macroblocks from SP-pictures will be replaced by SIntra 4x4 modes. Let L_{rec} be the quantized coefficients, see Section 8.2, that are used to reconstruct the SP-block. Define the difference levels L_{err} by:

$$L_{err} = L_{rec} - L_I$$

where L_I is the quantized transform coefficients of the predicted block from any of the intra prediction modes. Then a search over the possible intra prediction modes is performed and the mode resulting in the minimum number of bits is selected.

I.5 Encoding with Anticipation of Slice Losses

Low delay video transmission may lead to losses of slices. The decoder may then stop decoding until the next I picture or P picture may conduct a concealment, for example as explained in Appendix IV, and continue decoding. In the latter case, spatio-temporal error propagation occurs if the concealed picture content is referenced for motion compensation. There are various means to stop spatio-temporal error propagation including the usage of multiple reference pictures and Intra coding of macroblocks. For the latter case, a Lagrangian mode selection algorithm is suggested as follows.

Since transmission errors occur randomly, the decoding result is also a random process. Therefore, the average decoder distortion is estimated to control the encoder for a specified probability of packet losses p. The average decoding result is obtained by running N complete decoders at the encoder in parallel. The statistical process of loosing a slice is assumed to be independent for each of the N decoders. The slice loss process for each decoder is also assumed to be i.i.d. and a certain slice loss probability p is assumed to be known at the encoder. Obviously for large N the decoder gets a very good estimate of the average decoder distortion. However, with increasing N a linear increase of storage and decoder complexity in the encoder is incurred. Therefore, this method might not be practical in real-time encoding processes and complexity and memory efficient algorithms are currently under investigation.

To encode a macroblock in a P picture, the set of possible macroblock types is given as

$\mathcal{S}_{MB}$ = { SKIP, INTER_16x16, INTER_16x8, INTER_8x16, INTER_8x8, INTRA_16x16}

For each macroblock the coding mode m' is selected according to

$$m' = \min_{m \in \mathcal{S}_{MB}} \{ D_m + \lambda R_m \}$$

with D_m being the distortion in the current macroblock when selecting macroblock mode m and R_m being the corresponding rate, i.e. the number of bits. For the COPY_MB and all INTER_MxN types, the distortion D_m is computed as

$$D_m = \frac{1}{N} \sum_{n=1}^{N} \sum_{i} (f_i - \hat{f}_{i,n,m}(p))^2$$

with f_i being the original pixel value at position i within the macroblock and $\hat{f}_{i,n,m}$ being the reconstructed pixel value at position i for coding macroblock mode m in the simulated decoder n. The distortion for the INTRA macroblocks remains unchanged. Since the various reconstructed decoders also contain transmission errors, the Lagrangian cost function for the COPY_MB and all INTER_MxN types increases making INTRA_NxN types more popular.

The λ parameter for mode decision depends on the quantization parameter q as follows

$$\lambda = (1 - p) 0.85 \cdot 2^{QP/3} .$$

Appendix II Network Adaptation Layer

II.1 Byte Stream NAL Format

The byte stream NAL format is specified for use by systems that transmit JVT video as an ordered stream of bytes, such as ITU-T Rec. H.222.0 | ISO/IEC 13818-1 systems or ITU-T Rec. H.320 systems.

The byte stream NAL format consists of the sequence of video packets, each of which is prefixed as follows:

1. Optionally (at the discretion of the encoder if not prohibited by a system-level specification), any number of zero-stuffing bytes (ZSB) having the value zero.
2. A three-byte start code prefix (SCP), consisting of two bytes that are both equal to zero (0x00), followed by one byte having the value one (0x01).
3. The payload type indicator byte (PTIB),
4. One or more EBSP's then follows as determined by the PTIB.

Any number of zero-stuffing bytes (ZSB) may optionally (at the discretion of the encoder if not prohibited by a system-level specification) follow the last video packet in the byte stream.

The location of each SCP can be detected by scanning for the three-byte SCP value pattern in the byte stream.

The first EBSP starts immediately after the SCP and PTIB, and the last EBSP ends with the last non-zero byte prior to the next SCP.

II.2 IP NAL Format

This section covers the Network Adaptation Layer for non-managed, best effort IP networks using RTP [RFC1889] as the transport. The section will likely end up in the form of a standard's track RFC covering an RTP packetization for H.26L.

The NAL takes the information of the Interim File Format as discussed in section **Error! Reference source not found.** and converts it into packets that can conveyed directly over RTP. It is designed to be able to take advantage of more than one virtual transport stream (either within one RTP stream by unequal packet content protection currently discussed in the IETF and as Annex I of H.323, or by using several RTP streams with network or application layer unequal error protection).

In doing so, it has to

- arrange partitions in an intelligent way into packets
- eventually split/recombine partitions to match MTU size constraints
- avoid the redundancy of (mandatory) RTP header information and information in the video stream
- define receiver/decoder reactions to packet losses. Note: the IETF tends more and more to do this in a normative way, whereas in the ITU and in MPEG this is typically left to implementers. Issue has to be discussed one day. Current document provides information without makeing any assumptions about that.

II.2.1 Assumptions

Any packetization scheme has to make some assumptions on typical network conditions and constraints. The following set of assumptions have been used in earlier Q.15 research on packetization and are deemed to be still valid:

- MTU size: around 1500 bytes per packet for anything but dial-up links, 500 bytes for dial-up links.

- Packet loss characteristic: non-bursty (due to drop-tail router implementations, and assuming reasonable pacing algorithms (e.g. no bursting occurs at the sender).
- Packet loss rate: up to 20%

II.2.2 Combining of Partitions according to Priorities

In order to allow unequal protection of more important bits of the bitstream, exactly two packets per slice are generated (see Q15-J-53 for a detailed discussion). Slices should be used to ensure that both packets meet the MTU size constraints to avoid network splitting/recombining processes.

The 'First' packet contains the following partitions:

- TYPE_HEADER
- TYPE_MBHEADER
- TYPE_MVD
- TYPE_EOS

The 'Second' packet is assembled using the rest of the partitions

- TYPE_CBP Coded Block Patterm
- TYPE_2x2DC 2x2 DC Coefficients
- TYPE_COEFF_Y Luminance AC Coefficients
- TYPE_COEFF_C Chrominance AC Coefficients

This configuration allows decoding the first packet independently from the second (although not vice versa). As the first packet is more important both because motion information is important for struction [for what?] and because the 'First' packet is necessary to decode the 'Second', UEP should be used to protect the 'First' packet s higher.

II.2.3 Packet Structure

Each packet consists of a fixed 32 bit header a series of Part-of-Partition structures (POPs).

The packet header contains information

Bit 31	1 == This packet contains a picture header
Bit 30	1 == This packet contains a slice header
Bits 25..29	Reserved
Bits 10-24	StartMB. It is assumed that no picture has more than 2**14 Macroblocks
Bits 0..9	SliceID. It is assumed that a picture does not have more than 1024 slices

Note: The PictureID (TR) can be easily reconstructed from the RTP Timestamp and is therefore not coded again.

Note: The current software reconstructs QP and Format out of the VLC coded Picture/Slice header symbols. This is architecturally not nice and should be changed, probably by deleting these two values from the interim File Format.

Note: This header is likely to change once bigger picture formats etc. come into play.

Each Part-of-Partition structure contains a header of 16 bits whose format is as follows

Bits 15..12	Data Type
Bits 11..0	Length of VLC-coded POP payload (in bits, starting byte-aligned, 0 indicates 4096 bits of payload)

The reasoning behind the introduction of POP packets lies in avoiding large fixed length headers for (typically) small partitions. See Q15-J-53.

II.2.4 Packetization Process

The packetization process converts the Interim File Format (or, in a real world system, data partitioned symbols arriving through a software interface) into packets. The following RTP header fields are used (see RFC1889 for exact semantics):

- Timestamp: is calculated according to the rules of RFC1889 and RFC2429 based on a 90 KHz timestamp.
- Marker Bit: set for the very last packet of a picture ('Second' packet of the last Slice), otherwise cleared.
- Sequence Number is increased by one for every generated packet, and starts with 0 for easier debugging (this in contrast to RFC1889, where a random initialization is mandatory for security purposes).
- Version (V): 2
- Padding (P): 0
- Extension (X): 0
- Csourcecount (CC): 0
- Payload Type (PT): 0 (This in contrast to RFC1889 where 0 is forbidden)

The RTP header is followed by the payload, which follows the packet structure of section II.2.3.

The RTP packet file, used as the input to packet loss simulators and similar tools (note that this format is identical to the ones used for IP-related testing during the H.263++ project, so that the loss simulators, error paytterns etc, can be re-used):

Int32	size of the following packet in bytes
[]byte	packet content, starting with the RTP header.

II.2.5 De-packetization

The De-packetization process reconstructs a file in the Interim File Format from an RTP packet file (that is possible subject to packet losses). This task is straightforward and reverse to the packetization process. (Note that the QP and Format fields currently have to be reconstructed using the VLC-coded symbols in the TYPE_HEADER partition. This bug in the Interim File Format spec should be fixed some time).

II.2.6 Repair and Error Concealment

In order to take advantage of potential UEP for the 'First' packet and the ability of the decoder to reconstruct data where CBP/coefficient information was lost, a very simple error concealment strategy is used. This strategy repairs the bitstream by replacing a lost CBP partition with CBPs that indicate no coded coefficients. Unfortunately, the CBP codewords for Intra and Inter blocks are different, so that such a repair cannot be done context-insensitive. Instead of (partly) VLC-decoding the CBP partition in the NAL module in order to insert the correct type of CBP symbol in the (lost) partition, the decoder itself can be changed to report the appropriate CBP symbols saying "No coefficients" whenever the symbol fetch for a CBP symbol returns with the indication of a lost/empty partition.

Appendix III Interim File Format

III.1 General

Note: The intent of JVT is to move toward use of the ISO media file format as the defined method for JVT video content storage. This Appendix defines an interim file format that can be used until encapsulation of JVT video content into ISO media file format has been specified.

A file is self-contained.

A file consists of boxes, whose structure is identical to boxes of ISO/IEC 14496-1:2001 (ISO media file format).

A box may contain other boxes. A box may have member attributes. If a box contains attributes and other boxes, boxes shall follow the attribute values.

The attribute values in the boxes are stored with the most significant byte first, commonly known as network byte order or big-endian format.

A number of boxes contain index values into sequences in other boxes. These indexes start with the value 0 (0 is the first entry in the sequence).

The Syntactic Description Language (SDL) of ISO/IEC 14496-1:2001 is used to define the file format. In addition to the existing basic data types, the UVLC elementary data type is defined in this document. It shall be used to carry variable-length bit-fields that follow the JVT UVLC design.

Unrecognized boxes should be skipped and ignored.

III.2 File Identification

The File Type Box is the first box of the file. JVT files shall be identified from a major Brand field equal to 'jvt '.

The preferred file extension is '.jvt'.

III.3 Box

III.3.1 Definition

Boxes start with a header, which gives both size and type. The header permits compact or extended size (32 or 64 bits). Most boxes will use the compact (32-bit) size. The size is the entire size of the box, including the size and type header, fields, and all contained boxes. This facilitates general parsing of the file.

III.3.1.1 Syntax

```
aligned(8) class box (unsigned int(32) boxType)
    unsigned int(32) size;
    unsigned int(32) type = boxType;

    if (size==1) {
        unsigned int(64) largesize;
    } else if (size==0) {
        // box extends to end of file
    }
}
```

III.3.1.2 Semantics

- size is an integer that specifies the number of bytes in this box, including all its fields and contained boxes; if size is 1 then the actual size is in the field largesize; if size is 0, then this box is the last one in the file, and its contents extend to the end of the file (normally only used for an Alternate Track Media Box)

- type identifies the box type; standard boxes use a compact type, which is normally four printable characters, to permit ease of identification, and is shown so in the boxes below.

III.4 Box Order

An overall view of the normal encapsulation structure is provided in the following table.

The table shows those boxes that may occur at the top-level in the left-most column; indentation is used to show possible containment. Thus, for example, an Alternate Track Header Box (atrh) is found in a Segment Box (segm).

Not all boxes need be used in all files; the mandatory boxes are marked with an asterisk (*). See the description of the individual boxes for a discussion of what must be assumed if the optional boxes are not present.

There are restrictions in which order the boxes shall appear in a file. See the box definitions for these restrictions.

TABLE 17

Box types.

ftyp				*	**Error! Reference source not found.**	File Type Box, identifies the file format
jvth				*	**Error! Reference source not found.**	File Header Box, file-level meta-data
cinf					**Error! Reference source not found.**	Content Info Box, describes file contents
atin				*	**Error! Reference source not found.**	Alternate Track Info Box, describes characteristics of tracks
prms				*	**Error! Reference source not found.**	Parameter Set Box, enumerated set of frequently changing coding parameters

segm				*	**Error! Reference source not found.**	Segment Box, contains meta- and media data for a defined period of time
	atrh			*	**Error! Reference source not found.**	Alternate Track Header Box, meta-data for a track
		pici		*	III.5.8	Picture Information Box, meta-data for individual pictures
		layr			III.5.9	Layer Box, meta-data for a layer of pictures
			sseq		III.5.10	Sub-Sequence Box, meta-data for a sub-sequence within a layer
	swpc				**Error! Reference source not found.**	Switch Picture Box, identifies pictures that can be used to switch between tracks.
	atrm			*	III.5.11	Alternate Track Media Box, media data for a track

III.5 Box Definitions

III.5.1 File Type Box

III.5.1.1 Definition

Box Type: `ftyp'

Container: File

Mandatory: Yes

Quantity: Exactly one

A media-file structured according to the ISO media file format specification may be compatible with more than one detailed specification, and it is therefore not always possible to speak of a single 'type' or 'brand' for the file. This box identifies a JVT file in a similar fashion without claiming compatibility with the ISO format. However, it enables other file readers to identify the JVT file type. It must be placed first in the file.

III.5.1.2 Syntax

```
aligned(8) class FileTypeBox aligned(8) extends box('ftyp') {
    unsigned int(32) majorBrand = 'jvt ';
    unsigned int(16) jmMajorVersion;
    unsigned int(16) jmMinorVersion;
    unsigned int(32) compatibleBrands[];   // to end of the box
}
```

III.5.1.3 Semantics

This box identifies the specification to which this file complies.

majorBrand is a brand identifier for the interim JVT file format. Only 'jvt ' shall be used for majorBrand, as the file format is not compatible with any other format.

jmMajorVersion and jmMinorVersion define the version of the standard working draft the file complies with. For example, JM-1 files shall have jmMajorVersion equal to 1 and jmMinorVersion equal to 0.

compatibleBrands is a list, to the end of the box, of brands. Should only include the entry ‘jvt ’.

Note: As the interim JVT file format is based on the ISO media file format, it might be appropriate to allow a combination of many ISO media file format based file types into the same file. In such a case, the majorBrand might not be equal to ‘jvt ‘ but ‘jvt ‘ should be one of the compatibleBrands. As this option was not discussed in the Pattaya meeting, it is not reflected in the current specification of the interim JVT file format (this document).

III.5.2 File Header Box

III.5.2.1 Definition

Box Type: `jvth’

Container: File

Mandatory: Yes

Quantity: One or more

This box must be placed as the second box of the file.

The box can be repeated at any position of the file when no container box is open. A File Header Box identifies a random access point to the file. In other words, no data prior to a selected File Header Box is required to parse any of the succeeding data. Furthermore, any segment can be parsed without a forward reference to any of the data succeeding the particular segment.

III.5.2.2 Syntax

```
aligned(8) class fileHeaderBox extends box(‘jvth’) {
    unsigned int(8) majorVersion = 0x00;
    unsigned int(8) minorVersion = 0x00;
    unsigned int(32) timescale;
    unsigned int(32) numUnitsInTick;
    unsigned int(64) duration;
    unsigned int(16) pixAspectRatioX;
    unsigned int(16) pixAspectRatioY;
    unsigned int(16) maxPicId;
    unsigned int(8) numAlternateTracks;
    unsigned int(2) numBytesInPayloadCountMinusOne;
    unsigned int(2) numBytesInPictureOffsetMinusTwo;
    unsigned int(2) numBytesInPictureDisplayTimeMinusOne;
    unsigned int(2) numBytesInPictureCountMinusOne;
    unsigned int(2) numBytesInPayloadSizeMinusOne;
}
```

III.5.2.3 Semantics

majorVersion and minorVersion indicate the version of the file format. This specification defines the format for version 0.1 (majorVersion.minorVersion). Version numbering is independent of working draft document and joint model software as well as the version of the standard | recommendation. This allows parsers interpret the high-level syntax of the files, even if decoding of a file according to the indicated joint model or standard version was not supported.

timescale is the number of time units which pass in one second. For example, a time coordinate system that measures time in sixtieths of a second has a time scale of 60.

numUnitsInTick is the number of time units according to timescale that correspond to one clock tick. A clock tick is the minimum unit of time that can be presented in the file. For example, if the clock frequency of a video signal is (30 000) / 1001 Hz, timescale should be 30 000 and numUnitsInTick should be 1001.

duration is an integer that declares length of the file (in the indicated timescale). Value zero indicates that no duration information is available.

pixAspectRatioX and pixAspectRatioY define the pixel geometry, calculated by pixAspectRatioX / pixAspectRatioY. Value zero in either or both of the attributes indicate an unspecified pixel aspect ratio.

maxPicId gives the maximum value for the picture identifier.

numAlternateTracks gives the number of alternative encodings of the same source. Typically each encoding is targeted for different bit-rate. Each file shall contain at least one track.

numBytesInPayloadCountMinusOne indicates the number of bytes that are needed to signal the maximum number of payloads in any picture. For example, numBytesInPayloadCountMinusOne equal to zero indicates that one byte is needed to signal the number of payloads, and the maximum number of payloads is 255.

numBytesInPictureOffsetMinusTwo indicates the number of bytes that are needed to signal picture offsets. For example, numBytesInPictureOffsetMinusTwo equal to zero indicates that the offsets are two-byte integer values with a range of –32768 to 32767.

numBytesInPictureDisplayTimeMinusOne indicates the number of bytes that are needed to signal picture display time offsets.

numBytesInPictureCountMinusOne indicates the number of bytes that are needed to signal the maximum number of pictures in a segment.

numBytesInPayloadSizeMinusOne indicates the number of bytes to signal the maximum payload size in bytes.

III.5.3 Content Info Box

III.5.3.1 Definition

Box Type: `cinf´

Container: File

Mandatory: No

Quantity: Zero or more

This box gives information about the content of the file.

The box can be repeated at any position of the file when no container box is open.

III.5.3.2 Syntax

```
aligned(8) class contentInfoBox extends box('cinf') {
    unsigned int(64) creationTime;
    unsigned int(64) modificationTime;

    unsigned int(8) titleNumBytes;
    if (titleNumBytes)
        unsigned int(8)[titleNumBytes] title;

    unsigned int(8) authorNumBytes;
    if (authorNumBytes)
        unsigned int(8)[authorNumBytes] author;
```

```
    unsigned int(8) copyrightNumBytes;
    if (copyrightNumBytes)
        unsigned int(8)[copyrightNumBytes] copyright;

    unsigned int(16) descriptionNumBytes;
    if (descriptionNumBytes)
        unsigned int(8)[descriptionNumBytes] description;

    unsigned int(16) URINumBytes;
    if (URINumBytes)
        unsigned int(8)[URINumBytes] URI;
}
```

III.5.3.3 Semantics

creationTime is an integer that declares the creation time of the presentation (in seconds since midnight, Jan. 1, 1904).

modificationTime is an integer that declares the most recent time the presentation was modified (in seconds since midnight, Jan. 1, 1904.

titleNumBytes gives the number of bytes in title.

title, if present, contains the title of the file coded according to ISO/IEC 10646-1 UTF-8.

authorNumBytes gives the number of bytes in author.

author, if present, contains the author of the source or the encoded representation in the file coded according to ISO/IEC 10646-1 UTF-8.

copyrightNumBytes gives the number of bytes in copyright.

copyright shall be used only to convey intellectual property information regarding the source or the encoded representation in the file. copyright is coded according to ISO/IEC 10646-1 UTF-8.

descriptionNumBytes gives the number of bytes in description.

description shall be used only to convey descriptive information associated with the information contents of the file. description is coded according to ISO/IEC 10646-1 UTF-8.

URINumBytes gives the number of bytes in URI.

URI contains a uniform resource identifier (URI), as defined in IETF RFC 2396. URI is coded according to ISO/IEC 10646-1 UTF-8. URI shall be used to convey any related information to the file.

III.5.4 Alternate Track Info Box

III.5.4.1 Definition

Box Type: ‘atin’

Container: File

Mandatory: Yes

Quantity: One or more.

This box specifies the characteristics of alternate tracks. The box shall precede the first Segment Box. The box can be repeated at any position of the file when no container box is open.

III.5.4.2 Syntax

```
aligned(8) class alternateTrackInfo {
    unsigned int(16) displayWindowWidth;
    unsigned int(16) displayWindowHeight;
```

```
    unsigned int(16) maxSDUSize;
    unsigned int(16) avgSDUSize;
    unsigned int(32) avgBitRate;
}

aligned(8) class alternateTrackInfoBox
    extends box('atin') {
    (class alternateTrackInfo) trackInfo[numAlternateTracks];
}
```

III.5.4.3 Semantics

displayWindowWidth and displayWindowHeight declare the preferred size of the rectangular area on which video images are displayed. The values are interpreted as amount of pixels.

An SDU is defined as the payload and the payload header. maxSDUSize gives the size in bytes of the largest SDU of the track. avgSDUSize gives the average size of the SDU over the entire track. Value zero in either attribute indicates that no information is available.

avgBitRate gives the average bit-rate in bits/second over the entire track. Payloads and payload headers taken into account in the calculation.

III.5.5 Parameter Set Box

III.5.5.1 Definition

Box Type: 'prms'

Container: File

Mandatory: Yes

Quantity: One or more

This box specifies a parameter set.

Parameter sets can be repeated in the file to allow random access. A parameter set is uniquely identified within a file based on parameterSetID. Decoders can infer a repetition of a parameter set if a set with the same parameterSetID has already appeared in a file. A redundant copy of a parameter set can safely be ignored.

III.5.5.2 Syntax

```
aligned(8) class parameterSetBox
    extends box('prms') {
    unsigned int(16) parameterSetID;
    unsigned int(8) profile;
    unsigned int(8) level;
    unsigned int(8) version;
    unsigned int(16) pictureWidthInMBs;
    unsigned int(16) pictureHeightInMBs;
    unsigned int(16) displayRectangleOffsetTop;
    unsigned int(16) displayRectangleOffsetLeft;
    unsigned int(16) displayRectangleOffsetBottom;
    unsigned int(16) displayRectangleOffsetRight;
    unsigned int(8) displayMode;
    unsigned int(16) displayRectangleOffsetFromWindowTop;
```

```
    unsigned int(16) displayRectangleOffsetFromWindowLeftBorder;
    unsigned int(8) entropyCoding;
    unsigned int(8) motionResolution;
    unsigned int(8) partitioningType;
    unsigned int(8) intraPredictionType;
    bit requiredPictureNumberUpdateBehavior;
};
```

III.5.5.3 Semantics

parameterSetId gives the identifier of the parameter set. The identifier shall be unique within a file.

profile defines the coding profile in use.

level defines the level in use within the profile.

version defines the version in use within the profile and the level.

pictureWidthInMBs and pictureHeightInMBs define the extents of the coded picture in macroblocks.

displayRectangleOffsetTop, displayRectangleOffsetLeft, displayRectangleOffsetBottom, and displayRectangleOffsetRight define the rectangle to be displayed from the coded picture. Pixel units are used.

displayMode defines the preferred displaying mode. Value zero indicates that the display rectangle shall be rescaled to fit onto the display window. No scaling algorithm is defined. Image shall be as large as possible, no clipping shall be applied, image aspect ratio shall be maintained, and image shall be centered in the display window. Value one indicates that the display rectangle shall be located as indicated in displayRectangleOffsetFromWindowTop and displayRectangleFromWindowLeftBorder. No scaling shall be done and clipping shall be applied to areas outside the display window. No fill pattern is defined for areas in the display window that are not covered by the display rectangle.

displayRectangleOffsetFromWindowTop and displayWindowOffsetFromWindowLeftBorder indicate the location of the top-left corner of the display rectangle within the display window. The values are given in pixels. The values are valid only if displayMode is one.

FIGURE 30 clarifies the relation of different display rectangle and window related attributes. The dashed rectangle of in the decoded picture represents the display rectangle, which is indicated by displayRectangleOffsetTop, displayRectangleOffsetLeft, displayRectangleOffsetBottom, and displayRectangleOffsetRight.

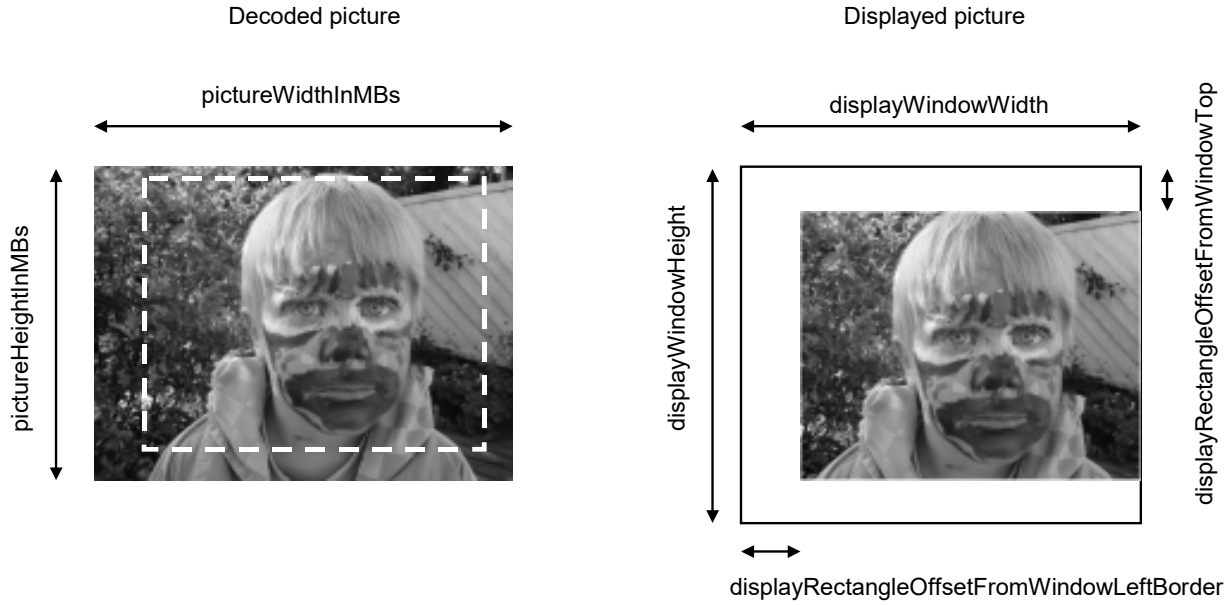


FIGURE 30

Relation of display window and rectangle attributes.

entropyCoding equal to zero stands for UVLC, whereas value one stands for CABAC.

motionResolution equal to zero stands for full-pixel motion resolution, one stands for half-pixel motion resolution, two stands for ¼-pixel motion resolution, and three stands for 1/8-pixel motion resolution.

partitioningType equal to zero stands for the single slice mode and one stands for the data partitioning mode.

intraPredictionType equal to zero stands for normal INTRA prediction, whereas one stands for the constrained INTRA prediction.

If requiredPictureNumberUpdateBehavior equals to one, decoder operation in case of missing picture numbers is normatively specified. Decoder operation is defined in section CROSS-REFERENCE TO BE ADDED.

III.5.6 Segment Box

III.5.6.1 Definition

Box Type: `segm'

Container: File

Mandatory: Yes

Quantity: One or more

A segment box contains data from a certain period of time. Segments shall not overlap in time. Segments shall appear in ascending order of time in the file. A segment box is a container box for several other boxes.

III.5.6.2 Syntax

```
aligned(8) class SegmentBox extends Box('segm') {
    unsigned int(64) fileSize;
    unsigned int(64) startTick;
    unsigned int(64) segmentDuration;
}
```

III.5.6.3 Semantics

fileSize indicates the number of bytes from the beginning of the Segment Box to the end of the file. Value zero indicates that no size information is available. When downloading a file to a device with limited storage capabilities, fileSize can be used to determine if a file fits into the available storage space. In a progressive downloading service, fileSize, startTick, and duration (in the File Header Box) can be used to estimate the average bit-rate of the file including meta-data. This estimation can then be used to decide how much initial buffering is needed before starting the playback.

startTick indicates the absolute time of the beginning of the segment since the beginning of the presentation (time zero). Any time offsets within the segment are relative to startTick.

segmentDuration indicates the duration of the segment. Value zero indicates that no duration information is available.

III.5.7 Alternate Track Header Box

III.5.7.1 Definition

Box Type: 'atrh'

Container: Segment Box ('segm')

Mandatory: Yes

Quantity: One or more

An alternate track represents an independent encoding of the same source as for the other alternate tracks. The Alternate Track Header Box contains meta-data for an alternate track. The boxes shall appear in the same order in all Segment Boxes and they can be indexed starting from zero. Each succeeding box is associated with an index one greater than the previous one. The index can be used to associate the box with a particular track and with the information given in the Alternate Track Info Box.
The Alternate Track Header Box is a container box including at least a Picture Information Box and optionally one or more Layer Boxes.

III.5.7.2 Syntax

```
aligned(8) class alternateTrackHeaderBox extends box('atrh') {
    unsigned int(8) numLayers;
}
```

III.5.7.3 Semantics

numLayers indicates the number of layers and Layer Boxes within the Alternate Track Header Box.

III.5.8 Picture Information Box

III.5.8.1 Definition

Box Type:	'pici'
Container:	Alternate Track Header Box ('atrh')
Mandatory:	Yes
Quantity:	One or more

The box contains an indication of the number of the pictures in the alternate track in this segment. In addition, the box contains picture information for each of these pictures. Picture information shall appear in ascending order of picture identifiers (in modulo arithmetic). In other words, picture information shall appear in coding/decoding order of pictures.

A picture information block contains a pointer to the coded representation of the picture. A picture is associated with a display time and with a number of so-called payloads.

A payload refers to a slice, a data partition, or a piece of supplemental enhancement information. A payload header refers to an equivalent definition as in VCEG-N72R1. For example, a payload header of a single slice includes the "first byte", an indication of the parameter set in use, and the slice header.

III.5.8.2 Syntax

```
aligned(8) class payloadInfo {
    unsigned int((numBytesInPayloadSizeMinusOne + 1) * 8) payloadSize;
    unsigned int(8) headerSize;
    unsigned int(4) payloadType;
    unsigned int(1) errorIndication;
    unsigned int(3) reserved = 0;
    if (payloadType == 0) { // single slice
        UVLC parameterSet;
        sliceHeader;
    }
    else if (payloadType == 1) { // partition A
        UVLC parameterSet;
        sliceHeader;
        UVLC sliceID;
```

```
    }
    else if (payloadType == 2 || payloadType == 3) { // Partition B or
C
        UVLC pictureID;
        UVLC sliceID;
    }
    else if (payloadType == 5) { // Supplemental enhancement
information
        // no additional codewords
    }
}

aligned(8) class pictureInfo {
    bit intraPictureFlag;
    bit syncPictureFlag;
    aligned(8) int((numBytesInPictureOffsetMinusTwo + 2) * 8)
pictureOffset;
    int((numBytesInPictureDisplayTimeMinusOne + 1) * 8)
pictureDisplayTime;
    if (numLayers) { // from AlternateTrackHeaderBox
        unsigned int(8) layerNumber;
        unsigned int(16) subSequenceIdentifier;
        if (syncPictureFlag) {
            unsigned int(8) originLayerNumber;
            unsigned int(16) originSubSequenceIdentifier;
        }
    }
    unsigned int((numBytesInPayloadCountMinusOne + 1) * 8)
numPayloads;
    (class payloadInfo) payloadData[numPayloads];
}

aligned(8) class PictureInformationBox extends Box('pici') {
    unsigned int((numBytesInPictureCountMinusOne + 1) * 8)
numPictures;
    (class pictureInfo) pictureData[numPictures];
}
```

III.5.8.3 Semantics

payloadInfo gives information related to a payload. payloadSize indicates the number of bytes in the payload (excluding the payload header). The value of headerSize is the number of bytes in the payload header, i.e., the number of bytes remaining in the structure. The rest of the data is defined in VCEG-N72R1.

pictureInfo gives information related to a picture.

intraPictureFlag is set to one, when the picture is an INTRA picture. The flag is zero otherwise.

If syncPictureFlag is one, the coded picture represents the same picture content than the previous or succeeding coded picture having syncPictureFlag equal to one. Any coded representation of a sync picture can be used to recover the reconstructed picture, and no noticeable difference on the reconstructed

picture or any picture based on that should occur. Reconstructred pictures that are exactly equal can be reached with SP pictures. The picture number of the sync pictures shall be the same, and, if present, the layer number and sub-sequence identifier of the sync pictures shall be the same.

A picture pointer is maintained to point to the beginning of the latest picture in the corresponding Alternate Track Media Box. The pointer is relative to the beginning of the Alternate Track Media Box. pictureOffset gives the increment or the decrement (in bytes) for the picture pointer to obtain the coded data for the picture. Initially, before updating the pointer for the first picture of the alternate track in a segment, the picture pointer shall be zero.

pictureDisplayTime gives the time when the picture is to be displayed. It is assumed that the picture remains visible until the next picture is to be displayed. The value is relative to the corresponding value of the previous picture.

layerNumber and subSequenceIdentifier are present if numLayers in the Alternate Track Header Box is greater than zero. layerNumber and subSequenceIdentifier identify to which layer and sub-sequence the picture belongs. In case of a sync picture, originLayerNumber and originSubSequence indicate the sub-sequence, based on which the sync picture was created. Notice that the sync picture itself may reside in a different sub-sequence.

numPayloads indicates the number of payloads in the picture. payloadData is an array of payloadInfo structures signaling the characteristics of the payloads.

numPictures indicates the number of pictures in the track during the period of the segment. pictureData is an array of pictureInfo structures signaling the meta-data of the pictures.

III.5.9 Layer Box

III.5.9.1 Definition

Box Type: ‘layr’

Container: Alternate Track Header Box (‘atrh’)

Mandatory: No

Quantity: Zero or more

This box defines the layer information of the pictures in the segment.

Layers can be ordered hierarchically based on their dependency on each other: The base layer is independently decodable. The first enhancement layer depends on some of the data in the base layer. The second enhancement layer depends on some of the data in the first enhancement layer and in the base layer and so on.

A layer number is assigned to layers. Number zero stands for the base layer. The first enhancement layer is associated with number one and each additional enhancement layer increments the number by one. Layer Boxes shall appear in ascending order of layer numbers starting from zero.

A Layer Box contains at least one Sub-Sequence Box.

III.5.9.2 Syntax

```
aligned(8) class LayerBox extends Box(‘layr’) {
    unsigned int(32) avgBitRate;
    unsigned int(32) avgFrameRate;
}
```

III.5.9.3 Semantics

avgBitRate gives the average bit-rate in bits/second of the layer within the segment. Payloads and payload headers taken into account in the calculation. Value zero means an undefined bit-rate.

avgFrameRate gives the average frame rate in frames/(256 seconds) of the layer within the segment. Value zero means an undefined frame rate.

III.5.10 Sub-Sequence Box

III.5.10.1 Definition

Box Type: 'sseq'

Container: Layer Box ('layr')

Mandatory: Yes

Quantity: One or more

This box defines the sub-sequence information of the pictures in a particular layer within a segment.

A sub-sequence shall not depend on any other sub-sequence in the same or in a more enhanced scalability layer. In other words, it shall only depend on one or more sub-sequences in one or more less enhanced scalability layers. A sub-sequence in the base layer can be decoded independently of any other sub-sequences.

A sub-sequence covers a certain period of time within the sequence. Sub-sequences within a layer and in different layers can partly or entirely overlap. A picture shall reside in one layer and in one sub-sequence only.

A sub-sequence identifier is assigned to sub-sequences. Sub-sequences within a particular layer in a segment shall have unique identifiers. If a sub-sequence continues in the next segment, it shall retain its identifier.

III.5.10.2 Syntax

```
aligned(8) class dependencyInfo{
    unsigned int(8) layerNumber;
    unsigned int(16) subSequenceIdentifier;
}
aligned(8) class SubSequenceBox extends Box('sseq') {
    unsigned int(16) subSequenceIdentifer;
    bit continuationFromPreviousSegmentFlag;
    bit continuationToNextSegmentFlag;
    bit startTickAvailableFlag;
    aligned(32) unsigned int(64) ssStartTick;
    unsigned int(64) ssDuration;
    unsigned int(32) avgBitRate;
    unsigned int(32) avgFrameRate;
    unsigned int(16) numReferencedSubSequences;
    (class dependencyInfo) dependencyData[numReferencedSubSequences];
}
```

III.5.10.3 Semantics

layerNumber and subSequenceIdentifier within the dependencyInfo class identify a sub-sequence that is used as a motion compensation reference for the current sub-sequence.

subSequenceIdentifier in the Sub-Sequence Box gives the identifier for the sub-sequence.

continuationFromPreviousSegmentFlag is equal to one, if the current sub-sequence continues from the previous segment.

continuationToNextSegmentFlag is equal to one, if the current sub-sequence continues in the next segment.

If startTickAvailableFlag equals to zero, the value of ssStartTick and ssDuration is undefined. Otherwise, ssStartTick indicates the start time of the sub-sequence relative to the start time of the segment.

ssDuration indicates the duration of the sub-sequence. ssDuration equal to zero indicates an undefined duration.

avgBitRate gives the average bit-rate in bits/second of the sub-sequence within the segment. Payloads and payload headers taken into account in the calculation. Value zero means an undefined bit-rate.

avgFrameRate gives the average frame rate in frames/(256 seconds) of the sub-sequence within the segment. Value zero means an undefined frame rate.

numReferencedSubSequences gives the number of directly referenced sub-sequences. dependencyData is an array of dependencyInfo structures giving the identification information of the referenced sub-sequences.

III.5.11 Alternate Track Media Box

III.5.11.1 Definition

Box Type: 'atrm'

Container: Segment Box ('segm')

Mandatory: Yes

Quantity: One or more

An alternate track represents an independent encoding of the same source as for the other alternate tracks. The Alternate Track Media Box contains the media-data for an alternate track and for the duration of the segment. The boxes shall appear in the same order in all Segment Boxes and they can be indexed starting from zero. Each succeeding box is associated with an index one greater than the previous one. The index can be used to associate the box with a particular track and with the information given in other track-related boxes.

Pictures can appear in the box in any order. This ensures that disposable pictures, such as conventional B pictures, can be located flexibly. Data for different pictures shall not overlap. Data for a picture consists of payloads, i.e., slices, data partitions, and pieces of supplemental enhancement information. Payloads shall appear in successive bytes, and the order of payloads shall be the same as in the Alternate Track Header Box.

III.5.11.2 Syntax

```
aligned(8) class AlternateTrackMediaBox extends Box('atrm') {
}
```

III.5.12 Switch Picture Box

III.5.12.1 Definition

Box Type: 'swpc'

Container: Segment Box ('segm')

Mandatory: No

Quantity: Zero or one

This box defines which pictures can be used to switch from an alternate track to another. Typically these pictures are SP pictures.

III.5.12.2 Syntax

```
aligned(8) class uniquePicture {
    unsigned int(8) alternateTrackIndex;
    unsigned int((numBytesInPictureCountMinusOne + 1) * 8)
pictureIndex;
}
```

```
aligned(8) class switchPictureSet {
    unsigned int(8) numSyncPictures;
    (class uniquePicture) syncPicture[numSyncPictures];
}

aligned(8) class switchPictureBox extends Box('swpc') {
    unsigned int((numBytesInPictureCountMinusOne + 1) * 8)
numSwitchPictures;
    (class switchPictureSet) switchPicture[numSwitchPictures];
}
```

III.5.12.3Semantics

uniquePicture uniquely identifies a picture within this segment. It contains two attributes: alternateTrackIndex and pictureIndex. alternateTrackIndex identifies the alternate track where the picture lies, and pictureIndex gives the picture index in coding order.

switchPictureSet gives a set of pictures that represent the same picture contents and can be used to replace any picture in the set as a reference picture for motion compensation. numSyncPictures gives the number of pictures in the set. syncPicture is an array of uniquePicture structures indicating which pictures belong to the set.

numSwitchPictures indicates the number of picture positions that have multiple interchangeable representations. switchPicture is an array of switchPictureSet structures indicating the set of pictures that can be used interchangeably for each picture position.

Appendix IV Non-Normative Error Concealment

IV.1 Introduction

It is assumed that no erroneous or incomplete slices are decoded. When all received slices of a picture have been decoded, skipped slices are concealed according to the presented algorithms. In practice, record is kept in a macroblock (MB) based status map of the frame. The status of an MB in the status map is "Correctly received" whenever the slice that the MB is included in was available for decoding, "Lost" otherwise. After the frame is decoded if the status map contains "Lost" MBs, concealment is started.

Given the slice structure and MB-based status map of a frame, the concealment algorithms were designed to work MB-based. The missing frame area (pixels) covered by MBs marked as "Lost" in the status map are concealed MB-by-MB (16x16 Y pixels, 8x8 U, V pixels). After an MB has been concealed it is marked in the status map as "Concealed". The order in which "Lost" MBs are concealed is important as also the "Concealed", and not only the "Correctly received" MBs are treated as reliable neighbors in the concealment process whenever no "Correctly received" immediate neighbor of a "Lost" MB exists. In such cases a wrong concealment can result in propagation of this concealment mistake to several neighbor concealed MBs. The processing order chosen is to take the MB columns at the edge of the frame first and then move inwards column-by-column so to avoid a concealment mistake made in the usually "difficult" (discontinuous motion areas, large coded prediction error) center part of the frame propagate to the "easy" (continuous motion area, similar motion over several frames) side parts of the frame.

FIGURE 31 shows a snapshot of the status map during the concealment phase where already concealed MBs have the status of "Concealed", and the currently processed (concealed) MB is marked as "Current MB".

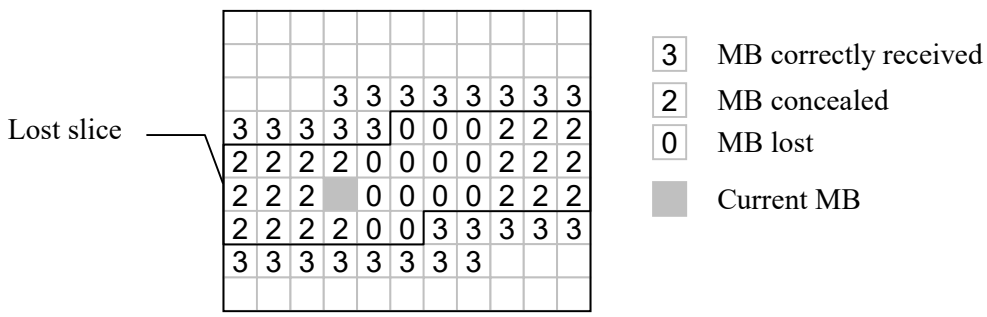


FIGURE 31

MB status map at the decoder

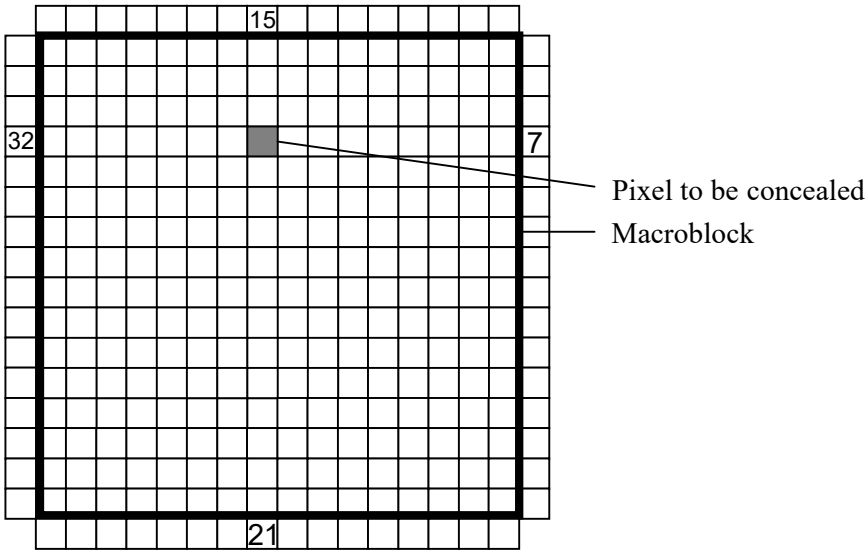
IV.2 INTRA Frame Concealment

Lost areas in INTRA frames have to be concealed spatially as no prior frame may resemble the INTRA frame. The selected spatial concealment algorithm is based on weighted pixel averaging presented in *A. K. Katsaggelos and N. P. Galatsanos (editors), "Signal Recovery Techniques for Image and Video Compression and Transmission", Chapter 7, P. Salama, N. B. Shroff, and E. J. Delp, "Error Concealment in Encoded Video Streams", Kluwer Academic Publishers, 1998*.

Each pixel value in a macroblock to be concealed is formed as a weighted sum of the closest boundary pixels of the selected adjacent macroblocks. The weight associated with each boundary pixel is relative to the inverse distance between the pixel to be concealed and the boundary pixel. The following formula is used:

Pixel value = $(\sum a_i \times (B-d_i)) / \sum (B-d_i)$

where a_i is the pixel value of a boundary pixel in an adjacent macroblock, B is the horizontal or vertical block size in pixels, and d_i is the distance between the destination pixel and the corresponding boundary pixel in the adjacent macroblock.



In FIGURE 32, the shown destination pixel is calculated as follows

Pixel value = (15x(16-3) + 21x(16-12) + 32x(16-7) + 7x(16-8)) / (13 + 4 + 9 + 8) ≈ 18

Only "Correctly received" neighboring MBs are used for concealment if at least two such MBs are available. Otherwise, neighboring "Concealed" MBs are also used in the averaging operation.

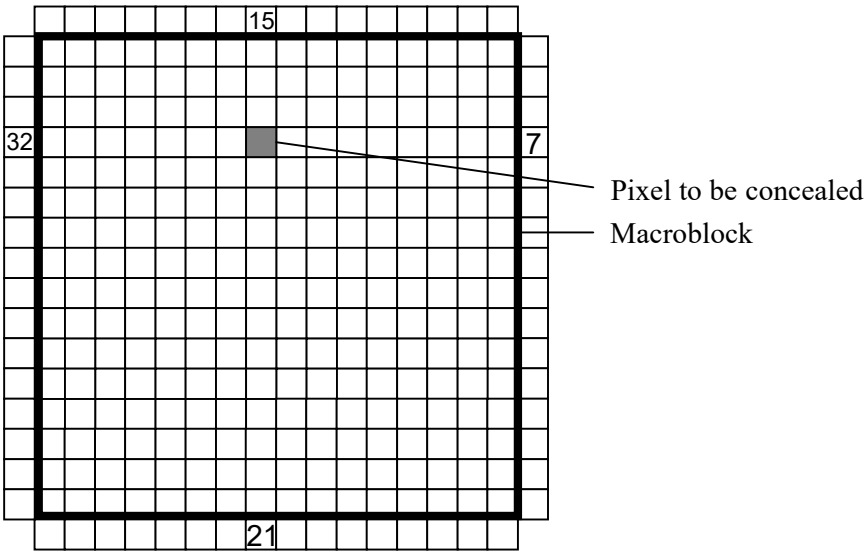


FIGURE 32

Spatial concealment based on weighted pixel averaging

IV.3 INTER and SP Frame Concealment

IV.3.1 General

Instead of directly operating in the pixel domain a more efficient approach is to try to "guess" the motion in the missing pixel area (MB) by some kind of prediction from available motion information of spatial or temporal neighbors. This "guessed" motion vector is then used for motion compensation using the reference frame. The copied pixel values give the final reconstructed pixel values for concealment, and no additional pixel domain operations are used. The presented algorithm is based on *W.-M. Lam, A. R. Reibman, and B. Liu, "Recovery of lost or erroneously received motion vectors," in Proc. ICASSP'93, Minneapolis, Apr. 1993, pp. V417–V420.*

IV.3.2 Concealment using motion vector prediction

The motion activity of the correctly received slices of the current picture is investigated first. If the average motion vector is smaller than a pre-defined threshold (currently ¼ pixels for each motion vector component), all the lost slices are concealed by copying from co-located positions in the reference frame. Otherwise, motion-compensated error concealment is used, and the motion vectors of the lost macroblocks are predicted as described in the following paragraphs.

The motion of a "Lost" MB is predicted from a spatial neighbor MB's motion relying on the statistical observation, that the motion of spatially neighbor frame areas is highly correlated. For example, in a frame area covered by a moving foreground scene object the motion vector field is continuous, which means that it is easy to predict.

The motion vector of the "Lost" MB is predicted from one of the neighbor MBs (or blocks). This approach assumes, that the motion vector of one of the neighbor MBs (or blocks) models the motion in the current MB well. It was found in previous experiments, that median or averaging over all neighbors' motion vectors does not give better results. For simplicity, in the current implementation the smallest neighbor block size that is considered separately as predictor is set to 8x8 Y pixels. The motion of any 8x8 block is calculated as the average of the motion of the spatially corresponding 4x4 or other shaped (e.g. 4x8) blocks.

The decision of which neighbor's motion vectors to use as prediction for the current MB is made based on the smoothness of the concealed (reconstructed) image. During this trial procedure the concealment pixel values are calculated using the motion vector of each candidate (motion compensated pixel values). The motion vector, which results in the smallest luminance change across block boundaries when the block is inserted into its place in the frame is selected. (see FIGURE 33). The zero motion vector case is always considered and this copy concealment (copy pixel values from the co-located MB in the reference frame) is evaluated similarly as the other motion vector candidates.

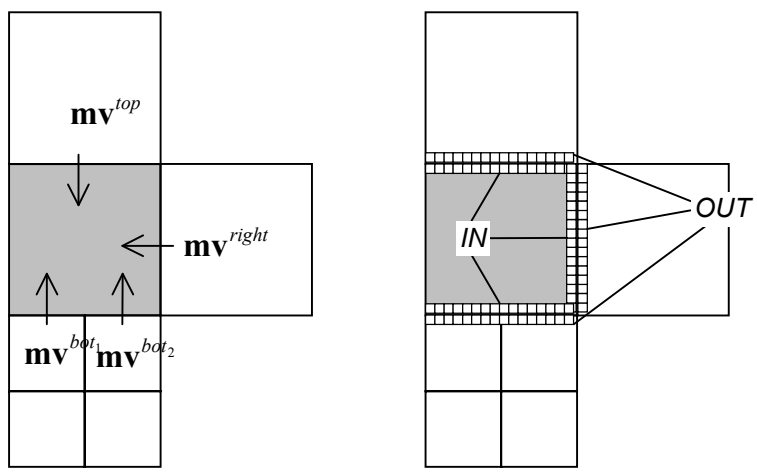


FIGURE 33

Selecting the motion vector for prediction

The winning predictor motion vector is the one which minimizes the side match distortion d_{sm}, which is the sum of absolute Y pixel value difference of the *IN*-block and neighboring *OUT*-block pixels at the boundaries of the current block:

$$\min_{dir \in \{top,bot,left,right\}} \arg \left\langle d_{sm} = \left(\sum_{j=1}^{N} \left| \hat{Y}(\mathbf{mv}^{dir})_j^{IN} - Y_j^{OUT} \right| \right) \Big/ N \right\rangle$$

When "Correctly received" neighbor MBs exist the side match distortion is calculated only for them. Otherwise all the "Concealed" neighbor MBs are included in the calculation.

IV.3.3 Handling of Multiple reference frames

When multiple references are used, the reference frame of the candidate motion vector is used as the reference frame for the current MB. That is, when calculating the side match distortion d_{sm}, the IN-block pixels are from the reference frame of the candidate motion vector.

IV.4 B Frame Concealment

A simple motion vector prediction scheme according to the prediction mode of the candidate MB is used as follows:

If the prediction mode of the candidate MB is

- forward prediction mode, use the forward MV as the prediction the same way as for P frames.
- backward prediction mode, use the backward MV as the prediction.
- bi-directional prediction mode, use the forward MV as the prediction, and discard the backward MV.
- direct prediction mode, use the backward MV as the prediction.

Note that 1) Each MV, whether forward or backward, has its own reference frame. 2) An Intra coded block is not used as a motion prediction candidate.

IV.5 Handling of Entire Frame Losses

TML currently lacks H.263 Annex U type of reference picture buffering. Instead, a simple sliding window buffer model is used, and a picture is referred using its index in the buffer. Consequently, when entire frames are lost, the reference buffer needs to be adjusted. Otherwise, the following received frames would use wrong reference frames. To solve this problem, the reference picture ID is used to infer how many frames are lost, and the picture indices in the sliding window buffer are shifted appropriately.

Appendix 5

Joint Collaborative Team on Video Coding (JCT-VC)
of ITU-T SG16 WP3 and ISO/IEC JTC1/SC29/WG11
2nd Meeting: Geneva, CH, 21-28 July, 2010

Document: JCTVC-B205

Title: **Test Model under Consideration**

Status: Output Document (draft0075)

Source: JCT-VC

Abstract

This document provides the description for a Test Model under Consideration (TMuC). This suggested Test Model is intended to provide a coding efficiency close to the best performing proposals in the subjective test of the CfP submissions and also to provide a complexity point that is close to that of the lowest complexity submissions shown to provide substantial improvement of coding efficiency. The inclusion of a technology in this document does not indicate a final adoption of the technology as an element of an approved test model of the committee. Rather, it indicates a preliminary selection which may require further evaluation and justification to achieve that status.

This TMuC is based on the decisions taken at the 1st meeting of JCT-VC in Dresden from 15-23 April 2010 and the further refinements agreed at the 2nd meeting of JCT-VC in Geneva from 21-28 July 2010. The principal documents agreed at the 2nd meeting of JCT-VC which affect this TMuC are:

- Unified intra prediction (JCTVC-B100)
- Rounding control and transform precision expansion (JCTVC-B074)

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1 Overview

This suggested Test Model is intended to provide a coding efficiency close to the best performing proposals in the subjective test of the CfP submissions and also to provide a complexity point that is close to that of the lowest complexity submissions shown to provide substantial improvement of coding efficiency. The inclusion of a technology in this document does not indicate a final adoption of the technology as an element of an approved test model of the committee. Rather, it indicates a preliminary selection which may require further evaluation and justification to achieve that status.

Note that the bit depth for signal processing flow elements in this design is increased relative to that for conventional 8 bit video coding design elements, although the picture buffer storage bit depth may be 8 bits when coding 8 bit source video.

2 Definitions

– **coding tree block (CTB)**: A basic unit for specifying the quadtree segmentation of the given square region. CTB can have various sizes of a square shape.

– **largest coding tree block (LCTB)**: Coding tree block of the largest size allowed in the slice. A slice consists of non-overlapped LCTBs.

– **smallest coding tree block (SCTB)**: Coding tree block of the smallest size allowed in the slice. SCTB is not allowed to be split into smaller CTBs.

– **prediction unit (PU)**: A basic unit for specifying the prediction process. The size of PU is the same as that of the CU which is not allowed to be split any more. PU can be split into multiple partitions which may have arbitrary shapes whereas CU is allowed to be split into four square shapes.

– **transform unit (TU)**: A basic unit for specifying transform and quantization process.

– **coding unit (CU)**: Same as coding tree block.

– **largest coding unit (LCU)**: Same as largest coding tree block.

– **smallest coding unit (SCU)**: Same as smallest coding tree block.

[Ed.: every CU, LCU and SCU in the text to be replaced by CTB, LCTB and SCTB]

– **smallest unit size**: Smallest size among the various allowed unit sizes of CTB, PU and TU.

– **prediction unit partition**: A basic unit for specifying the arbitrary shape region inside the PU.

– **maximum hierarchy depth**: The maximum number of allowed splitting from the LCTB.

– **PIPE**: Probability interval partitioning for entropy coding ~~(a method of entropy coding)~~

– **V2V**: Variable Length to Variable Length code

3 Conventions

NOTE – The mathematical operators used in this Specification are similar to those used in the C programming language. However, integer division and arithmetic shift operations are specifically defined. Numbering and counting conventions generally begin from 0.

3.1 Arithmetic operators

The following arithmetic operators are defined as follows:

+	Addition
−	Subtraction (as a two-argument operator) or negation (as a unary prefix operator)
*	Multiplication, including matrix multiplication
x^y	Exponentiation. Specifies x to the power of y. In other contexts, such notation is used for superscripting not intended for interpretation as exponentiation.
/	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.
÷	Used to denote division in mathematical equations where no truncation or rounding is intended.
$\frac{x}{y}$	Used to denote division in mathematical equations where no truncation or rounding is intended.
$\sum_{i=x}^{y} f(i)$	The summation of f(i) with i taking all integer values from x up to and including y.
x % y	Modulus. Remainder of x divided by y, defined only for integers x and y with x >= 0 and y > 0.

3.2 Logical operators

The following logical operators are defined as follows:

x && y	Boolean logical "and" of x and y.
x || y	Boolean logical "or" of x and y.
!	Boolean logical "not".
x ? y : z	If x is TRUE or not equal to 0, evaluates to the value of y; otherwise, evaluates to the value of z.

3.3 Relational operators

The following relational operators are defined as follows:

>	Greater than.

>= Greater than or equal to.

< Less than.

<= Less than or equal to.

= = Equal to.

!= Not equal to.

When a relational operator is applied to a syntax element or variable that has been assigned the value "na" (not applicable), the value "na" is treated as a distinct value for the syntax element or variable. The value "na" is considered not to be equal to any other value.

3.4 Bit-wise operators

The following bit-wise operators are defined as follows:

& Bit-wise "and". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.

| Bit-wise "or". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.

^ Bit-wise "exclusive or". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.

x >> y Arithmetic right shift of a two's complement integer representation of x by y binary digits. This function is defined only for positive integer values of y. Bits shifted into the MSBs as a result of the right shift have a value equal to the MSB of x prior to the shift operation.

x << y Arithmetic left shift of a two's complement integer representation of x by y binary digits. This function is defined only for positive integer values of y. Bits shifted into the LSBs as a result of the left shift have a value equal to 0.

3.5 Assignment operators

The following arithmetic operators are defined as follows:

= Assignment operator.

++ Increment, i.e., x++ is equivalent to $x = x + 1$; when used in an array index, evaluates to the value of the variable prior to the increment operation.

−− Decrement, i.e., x−− is equivalent to $x = x - 1$; when used in an array index, evaluates to the value of the variable prior to the decrement operation.

+= Increment by amount specified, i.e., x += 3 is equivalent to x = x + 3, and x += (−3) is equivalent to x = x + (−3).

−= Decrement by amount specified, i.e., x −= 3 is equivalent to x = x − 3, and x −= (−3) is equivalent to x = x − (−3).

3.6 Range notation

The following notation is used to specify a range of values:

x = y..z x takes on integer values starting from y to z, inclusive, with x, y, and z being integer numbers.

3.7 Mathematical functions

The following mathematical functions are defined as follows:

$$\mathrm{Abs}(x) = \begin{cases} x & ; \quad x >= 0 \\ -x & ; \quad x < 0 \end{cases} \tag{1}$$

Ceil(x) the smallest integer greater than or equal to x. (2)

$$\text{Clip1}_Y(x) = \text{Clip3}(0, (1 << \text{BitDepth}_Y) - 1, x) \quad (3)$$

$$\text{Clip1}_C(x) = \text{Clip3}(0, (1 << \text{BitDepth}_C) - 1, x) \quad (4)$$

$$\text{Clip3}(x, y, z) = \begin{cases} x & ; \quad z < x \\ y & ; \quad z > y \\ z & ; \quad \text{otherwise} \end{cases} \quad (5)$$

Floor(x) the greatest integer less than or equal to x. (6)

$$\text{InverseRasterScan}(a, b, c, d, e) = \begin{cases} (a\%(d/b))*b & ; \quad e == 0 \\ (a/(d/b))*c & ; \quad e == 1 \end{cases} \quad (7)$$

Log2(x) returns the base-2 logarithm of x. (8)

Log10(x) returns the base-10 logarithm of x. (9)

$$\text{Median}(x, y, z) = x + y + z - \text{Min}(x, \text{Min}(y, z)) - \text{Max}(x, \text{Max}(y, z)) \quad (10)$$

$$\text{Min}(x, y) = \begin{cases} x & ; \quad x <= y \\ y & ; \quad x > y \end{cases} \quad (11)$$

$$\text{Max}(x, y) = \begin{cases} x & ; \quad x >= y \\ y & ; \quad x < y \end{cases} \quad (12)$$

$$\text{Round}(x) = \text{Sign}(x) * \text{Floor}(\text{Abs}(x) + 0.5) \quad (13)$$

$$\text{Sign}(x) = \begin{cases} 1 & ; \quad x >= 0 \\ -1 & ; \quad x < 0 \end{cases} \quad (14)$$

$$\text{Sqrt}(x) = \sqrt{x} \quad (15)$$

3.8 Order of operation precedence

When order of precedence in an expression is not indicated explicitly by use of parentheses, the following rules apply:

– operations of a higher precedence are evaluated before any operation of a lower precedence,

– operations of the same precedence are evaluated sequentially from left to right.

Table 3-1 specifies the precedence of operations from highest to lowest; a higher position in the table indicates a higher precedence.

NOTE – For those operators that are also used in the C programming language, the order of precedence used in this Specification is the same as used in the C programming language.

Table 3-1 Operation precedence from highest (at top of table) to lowest (at bottom of table)

operations (with operands x, y, and z)
"x++", "x− −"
"!x", "−x" (as a unary prefix operator)
x^y
"x * y", "x / y", "x ÷ y", "$\frac{x}{y}$", "x % y"
"x + y", "x − y" (as a two-argument operator), "$\sum_{i=x}^{y} f(i)$"
"x << y", "x >> y"
"x < y", "x <= y", "x > y", "x >= y"
"x = = y", "x != y"
"x & y"
"x | y"
"x && y"
"x | | y"
"x ? y : z"
"x = y", "x += y", "x −= y"

3.9 Variables, syntax elements, and tables

Syntax elements in the bitstream are represented in **bold** type. Each syntax element is described by its name (all lower case letters with underscore characters), its one or two syntax categories, and one or two descriptors 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.

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. Variables starting with an upper case letter may be used in the decoding process for later syntax structures without mentioning the originating syntax structure of the variable. Variables starting with a lower case letter are only used within the subclause in which they are derived.

In some cases, "mnemonic" names for syntax element values or variable values are used interchangeably with their numerical values. Sometimes "mnemonic" names are used without any associated numerical values. The association of values and names is specified in the text. The names are constructed from one or more groups of letters separated by an underscore character. Each group starts with an upper case letter and may contain more upper case letters.

NOTE – The syntax is described in a manner that closely follows the C-language syntactic constructs.

Functions that specify properties of the current position in the bitstream are referred to as syntax functions. These functions are specified in subclause [Ed. insert reference] and assume the existence of a bitstream pointer with an indication of the position of the next bit to be read by the decoding process from the bitstream. Syntax functions are described by their names, which are constructed as syntax element names and end with left and right round parentheses including zero or more variable names (for definition) or values (for usage), separated by commas (if more than one variable).

Functions that are not syntax functions (including mathematical functions specified in subclause 3.7) are described by their names, which start with an upper case letter, contain a mixture of lower and upper case letters without any

underscore character, and end with left and right parentheses including zero or more variable names (for definition) or values (for usage) separated by commas (if more than one variable).
A one-dimensional array is referred to as a list. A two-dimensional array is referred to as a matrix. Arrays can either be syntax elements or variables. Subscripts or square parentheses are used for the indexing of arrays. In reference to a visual depiction of a matrix, the first subscript is used as a row (vertical) index and the second subscript is used as a column (horizontal) index. The indexing order is reversed when using square parentheses rather than subscripts for indexing. Thus, an element of a matrix s at horizontal position x and vertical position y may be denoted either as s[x, y] or as s_{yx}.
Binary notation is indicated by enclosing the string of bit values by single quote marks. For example, '01000001' represents an eight-bit string having only its second and its last bits (counted from the most to the least significant bit) equal to 1.
Hexadecimal notation, indicated by prefixing the hexadecimal number by "0x", may be used instead of binary notation when the number of bits is an integer multiple of 4. For example, 0x41 represents an eight-bit string having only its second and its last bits (counted from the most to the least significant bit) equal to 1.
Numerical values not enclosed in single quotes and not prefixed by "0x" are decimal values.
A value equal to 0 represents a FALSE condition in a test statement. The value TRUE is represented by any value different from zero.

3.10 Text description of logical operations

In the text, a statement of logical operations as would be described in pseudo-code as

```
if( condition 0 )
   statement 0
else if ( condition 1 )
   statement 1
…
else /* informative remark on remaining condition */
   statement n
```

may be described in the following manner:

... as follows / ... the following applies.

- If condition 0, statement 0
- Otherwise, if condition 1, statement 1
- …
- Otherwise (informative remark on remaining condition), statement n

Each "If ... Otherwise, if ... Otherwise, ..." statement in the text is introduced with "... as follows" or "... the following applies" immediately followed by "If ... ". The last condition of the "If ... Otherwise, if ... Otherwise, ..." is always an "Otherwise, ...". Interleaved "If ... Otherwise, if ... Otherwise, ..." statements can be identified by matching "... as follows" or "... the following applies" with the ending "Otherwise, ...".
In the text, a statement of logical operations as would be described in pseudo-code as

```
if( condition 0a    &&    condition 0b )
   statement 0
else if ( condition 1a    ||    condition 1b )
   statement 1
…
else
   statement n
```

may be described in the following manner:

... as follows / ... the following applies.

- If all of the following conditions are true, statement 0
  - condition 0a
  - condition 0b
- Otherwise, if any of the following conditions are true, statement 1
  - condition 1a

- condition 1b
- …
- Otherwise, statement n

In the text, a statement of logical operations as would be described in pseudo-code as:

```
if( condition 0 )
   statement 0
if ( condition 1 )
   statement 1
```

may be described in the following manner:

When condition 0, statement 0

When condition 1, statement 1

3.11 Processes

Processes are used to describe the decoding of syntax elements. A process has a separate specification and invoking. All syntax elements and upper case variables that pertain to the current syntax structure and depending syntax structures are available in the process specification and invoking. A process specification may also have a lower case variable explicitly specified as the input. Each process specification has explicitly specified an output. The output is a variable that can either be an upper case variable or a lower case variable.
When invoking a process, the assignment of variables is specified as follows.

- If the variables at the invoking and the process specification do not have the same name, the variables are explicitly assigned to lower case input or output variables of the process specification.
- Otherwise (the variables at the invoking and the process specification have the same name), assignment is implied.

In the specification of a process, a specific macroblock may be referred to by the variable name having a value equal to the address of the specific macroblock.

4 Source, coded, decoded and output data formats, scanning processes, and neighbouring relationships

[Ed.: Consider giving the section a shorter name]

4.1 Spatial subdivision of pictures and slices

This subclause specifies how a picture is partitioned into slices and various kinds of units. Pictures are divided into slices. A slice is a sequence of largest coding units. Location of largest coding unit is specified by the largest coding unit address **lcuAddr**.

Each coding unit including the largest coding unit is divided into four coding units recursively. It results in a quadtree segmentation of the largest coding unit. The location of a coding unit is specified by the coding unit index **cuIdx** relative to the upper-left sample of the largest coding unit.

Once the coding unit is not allowed to be split, it shall be considered as the prediction unit. Similar to the coding unit, the location of a prediction unit is specified by the prediction unit index **puIdx** relative to the upper-left sample of the largest coding unit.

The prediction unit may have multiple partitions. The location of a prediction unit partition is specified by the prediction unit partition index **puPartIdx** relative to the upper-left sample of the prediction unit.

The prediction unit may have multiple transform units. Similar to the coding unit, a transform unit may be split into four small size transform units recursively, which allows quadtree segmentation of the residue signal. Location of the transform unit is specified by the transform unit index **tuIdx** relative to the upper-left sample of the prediction unit.

Fig. 4-1 summarizes the spatial subdivision of one slice with various units and their indices.

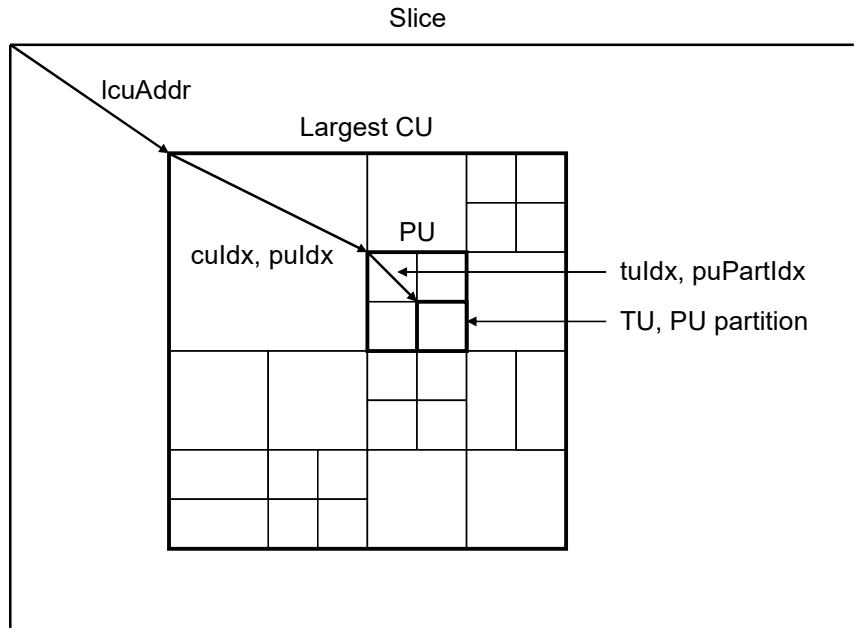


Fig. 4-1 Spatial subdivision of the slice using various units and indices (informative)

4.2 Inverse scanning processes

This subclause specifies inverse scanning processes; i.e, the mapping of indices to locations.

4.2.1 Inverse largest coding unit scanning process

Input to this process is a largest coding unit address lcuAddr.

Output of this process is the location (x, y) of the upper-left luma sample for the largest coding unit with address lcuAddr relative to the upper-left sample of the picture.

The inverse largest coding unit scanning process is specified as follows.

– x = InverseRasterScan(lcuAddr, LcuSize, LcuSize, PicWidthInSamplesN, 0)

  y = InverseRasterScan(lcuAddr, LcuSize, LcuSize, PicWidthInSamplesN, 1)

4.2.2 Recursive coding unit scanning process

Location of coding unit is specified by a raster index cuIdx defined by the smallest unit size, SuSize, as shown in Fig. 4-2.

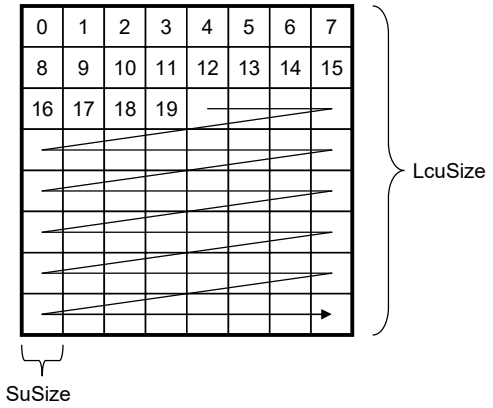


Fig. 4-2 Raster index based on smallest unit size

Coding unit of size CuSize may be split into four smaller coding units, CU_0, CU_1, CU_2 and CU_3 of size CuSize / 2 as shown in Fig. 4-3.

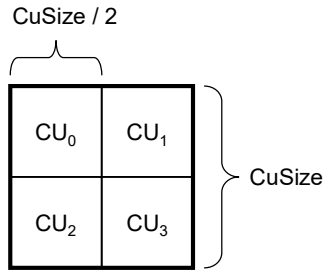


Fig. 4-3 coding unit split

For each split coding unit, the size is equal to CuSize / 2 and the split coding unit index cuIdx is specified as follows.

– cuIdx of CU_0 is assigned to be equal to cuIdx

– cuIdx of CU_1 is assigned to be equal to cuIdx + CuSizeInSu / 2

– cuIdx of CU_2 is assigned to be equal to cuIdx + CuSizeInSu / 2 * LcuSizeInSu

– cuIdx of CU_3 is assigned to be equal to cuIdx + CuSizeInSu / 2 + CuSizeInSu / 2 * LcuSizeInSu

Four each split coding unit, the splitting may be done repeatedly until the size of coding unit is equal to that of the smallest coding unit or the splitting is not allowed any more. It results in the typical z-scan or depth-first quad-tree scanning as shown in Fig. 4-4.

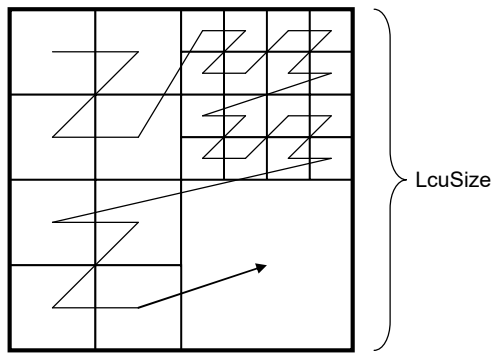


Fig. 4-4 Recursive coding unit scanning example (informative)

4.2.3 Inverse coding unit scanning process

Input to this process is a coding unit index cuIdx.

Output of this process is the location (x, y) of the upper-left luma sample for the coding unit with index cuIdx relative to the upper-left sample of the largest coding unit.

The inverse coding unit scanning process is specified as follows.

– x = InverseRasterScan(cuIdx, SuSize, SuSize, LcuSize, 0)

  y = InverseRasterScan(cuIdx, SuSize, SuSize, LcuSize, 1)

4.2.4 Inverse prediction unit, partition and transform unit scanning process

Once coding unit is decided not to be split any more, it shall be considered to be the prediction unit. Similar to coding unit, location of prediction unit is specified by puIdx defined by the smallest unit size, SuSize. However, prediction unit may be partitioned without any restrictions of a square shape. Fig. 4-5 shows the possible partitions and scans for the prediction unit. [Ed.: geometric partition to be added] The number in each partition specifies the index of the inverse prediction unit partition scan.

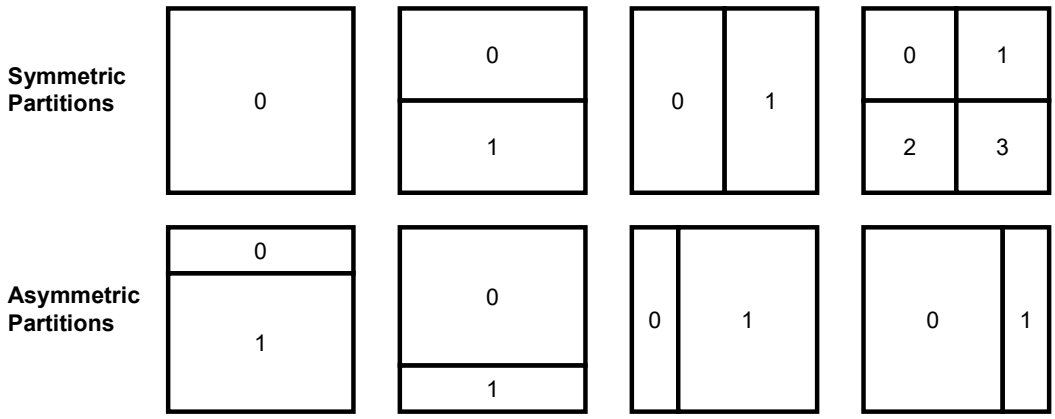


Fig. 4-5 Prediction unit partitions and scans

The functions PuPartWidth( ) and PuPartHeight( ) describing the width and height of prediction unit partitions are specified in Table 5-14 and the function PuPartOffset( ) describing the offset value for the prediction unit partition is specified in Table 5-15. PuPartWidth( ), PuPartHeight( ) and PuPartOffset( ) are set to appropriate values for each prediction unit, depending on the prediction mode and the partitioning type.

4.2.4.1 Inverse prediction unit scanning process

Input to this process is a prediction unit index puIdx.

Output of this process is the location (x, y) of the upper-left luma sample for the prediction unit with index puIdx relative to the upper-left sample of the largest coding unit.

The inverse prediction unit scanning process is specified as follows.

– x = InverseRasterScan(puIdx, SuSize, SuSize, LcuSize, 0)

  y = InverseRasterScan(puIdx, SuSize, SuSize, LcuSize, 1)

4.2.4.2 Inverse prediction unit partition scanning process

Input to this process is a prediction unit partition index puPartIdx.

Output of this process is the location (x, y) of the upper-left luma sample for the prediction unit partition with index puPartIdx relative to the upper-left sample of the prediction unit.

The inverse prediction unit partition scanning process is specified as follows.

– x = InverseRasterScan(PuPartOffset(puPartIdx), SuSize, SuSize, PuSize, 0)

  y = InverseRasterScan(PuPartOffset(puPartIdx), SuSize, SuSize, PuSize, 1)

4.2.4.3 Inverse transform unit scanning process

Input to this process is a transform unit index tuIdx.

Output of this process is the location (x, y) of the upper-left luma sample for the transform unit with index tuIdx relative to the upper-left sample of the prediction unit.

The inverse transform unit scanning process is specified as follows.

– x = InverseRasterScan(tuIdx, SuSize, SuSize, PuSize, 0)

  y = InverseRasterScan(tuIdx, SuSize, SuSize, PuSize, 1)

4.3 *Derivation processes for neighbours*

4.3.1 Derivation process of the availability for largest coding unit addresses

Input to this process is a largest coding unit address lcuAddr.

Output of this process is the availability of the lcuAddr.

The largest coding unit is marked as available, unless any of the following conditions is true in which case the largest coding unit is marked as not available:

– lcuAddr < 0

– lcuAddr > CurrLcuAddr

– the largest coding unit with address lcuAddr belongs to a different slice than the largest coding unit with address CurrLcuAddr

4.3.2 Derivation process for neighbouring largest coding unit addresses and their availability

The outputs of this process are

– lcuAddrA: the address and availability status of the largest coding unit to the left of the current largest coding unit

– lcuAddrB: the address and availability status of the largest coding unit above the current largest coding unit

– lcuAddrC: the address and availability status of the largest coding unit above-right of the current largest coding unit

– lcuAddrD: the address and availability status of the largest coding unit above-left of the current largest coding unit

– lcuAddrE: the address and availability status of the largest coding unit below-left of the current largest coding unit

Fig. 4-6 shows the relative spatial locations of the largest coding units with lcuAddrA, lcuAddrB, lcuAddrC, lcuAdddrD and lcuAddrE relative to the current largest coding unit with CurrLcuAddr.

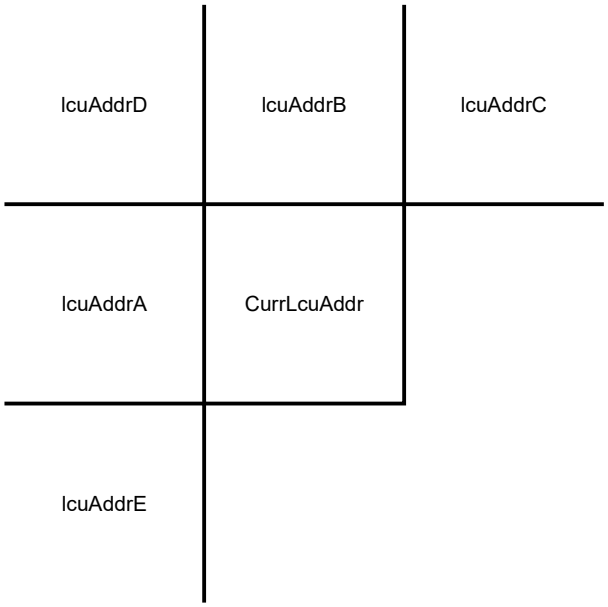


Fig. 4-6 Neighbouring largest coding units for a given largest coding unit

Input to the process in subclause 4.3.1 is lcuAddrA = CurrlcuAddr - 1 and the output is whether the largest coding unit lcuAddrA is available. In addition, lcuAddrA is marked as not available when CurrLcuAddr % PicWidthInLCUs is equal to 0.

Input the process in subclause 4.3.1 is lcuAddrB = CurrLcuAddr - PicWidthInLCUs and the output is whether the largest coding unit lcuAddrB is available.

Input the process in subclause 4.3.1 is lcuAddrC = CurrLcuAddr - PicWidthInLCUs + 1 and the output is whether the largest coding unit lcuAddrC is available. In addition, lcuAddrC is marked as not available when (CurrLcuAddr + 1) % PicWidthInLCUs is equal to 0.

Input the process in subclause 4.3.1 is lcuAddrD = CurrLcuAddr - PicWidthInLCUs − 1 and the output is whether the largest coding unit lcuAddrD is available. In addition, lcuAddrD is marked as not available when CurrLcuAddr % PicWidthInLCUs is equal to 0.

Input the process in subclause 4.3.1 is lcuAddrE = CurrLcuAddr + PicWidthInLCUs − 1 and the output is whether the largest coding unit lcuAddrE is available. In addition, lcuAddrE is marked as not available when CurrLcuAddr % PicWidthInLCUs is equal to 0.

4.3.3 Derivation process of the availability for coding units

Input to this process is a coding unit index cuIdx and the corresponding largest coding unit address lcuAddr.

Output of this process is the availability of the coding unit.

The coding unit is marked as available, unless any of the following conditions is true in which case the coding unit marked as not available:

– lcuAddr < 0

– lcuAddr > CurrLcuAddr

– the LCU address lcuAddr belongs to a different slice than the current slice

– ConvertRasterToZscan(cuIdx) > ConvertRasterToZscan(CurrCuIdx)

4.3.4 Derivation process for neighbouring units and partitions

Subclause 4.3.4.1 specifies the derivation process for neighbouring largest coding units.

Subclause 4.3.4.2 specifies the derivation process for neighbouring coding units.

Subcaluse 4.3.4.3 specifies the derivation process for neighbouring prediction units.

Subcaluse 4.3.4.4 specifies the derivation process for neighbouring partitions.

Table 4-1 specifies the values for the difference of luma location (xD, yD) for the input and the replacement for N in lcuAddrN, cuIdxN, puIdxN and puPartIdxN for the output. These input and output assignments are used in subclauses 4.3.4.1 to 4.3.4.4. The variables PuPartWidth and PuPartHeight are specified when Table 5-14 is referred to.

Table 4-1 Specification of input and output assignments for subclauses 4.3.4 to 4.3.5

N	xD	yD
A	−1	0
B	0	-1
C	PuPartWidth	-1
D	-1	-1
E	-1	PuPartHeight

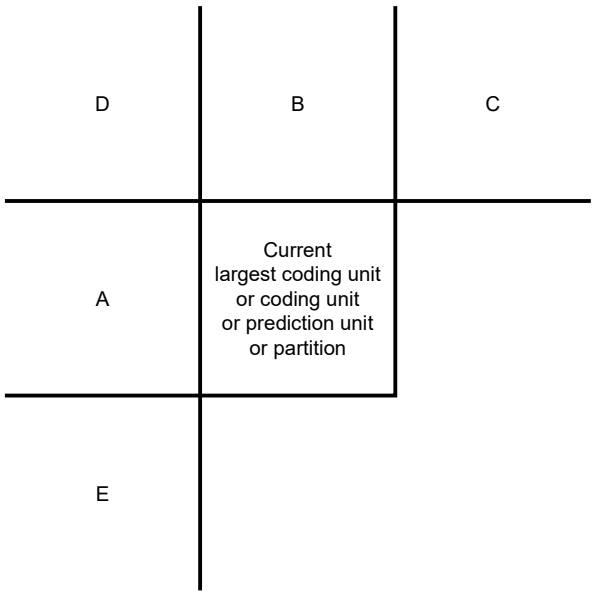


Fig. 4-7 Determination of the neighbouring largest coding units, coding units, prediction units and partitions (informative)

4.3.4.1 Derivation process for neighbouring largest coding units

Input to this process is a largest coding unit index lcuAddr.

The outputs of this process are

– lcuAddrA: the address and its availability status of the largest coding unit to the left of the current largest coding unit

– lcuAddrB: the address and its availability status of the largest coding unit above the current largest coding unit

lcuAddN (with N being A or B) are derived as follows.

– The difference of luma location (xD, yD) is set according to Table 4-1.

– The derivation process for neighbouring locations as specified in subclause 4.3.5 is invoked for luma locations with (xN, yN) equal to (xD, yD), and the output is assigned to lcuAddrN.

4.3.4.2 Derivation process for neighbouring coding units

Input to this process is a largest coding unit index lcuAddr and a coding unit index cuIdx.

The outputs of this process are

– lcuAddrA: the address and its availability status of the largest coding unit to the left of the current largest coding unit

– cuIdxA: the index and its availability status of the coding unit to the left of the current coding unit

– lcuAddrB: the address and its availability status of the largest coding unit above the current largest coding unit

– cuIdxB: the index and its availability status of the coding unit above the current coding unit

lcuAddrN and cuIdxN (with N being A or B) are derived as follows.

– The difference of luma location (xD, yD) is set according to Table 4-1.

– Input to the process in subclause 4.2.3 is cuIdxN and the output is the luma location (x, y).

– The luma location (xN, yN) is specified by

$$xN = x + xD$$

$$yN = y + yD$$

– The derivation process for neighbouring locations as specified in subclause 4.3.5 is invoked for luma locations with (xN, yN) as the input and the output is assigned to lcuAddrN and (xW, yW).

– The variable cuIdxN is derived as follows.

  - If lcuAddrN is not available, cuIdxN is marked as not available.

  - Otherwise (lcuAddrN is available), the coding unit index in the largest coding unit lcuAddrN covering the luma location (xW, yW) shall be assigned to cuIdxN.

4.3.4.3 Derivation process for neighbouring prediction units

Input to this process is a largest coding unit index lcuAddr and a prediction unit index puIdx.

The outputs of this process are

– lcuAddrA: the address and its availability status of the largest coding unit to the left of the current largest coding unit

– puIdxA: the index and its availability status of the prediction unit to the left of the current prediction unit

– lcuAddrB: the address and its availability status of the largest coding unit above the current largest coding unit

– puIdxB: the index and its availability status of the prediction unit above the current prediction unit

– lcuAddrC: the address and its availability status of the largest coding unit above-right of the current largest coding unit

– puIdxC: the index and availability status of the prediction unit above-right of the current prediction unit

– lcuAddrD: the address and its availability status of the largest coding unit above-left of the current largest coding unit

– puIdxD: the index and availability status of the prediction unit above-left of the current prediction unit

– lcuAddrE: the address and its availability status of the largest coding unit below-left of the current largest coding unit

– puIdxE: the index and availability status of the largest coding unit below-left of the current prediction unit

lcuAddrN and puIdxN (with N being A, B, C, D or E) are derived as follows.

– The difference of luma location (xD, yD) is set according to Table 4-1.

– Input to the process in subclause 4.2.4.1 is puIdxN and the output is the luma location (x, y).

– The luma location (xN, yN) is specified by

$$xN = x + xD$$

$$yN = y + yD$$

– The derivation process for neighbouring locations as specified in subclause 4.3.5 is invoked for luma locations with (xN, yN) as the input and the output is assigned to lcuAddrN and (xW, yW).

– The variable puIdxN is derived as follows.

  - If lcuAddrN is not available, puIdxN is marked as not available.

  - Otherwise (lcuAddrN is available), the prediction unit index in the largest coding unit lcuAddN covering the luma location (xW, yW) shall be assigned to puIdxN.

4.3.4.4 Derivation process for neighbouring partitions

Input to this process is a largest coding unit index lcuAddr, a prediction unit index puIdx and a partition index puPartIdx.

The outputs of this process are

– lcuAddrA: the address and its availability status of the largest coding unit to the left of the current largest coding unit

– puIdxA: the index and its availability status of the prediction unit to the left of the current prediction unit

– puPartIdxA: the index and its availability status of the partition index to the left of the current partition index

– lcuAddrB: the address and its availability status of the largest coding unit above the current largest coding unit

– puIdxB: the index and its availability status of the prediction unit above the current prediction unit

– puPartIdxB: the index and its availability status of the partition index above the current partition index

– lcuAddrC: the address and its availability status of the largest coding unit above-right of the current largest coding unit

– puIdxC: the index and availability status of the prediction unit above-right of the current prediction unit

– puPartIdxC: the index and its availability status of the partition index above-right of the current partition index

– lcuAddrD: the address and its availability status of the largest coding unit above-left of the current largest coding unit

– puIdxD: the index and availability status of the prediction unit above-left of the current prediction unit

– puPartIdxD: the index and its availability status of the partition index above-left of the current partition index

– lcuAddrE: the address and its availability status of the largest coding unit below-left of the current largest coding unit

– puIdxE: the index and availability status of the largest coding unit below-left of the current prediction unit

– puPartIdxE: the index and its availability status of the partition index below-left of the current partition index

lcuAddrN, puIdxN and puPartIdxN (with N being A, B, C, D or E) are derived as follows.

– The difference of luma location (xD, yD) is set according to Table 4-1.

– Input to the process in subclause 4.2.4.1 is puIdxN and the output is the luma location (x, y).

– Input to the process in subclause 4.2.4.2 is puPartIdxN and the output is the difference of luma location (xP, yP)

– The luma location (xN, yN) is specified by

  xN = x + xP + xD

  yN = y + yP + yD

– The derivation process for neighbouring locations as specified in subclause 4.3.5 is invoked for luma locations with (xN, yN) as the input and the output is assigned to lcuAddrN and (xW, yW).

– The variable puIdxN and puPartIdxN are derived as follows.

  – If lcuAddrN is not available, puIdxN and puPartIdxN are marked as not available.

  – Otherwise (lcuAddrN is available), the prediction unit index and the partition index in the largest coding unit lcuAddN covering the luma location (xW, yW) shall be assigned to puIdxN and partIdxN.

4.3.5 Derivation process for neighbouring locations

Input to this process is a luma or chroma location (xN, yN) expressed relative to the upper left corner of the current largest coding unit.

Outputs of this process are

– lcuAddrN: either equal to CurrLcuAddr or to the address of neighbouring largest coding unit that containts (xN, yN) and its availability status,

– (xW, yW): the location (xN, yN) expressed relative to the upper-left corner of the largest coding unit lcuAddrN (rather than relative to the upper-left corner of the current largest coding unit).

Let maxW and maxH be variables specifying maximum values of the location components xN, xW and yN, yW, respectively. maxW and maxH are derived as follows.

– if this process is invoked for neighbouring luma locations,

maxW = maxH = LcuSize

– Otherwise (this process is invoked for neighbouring chroma locations),

maxW = maxH = LcuSizeC

The derivation process for neighbouring largest coding unit addresses and their availability in subclause 4.3.2 is invoked with lcuAddrA, lcuAddrB, lcuAddrC, lduAddrD and lcuAddrE as well as their availability status as the output.

Table 4-2 specifies lcuAddrN depending on (xN, yN).

Table 4-2 Specification of lcuAddrN

xN	**yN**	**lcuAddrN**
< 0	< 0	lcuAddrD
< 0	0..maxH − 1	lcuAddrA
0..maxW − 1	< 0	lcuAddrB
0..maxW − 1	0..maxH − 1	CurrLcuAddr
> maxW − 1	< 0	lcuAddrC
> maxW − 1	0..maxH − 1	not available
< 0	> maxH – 1	lcuAddrE
0..maxW – 1	> maxH − 1	not available

The neighbouring location (xW, yW) relative to the upper-left corner of the largest coding unit lcuAddrN is derived as

xW = (xN + maxW) % maxW

yW = (yN + maxH) % maxH

5 Syntax and Semantics

5.1 Syntax

[Ed.: preliminary draft]

5.1.1 NAL unit syntax

nal_unit(NumBytesInNALunit) {	C	Descriptor
forbidden_zero_bit	All	f(1)
nal_ref_idc	All	u(2)
nal_unit_type	All	u(5)
NumBytesInRBSP = 0		
nalUnitHeaderBytes = 1		
if(nal_unit_type = = 1 | | nal_unit_type = = 5) {		
temporal_id	**All**	**u(3)**
output_flag	**All**	**u(1)**
reserved_zero_4bits	**All**	**u(4)**
nalUnitHeaderBytes += 1		
}		
for(i = nalUnitHeaderBytes; i < NumBytesInNALunit; i++) {		
if(i + 2 < NumBytesInNALunit && next_bits(24) = = 0x000003) {		
rbsp_byte[NumBytesInRBSP++ **]**	All	b(8)
rbsp_byte[NumBytesInRBSP++ **]**	All	b(8)
i += 2		
emulation_prevention_three_byte /* equal to 0x03 */	All	f(8)
} else		
rbsp_byte[NumBytesInRBSP++ **]**	All	b(8)
}		
}		

z

5.1.2 Sequence parameter set RBSP syntax

[Ed.: Parameters to be removed and/or added as appropriate.]

seq_parameter_set_rbsp( ) {	C	Descriptor
profile_idc	0	u(8)
reserved_zero_8bits /* equal to 0 */	0	u(8)
level_idc	0	u(8)
seq_parameter_set_id	0	ue(v)
bit_depth_luma_minus8	0	ue(v)
bit_depth_chroma_minus8	0	ue(v)
increased_bit_depth_luma	0	ue(v)
ine_bit_depth_chroma	0	ue(v)
log2_max_frame_num_minus4	0	ue(v)
pic_order_cnt_type	0	ue(v)
if(pic_order_cnt_type == 0)		
log2_max_pic_order_cnt_lsb_minus4	0	ue(v)
else if(pic_order_cnt_type == 1) {		
delta_pic_order_always_zero_flag	0	u(1)
offset_for_non_ref_pic	0	se(v)
num_ref_frames_in_pic_order_cnt_cycle	0	ue(v)
for(i = 0; i < num_ref_frames_in_pic_order_cnt_cycle; i++)		
offset_for_ref_frame[i]	0	se(v)
}		
max_num_ref_frames	0	ue(v)
gaps_in_frame_num_value_allowed_flag	0	u(1)
max_coding_unit_width	0	ue(v)
max_coding_unit_height	0	ue(v)
max_coding_unit_hierarchy_depth_correct	0	u(1)
log2_min_transform_unit_size_minus2	0	ue(v)
if(log2_min_transform_unit_size_minus2 < 4)		
max_transform_unit_hierarchy_depth	0	ue(v)
pic_height_in_luma_samples	0	u(16)
numExtraFilters	0	ue(v)
for(i=0; i< numExtraFilters; i++){		
log2_filterCoeffPrecision	0	ue(v)
halfNumTap	0	ue(v)
for(j=0;j<(3*halfNumTap); j++){		
filterCoef[i][j]	0	i(v)
}		
}		
adaptive_intra_smoothing_flag	0	u(1)
inter_merge_flag	0	u(1)
interleaved_motion_vector_predictor_flag	0	u(1)
pbic_flag	0	u(1)
rbsp_trailing_bits( )	0	
}		

5.1.3 Picture parameter set RBSP syntax

[Ed.: Parameters to be removed and/or added as appropriate.]

pic_parameter_set_rbsp( ) {	C	Descriptor
pic_parameter_set_id	1	ue(v)
seq_parameter_set_id	1	ue(v)
entropy_coding_mode_flag	1	u(1)
num_ref_idx_l0_default_active_minus1	1	ue(v)
num_ref_idx_l1_default_active_minus1	1	ue(v)
pic_init_qp_minus26 /* relative to 26 */	1	se(v)
constrained_intra_pred_flag	1	u(1)
for(i=0;i<15; i++){		
numAllowedFilters[i]	1	ue(v)
for(j=0;j<numAllowedFilters;j++){		
filtIdx[i][j]	1	ue(v)
}		
}		
rbsp_trailing_bits( )	1	
}		

5.1.4 Supplemental enhancement information RBSP syntax

sei_rbsp( ) {	C	Descriptor
do		
sei_message( )	5	
while(more_rbsp_data( ))		
rbsp_trailing_bits( )	5	
}		

5.1.5 Supplemental enhancement information message syntax

sei_message( ) {	C	Descriptor
payloadType = 0		
while(next_bits(8) == 0xFF) {		
ff_byte /* equal to 0xFF */	5	f(8)
payloadType += 255		
}		
last_payload_type_byte	5	u(8)
payloadType += last_payload_type_byte		
payloadSize = 0		
while(next_bits(8) == 0xFF) {		
ff_byte /* equal to 0xFF */	5	f(8)
payloadSize += 255		
}		
last_payload_size_byte	5	u(8)
payloadSize += last_payload_size_byte		
sei_payload(payloadType, payloadSize)	5	
}		

5.1.6 Access unit delimiter RBSP syntax

access_unit_delimiter_rbsp( ) {	C	Descriptor
primary_pic_type	6	u(3)
rbsp_trailing_bits( )	6	
}		

5.1.7 Filler data RBSP syntax

filler_data_rbsp( ) {	C	Descriptor
while(next_bits(8) == 0xFF)		
ff_byte /* equal to 0xFF */	9	f(8)
rbsp_trailing_bits( )	9	
}		

5.1.8 Slice layer RBSP syntax

slice_layer_rbsp( ) {	C	Descriptor
slice_header( )	2	
slice_data( ) /* all categories of slice_data( ) syntax */	2 | 3 | 4	
rbsp_slice_trailing_bits( )	2	
}		

5.1.9 RBSP slice trailing bits syntax

rbsp_slice_trailing_bits( ) {	C	Descriptor
rbsp_trailing_bits( )	All	
if(entropy_coding_mode_flag)		
while(more_rbsp_trailing_data( ))		
cabac_zero_word /* equal to 0x0000 */	All	f(16)
}		

5.1.10 RBSP trailing bits syntax

rbsp_trailing_bits( ) {	C	Descriptor
rbsp_stop_one_bit /* equal to 1 */	All	f(1)
while(!byte_aligned( ))		
rbsp_alignment_zero_bit /* equal to 0 */	All	f(1)
}		

5.1.11 Slice header syntax

[Ed.: Parameters to be removed and/or added as appropriate.]

slice_header( ) {	C	Descriptor
first_lctb_in_slice	2	ue(v)
slice_type	2	ue(v)
pic_parameter_set_id	2	ue(v)
frame_num	2	u(v)
if(IdrPicFlag)		
idr_pic_id	2	ue(v)
pic_order_cnt_lsb	2	u(v)
if(slice_type == P || slice_type == B) {		
num_ref_idx_active_override_flag	2	u(1)
if(num_ref_idx_active_override_flag) {		
num_ref_idx_l0_active_minus1	2	ue(v)
if(slice_type == B)		
num_ref_idx_l1_active_minus1	2	ue(v)
}		
}		
ref_pic_list_modification( )		
if(nal_ref_idc != 0)		
dec_ref_pic_marking( )	2	
if(entropy_coding_mode_flag) {		
pipe_multi_codeword_flag	2	u(1)
if(!pipe_multi_codeword_flag)		
pipe_max_delay_shift_6	2	ue(v)
else		
balanced_cpus	2	u(8)
if(slice_type != I)		
cabac_init_idc	2	ue(v)
}		
slice_qp_delta	2	se(v)
alf_param()		
if(slice_type == P || slice_type == B) {		
mc_interpolation_idc	2	ue(v)
mv_competition_flag	2	u(1)
if (mv_competition_flag) {		
mv_competition_temporal_flag	2	u(1)
}		
}		
if (slice_type == B && mv_competition_flag)		
collocated_from_l0_flag	2	u(1)
sifo_param()		
~~if (entropy_coding_mode_flag == 3)~~		
~~parallel_v2v_header()~~	~~2~~	
edge_based_prediction_flag	2	u(1)

if(edge_prediction_ipd_flag = = 1)		
threshold_edge	2	u(8)
}		

5.1.11.1 Reference picture list modification syntax

ref_pic_list_modification( ) {	C	Descriptor
if(slice_type % 5 != 2) {		
ref_pic_list_modification_flag_l0	2	u(1)
if(ref_pic_list_modification_flag_l0)		
do {		
modification_of_pic_nums_idc	2	u(1)
if(modification_of_pic_nums_idc = = 0 | | modification_of_pic_nums_idc = = 1)		
abs_diff_pic_num_minus1	2	ue(v)
else (modification_of_pic_nums_idc = = 2)		
long_term_pic_num	2	ue(v)
} while(modification_of_pic_nums_idc != 3)		
}		
if(slice_type % 5 = = 1) {		
ref_pic_list_modification_flag_l1	2	u(1)
if(ref_pic_list_modification_flag_l1)		
do {		
modification_of_pic_nums_idc	2	u(1)
if(modification_of_pic_nums_idc = = 0 | | modification_of_pic_nums_idc = = 1)		
abs_diff_pic_num_minus1	2	ue(v)
else if(modification_of_pic_nums_idc = = 2)		
long_term_pic_num	2	ue(v)
} while(modification_of_pic_nums_idc != 3)		
}		
}		

5.1.11.2 Decoded reference picture marking syntax

dec_ref_pic_marking( ) {	C	Descriptor
if(IdrPicFlag) {		
no_output_of_prior_pics_flag	2 | 5	u(1)
long_term_reference_flag	2 | 5	u(1)
} else {		
adaptive_ref_pic_marking_mode_flag	2 | 5	u(1)
if(adaptive_ref_pic_marking_mode_flag)		
do {		
memory_management_control_operation	2 | 5	ue(v)
if(memory_management_control_operation = = 1 | | memory_management_control_operation = = 3)		
difference_of_pic_nums_minus1	2 | 5	ue(v)
if(memory_management_control_operation = = 2)		
long_term_pic_num	2 | 5	ue(v)
if(memory_management_control_operation = = 3 | | memory_management_control_operation = = 6)		
long_term_frame_idx	2 | 5	ue(v)

if(memory_management_control_operation == 4)		
max_long_term_frame_idx_plus1	2 | 5	ue(v)
} while(memory_management_control_operation != 0)		
}		
}		

5.1.11.3 Adaptive loop filter parameter syntax

[3-Input-ALF is still missing]

alf_param() {	C	Descriptor
adaptive_loop_filter_flag	2	u(1)
if (adaptive_loop_filter_flag) {		
alf_length_luma_~~hor_minus_5~~minus5_div2	2	ue(v)
~~**alf_length_luma_ver_minus_5_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_luma_pred_hor_minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_luma_pred_ver_minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_luma_qpe_hor minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_luma_qpe_ver minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_quant_step_size_luma_hor**~~	~~2~~	~~ue(v)~~
~~**alf_quant_step_size_luma_ver**~~	~~2~~	~~ue(v)~~
~~**alf_minKStart_minus1**~~	~~2~~	~~ue(v)~~
~~for (i=0; i < AlfmaxDepth; i++) {~~		
~~**alf_golombIndexBit**~~	~~2~~	~~u(1)~~
~~}~~		
alf_noFilters_minus1	2	ue(v)
if (alf_noFilters_minus1 == 1) {		
alf_startSecondFilter	2	ue(v)
}		
else if (alf_noFilters_minus1 > 1) {		
for (i=0; i< AlfMaxNumFilters; i++) {		
alf_filter_pattern[i]	2	u(1)
}		
}		
if (AlfNumFilters > 1) {		
alf_predMethod	2	u(1)
}		
alf_minKStart_minus1	2	ue(v)
for (i=0; i~~< AlfNumFilters~~ < AlfmaxDepth; i++) {		
~~for (j=0; j< AlfLengthLuma_hor; j++) {~~		
~~scanPos = DepthTable[j]-1;~~		
~~**alf_coeff_luma_hor**[i][j] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~for (j=0; j< AlfLengthLuma_pred_hor; j++) {~~		
~~scanPos = DepthTable[j]-1;~~		
~~**alf_coeff_luma_pred_hor**[i][j] = golombDecodek (kMinTap[scanPos])~~ **alf_golombIndexBit**	2	~~ge(v~~u(1)
}		
for (~~j~~i=0; ~~j< AlfLengthLuma_qpe_hor; j~~i< AlfNumFilters; i++) {		
~~scanPos = DepthTable[j]-1;~~		
~~**alf_coeff_luma_qpe_hor**[i][j] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
for (j=0; j< ~~AlfLengthLuma_ver~~AlfNumCoeffLuma; j++) {		
scanPos = DepthTable[j]-1;		
alf_coeff_luma~~_ver~~ [i][j] = golombDecodek (kMinTap[scanPos])		ge(v)
}		

for (j=0; j< AlfLengthLuma_pred_ver; j++) { }		
scanPos = DepthTable[j] 1;		
alf_coeff_luma_pred_ver[i][j] = golombDecodek (kMinTap[scanPos])		ge(v)
}		
for (j=0; j< AlfLengthLuma_qpe_ver; j++) {		
scanPos = DepthTable[j] 1;		
alf_coeff_luma_qpe_ver[i][j] = golombDecodek (kMinTap[scanPos])		ge(v)
}		
}		
alf_chroma_idc	2	ue(v)
if (alf_chroma_idc) {		
alf_reuse_coefficients_for_chroma_flag	2	u(1)
if (alf_reuse_coefficients_for_chroma_flag)		
{		
alf_length_chroma_hor_minus_5minus5_div2 = alf_length_luma_hor_minus_5_div2	2	ue(v)
alf_length_chroma_ver minus_5_div2 = alf_length_luma_ver minus_5_div2		
alf_length_chroma_pred_hor minus_1_div2 = alf_length_luma_pred_hor minus_1_div2		
alf_length_chroma_pred_ver_minus_1_div2 = alf_length_luma_pred_ver_minus_1_div2		
alf_length_chroma_qpe_hor_minus_1_div2 = alf_length_luma_qpe_hor_minus_1_div2		
alf_length_chroma_qpe_ver minus_1_div2 = alf_length_luma_qpe_ver minus_1_div2		
alf_quant_step_size_chroma_hor = alf_quant_step_size_luma_hor		
alf_quant_step_size_chroma_ver = alf_quant_step_size_luma_ver		
for(i = 0; i< AlfLengthChroma_horAlfNumCoeffChroma; i++) {		
alf_coeff_chroma_hor [i] = alf_coeff_luma_hor [i]	2	se(v)
}		
for(i = 0; i< AlfLengthChroma_pred_hor; i++) { }		
alf_coeff_chroma_pred_hor [i] = alf_coeff_luma_pred_hor [i]		
}		
for(i = 0; i< AlfLengthChroma_qpe_hor; i++) {		
alf_coeff_chroma_qpe_hor [i] = alf_coeff_luma_qpe_hor [i]		
}		
for(i = 0; i< AlfLengthChroma_ver; i++) {		
alf_coeff_chroma_ver [i] = alf_coeff_luma_ver [i]		
}		
for(i = 0; i< AlfLengthChroma_pred_ver; i++) {		
alf_coeff_chroma_pred_ver [i]= alf_coeff_luma_pred_ver [i]		
}		
for(i = 0; i< AlfLengthChroma_qpe_ver; i++) {		
alf_coeff_chroma_qpe_ver [i] = alf_coeff_luma_qpe_ver [i]		
}		

~~} else {~~		
~~**alf_length_chroma_hor_minus_5_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_chroma_ver minus_5_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_chroma_pred_hor minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_chroma_pred_ver_minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_chroma_qpe_hor_minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_length_chroma_qpe_ver minus_1_div2**~~	~~2~~	~~ue(v)~~
~~**alf_quant_step_size_chroma_hor**~~	~~2~~	~~ue(v)~~
~~**alf_quant_step_size_chroma_ver**~~	~~2~~	~~ue(v)~~
~~for(i = 0; i< AlfLengthChroma_hor; i++) {~~		
~~scanPos = DepthTable[j] 1;~~		
~~**alf_coeff_chroma_hor** [i] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~for(i = 0; i< AlfLengthChroma_pred_hor; i++) {~~		
~~scanPos = DepthTable[j] 1;~~		
~~**alf_coeff_chroma_pred_hor** [i] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~for(i = 0; i< AlfLengthChroma_qpe_hor; i++) {~~		
~~scanPos = DepthTable[j]-1;~~		
~~**alf_coeff_chroma_qpe_hor** [i] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~for(i = 0; i< AlfLengthChroma_ver; i++) {~~		
~~scanPos = DepthTable[j] 1;~~		
~~**alf_coeff_chroma_ver** [i] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~for(i = 0; i< AlfLengthChroma_pred_ver; i++) {~~		
~~scanPos = DepthTable[j] 1;~~		
~~**alf_coeff_chroma_pred_ver** [i] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~for(i = 0; i< AlfLengthChroma_qpe_ver; i++) {~~		
~~scanPos = DepthTable[j] 1;~~		
~~**alf_coeff_chroma_qpe_ver** [i] = golombDecodek (kMinTap[scanPos])~~		~~ge(v)~~
~~}~~		
~~}~~		
~~}~~		
alf_cu_control_flag	2	u(1)
if (alf_cu_control_flag) {		
alf_cu_control_max_depth	2	ue(v)
if (alf_cu_control_max_depth) {		
alf_length_cu_control_info	2	u(v)
}		
for(i = 0; i< NumAlfCuFlag; i++)		
alf_cu_flag [i]	2	u(1) | ae(v)
}		

}		
}		

5.1.11.4 Switched Filter with Offsets parameter syntax

sifo_param() {	C	Descriptor
if (slice_type == P || slice_type == B)		
predict_filter_flag	2	u(1)
if (slice_type == P) {		
if (!predict_filter_flag) {		
sifo_type	2	u(2)
if(sifo_type == 0 || sifo_type ==1) {		
for(i=0; i<15; i++)		
sifo_filter[i]	2	u(v)
}		
if(sifo_type==2) {		
sifo_filter[0]	2	u(v)
for(i=1; i<15; i++)		
sifo_filter[i] = sifo_filter[0]		
}	2	u(v)
} else {		
sifo_type	2	u(1)
if(sifo_type == 0) {		
for(i=0; i<15; i++) {		
use_prev_filter_flag	2	u(1)
if(use_prev_filter_flag)		
sifo_filter[i] = prev_filter[i]		
else		
sifo_filter[i]	2	u(v)
}		
} else {		
sifo_filter[0]	2	u(v)
for(i=1; i<15; i++)		
sifo_filter[i] = sifo_filter[0]		
}		
}		
}		
if (slice_type == B) {		
sifo_type	2	u(1)
if(sifo_type==1){		
sifo_filter[0]	2	u(v)
for(i=1; i<15; i++)		
sifo_filter[i] = sifo_filter[0]		
}		
if(sifo_type==0){		
if (!predict_filter_flag){		

for(i=0; i<15; i++)		
sifo_filter[i]	2	u(v)
} else {		
use_prev_filter_flag	2	u(1)
if(use_prev_filter_flag)		
sifo_filter[i] = prev_filter[i]		
else		
sifo_filter[i]	2	u(v)
}		
}		
}		
if (slice_type == P || slice_type == B) {		
zero_offset_flag	2	u(1)
if(! zero_offset_flag) {		
for(i = 0; i <= num_ref_idx_l0_active_minus1; i++) {		
if(i==0){		
for(j=0; j<16; j++) {		
sifo_offset_l0[i]	2	se(v)
sifo_offset[i]_l0 *= (1 << increased_bit_depth_luma)		
}		
} else {		
img_offset_l0[i]	2	se(v)
img_offset_l0[i] *= (1 << increased_bit_depth_luma)		
}		
}		
if (slice_type == B) {		
for(i = 0; i <= num_ref_idx_l1_active_minus1; i++) {		
if(i==0){		
for(j=0; j<16; j++) {		
sifo_offset_l1[i]	2	se(v)
sifo_offset_l1[i] *= (1 << increased_bit_depth_luma)		
}		
} else {		
img_offset_l1[i]	2	se(v)
img_offset_l1[i] *= (1 << increased_bit_depth_luma)		
}		
}		
}		
}		
}		

5.1.12 Slice data syntax

[Ed. preliminary draft]

slice_data( ) {	C	Descriptor
if(entropy_coding_mode_flag && pipe_multi_codeword_flag) {		
pipe_partition_start[11] = currBitStreamPointer [Ed. define]		
for(partIdx = 11; partIdx > 0; partIdx--) {		
pipe_partition_size(partIdx)		
pipe_partition_start[partIdx – 1] = pipe_partition_start[partIdx] + partSize[partIdx]		
}		
for(i=0; i<balanced_cpus-1; i++)		
balanced_offsets[i]		u(8)
}		
CurrMbAddr = first_lctb_in_slice		
moreDataFlag = 1		
do {		
xCU = HorLumaLocation(CurrMbAddr)		
yCU = VerLumaLocation(CurrMbAddr)		
coding_unit(xCU, yCU, MaxCodingUnitSize)	2 | 3 | 4	
if(!entropy_coding_mode_flag)		
moreDataFlag = more_rbsp_data( )		
else {		
end_of_slice_flag	2	ae(v)
moreDataFlag = !end_of_slice_flag		
}		
CurrMbAddr = NextMbAddress(CurrMbAddr)		
} while(moreDataFlag)		
}		

[Ed. preliminary draft]

pipe_partition_size(pIdx) {	C	Descriptor
part_size_byte_one	2	u(8)
partSize[pIdx] = part_size_byte_one		
if((partSize[pIdx] & 1) == 0)		
partSize[pIdx] >>= 1		
else {		
partSize[pIdx] >>= 1		
part_size_byte_two	2	u(8)
partSize[pIdx] += (part_size_byte_two << 7)		
if((partSize[pIdx] & 1) == 0)		
partSize[pIdx] = 128 + (partSize[pIdx] >> 1)		
else {		
partSize[pIdx] >>= 1		
part_size_byte_three	2	u(8)
partSize[pIdx] += (part_size_byte_two << 14)		
if((partSize[pIdx] & 1) == 0)		
partSize[pIdx] = 16 512 + (partSize[pIdx] >> 1)		
else {		
partSize[pIdx] >>= 1		
part_size_byte_four	2	u(8)
partSize[pIdx] += (part_size_byte_two << 21)		
partSize[pIdx] = 2 113 664		
}		
}		
}		
}		

5.1.13 Coding unit syntax

[Ed. preliminary draft]

coding_unit(x0, y0, currCodingUnitSize) {	C	Descriptor
if(x0+currCodingUnitSize < $PicWidthInSamples_L$ && y0+currCodingUnitSize < $PicHeightInSamples_L$ &&		
currCodingUnitSize > MinCodingUnitSize)		
split_coding_unit_flag	2	u(1) | ae(v)
if(split_coding_unit_flag) {		
splitCodingUnitSize = currCodingUnitSize >> 1		
x1 = x0 + splitCodingUnitSize		
y1 = y0 + splitCodingUnitSize		
coding_unit(x0, y0, splitCodingUnitSize)	2 | 3 | 4	
if(x1 < $PicWidthInSamples_L$)		
coding_unit(x1, y0, splitCodingUnitSize)	2 | 3 | 4	
if(y1 < $PicHeightInSamples_L$)		
coding_unit(x0, y1, splitCodingUnitSize)	2 | 3 | 4	
if(x1 < $PicWidthInSamples_L$ && y1 < $PicHeightInSamples_L$)		
coding_unit(x1, y1, splitCodingUnitSize)	2 | 3 | 4	
} else {		

prediction_unit(x0, y0, currCodingUnitSize)	2	
if(PredMode != MODE_SKIP ‖ !(PredMode == MODE_INTRA && **planar_flag** == 1))		
if(entropy_coding_mode_flag) {		
transform_unit_tree(x0, y0, currCodingUnitSize, 0)	3 | 4	
transform_unit_coeff(x0, y0, currCodingUnitSize, 0, 0)	3 | 4	
transform_unit_coeff(x0, y0, currCodingUnitSize, 0, 1)	3 | 4	
transform_unit_coeff(x0, y0, currCodingUnitSize, 0, 2)	3 | 4	
} else		
transform_unit_vlc(x0, y0, currCodingUnitSize)	3 | 4	
}		
}		

5.1.14 Prediction unit syntax

[Ed. preliminary draft]

prediction_unit(x0, y0, currPredUnitSize) {	C	Descriptor
if(slice_type != I)		
skip_flag		
if(skip_flag) {		
if(mv_competition_flag) {		
if(inter_pred_idc != Pred_L1 && NumMVPCand(L0) > 1)		
mvp_idx_l0	2	ue(v) | ae(v)
if(inter_pred_idc != Pred_L0 && NumMVPCand(L1) > 1)		
mvp_idx_l1	2	ue(v) | ae(v)
}		
if(pbic_flag) {		
if(NumICPCand > 1)		
icp_idx	2	ue(v) | ae(v)
}		
}		
else {		
if(!entropy_coding_mode_flag)		
mode_table_idx		vlc(n,v)
else {		
if(slice_type != I)		
pred_mode	2	u(1) | ae(v)
}		
if(PredMode == MODE_INTRA) {		
planar_flag	2	u(1) | ae(v)
if(planar_flag) {		
planar_delta_y = getPlanarDelta()		
planar_delta_uv_present_flag	2	u(1) | ae(v)
if(planar_delta_uv_present_flag) {		
planar_delta_u = getPlanarDelta()		
planar_delta_v = getPlanarDelta()		
}		
} else {		
if(entropy_coding_mode_flag)		
intra_split_flag	2	ae(v)
combined_intra_pred_flag	2	u(1) | ae(v)
for(i = 0; i < (intra_split_flag ? 4 : 1); i++) {		
prev_intra_luma_pred_ flag	2	u(1) | ae(v)
if(!prev_intra_pred_luma_flag)		
rem_intra_luma_pred_mode	2	ue(v) | ae(v)
if(adaptive_intra_smoothing_flag)		
intra_luma_filt_flag	2	u(1) | ae(v)
}		
}		
if(chroma_format_idc != 0)		

intra_chroma_pred_mode	2	ue(v) | ae(v)
}		
}		
else if(PredMode == MODE_INTER) {		
if(entropy_coding_mode_flag)		
inter_partitioning_idc	2	ue(v) | ae(v)
for(i= 0; i < NumPuParts(inter_partitioning_idc); i++) {		
if(NumMergeCandidates > 0) {		
merge_flag[i]	2	ue(1) | ae(v)
if(merge_flag[i] && NumMergeCandidates > 1)		
merge_left_flag[i]	2	ue(1) | ae(v)
}		
if(!merge_flag[i]) {		
if(slice_type == B)		
inter_pred_idc[i]	2	ue(v) | ae(v)
if(inter_pred_idc[i] != Pred_L1) {		
if(entropy_coding_mode_flag) {		
if(num_ref_idx_l0_active_minus1 > 0)		
ref_idx_l0[i **]**	2	ue(v) | ae(v)
if (!pbic_flag)		
mvres_l0 [i **]**	2	ue(1) | ae(v)
}		
else {		
ref_idx_mvres_l0[i **]**	2	ue(v) | ae(v)
}		
if (!pbic_flag) {		
mvd_l0[i **][** 0 **]**	2	se(v) | ae(v)
mvd_l0[i **][** 1 **]**	2	se(v) | ae(v)
if(mv_competition_flag && NumMVPCand(L0, i) > 1)		
mvp_idx_l0[i]	2	ue(v) | ae(v)
}		
}		
if(inter_pred_idc[i] != Pred_L0) {		
if(entropy_coding_mode_flag) {		
if(num_ref_idx_l1_active_minus1 > 0)		
ref_idx_l1[i **]**	2	ue(v) | ae(v)
if (!pbic_flag)		
mvres_l1 [i **]**	2	ue(1) | ae(v)
}		
else {		
ref_idx_mvres_l1[i **]**	2	ue(v) | ae(v)
}		
if (!pbic_flag) {		
mvd_l1[i **][** 0 **]**	2	se(v) | ae(v)
mvd_l1[i **][** 1 **]**	2	se(v) | ae(v)

_if(mv_competition_flag && _NumMVPCand(L1, i) > 1)		
_mvp_idx_l1[i]	2	ue(v) | ae(v)
}		
}		
if(pbic_flag) {		
if(inter_pred_idc[i] != Pred_L1)		
mvres_l0 [i]	2	ue(1) | ae(v)
if(inter_pred_idc[i] != Pred_L0)		
mvres_l1 [i]	2	ue(1) | ae(v)
if (inter_pred_idc[i] != Pred_L1 &&		
inter_pred_idc[i] != Pred_L0)		
ztree_type = 1		
else		
ztree_type = 0		
decZeroTree(ztree_type, ztree_data)	2	
if(ztree_type) {		
if (ztree_data[0] != 0)		
mvd_l0[i][0]	2	se(v) | ae(v)
if (ztree_data[1] != 0)		
mvd_l0[i][1]	2	se(v) | ae(v)
if (ztree_data[2] != 0)		
mvd_l1[i][0]	2	se(v) | ae(v)
if (ztree_data[3] != 0)		
mvd_l1[i][1]	2	se(v) | ae(v)
if (ztree_data[4] != 0)		
icd[i][0]	2	se(v) | ae(v)
if (ztree_data[5] != 0)		
icd[i][1]	2	se(v) | ae(v)
if (ztree_data[6] != 0)		
icd[i][2]	2	se(v) | ae(v)
} else { // if(ztree_type)		
if(inter_pred_idc[i] != Pred_L1) {		
if (ztree_data[0] != 0)		
mvd_l0[i][0]	2	se(v) | ae(v)
if (ztree_data[1] != 0)		
mvd_l0[i][1]	2	se(v) | ae(v)
}		
if(inter_pred_idc[i] != Pred_L0) {		
if (ztree_data[0] != 0)		
mvd_l1[i][0]	2	se(v) | ae(v)
if (ztree_data[1] != 0)		
mvd_l1[i][1]	2	se(v) | ae(v)
}		
if (ztree_data[2] != 0)		
icd[i][0]	2	se(v) | ae(v)
if (ztree_data[3] != 0)		

icd[i][2]	2	se(v) | ae(v)
} // if(ztree_type)		
if(mv_competition_flag) {		
if(inter_pred_idc[i] != Pred_L1 && NumMVPCand(L0, i) > 1)		
mvp_idx_l0[i]	2	ue(v) | ae(v)
if(inter_pred_idc[i] != Pred_L0 && NumMVPCand(L1, I) > 1)		
mvp_idx_l1[i]	2	ue(v) | ae(v)
}		
if(NumICPCand > 1)		
icp_idx[i]	2	ue(v) | ae(v)
}		
}		
}		
}		
else if(PredMode == MODE_DIRECT) {		
if(slice_type == B)		
inter_pred_idc	2	ue(v) | ae(v)
if(mv_competition_flag) {		
if(inter_pred_idc != Pred_L1 && NumMVPCand(L0) > 1)		
mvp_idx_l0	2	ue(v) | ae(v)
if(inter_pred_idc != Pred_L0 && NumMVPCand(L1) > 1)		
mvp_idx_l1	2	ue(v) | ae(v)
}		
if(pbic_flag) {		
if(NumICPCand > 1)		
icp_idx	2	ue(v) | ae(v)
}		
}		
}		

getPlanarDelta() {	C	Descriptor
planar_qdelta_indicator		vlc(5,v) | ae(v)
if (qdelta_indicator > 21)		
Qdelta = ((qdelta_indicator - 14) << 3) + 4		
else if(qdelta_indicator > 9)		
Qdelta = ((qdelta_indicator - 6) << 2) + 2		
else if (qdelta_indicator > 3)		
Qdelta = (qdelta_indicator - 2) << 1		
else		
Qdelta = qdelta_indicator		
if (qDelta > 0) {		
planar_sign		u(1) | ae(v)
PlanarDelta = sign ? – Qdelta: Qdelta		

}		
else		
PlanarDelta = Qdelta		
}		

decZeroTree(type, data) {	C	Descriptor
q = 0		
zero_blk	2	u(1) | ae(v)
val = 1 - zero_blk		
sp = 0		
for(i=0; i<2*ztree_size[type]-1; i++) {		
if(ztree_structure[type][i] = = 0) { // leaf node		
data[ztree_leaf_index[type][q]] = val		
val = stack[--sp]		
q++		
} else {		
if(val) {		
ztree_node_both	2	u(1) | ae(v)
if(ztree_node_both)		
stack[sp++] = true		
else {		
ztree_node_left	2	u(1) | ae(v)
if(ztree_node_left)		
stack[sp++] = false		
else {		
stack[sp++] = true		
val = false		
}		
}// if(ztree_node_both)		
} else		
stack[sp++] = false		
}// if(ztree_structure[type][i] = = 0)		
}// for(i=0; i<2*ztree_size[type]-1; i++)		
}		

5.1.15 Transform unit syntax

[Ed. preliminary draft]

[Note: signalling of chroma coded block flag not complete yet]

transform_unit_tree(x0, y0, currTransformUnitSize, layer) {	C	Descriptor
if(currTransformUnitSize > MinTransformUnitSize && currTransformUnitSize <= MaxTransformUnitSize)		
split_transform_unit_flag[x0][y0][layer]	3 | 4	u(1) | ae(v)
if(currTransformUnitSize <= MaxTransformUnitSize) {		
if(needChromaCbfU()) {		
coded_block_flag_chroma_u	3 | 4	u(1) | ae(v)
codedBlockFlag[x0][y0][layer][1] = coded_block_flag_chroma_u		
}		
if(needChromaCbfV()) {		
coded_block_flag_chroma_v	3 | 4	u(1) | ae(v)
codedBlockFlag[x0][y0][layer][2] = coded_block_flag_chroma_v		
}		
}		
if(split_transform_unit_flag[x0][y0][layer]) {		
splitTransformUnitSize = currTransformUnitSize >> 1		
x1 = x0 + splitTransformUnitSize		
y1 = y0 + splitTransformUnitSize		
transform_unit_tree(x0, y0, splitTransformUnitSize, layer+1)	3 | 4	
for(i=0; i<=2; i++)		
codedBlockFlag[x0][y0][layer][i] |= codedBlockFlag[x0][y0][layer+1][i]		
if(x1 < $PicWidthInSamples_L$) {		
transform_unit_tree(x1, y0, splitTransformUnitSize, layer+1)	3 | 4	
for(i=0; i<=2; i++)		
codedBlockFlag[x0][y0][layer][i] |= codedBlockFlag[x1][y0][layer+1][i]		
}		
if(y1 < $PicHeightInSamples_L$) {		
transform_unit_tree(x0, y1, splitTransformUnitSize, layer+1)	3 | 4	
for(i=0; i<=2; i++)		
codedBlockFlag[x0][y0][layer][i] |= codedBlockFlag[x0][y1][layer+1][i]		
}		
if(x1 < $PicWidthInSamples_L$ && y1 < $PicHeightInSamples_L$) {		
transform_unit_tree(x1, y1, splitTransformUnitSize, layer+1)	3 | 4	
for(i=0; i<=2; i++)		
codedBlockFlag[x0][y0][layer][i] |= codedBlockFlag[x1][y1][layer+1][i]		
}		
} else if(coded_block_flag_chroma_u || coded_block_flag_chroma_v) {		
coded_block_flag_luma	3 | 4	u(1) | ae(v)

codedBlockFlag[x0][y0][layer][0] = coded_block_flag_luma		
}		
}		

[Ed. preliminary draft]

transform_unit_coeff(x0, y0, currTransformUnitSize, layer, plane) {	C	Descriptor
if(codedBlockFlag[x0][y0][layer][plane]) {		
if(split_transform_unit_flag[x0][y0][layer]) {		
splitTransformUnitSize = currTransformUnitSize >> 1		
x1 = x0 + splitTransformUnitSize		
y1 = y0 + splitTransformUnitSize		
transform_unit_coeff(x0, y0, splitTransformUnitSize, layer+1, plane)	3 | 4	
if(x1 < $PicWidthInSamples_L$)		
transform_unit_coeff(x1, y0, splitTransformUnitSize, layer+1, plane)	3 | 4	
if(y1 < $PicHeightInSamples_L$)		
transform_unit_coeff(x0, y1, splitTransformUnitSize, layer+1, plane)	3 | 4	
if(x1 < $PicWidthInSamples_L$ && y1 < $PicHeightInSamples_L$)		
transform_unit_coeff(x1, y1, splitTransformUnitSize, layer+1, plane)	3 | 4	
} else {		
residual_block_pipe( )		
}		
}		
}		

[Ed. preliminary draft]

transform_unit_vlc(x0, y0, currTransformUnitSize) {	C	Descriptor
if(currTransformUnitSize > MinTransformUnitSize && currTransformUnitSize <= MaxTransformUnitSize)		
split_transform_unit_flag	3 | 4	u(1) | ae(v)
if(split_transform_unit_flag) {		
splitTransformUnitSize = currTransformUnitSize >> 1		
x1 = x0 + splitTransformUnitSize		
y1 = y0 + splitTransformUnitSize		
if(!entropy_coding_mode_flag)		
getVLCCBP( )		
transform_unit_vlc(x0, y0, splitTransformUnitSize)	3 | 4	
if(x1 < $PicWidthInSamples_L$)		
transform_unit_vlc(x1, y0, splitTransformUnitSize)	3 | 4	
if(y1 < $PicHeightInSamples_L$)		
transform_unit_vlc(x0, y1, splitTransformUnitSize)	3 | 4	
if(x1 < $PicWidthInSamples_L$ && y1 < $PicHeightInSamples_L$)		
transform_unit_vlc(x1, y1, splitTransformUnitSize)	3 | 4	
} else {		
if(entropy_coding_mode_flag)		

coded_block_flag	3 | 4	u(1) | ae(v)
if(coded_block_flag) {		
rotational_transform_idx	3 | 4	ue(v) | ae(v)
if(!entropy_coding_mode_flag)		
residual_block_vlc( )		
else		
residual_block_v2v( )		
}		
}		
}		

[Ed. preliminary draft]

residual_block_vlc (puIdx, tuSize, ctxID) {	C	Descriptor
last_pos_table_idx	3 | 4	vlc(n,v)
if(levelMagnitudeGreaterThanOneFlag)		
last_pos_level	3 | 4	vlc(0,v)
last_pos_sign	3 | 4	u(1)
runMode = 1		
while(runMode && i < numCodedCoeff) {		
isLevelOne_run	3 | 4	vlc(vlcIdx,v)
i += run		
if(!isLevelOne) {		
level_magnitude_minus2	3 | 4	vlc(0,v)
level_sign		
} else		
level_sign	3 | 4	u(1)
}		
while (i < numCodedCoeff) {		
level_magnitude	3 | 4	vlc(n,v)
if(level_magnitude)		
level_sign	3 | 4	u(1)
i++		
}		
}		

[Ed. preliminary draft]

getVLCCBP( ) {	C	Descriptor
if(modeIdx == 2) {		
cbp_id0	3 | 4	u(1)
}		
else if (modeIdx == 7) {		
cbp_id1	3 | 4	u(1)
if(cbp_id1 < 2)		
cbp_id2	3 | 4	u(1)
}		
else if (modeIdx == 4 || modeIdx == 8 || modeIdx == 10 || modeIdx == 12 || modeIdx == 14 || modeIdx == 15) {		
if(PredMode != MODE_INTRA && PuSize != PU_8x8 && currTransformUnitSize ! = TU_16x16)	3 | 4	u(1)
cbp_table_idx		
}		
}		

[Ed. preliminary draft: needs significant improvement]

residual_block_pipe(tuSize) {	C	Descriptor
log2tuSize = Log2(tuSize)		
maxScanPos = $tuSize^2$		
scanDirection = 1		
scanTopRight = 0		
scanBottomLeft = 0		
lastReceived = 0		
maxSubBlocks = $(tuSize >> 2)^2$		
for(scanPos = 0; scanPos < maxScanPos; scanPos++) {		
blockPos = scanPosLookUp[tuSize][scanDirection][scanPos]		
posY = blockPos >> log2tuSize		
posX = blockPos – (posY << log2tuSize)		
sig_flag	3 | 4	u(1)
if(sig_flag == 1) {		
if(posX > posY) {		
scanTopRight++;		
} else if(posY > posX) {		
scanBottomLeft++;		
}		
last_flag	3 | 4	u(1)
if(last_flag == 1) {		
lastReceived = 1		
break;		
}		
if(scanDirection = 1 && (posX == 0 || posY == tuSize - 1) || scanDirection = 0 && (posY == 0 || posX == tuSize - 1) {		
if(scanTopRight > scanBottomLeft) {		
scanDirection = 1		

} else {		
scanDirection = 0		
}		
}		
if(lastReceived) {		
levels[maxScanPos-1] = 1		
}		
for(subBlocks = 0; subBlocks < maxSubBlocks; subBlocks++) {		
numSigInSubBlock [Ed. todo]		
if(numSigInSubBlock > 0) {		
c1 = 0		
c2 = 0		
if(isFirstSubBlock) {		
ctxOffsest = 5		
} else {		
ctxOffset = numLevelsGreaterOne / 16		
numLevelsGreaterOne = 0		
}		
for(scanPos = 0; scanPos < 16; scanPos++) {		
blockPos = scanLookUpInverseRaster[scanPos] [need offset]		
c1 = min(c1, 4)		
ctxId = c1 + ctxOffset * 5		
abs_greater_one	3 | 4	vlc(n,v)
abs_level = abs_greater_one		
if(abs_level == 1) {		
c2 = min(c2, 4)		
ctxId = c2 + ctxOffset * 5		
coeff_abs_level	3 | 4	vlc(n,v)
abs_level = coeff_abs_level + 2		
c1 = 0		
c2++		
numLevelsGreaterOne++		
} else if(c1 > 0) {		
c1++;		
abs_level++		
} else {		
abs_level++		
}		
sign	3 | 4	u(1)
levels[scanPos] = sign || abs_level		
}		
}		
}		

5.2 Semantics

5.2.1 NAL unit semantics

NumBytesInNALunit specifies the size of the NAL unit in bytes. This value is required for decoding of the NAL unit. Some form of demarcation of NAL unit boundaries is necessary to enable inference of NumBytesInNALunit. One such demarcation method is specified in Annex B of ITU-T Rec. H.264 | ISO/IEC 14496-10 for the byte stream format.

forbidden_zero_bit shall be equal to 0.

nal_ref_idc not equal to 0 specifies that the content of the NAL unit contains a sequence parameter set, a picture parameter set, or a slice of a reference picture. nal_ref_idc equal to 0 for a NAL unit containing a slice indicates that the slice is part of a non-reference picture.

nal_ref_idc shall not be equal to 0 for sequence parameter set or picture parameter set NAL units. When nal_ref_idc is equal to 0 for one slice data NAL unit of a particular picture, it shall be equal to 0 for all slice data NAL units of the picture. nal_ref_idc shall not be equal to 0 for NAL units with nal_unit_type equal to 5.

nal_unit_type specifies the type of RBSP data structure contained in the NAL unit as specified in Table 5-1.

The column marked "C" in Table 5-1 lists the categories of the syntax elements that may be present in the NAL unit. In addition, syntax elements with syntax category "All" may be present, as determined by the syntax and semantics of the RBSP data structure. The presence or absence of any syntax elements of a particular listed category is determined from the syntax and semantics of the associated RBSP data structure. VCL and non-VCL NAL units are specified in Table 5-1 in the column labelled " NAL unit type class".

When the value of nal_unit_type is equal to 5 for a slice data NAL unit of a particular picture, all slice data NAL units of the picture shall have nal_unit_type equal to 5.

Table 5-1 – NAL unit type codes, syntax element categories, and NAL unit type classes

nal_unit_type	Content of NAL unit and RBSP syntax structure	C	NAL unit type class
0	Unspecified		non-VCL
1	Coded slice of a non-IDR picture slice_layer_rbsp( )	2, 3, 4	VCL
2..4	Reserved		non-VCL
5	Coded slice of an IDR picture slice_layer_rbsp( )	2, 3	VCL
6	Supplemental enhancement information (SEI) sei_rbsp( )	5	non-VCL
7	Sequence parameter set seq_parameter_set_rbsp( )	0	non-VCL
8	Picture parameter set pic_parameter_set_rbsp( )	1	non-VCL
9	Access unit delimiter access_unit_delimiter_rbsp( )	6	non-VCL
10..11	Reserved		non-VCL
12	Filler data filler_data_rbsp( )	9	non-VCL
13..23	Reserved		non-VCL
24..31	Unspecified		non-VCL

In the text, coded slice NAL unit collectively refers to a coded slice of a non-IDR picture NAL unit or to a coded slice of an IDR picture NAL unit. The variable IdrPicFlag is specified as

$$\text{IdrPicFlag} = ((\text{nal_unit_type} == 5) \ ? \ 1 \ : \ 0) \tag{16}$$

When the value of nal_unit_type is equal to 5 for a NAL unit containing a slice of a particular picture, the picture shall not contain NAL units with nal_unit_type equal to 1. Such a picture is referred to as an IDR picture.

temporal_id specifies a temporal identifier for the NAL unit. The assignment of values to temporal_id is constrained by the sub-bitstream extraction process as specified in subclause XX.

The value of temporal_id shall be the same for all NAL units of an access unit. When an access unit contains any NAL unit with nal_unit_type equal to 5, temporal_id shall be equal to 0.

output_flag affects the decoded picture output and removal processes as specified in Annex C.

reserved_zero_4bits shall be equal to 0. Decoders shall ignore the value of reserved_zero_4bits.

rbsp_byte[i **]** is the i-th byte of an RBSP. An RBSP is specified as an ordered sequence of bytes as follows.

The RBSP contains an SODB as follows.

– If the SODB is empty (i.e., zero bits in length), the RBSP is also empty.

– Otherwise, the RBSP contains the SODB as follows:

  1) The first byte of the RBSP contains the (most significant, left-most) eight bits of the SODB; the next byte of the RBSP shall contain the next eight bits of the SODB, etc., until fewer than eight bits of the SODB remain.

  2) rbsp_trailing_bits( ) are present after the SODB as follows:

     i) The first (most significant, left-most) bits of the final RBSP byte contains the remaining bits of the SODB (if any).

     ii) The next bit consists of a single rbsp_stop_one_bit equal to 1.

     iii) When the rbsp_stop_one_bit is not the last bit of a byte-aligned byte, one or more rbsp_alignment_zero_bit is present to result in byte alignment.

  3) One or more cabac_zero_word 16-bit syntax elements equal to 0x0000 may be present in some RBSPs after the rbsp_trailing_bits( ) at the end of the RBSP.

Syntax structures having these RBSP properties are denoted in the syntax tables using an "_rbsp" suffix. These structures shall be carried within NAL units as the content of the rbsp_byte[i] data bytes. The association of the RBSP syntax structures to the NAL units shall be as specified in Table 5-1.

emulation_prevention_three_byte is a byte equal to 0x03. When an emulation_prevention_three_byte is present in the NAL unit, it shall be discarded by the decoding process.

The last byte of the NAL unit shall not be equal to 0x00.

Within the NAL unit, the following three-byte sequences shall not occur at any byte-aligned position:

– 0x000000

– 0x000001

– 0x000002

Within the NAL unit, any four-byte sequence that starts with 0x000003 other than the following sequences shall not occur at any byte-aligned position:

– 0x00000300

– 0x00000301

– 0x00000302

– 0x00000303

5.2.2 Sequence parameter set RBSP semantics

[Ed.: Parameters to be removed and/or added as appropriate.]

profile_idc and **level_idc** indicate the profile and level to which the coded video sequence conforms.

reserved_zero_8bits shall be equal to 0. Decoders shall ignore the value of reserved_zero_8bits.

seq_parameter_set_id identifies the sequence parameter set that is referred to by the picture parameter set. The value of seq_parameter_set_id shall be in the range of 0 to 31, inclusive.

bit_depth_luma_minus8 specifies the bit depth of the samples of the luma array and the value of the luma quantisation parameter range offset $QpBdOffset_Y$, as specified by

$$BitDepth_Y = 8 + bit_depth_luma_minus8 \quad (17)$$
$$QpBdOffset_Y = 6 * bit_depth_luma_minus8 \quad (18)$$

bit_depth_luma_minus8 shall be in the range of 0 to 6, inclusive.

bit_depth_chroma_minus8 specifies the bit depth of the samples of the chroma arrays and the value of the chroma quantisation parameter range offset $QpBdOffset_C$, as specified by

$$BitDepth_C = 8 + bit_depth_chroma_minus8 \quad (19)$$
$$QpBdOffset_C = 6 * bit_depth_chroma_minus8 \quad (20)$$

bit_depth_chroma_minus8 shall be in the range of 0 to 6, inclusive.

increased_bit_depth_luma specifies the increased bit depth of the samples of the luma array and the value of the luma quantisation parameter range offset $QpIBdOffset_Y$, as specified by

$$QpIBdOffset_Y = 6 * increased_bit_depth_luma \quad (21)$$

increased_bit_depth_chroma specifies the increased bit depth of the samples of the chroma array and the value of the chroma quantisation parameter range offset $QpIBdOffset_C$, as specified by

$$QpIBdOffset_C = 6 * increased_bit_depth_chroma \quad (22)$$

log2_max_frame_num_minus4 specifies the value of the variable MaxFrameNum that is used in frame_num related derivations as follows:

$$MaxFrameNum = 2^{(\, log2_max_frame_num_minus4 + 4\,)} \quad (23)$$

The value of log2_max_frame_num_minus4 shall be in the range of 0 to 12, inclusive.

pic_order_cnt_type specifies the method to decode picture order count (as specified in subclause XX). The value of pic_order_cnt_type shall be in the range of 0 to 2, inclusive.

pic_order_cnt_type shall not be equal to 2 in a coded video sequence that contains an access unit containing a non-reference frame followed immediately by an access unit containing a non-reference picture,

log2_max_pic_order_cnt_lsb_minus4 specifies the value of the variable MaxPicOrderCntLsb that is used in the decoding process for picture order count as follows:

$$MaxPicOrderCntLsb = 2^{(\, log2_max_pic_order_cnt_lsb_minus4 + 4\,)} \quad (24)$$

The value of log2_max_pic_order_cnt_lsb_minus4 shall be in the range of 0 to 12, inclusive.

delta_pic_order_always_zero_flag equal to 1 specifies that delta_pic_order_cnt[0] and delta_pic_order_cnt[1] are not present in the slice headers of the sequence and shall be inferred to be equal to 0.

delta_pic_order_always_zero_flag equal to 0 specifies that delta_pic_order_cnt[0] is present in the slice headers of the sequence and delta_pic_order_cnt[1] may be present in the slice headers of the sequence.

offset_for_non_ref_pic is used to calculate the picture order count of a non-reference picture as specified in subclause XX. The value of offset_for_non_ref_pic shall be in the range of $-2^{31}+1$ to $2^{31}-1$, inclusive.

num_ref_frames_in_pic_order_cnt_cycle is used in the decoding process for picture order count as specified in subclause XX. The value of num_ref_frames_in_pic_order_cnt_cycle shall be in the range of 0 to 255, inclusive.

offset_for_ref_frame[i] is an element of a list of num_ref_frames_in_pic_order_cnt_cycle values used in the decoding process for picture order count as specified in subclause XX. The value of offset_for_ref_frame[i] shall be in the range of $-2^{31}+1$ to $2^{31}-1$, inclusive.

When pic_order_cnt_type is equal to 1, the variable ExpectedDeltaPerPicOrderCntCycle is derived by

```
ExpectedDeltaPerPicOrderCntCycle = 0
for( i = 0;   i < num_ref_frames_in_pic_order_cnt_cycle;   i++ )
    ExpectedDeltaPerPicOrderCntCycle += offset_for_ref_frame[ i ]
```
(25)

max_num_ref_frames specifies the maximum number of short-term and long-term reference frames, complementary reference field pairs, and non-paired reference fields that may be used by the decoding process for inter prediction of any picture in the sequence. max_num_ref_frames also determines the size of the sliding window operation. The value of max_num_ref_frames shall be in the range of 0 to MaxDpbFrames, inclusive.

gaps_in_frame_num_value_allowed_flag specifies the allowed values of frame_num and the decoding process in case of an inferred gap between values of frame_num.

max_coding_unit_width specifies the maximum width of a coding unit

max_coding_unit_height specifies the maximum height of a coding unit

log2_min_transform_unit_size_minus2 specifies the minimum size of a transform unit.

The variable MinTransformUnitSize is derived as

```
MinTransformUnitSize = 1 << ( log2_min_transform_unit_size_minus2 + 2 )
```
(26)

max_transform_unit_hierarchy_depth specifies the maximum hierarchy depth for transform units. If not parsed, this element is set to 0.

The variable MaxTransformUnitSize is derived as

```
MaxTransformUnitSize = 1 << ( log2_min_transform_unit_size_minus2 + 2 +
                                max_transform_unit_hierarchy_depth )
```
(27)

The bitstream shall not contain data that result in a value of MaxTransformUnitSize that is greater than MaxCodingUnitSize.

max_coding_unit_hierarchy_depth_correct equal to 0 specifies that the coding unit hierarchy depth is not incremented. max_coding_unit_hierarchy_depth_correct equal to 1 specifies that the coding unit hierarchy depth is incremented by 1.

The variable MaxCodingUnitDepth is derived as

```
AddCUDepth = 0
While     ( max_coding_unit_width >> max_coding_unit_hierarchy_depth_correct ) >
          ( 1 << ( log2_min_transform_unit_size_minus2 ) + AddCUDepth ) ) ) {
      AddCuDepth
}
MaxCodingUnitHierarchyDepth = max_coding_unit_hierarchy_depth_correct + AddCUDepth
```

pic_width_in_luma_samples specifies the width of each decoded picture in luma samples.

[Ed.: macroblock may be replaced by smallest coding unit and mbs may be replaced by mcu, MinCodingUnitSize]

[Ed: Need to coordinate frame size signaling with cropping, etc.]

pic_height_in_luma_samples specifies the height of each decoded picture in luma samples.

numExtraFilters specifies the number of extra filters to be used along with the fixed set of filters described in Table 5-5, 5-6 and 5-8.

log2_filterCoeffPrecision specifies the number of bits to represent filter coefficient.

halfNumTap specifies half the number of filter tap.

filterCoef[i][j] specifies signed value of jth coefficient of ith extra filter and shall be represented by log2_filterCoeffPrecision bits.

adaptive_intra_smoothing_flag equal to 1 specifies that a flag for applying an additional smoothing filter on intra reference pixels.can be present for intra modes in prediction unti syntax. adaptive_intra_smoothing_flag equal to 0 specifies that no additional flag is present.

inter_merge_flag equal to 1 specifies that motion partition merging is can be applied.

interleaved_motion_vector_predictor_flag equal to 1 specifies that interleaved motion vector prediction can be applied.

pbic_flag equal to 1 specifies that partition based illumination compensation is applied.

5.2.3 Picture parameter set RBSP semantics

[Ed.: Parameters to be removed and/or added as appropriate.]

pic_parameter_set_id identifies the picture parameter set that is referred to in the slice header. The value of pic_parameter_set_id shall be in the range of 0 to 255, inclusive.

seq_parameter_set_id refers to the active sequence parameter set. The value of seq_parameter_set_id shall be in the range of 0 to 31, inclusive.

entropy_coding_mode_flag selects the entropy decoding method to be applied for the syntax elements for which two descriptors appear in the syntax tables as follows.

- If entropy_coding_mode_flag is equal to 0, the method specified by the left descriptor in the syntax table is applied.
- Otherwise (entropy_coding_mode_flag is equal to 1), the method specified by the right descriptor in the syntax table is applied.

num_ref_idx_l0_default_active_minus1 specifies how num_ref_idx_l0_active_minus1 is inferred for P and B slices with num_ref_idx_active_override_flag equal to 0. The value of num_ref_idx_l0_default_active_minus1 shall be in the range of 0 to 31, inclusive.

num_ref_idx_l1_default_active_minus1 specifies how num_ref_idx_l1_active_minus1 is inferred for B slices with num_ref_idx_active_override_flag equal to 0. The value of num_ref_idx_l1_default_active_minus1 shall be in the range of 0 to 31, inclusive.

pic_init_qp_minus26 specifies the initial value minus 26 of $SliceQP_Y$ for each slice. The initial value is modified at the slice layer when a non-zero value of slice_qp_delta is decoded, and is modified further when a non-zero value of mb_qp_delta is decoded at the macroblock layer. The value of pic_init_qp_minus26 shall be in the range of $-(26 + QpBdOffset_Y)$ to +25, inclusive.

constrained_intra_pred_flag equal to 0 specifies that intra prediction allows usage of residual data and decoded samples of neighbouring macroblocks coded using Inter macroblock prediction modes for the prediction of macroblocks coded using Intra macroblock prediction modes. constrained_intra_pred_flag equal to 1 specifies constrained intra prediction, in which case prediction of macroblocks coded using Intra macroblock prediction modes only uses residual data and decoded samples from I macroblock types.

numAllowedFilters[i] specifies the number of filters to be used during filtering process for $(i+1)^{th}$ subpel.

filtIdx[i][j] specifies the index of jth filter for $(i+1)^{th}$ subpel to be used during filtering process.

5.2.4 Supplemental enhancement information RBSP semantics

The Supplemental Enhancement Information (SEI) contains information that is not necessary to decode the samples of coded pictures from VCL NAL units.

5.2.5 Supplemental enhancement information message semantics

An SEI RBSP contains one or more SEI messages. Each SEI message consists of the variables specifying the type payloadType and size payloadSize of the SEI payload. SEI payloads are specified in Annex XX. The derived SEI payload size payloadSize is specified in bytes and shall be equal to the number of RBSP bytes in the SEI payload.

NOTE – The NAL unit byte sequence containing the SEI message might include one or more emulation prevention bytes (represented by emulation_prevention_three_byte syntax elements). Since the payload size of an SEI message is specified in RBSP bytes, the quantity of emulation prevention bytes is not included in the size payloadSize of an SEI payload.

ff_byte is a byte equal to 0xFF identifying a need for a longer representation of the syntax structure that it is used within.

last_payload_type_byte is the last byte of the payload type of an SEI message.

last_payload_size_byte is the last byte of the payload size of an SEI message.

5.2.6 Access unit delimiter RBSP semantics

The access unit delimiter may be used to indicate the type of slices present in a primary coded picture and to simplify the detection of the boundary between access units. There is no normative decoding process associated with the access unit delimiter.

primary_pic_type indicates that the slice_type values for all slices of the primary coded picture are members of the set listed in Table 5-2 for the given value of primary_pic_type.

Table 5-2 – Meaning of primary_pic_type

primary_pic_type	slice_type values that may be present in the primary coded picture
0	2, 7
1	0, 2, 5, 7
2	0, 1, 2, 5, 6, 7
3..7	Reserved

5.2.7 Filler data RBSP semantics

The filler data RBSP contains bytes whose value shall be equal to 0xFF. No normative decoding process is specified for a filler data RBSP.

ff_byte is a byte equal to 0xFF.

5.2.8 Slice layer RBSP semantics

The slice layer RBSP consists of a slice header and slice data.

5.2.9 RBSP slice trailing bits semantics

cabac_zero_word is a byte-aligned sequence of two bytes equal to 0x0000.

5.2.10 RBSP trailing bits semantics

rbsp_stop_one_bit shall be equal to 1.

rbsp_alignment_zero_bit shall be equal to 0.

5.2.11 Slice header semantics

[Ed.: Parameters should be removed and/or added as appropriate.]

When present, the value of the slice header syntax elements pic_parameter_set_id, frame_num, field_pic_flag, bottom_field_flag, idr_pic_id, pic_order_cnt_lsb, delta_pic_order_cnt_bottom, delta_pic_order_cnt[0], delta_pic_order_cnt[1], and slice_group_change_cycle shall be the same in all slice headers of a coded picture.

first_lctb_in_slice specifies the address of the first largest coding tree block in the slice.

The first largest coding tree block address of the slice is derived as follows.

– TBD.

slice_type specifies the coding type of the slice according to Table 5-3.

Table 5-3 – Name association to slice_type

slice_type	Name of slice_type
0	P (P slice)
1	B (B slice)
2	I (I slice)
5	P (P slice)
6	B (B slice)
7	I (I slice)

When slice_type has a value in the range 5..7, it is a requirement of bitstream conformance that all other slices of the current coded picture shall have a value of slice_type equal to the current value of slice_type or equal to the current value of slice_type minus 5.

When nal_unit_type is equal to 5 (IDR picture), slice_type shall be equal to 2 or 7.

When max_num_ref_frames is equal to 0, slice_type shall be equal to 2 or 7.

pic_parameter_set_id specifies the picture parameter set in use. The value of pic_parameter_set_id shall be in the range of 0 to 255, inclusive.

frame_num is used as an identifier for pictures and shall be represented by log2_max_frame_num_minus4 + 4 bits in the bitstream. frame_num is constrained as follows:
The variable PrevRefFrameNum is derived as follows.

– If the current picture is an IDR picture, PrevRefFrameNum is set equal to 0.
– Otherwise (the current picture is not an IDR picture), PrevRefFrameNum is set as follows.
  – If the decoding process for gaps in frame_num was invoked by the decoding process for an access unit that contained a non-reference picture that followed the previous access unit in decoding order that contained a reference picture, PrevRefFrameNum is set equal to the value of frame_num for the last of the "non-existing" reference frames inferred by the decoding process for gaps in frame_num.
  – Otherwise, PrevRefFrameNum is set equal to the value of frame_num for the previous access unit in decoding order that contained a reference picture.

The value of frame_num is constrained as follows.

– If the current picture is an IDR picture, frame_num shall be equal to 0.
– Otherwise (the current picture is not an IDR picture), referring to the primary coded picture in the previous access unit in decoding order that contains a reference picture as the preceding reference picture, the value of frame_num for the current picture shall not be equal to PrevRefFrameNum unless both of the following conditions are true.
  – the current picture and the preceding reference picture belong to consecutive access units in decoding order
  – one or more of the following conditions is true

- the preceding reference picture is an IDR picture
- the preceding reference picture includes a memory_management_control_operation syntax element equal to 5

  NOTE 1 – When the preceding reference picture includes a memory_management_control_operation syntax element equal to 5, PrevRefFrameNum is equal to 0.
- there is a primary coded picture that precedes the preceding reference picture and the primary coded picture that precedes the preceding reference picture does not have frame_num equal to PrevRefFrameNum
- there is a primary coded picture that precedes the preceding reference picture and the primary coded picture that precedes the preceding reference picture is not a reference picture

When the value of frame_num is not equal to PrevRefFrameNum, the following applies.

- There shall not be any previous frame in decoding order that is currently marked as "used for short-term reference" that has a value of frame_num equal to any value taken on by the variable UnusedShortTermFrameNum in the following:

```
UnusedShortTermFrameNum = ( PrevRefFrameNum + 1 ) % MaxFrameNum
while( UnusedShortTermFrameNum   !=   frame_num )
    UnusedShortTermFrameNum = ( UnusedShortTermFrameNum + 1 ) % MaxFrameNum
```

- The value of frame_num is constrained as follows.
  - If gaps_in_frame_num_value_allowed_flag is equal to 0, the value of frame_num for the current picture shall be equal to (PrevRefFrameNum + 1) % MaxFrameNum.
  - Otherwise (gaps_in_frame_num_value_allowed_flag is equal to 1), the following applies.
    - If frame_num is greater than PrevRefFrameNum, there shall not be any non-reference pictures in the bitstream that follow the previous reference picture and precede the current picture in decoding order in which either of the following conditions is true.
      - The value of frame_num for the non-reference picture is less than PrevRefFrameNum.
      - The value of frame_num for the non-reference picture is greater than the value of frame_num for the current picture.
    - Otherwise (frame_num is less than PrevRefFrameNum), there shall not be any non-reference pictures in the bitstream that follow the previous reference picture and precede the current picture in decoding order in which both of the following conditions are true.
      - The value of frame_num for the non-reference picture is less than PrevRefFrameNum.
      - The value of frame_num for the non-reference picture is greater than the value of frame_num for the current picture.

A picture including a memory_management_control_operation equal to 5 shall have frame_num constraints as described above and, after the decoding of the current picture and the processing of the memory management control operations, the picture shall be inferred to have had frame_num equal to 0 for all subsequent use in the decoding process.

idr_pic_id identifies an IDR picture. The values of idr_pic_id in all the slices of an IDR picture shall remain unchanged. When two consecutive access units in decoding order are both IDR access units, the value of idr_pic_id in the slices of the first such IDR access unit shall differ from the idr_pic_id in the second such IDR access unit. The value of idr_pic_id shall be in the range of 0 to 65535, inclusive.

pic_order_cnt_lsb specifies the picture order count modulo MaxPicOrderCntLsb for the top field of a coded frame or for a coded field. The length of the pic_order_cnt_lsb syntax element is log2_max_pic_order_cnt_lsb_minus4 + 4 bits. The value of the pic_order_cnt_lsb shall be in the range of 0 to MaxPicOrderCntLsb − 1, inclusive.

num_ref_idx_active_override_flag equal to 1 specifies that the syntax element num_ref_idx_l0_active_minus1 is present for P and B slices and that the syntax element num_ref_idx_l1_active_minus1 is present for B slices. num_ref_idx_active_override_flag equal to 0 specifies that the syntax elements num_ref_idx_l0_active_minus1 and num_ref_idx_l1_active_minus1 are not present.

When the current slice is a P or B slice and field_pic_flag is equal to 0 and the value of num_ref_idx_l0_default_active_minus1 in the picture parameter set exceeds 15, num_ref_idx_active_override_flag shall be equal to 1.

When the current slice is a B slice and field_pic_flag is equal to 0 and the value of num_ref_idx_l1_default_active_minus1 in the picture parameter set exceeds 15, num_ref_idx_active_override_flag shall be equal to 1.

num_ref_idx_l0_active_minus1 specifies the maximum reference index for reference picture list 0 that shall be used to decode the slice.

When the current slice is a P or B slice and num_ref_idx_l0_active_minus1 is not present, num_ref_idx_l0_active_minus1 shall be inferred to be equal to num_ref_idx_l0_default_active_minus1.

The range of num_ref_idx_l0_active_minus1 is specified as follows.p

– If field_pic_flag is equal to 0, num_ref_idx_l0_active_minus1 shall be in the range of 0 to 15, inclusive. When MbaffFrameFlag is equal to 1, num_ref_idx_l0_active_minus1 is the maximum index value for the decoding of frame macroblocks and 2 * num_ref_idx_l0_active_minus1 + 1 is the maximum index value for the decoding of field macroblocks.
– Otherwise (field_pic_flag is equal to 1), num_ref_idx_l0_active_minus1 shall be in the range of 0 to 31, inclusive.

num_ref_idx_l1_active_minus1 specifies the maximum reference index for reference picture list 1 that shall be used to decode the slice.

When the current slice is a B slice and num_ref_idx_l1_active_minus1 is not present, num_ref_idx_l1_active_minus1 shall be inferred to be equal to num_ref_idx_l1_default_active_minus1.

The range of num_ref_idx_l1_active_minus1 is constrained as specified in the semantics for num_ref_idx_l0_active_minus1 with l0 and list 0 replaced by l1 and list 1, respectively.

pipe_multi_codeword_flag equal to 1 specifies that multi-codeword PIPE is used as entropy coding method and the V2V codewords for the slice data syntax are coded in 12 separate partitions. pipe_multi_codeword_flag equal to 0 specifies that the V2V codeword are interleaved.

pipe_max_delay_in_bits_shift_6 multiplied by 32 specifies the maximum delay in bits for PIPE decoding if pipe_multi_codeword_flag is equal to 0.

Balanced_cpus equal to 1 specifies that mutli-codeword PIPE with V2V codewords is used as a parallel entropy coding method without load balancing. Balanced_cpus>1 specifies the number of load balanced parallel entropy partitions.

cabac_init_idc specifies the index for determining the initialisation table used in the initialisation process for context variables. The value of cabac_init_idc shall be in the range of 0 to 2, inclusive.

slice_qp_delta specifies the initial value of QP_Y to be used for all the macroblocks in the slice until modified by the value of mb_qp_delta in the macroblock layer. The initial QP_Y quantisation parameter for the slice is computed as

$$SliceQP_Y = 26 + pic_init_qp_minus26 + slice_qp_delta \quad (28)$$

The value of slice_qp_delta shall be limited such that $SliceQP_Y$ is in the range of $-QpBdOffset_Y$ to +51, inclusive.

mc_interpolation_idc specifies the method that is used for deriving Inter prediction samples.

mv_competition_flag specifies whether motion vector competition is used. When the motion vector competition is used, the function NumMVPCand(LX, puPartIdx) returns the total number of motion vector prediction candidates with the prediction unit partition puPartIdx and reference list LX as arguments.

mv_competition_temporal_flag specifies whether temporally collocated motion vector is used in the motion competition process.

collocated_from_l0_flag specifies that the reference picture list 0 is used in the derivation process for the temporal motion vector predictor. Otherwise, the reference picture list 1 is used. When collocated_from_l0_flag is not present, it shall be inferred to be equal to 1.

edge_based_prediction_flag: indicates whether the edge based prediction process shall be invoked during intra prediction. A value of 0 indicates that the edge based prediction process shall not be applied, a value of 1 indicates that the edge based prediction process shall be one of the candidate modes for intra prediction.

threshold_edge: specifies the threshold for the decision between the edge based prediction mode and the DC prediction mode during intra prediction. When edge_based_prediction_flag is equal to 0, threshold_edge shall not be present in the bitstream.

5.2.11.1 Reference picture list modification semantics

The syntax elements modification_of_pic_nums_idc, abs_diff_pic_num_minus1, and long_term_pic_num specify the change from the initial reference picture lists to the reference picture lists to be used for decoding the slice.

ref_pic_list_modification_flag_l0 equal to 1 specifies that the syntax element modification_of_pic_nums_idc is present for specifying reference picture list 0. ref_pic_list_modification_flag_l0 equal to 0 specifies that this syntax element is not present.

When ref_pic_list_modification_flag_l0 is equal to 1, the number of times that modification_of_pic_nums_idc is not equal to 3 following ref_pic_list_modification_flag_l0 shall not exceed num_ref_idx_l0_active_minus1 + 1.

When RefPicList0[num_ref_idx_l0_active_minus1] in the initial reference picture list produced as specified in subclause XX is equal to "no reference picture", ref_pic_list_modification_flag_l0 shall be equal to 1 and modification_of_pic_nums_idc shall not be equal to 3 until RefPicList0[num_ref_idx_l0_active_minus1] in the modified list produced as specified in subclause XX is not equal to "no reference picture".

ref_pic_list_modification_flag_l1 equal to 1 specifies that the syntax element modification_of_pic_nums_idc is present for specifying reference picture list 1. ref_pic_list_modification_flag_l1 equal to 0 specifies that this syntax element is not present.

When ref_pic_list_modification_flag_l1 is equal to 1, the number of times that modification_of_pic_nums_idc is not equal to 3 following ref_pic_list_modification_flag_l1 shall not exceed num_ref_idx_l1_active_minus1 + 1.

When decoding a slice with slice_type equal to 1 or 6 and RefPicList1[num_ref_idx_l1_active_minus1] in the initial reference picture list produced as specified in subclause XX is equal to "no reference picture", ref_pic_list_modification_flag_l1 shall be equal to 1 and modification_of_pic_nums_idc shall not be equal to 3 until RefPicList1[num_ref_idx_l1_active_minus1] in the modified list produced as specified in subclause XX is not equal to "no reference picture".

modification_of_pic_nums_idc together with abs_diff_pic_num_minus1 or long_term_pic_num specifies which of the reference pictures are re-mapped. The values of modification_of_pic_nums_idc are specified in Table Table 5-4. The value of the first modification_of_pic_nums_idc that follows immediately after ref_pic_list_modification_flag_l0 or ref_pic_list_modification_flag_l1 shall not be equal to 3.

Table 5-4 – modification_of_pic_nums_idc operations for modification of reference picture lists

modification_of_pic_nums_idc	modification specified
0	abs_diff_pic_num_minus1 is present and corresponds to a difference to subtract from a picture number prediction value
1	abs_diff_pic_num_minus1 is present and corresponds to a difference to add to a picture number prediction value
2	long_term_pic_num is present and specifies the long-term picture number for a reference picture
3	End loop for modification of the initial reference picture list

abs_diff_pic_num_minus1 plus 1 specifies the absolute difference between the picture number of the picture being moved to the current index in the list and the picture number prediction value. abs_diff_pic_num_minus1 shall be in the range of 0 to MaxPicNum − 1. The allowed values of abs_diff_pic_num_minus1 are further restricted as specified in subclause XX.

long_term_pic_num specifies the long-term picture number of the picture being moved to the current index in the list. When decoding a coded frame, long_term_pic_num shall be equal to a LongTermPicNum assigned to one of the reference frames marked as "used for long-term reference".

5.2.11.2 Decoded reference picture marking semantics

The syntax elements no_output_of_prior_pics_flag, long_term_reference_flag, adaptive_ref_pic_marking_mode_flag, memory_management_control_operation, difference_of_pic_nums_minus1, long_term_frame_idx, long_term_pic_num, and max_long_term_frame_idx_plus1 specify marking of the reference pictures.

The marking of a reference picture can be "unused for reference", "used for short-term reference", or "used for long-term reference", but only one among these three. When a reference picture is referred to as being marked as "used for reference", this collectively refers to the picture being marked as "used for short-term reference" or "used for long-term reference" (but not both). A reference picture that is marked as "used for short-term reference" is referred to as a short-term reference picture. A reference picture that is marked as "used for long-term reference" is referred to as a long-term reference picture.

The content of the decoded reference picture marking syntax structure shall be the same in all slice headers of the primary coded picture. When one or more redundant coded pictures are present, the content of the decoded reference picture marking syntax structure shall be the same in all slice headers of a redundant coded picture with a particular value of redundant_pic_cnt.

The syntax category of the decoded reference picture marking syntax structure shall be inferred as follows.

– If the decoded reference picture marking syntax structure is in a slice header, the syntax category of the decoded reference picture marking syntax structure is inferred to be equal to 2.

– Otherwise (the decoded reference picture marking syntax structure is in a decoded reference picture marking repetition SEI message), the syntax category of the decoded reference picture marking syntax structure is inferred to be equal to 5.

no_output_of_prior_pics_flag specifies how the previously-decoded pictures in the decoded picture buffer are treated after decoding of an IDR picture. When the IDR picture is the first IDR picture in the bitstream, the value of no_output_of_prior_pics_flag has no effect on the decoding process. When the IDR picture is not the first IDR picture in the bitstream and the value of PicWidthInMbs, FrameHeightInMbs, or max_dec_frame_buffering derived from the active sequence parameter set is different from the value of PicWidthInMbs, FrameHeightInMbs, or max_dec_frame_buffering derived from the sequence parameter set active for the preceding picture, no_output_of_prior_pics_flag equal to 1 may (but should not) be inferred by the decoder, regardless of the actual value of no_output_of_prior_pics_flag.

long_term_reference_flag equal to 0 specifies that the MaxLongTermFrameIdx variable is set equal to "no long-term frame indices" and that the IDR picture is marked as "used for short-term reference". long_term_reference_flag equal to 1 specifies that the MaxLongTermFrameIdx variable is set equal to 0 and that the current IDR picture is marked "used for long-term reference" and is assigned LongTermFrameIdx equal to 0. When max_num_ref_frames is equal to 0, long_term_reference_flag shall be equal to 0.

adaptive_ref_pic_marking_mode_flag selects the reference picture marking mode of the currently decoded picture as specified in Table 5-5. adaptive_ref_pic_marking_mode_flag shall be equal to 1 when the number of frames, complementary field pairs, and non-paired fields that are currently marked as "used for long-term reference" is equal to Max(max_num_ref_frames, 1).

Table 5-5 – Interpretation of adaptive_ref_pic_marking_mode_flag

adaptive_ref_pic_marking_mode_flag	Reference picture marking mode specified
0	Sliding window reference picture marking mode: A marking mode providing a first-in first-out mechanism for short-term reference pictures.
1	Adaptive reference picture marking mode: A reference picture marking mode providing syntax elements to specify marking of reference pictures as "unused for reference" and to assign long-term frame indices.

memory_management_control_operation specifies a control operation to be applied to affect the reference picture marking. The memory_management_control_operation syntax element is followed by data necessary for the operation specified by the value of memory_management_control_operation. The values and control operations associated with memory_management_control_operation are specified in Table 5-6. The

memory_management_control_operation syntax elements are processed by the decoding process in the order in which they appear in the slice header, and the semantics constraints expressed for each memory_management_control_operation apply at the specific position in that order at which that individual memory_management_control_operation is processed.

For interpretation of memory_management_control_operation, the term reference picture is interpreted as follows.

– If the current picture is a frame, the term reference picture refers either to a reference frame or a complementary reference field pair.

– Otherwise (the current picture is a field), the term reference picture refers either to a reference field or a field of a reference frame.

memory_management_control_operation shall not be equal to 1 in a slice header unless the specified reference picture is marked as "used for short-term reference" when the memory_management_control_operation is processed by the decoding process.

memory_management_control_operation shall not be equal to 2 in a slice header unless the specified long-term picture number refers to a reference picture that is marked as "used for long-term reference" when the memory_management_control_operation is processed by the decoding process.

memory_management_control_operation shall not be equal to 3 in a slice header unless the specified reference picture is marked as "used for short-term reference" when the memory_management_control_operation is processed by the decoding process.

memory_management_control_operation shall not be equal to 3 or 6 if the value of the variable MaxLongTermFrameIdx is equal to "no long-term frame indices" when the memory_management_control_operation is processed by the decoding process.

Not more than one memory_management_control_operation equal to 4 shall be present in a slice header.

Not more than one memory_management_control_operation equal to 5 shall be present in a slice header.

Not more than one memory_management_control_operation equal to 6 shall be present in a slice header.

memory_management_control_operation shall not be equal to 5 in a slice header unless no memory_management_control_operation in the range of 1 to 3 is present in the same decoded reference picture marking syntax structure.

A memory_management_control_operation equal to 5 shall not follow a memory_management_control_operation equal to 6 in the same slice header.

When a memory_management_control_operation equal to 6 is present, any memory_management_control_operation equal to 2, 3, or 4 that follows the memory_management_control_operation equal to 6 within the same slice header shall not specify the current picture to be marked as "unused for reference".

Table 5-6 – Memory management control operation (memory_management_control_operation) values

memory_management_control_operation	Memory Management Control Operation
0	End memory_management_control_operation syntax element loop
1	Mark a short-term reference picture as "unused for reference"
2	Mark a long-term reference picture as "unused for reference"
3	Mark a short-term reference picture as "used for long-term reference" and assign a long-term frame index to it
4	Specify the maximum long-term frame index and mark all long-term reference pictures having long-term frame indices greater than the maximum value as "unused for reference"
5	Mark all reference pictures as "unused for reference" and set the MaxLongTermFrameIdx variable to "no long-term frame indices"
6	Mark the current picture as "used for long-term reference" and assign a long-term frame index to it

When decoding a field and a memory_management_control_operation command equal to 3 is present that assigns a long-term frame index to a field that is part of a short-term reference frame or part of a complementary reference field pair, another memory_management_control_operation command (equal to 3 or 6) to assign the same long-term frame index to the other field of the same frame or complementary reference field pair shall be present in the same decoded reference picture marking syntax structure.

When the first field (in decoding order) of a complementary reference field pair included a long_term_reference_flag equal to 1 or a memory_management_control_operation command equal to 6, the decoded reference picture marking syntax structure for the second field of the complementary reference field pair shall contain a memory_management_control_operation command equal to 6 that assigns the same long-term frame index to the second field.

When the second field (in decoding order) of a complementary reference field pair includes a memory_management_control_operation command equal to 6 that assigns a long-term frame index to this field and the first field of the complementary reference field pair is marked as "used for short-term reference" when the memory_management_control_operation command equal to 6 is processed by the decoding process, the decoded reference picture marking syntax structure of that second field shall contain either a memory_management_control_operation command equal to 1 that marks the first field of the complementary field pair as "unused for reference" or a memory_management_control_operation command equal to 3 that marks the first field of the complementary field pair as "used for long-term reference" and assigns the same long-term frame index to the first field.

difference_of_pic_nums_minus1 is used (with memory_management_control_operation equal to 3 or 1) to assign a long-term frame index to a short-term reference picture or to mark a short-term reference picture as "unused for reference". When the associated memory_management_control_operation is processed by the decoding process, the resulting picture number derived from difference_of_pic_nums_minus1 shall be a picture number assigned to one of the reference pictures marked as "used for reference" and not previously assigned to a long-term frame index.

The resulting picture number is constrained as follows.

– If field_pic_flag is equal to 0, the resulting picture number shall be one of the set of picture numbers assigned to reference frames or complementary reference field pairs.

– Otherwise (field_pic_flag is equal to 1), the resulting picture number shall be one of the set of picture numbers assigned to reference fields.

long_term_pic_num is used (with memory_management_control_operation equal to 2) to mark a long-term reference picture as "unused for reference". When the associated memory_management_control_operation is

processed by the decoding process, long_term_pic_num shall be equal to a long-term picture number assigned to one of the reference pictures that is currently marked as "used for long-term reference".

The resulting long-term picture number is constrained as follows.

– If field_pic_flag is equal to 0, the resulting long-term picture number shall be one of the set of long-term picture numbers assigned to reference frames or complementary reference field pairs.

– Otherwise (field_pic_flag is equal to 1), the resulting long-term picture number shall be one of the set of long-term picture numbers assigned to reference fields.

long_term_frame_idx is used (with memory_management_control_operation equal to 3 or 6) to assign a long-term frame index to a picture. When the associated memory_management_control_operation is processed by the decoding process, the value of long_term_frame_idx shall be in the range of 0 to MaxLongTermFrameIdx, inclusive.

max_long_term_frame_idx_plus1 minus 1 specifies the maximum value of long-term frame index allowed for long-term reference pictures (until receipt of another value of max_long_term_frame_idx_plus1). The value of max_long_term_frame_idx_plus1 shall be in the range of 0 to max_num_ref_frames, inclusive.

5.2.11.3 Adaptive loop filter parameter semantics

adaptive_loop_filter_flag specifies whether adaptive loop filter applies or not for the current slice

alf_length_luma_~~hor~~_minus5_div2 specifies the filter length ~~in horizontal direction~~ for the luma component used in the adaptive loop filter process. ~~This filter shall be applied to the reconstructed signal.~~ The filter length used to define the number of coded ~~luma~~ filter cofficients is specified as follows:

AlfLengthLuma~~_hor = (~~ = (alf_length_luma_~~hor~~_minus5_div2~~<<~~ << 1~~)+~~) + 5

~~**alf_length_luma_ver_minus5_div2** specifies the filter length in vertical direction for the luma component used in the adaptive loop filter process. This filter shall be applied to the reconstructed signal. The filter length used to define the number of coded luma filter cofficients is specified as follows:~~

The number of coded luma filter coefficients is specified as follows:

AlfNumCoeffLuma = ((AlfLengthLuma~~_ver = (alf_length_luma_ver_minus5_div2<<1)+5~~

~~**alf_length_luma_pred_hor_minus1_div2** specifies the filter length in horizontal direction for the luma component used in the adaptive loop filter process. This filter shall be applied to the prediction signal. The filter length used to define the number of coded luma filter cofficients is specified as follows:~~

~~*~~ * AlfLengthLuma~~_pred_hor = (alf_length_luma_pred_hor_minus1_div2<<1)+1~~ + 2) >> 2) + 2

~~**alf_length_luma_pred_ver_minus1_div2** specifies the filter length in vertical direction for the luma component used in the adaptive loop filter process. This filter shall be applied to the prediction signal. The filter length used to define the number of coded luma filter cofficients is specified as follows:~~

~~AlfLengthLuma_pred_ver = (alf_length_luma_pred_ver_minus1_div2 <<1)+1~~

~~**alf_length_luma_qpe_hor_minus1_div2** specifies the filter length in horizontal direction for the luma component used in the adaptive loop filter process. This filter shall be applied to the quantized prediction error signal. The filter length used to define the number of coded luma filter cofficients is specified as follows:~~

~~AlfLengthLuma_qpe_hor = (alf_length_luma_qpe_hor_minus1_div2<<1)+1~~

~~**alf_length_luma_qpe_ver_minus1_div2** specifies the filter length in vertical direction for the luma component used in the adaptive loop filter process. This filter shall be applied to the quantized prediction error signal. The filter length used to define the number of coded luma filter cofficients is specified as follows:~~

~~AlfLengthLuma_qpe_ver = (alf_length_luma_qpe_ver_minus1_div2<<1)+1~~

~~**alf_quant_step_size_luma_hor** specifies the quantization step size of the filter coefficients that are used for the horizontal filtering of the luma component. Table 5-7 specifies the step size Alf_filter_precision_Luma_hor.~~

~~**alf_quant_step_size_luma_ver** specifies the quantization step size of the filter coefficients that are used for the vertical filtering of the luma component.Table 5-8 specifies the step size Alf_filter_precision_ Luma_ver.~~

~~**Table 5-7 Specification of Alf_filter_precision_Luma_hor**~~

~~alf_quant_step_size_luma_hor~~	~~Alf_filter_precision_Luma_hor~~
~~0~~	~~3~~
~~4~~	~~4~~
~~2~~	~~5~~
~~3~~	~~6~~
~~4~~	~~7~~
~~5~~	~~8~~
~~6~~	~~9~~
~~7~~	~~10~~
~~8~~	~~11~~
~~9~~	~~12~~
~~10~~	~~13~~
~~11~~	~~14~~

~~**Table 5-8 Specification of Alf_filter_precision_Luma_ver**~~

~~alf_quant_step_size_luma_ver~~	~~Alf_filter_precision_Luma_ver~~
~~0~~	~~3~~
~~4~~	~~4~~
~~2~~	~~5~~
~~3~~	~~6~~
~~4~~	~~7~~
~~5~~	~~8~~
~~6~~	~~9~~
~~7~~	~~10~~
~~8~~	~~11~~
~~9~~	~~12~~
~~10~~	~~13~~
~~11~~	~~14~~

alf_noFilters_minus1 specifies the number of filter sets for the current slice

AlfNoFilters shall be computed as

AlfNoFilters = alf_noFilters_minus1+1

If AlfNoFilters is less than 3, the number of filter sets shall be defined as

AlfNumFilters = AlfNoFilters

Otherwise, AlfNumFilters shall be defined as

AlfNumFilters = ∑ (alf_filter_pattern[i]) with i=0... AlfMaxNumFilters-1

Note that AlfMaxNumFilters is the number of maximum filter sets used, i.e., 16.

alf_startSecondFilter specifies the index where the second filter is applied, when AlfNoFilters is less than 3.

Index table is alfVarIndTab[i] is defined based on **alf_startSecondFilter.** alfVarIndTab[i] is set equal to 0 for i=0... alf_startSecondFilter-1, and set equal to 1 for i=alf_startSecondFilter...AlfMaxNumFilters-1. The first filter is applied to pixels which have activity measure index is equal to from 0 to alf_startSecondFilter-1. Otherwise the second filter is applied.

alf_filter_pattern[i] specifies the indices where each filter is applied, when AlfNoFilters is more than 2.

when AlfNoFilters is greater than 2, alfVarIndTab is defined as follows:.

alfVarIndTab[0]=0

for (i=1; i< AlfMaxNumFilters; i++) {

if (alf_filter_pattern[i]!=0) alfVarIndTab[i] = alfVarIndTab[i-1] + 1

otherwise alfVarIndTab[i] = alfVarIndTab[i-1]

}

alf_predMethod specifies whether filter prediction method is used for filter coefficients coding.

alf_coeff_luma~~_**hor**~~[[i][j]~~[i]~~] specifies the ~~i~~j-th ~~filter~~ coefficient of ~~j~~i-th ~~horizontal~~ filter for the ~~reconstructed signal of the luma component.~~

~~**alf_coeff_luma_ver**[j][i] specifies the i-th filter coefficient of j-th vertical filter for the reconstructed signal of the luma component.~~

~~**alf_coeff_luma_pred_hor**[j][i] specifies the i-th filter coefficient of j-th horizontal filter for the prediction signal of the luma component.~~

~~**alf_coeff_luma_ pred_ver**[j][i] specifies the i-th filter coefficient of j-th vertical filter for the prediction signal of the luma component.~~

~~**alf_coeff_luma_qpe_hor**[j][i] specifies the i-th filter coefficient of j-th horizontal filter for the quantized prediction error signal of the luma component.~~

~~**alf_coeff_luma_ qpe_ver**[j][i] specifies the i-th filter coefficient of j-th vertical filter for the quantized prediction error signal of the~~ luma component.

alf_minKStart_minus1 specifies the minimum order k of k-th order exponential golomb code for the ALF luma coefficients coding.

alf_golombIndexBit specifies the difference in order k of k-th order exponential golomb code for the different groups of ALF luma coefficients. Note that there are several groups of ALF luma coefficients where each group may have different order k. Above group mapping is defined by DepthTable[i] with i=0...AlfNumCoeffLuma-1. Different AlfLengthLuma leads to different DepthTable[i]. From alf_minKStart_minus1 and alf_golombIndexBit, the order k of each group, kMinTab[i] with i=0...AlfmaxDepth-1, shall be decided as follows. kMin=alf_minKStart_minus1+1

for (i=0; i< AlfmaxDepth; i++) {

if (alf_golombIndexBit) kMinTab[i]=kMin+1

otherwise kMinTab[i]=kMin

kMin = kMinTab[i]

}

where AlfmaxDepth is the maximum number of groups for ALF luma coefficients coding.

Table 5-9 Specification of DepthTable

Coefficient index	AlfLengthLuma=5	AlfLengthLuma=7	AlfLengthLuma=9
0	3	4	5
1	3	4	5
2	4	5	6
3	3	4	5
4	3	4	5
5	4	5	6
6	5	6	7
7	5	5	6
8		4	5
9		4	5
10		5	6
11		6	7
12		7	8
13		7	7
14			6
15			5
16			5
17			6
18			7
19			8
20			9
21			9

alf_chroma_idc specifies which chroma components are to be filtered.

Table 5-10 Specification of alf_chroma_idc

alf_chroma_idc	chroma component to be filtered
0	None
1	Cr
2	Cb
3	Cb and Cr

~~**alf_reuse_coefficients_for_chroma_flag** specifies if the filters for the luma component are also applied to the chroma components.~~

~~If alf_reuse_coefficients_for_chroma_flag is equal to 1, the same filters are used~~

~~If alf_reuse_coefficients_for_chroma_flag is equal to 0, individual filters are used~~

alf_length_chroma_~~hor_minus_5~~minus5_div2 specifies the filter length ~~in horizontal direction for the~~for the chroma components used in the adaptive loop filter process. This filter shall be applied to the reconstructed signal. The filter length used to define the number of coded ~~chroma~~ filter cofficients is specified as follows:

AlfLengthChroma~~_hor = (~~ = (alf_length_chroma_~~hor_minus_5~~minus5_div2 << 1~~)+~~) + 5

~~**alf_length_chroma_ver_minus_5_div2** specifies the filter length in vertical direction for the chroma components used in the adaptive loop filter process. This filter shall be applied to the reconstructed signal. The filter length used to define the number of coded chroma filter cofficients is specified as follows:~~

The number of coded chroma filter coefficients is specified as follows:

AlfNumCoeffChroma = ((AlfLengthChroma~~_ver = (alf_length_chroma_ver_minus_5_div2 <<1)+5~~

alf_length_chroma_pred_hor_minus_1_div2 specifies the filter length in horizontal direction for the chroma components used in the adaptive loop filter process. This filter shall be applied to the prediction signal. The filter length used to define the number of coded chroma filter cofficients is specified as follows:

* AlfLengthChroma_pred_hor = (alf_length_chroma_pred_hor_minus_1_div2 <<1)+ + 1) >> 1) + 1

alf_length_chroma_pred_ver_minus_1_div2 specifies the filter length in vertical direction for the chroma components used in the adaptive loop filter process. This filter shall be applied to the prediction signal. The filter length used to define the number of coded chroma filter cofficients is specified as follows:

AlfLengthChroma_pred_ver = (alf_length_chroma_pred_ver_minus_1_div2 <<1)+1

alf_length_chroma_qpe_hor_minus_1_div2 specifies the filter length in horizontal direction for the chroma components used in the adaptive loop filter process. This filter shall be applied to the quantized prediction error signal. The filter length used to define the number of coded chroma filter cofficients is specified as follows:

AlfLengthChroma_qpe_hor = (alf_length_chroma_qpe_hor_minus_1_div2 <<1)+1

alf_length_chroma_qpe_ver_minus_1_div2 specifies the filter length in vertical direction for the chroma components used in the adaptive loop filter process. This filter shall be applied to the quantized prediction error signal. The filter length used to define the number of coded chroma filter cofficients is specified as follows:

AlfLengthChroma_qpe_ver = (alf_length_chroma_qpe_ver_minus_1_div2 <<1)+1

alf_quant_step_size_chroma_hor specifies the quantization step size of the filter coefficients that are used for the horizontal filtering of the chroma components. Table 5-11 specifies the step size Alf_filter_precision_Chroma_hor.

alf_quant_step_size_chroma_ver specifies the quantization step size of the filter coefficients that are used for the vertical filtering of the chroma components. Table 5-12 specifies the step size Alf_filter_precision_Chroma_ver.

Table 5-11 Specification of Alf_filter_precision_Chroma_hor

alf_quant_step_size_chroma_hor	Alf_filter_precision_Chroma_hor
0	3
4	4
2	5
3	6
4	7
5	8
6	9
7	10
8	11
9	12
10	13
11	14

Table 5-12 Specification of Alf_filter_precision_Chroma_ver

~~alf_quant_step_size_chroma_ver~~	~~Alf_filter_precision_Chroma_ver~~
~~0~~	~~3~~
~~4~~	~~4~~
~~2~~	~~5~~
~~3~~	~~6~~
~~4~~	~~7~~
~~5~~	~~8~~
~~6~~	~~9~~
~~7~~	~~10~~
~~8~~	~~11~~
~~9~~	~~12~~
~~10~~	~~13~~
~~11~~	~~14~~

alf_coeff_chroma~~_hor~~[i] specifies the ith filter coefficient ~~of the horizontal filter for the reconstructed signal of the chroma components.~~

~~**alf_coeff_chroma_ver**[i] specifies the ith filter coefficient of the vertical filter for the reconstructed signal of the chroma components.~~

~~**alf_coeff_chroma_pred_hor**[i] specifies the ith filter coefficient of the horizontal filter for the prediction signal of the chroma components.~~

~~**alf_coeff_chroma_ pred_ver**[i] specifies the ith filter coefficient of the vertical filter for the prediction signal of the chroma components.~~

~~**alf_coeff_chroma_qpe_hor**[i] specifies the ith filter coefficient of the horizontal filter for the quantized prediction error signal of the chroma components.~~

~~**alf_coeff_chroma_ qpe_ver**[i] specifies the ith filter coefficient of the vertical filter for the quantized prediction error signal of the~~for the chroma components.

alf_cu_control_flag specifies whether the adaptive loop filter process for luma component shall be applied adaptively. If alf_cu_control_flag is equal to 1, the filtering process shall be applied only when alf_flag is equal to 1, otherwise, the filtering process shall be applied to all luma samples in the current slice.

alf_cu_control_max_depth specifies the maximum split depth from the largest coding unit for deciding the application of the adaptive loop filter process. The minimum coding unit size used for the decision shall be computed as

$$\text{AlfCtrlMinCodingUnitSize} = \text{MaxCodingUnitSize} >> \text{alf_cu_control_max_depth}$$

alf_length_cu_control_info specifies the information of the number of alf_cu_flag succeeding this information. alf_length_cu_control_info shall present unless alf_cu_control_max_depth is 0. alf_length_cu_control_info is a fixed length code, and the number of bits for alf_length_cu_control_info shall be computed as

$$\text{Ceil}\ (\ \text{Log2}\ (\text{NumLCUsInPicture} * (4^{\text{alf_cu_control_max_depth}} - 1)\ )\ )$$

where NumLCUsInPicture is the number of LCUs in a picture. When alf_length_cu_control_info is not present, it shall be inferred to be 0. NumAlfCuFlag, the number alf_cu_flag, shall be computed as

$$\text{NumAlfCuFlag} = \text{alf_length_cu_control_info} + \text{NumLCUsInPicture}$$

alf_cu_flag[i] specifies whether a coding unit is filtered when the adaptive loop filter is applied. During the CU decoding, alf_cu_flag[i] is used for the adaptive loop filter control flag of the current CU, if one of the following conditions is true:

- currCodingUnitSize is equal to AlfMinCtrlCodingUnitSize and split_coding_unit_flag is 1,
- currCodingUnitSize is greater than AlfCtrlMinCodingUnitSize and split_coding_unit_figag is 0,

where i starts with 0 and i is incremented when alf_cu_flag[i] is used for the current CU.

[3-Input-ALF is still missing]

5.2.11.4 Switched Filter with Offsets parameter syntax

predict_filter_flag specifies whether to use prediction of the filter or not.

If mc_interpolation_idc is equal to 3, the variable numFilters is set to 4, otherwise if mc_interpolation_idc is equal to 4, the variable numFilters is set to 2.

Variable log2_numFilters is derived from numFilters as follows:

log2_numFilters = $\log_2$(numFilters)

sifo_type is used as an identifier for deriving the value of sifo_filters[i].

sifo_filter[i] is used as an identifier for filter index to be used during filtering process for $(i+1)^{th}$ subpel and shall be represented by log2_numFilters bits, where i = $xFrac_L$+($yFracy_L$<<2)

bitsForFilter is derived as follows:

slice_type	predict_filter_flag	sifo_type	i	BitsforFilter
P	0	0	1,2,3,4,8,12	log2_numFilters
			5,6,7,9,10,11,13,14,15	2*log2_numFilters
		1	all subpels	log2_numFilters
		2	-	log2_numFilters
	1	0	1,2,3,4,8,12	log2_numFilters
			5,6,7,9,10,11,13,14,15	2*log2_numFilters
		1	-	log2_numFilters
B	-	-	-	log2_numFilters

The variable bitsForFilter is derived as follows.

- If slice_type is equal to P slice, and if sifo_type is equal to 0, and if both xFracL and yFracL are greather than 1, sifo_filter[i] is represented by 2* log2_numFilters bits.
- Otherwise sifo_filter[i] is represented by log2_numFilters bits.

The variable prev_filter[i] for each $(i+1)^{th}$ subpel is derived as follows.

- If the current picture is an IDR picture, prev_filter[i] is set equal to 0.
- Otherwise (the current picture is not an IDR picture), prev_filter[i] is set equal to the value of sifo_filter[i] for the previous access unit in decoding order that is of the same slice_type as the current slice_type being decoded.

zero_offset_flag eaual to 0 specifies that all the offsets values are zero.

sifo_offset_l0[i **]**, **sifo_offset_l1[** i **]** specify the offset value for i^{th} subpel location for list 0 and list 1 , respectively.

img_offset_l0[i **]**, **img_offset_l1[** i **]** specify the offset value for i^{th} reference picture in list 0 and list 1 , respectively.

5.2.12 Slice data semantics

part_size_byte_one, part_size_byte_two, part_size_byte_three, part_size_byte_four are used to specify the partition size of a V2V partitions as specified by the syntax.

end_of_slice_flag equal to 0 specifies that another macroblock is following in the slice. end_of_slice_flag equal to 1 specifies the end of the slice and that no further macroblock follows.

5.2.13 Coding unit semantic

split_coding_unit_flag specifies whether a coding unit is split into coding units with half horizontal and vertical size. When split_coding_unit_flag is not present, it shall be inferred to be equal to 0 when the current coding unit size is equal to MinCodingUnitSize otherwise it shall be inferred to be equal to 1.

5.2.14 Prediction unit semantics

skip_flag specifies whether current coding unit shall be skipped or not. If skip_flag is equal to 1, no more syntax elements except mvp_idx are parsed after skip_flag. When skip_flag is not present, it shall be inferred to be equal to 0.

mvp_idx_l0[i **] and mvp_idx_l1[** i **]** specify ith the motion vector predictor indices of list 0 and list 1, respectively, where i is the prediction unit index. When mvp_idx_l0[i] or mvp_idx_l1[i] is not present, it shall be inferred to be equal to 0.

icp_idx[i **]** specifies the illumination compensation predictor index for the current partition with partition index i. When icp_idx [i] is not present, it shall be inferred to be equal to 0. NumICPCand is the total number of illumination compensation prediction candidates for the current partition.

pred_mode specifies prediction mode of current prediction unit. The semantics of pred_mode depend on the slice type. Name association to pred_mode, PredMode, shall be done as defined in Table 5-1. When pred_mode is not present, PredMode shall be inferred to be MODE_INTRA when slice_type is equal to I slice and MODE_SKIP when slice_type is equal to P slice or B slice.

Table 5-13 Specification of prediction mode

slice_type	pred_mode	Name association to pred_mode (PredMode)
I	inferred	MODE_INTRA
P and B	0	MODE_DIRECT
	1	MODE_INTER
	2	MODE_INTRA
	inferred	MODE_SKIP

inter_partitioning_idc specifies partitioning type for current coding unit for the purpose of inter prediction. Total number of prediction units within the current prediction unit shall be obtained by NumPuParts syntax function with inter_partitioning_idc as an argument.

Table 5-14 Specification of partitioning type

inter_ partioning_ idc	Name association to inter_partioning_idc (PartMode)	Number of Partitions (NumPuParts)	PuPartWidth( ) 0) first partition 1) second partition	PuPartHeight( ) 0) first partition 1) second partition
0	PART_2Nx2N	1	PuSize	PuSize
1	PART_2NxN	2	PuSize	PuSize / 2
2	PART_Nx2N	2	PuSize / 2	PuSize
3	PART_NxN	4	PuSize / 2	PuSize / 2
4	PART_2NxnU	2	PuSize	0) PuSize / 4 1) PuSize * 3 / 4
5	PART_2NxnD	2	PuSize	0) PuSize * 3 / 4 1) PuSize / 4
6	PART_nLx2N	2	0) PuSize / 4 1) PuSize * 3 / 4	PuSize
7	PART_nRx2N	2	0) PuSize * 3 / 4 1) PuSize / 4	PuSize

Table 5-15 Specification of offset for each partitioning type

inter_ partioning_ idc	Name association to inter_partioning_idc (PartMode)	puPartIdx	PuPartOffset( ) (PuSizeInSu = PuSize / SuSize)
0	PART_2Nx2N	0	0
1	PART_2NxN	0 1	0 PuSizeInSu / 2 * PuSizeInSu
2	PART_Nx2N	0 1	0 PuSizeInSu / 2
3	PART_NxN	0 1 2 3	0 PuSizeInSu / 2 PuSizeInSu / 2 * PuSizeInSu PuSizeInSu / 2 + PuSizeInSu / 2 * PuSizeInSu
4	PART_2NxnU	0 1	0 PuSizeInSu / 4 * PuSizeInSu
5	PART_2NxnD	0 1	0 PuSizeInSu * 3 / 4 * PuSizeInSu
6	PART_nLx2N	0 1	0 PuSizeInSu / 4
7	PART_nRx2N	0 1	0 PuSizeInSu * 3 /4

merge_flag[i **]** specifies whether the inter prediction parameters for the current partition with partition index i are inferred from a neighbouring inter-predicted partition.

merge_left_flag[i **]** specifies whether the inter prediction parameters for the current partition with partition index i are inferred from the left or the top neighbouring inter-predicted partition.

inter_pred_idc[i **]** specifies whether list 0, list 1, or bi-prediction is used for the current partition with partition index i. When inter_pred_idc[i] is not present, it shall be inferred to be equal to Pred_L0 when slice_type is equal to P slice and BiPred when slice_type is equal to B slice.

ref_idx_l0[i **]**, **ref_idx_l1[** i **]** specify the list 0 and list 1 reference picture indices, respectively, for the current partition with partition index i.

mvres_l0[i **]**, **mvres_l1[** i **]** specify the list 0 and list 1 motion resolution, respectively, for the current partition with partition index i.

ref_idx_mvres_l0[i **]**, **ref_idx_mvres_l1[** i **]** specify the list 0 and list 1 reference picture indices and motion resolution, respectively, for the current partition with partition index i when entropy_coding_mode_flag is not equal to 0. The reference index and motion resolution can be calculated as

```
if(ref_idx_mvres_lX[ i ]==0)
{
    ref_idx_lX[ i ] = 0
    mvres_lX[ i ] = 1
}
else if (ref_idx_mvres_lX[ i ]==1)
{
    ref_idx_lX[ i ] = 0
    mvres_lX[ i ] = 0
}
```

```
else
{
    ref_idx_lX[ i ] =   ref_idx_mvres_lX[ i ] -1
    mvres_lX[ i ] = 1
}
```

mvd_l0[i **][** 0 **]**, **mvd_l0[** i **][** 1 **]** specify the horizontal and vertical component, respectively, of the list 1 motion vector difference for the current partition with partition index i. If mvres_l0[i] is equal to 1, mvd_l0[i][0] and mvd_l0[i][1] are in one-fourth scale. Otherwise, mvd_l0[i][0], mvd_l0[i][1] are in one-eighth scale. When any of the two components is not present, the inferred value is 0.

mvd_l1[i **][** 0 **]**, **mvd_l1[** i **][** 1 **]** specify the horizontal and vertical component, respectively, of the list 1 motion vector difference for the current partition with partition index i. If mvres_l1[i] is equal to 1, mvd_l1[i][0] and mvd_l0[i][1] are in one-fourth scale. Otherwise, mvd_l1[i][0], mvd_l1[i][1] are in one-eighth scale. When any of the two components is not present, the inferred value is 0.

icd[i **][** 0 **], icd[** i **][** 1 **], icd[** i **][** 2 **]** specify the difference values of transformed scale t0, transformed scale t1 and offset o respectively, for the current partition with partition index i. When any of the three components is not present, the inferred value is 0.

intra_split_flag specifies whether a prediction unit is split into four prediction units with half horizontal and vertical size. When intra_split_flag is not present, it shall be inferred to be equal to 0.
mode_table_idx indicates the rank of the modeIdx variable in the modeCtxList context list array. modeIdx variable is used to compute the values of the following elements: pred_mode, intra_split_flag, inter_partitioning_idc, ref_idx_l0, inter_pred_idc, split_transform_unit_flag, PU_dQP_idx.

planar_flag specifies if planar prediction mode is enabled for the prediction unit.

planar_delta_uv_present_flag specifies if the planar coding utilizes non-zero delta values for chrominance components

planar_sign specifies the sign of the planar delta variable.

planar_qdelta_indicator specifies the magnitude of the planar delta variable. From this and planar_sign value, the planar delta variable is calculated as

```
if (planar_qdelta_indicator > 21)
    Qdelta = ((planar_qdelta_indicator - 14) << 3) + 4
else if(planar_qdelta_indicator > 9)
    Qdelta = ((planar_qdelta_indicator - 6) << 2) + 2
else if (planar_qdelta_indicator > 3)
    Qdelta = (planar_qdelta_indicator - 2) << 1
else
    Qdelta = planar_qdelta_indicator
if(planar_sign == 1)
    Qdelta = -1*Qdelta
```

combined_intra_pred_flag specifies whether the combined intra prediction process is invoked for the intra-predicted samples.

prev_intra_luma_pred_flag[i] and rem_intra_luma_pred_mode[i] specifies the intra prediction mode of the ith prediction unit for luma samples with index i = 0 when intra_split_flag is equal to 0 or i =0..3 when intra_split_flag is equal to 1. When prev_intra_luma_pred_flag[i] is equal to 1, the intra prediction mode is inferred from a neighbouring intra-predicted prediction unit. The number of bins/bits indicating the rem_intra_luma_pred_mode[i] depends on the size of the prediction unit and limits the number of available prediction modes as follows:

PuSize	Bins/bins	Number of modes
PU_2x2	1	3
PU_4x4	4	17
PU_8x8	5	34
PU_16x16	5	34
PU_32x32	5	34
PU_64x64	2	5
PU_128x128	2	5

In the case of PU_8x8, PU_16x16 and PU_32x32 when all the 5 bins/bins are set to 1, an additional bin/bit is read to distinguish between modes 32 (the additional bin/bit set to 0) and 33 (the additional bin/bit set to 1).

intra_luma_filt_flag equal to 1 specifies that the reference samples used in intra prediction for the current prediction unit are filtered. intra_luma_filt_flag equal to 0 specifies that the reference samples are not filtered

intra_chroma_pred_mode specifies the intra prediction direction for chroma samples of the current prediction unit. The value shall be in the range of 0 to 4. 0: DC prediction, 1: vertical prediction, 2: horizontal prediction, 3: diagonal prediction and 4: same mode with IntraLumaPredMode. The diagonal prediction is specified as IntraPredType = = Intra_Vertical and IntraPredAngleID = = -8.

Table 5-1. Specification of intra prediction mode for chroma samples

intra_pred_mode_chroma	Meaning of intra_pred_mode_chroma
0	DC prediction
1	vertical prediction
2	horizontal prediction
3	diagonal prediction
4	same mode with luma samples

ztree_size[i] specifies the number of leaf nodes in zero-tree with index i.
ztree_structure[i][j] specifies whether the node j in a zero-tree with index i is a leaf node. A value 0 indicates a leaf node.
ztree_leaf_index[i][j] specifies the index in the data array that holds the zero/non-zero status for leaf node j in a zero-tree with index i.
Table 5-18 specifies the zero-trees used.

Table 5-18 Specification of Zero-trees

Index	ztree_size	ztree_structure	ztree_leaf_index	Mapping to syntax elements
0	4	{ 1, 1, 0, 0, 1, 0, 0 }	{ 0, 1, 2, 3 }	{ mvd_lx[i][0], mvd_lx[i][1], icd[i][0], icd[i][2] } x is either 0 or 1 depending on list used
1	7	{ 1, 1, 1, 0, 0, 1, 0, 0, 1, 0, 1, 0, 0 }	{ 0, 2, 1, 3, 4, 5, 6 }	{ mvd_l0[i][0], mvd_l1[i][0], mvd_l0[i][1], mvd_l1[i][1], icd[i][0], icd[i][1], icd[i][2] }

zero_blk equal to 1 specifies that all leaf nodes of a zero-tree are zero.

ztree_node_both equal to 1 specifies that both subtrees of a zero-tree node contain nonzero leaf nodes.

ztree_node_left equal to 1 specifies that the left subtree of a zero-tree node contains nonzero leaf nodes.

5.2.15 Transform unit semantics

split_transform_unit_flag[x0][y0][layer] specifies whether a coding unit is split into coding units with half horizontal and vertical size. The array indices x0, y0 are the top-left coordinate of the block for which this syntax specifies whether it shall be split, layer gives the subdivision hierarchy level, starting with 0 at CTB level. When split_transform_unit_flag[x0][y0][layer] is not present, it shall be inferred to be equal to (currTransformUnitSize > MinTransformUnitSize ? 1 : 0).

coded_block_flag_luma specifies whether the transform unit contains one or more non-zero transform coefficient levels for the luma plane.

coded_block_flag_chroma_u specifies whether the transform unit contains one or more non-zero transform coefficient levels for the chroma (U) plane.

coded_block_flag_chroma_v specifies whether the transform unit contains one or more non-zero transform coefficient levels for the chroma (V) plane.

split_transform_unit_flag specifies whether a coding unit is split into coding units with half horizontal and vertical size. When split_transform_unit_flag is not present, it shall be inferred to be equal to (currTransformUnitSize > MinTransformUnitSize ? 1 : 0).

coded_block_flag specifies whether the transform unit contains one or more non-zero transform coefficient levels.

rotational_transform_idx specifies the rotational transform index used in the rotational transform process for the transform coefficients.
last_pos_table_idx specifies the rank of the lastPosIdx variable in the lastPosCtxList context list array. lastPosIdx variable is used to decode the position of the last non-zero coefficient in zigzag scan order given by lastPos variable, and if the magnitude of the last non-zero coefficient in zigzag scan order is greater than one given by levelMagnitudeGreaterThanOneFlag variable.
last_pos_level specifies the magnitude of the last non-zero coefficient in zigzag scan order.
last_pos_sign specifies the sign of the last non-zero coefficient in zigzag scan order.
is_level_one_run specifies jointly the values for isLevelOne and run variables. isLevelOne variable specifies if the magnitude of the next non-zero coefficient is greater than one (1) or not (0). run specifies the number of zero-coefficients before the next non-zero coefficient in reverse zigzag scan order,
level_magnitude_sign specifies the magnitude and sign of the next non-zero coefficient in reverse zigzag scan order.
level_sign specifies the sign of the next non-zero coefficient in reverse zigzag scan order.
cbp_table_idx indicates the rank of cbpIdx variable in the cbpCtxList context list array. cbpIdx variable is used to compute the coded block pattern for luminance and chrominance for certain values of mode_idx syntax element.
cbp_id0, cbp_id1, cbp_id2 are the syntax elements used to code the coded block pattern for luminance and chrominance blocks for certain values of mode_idx syntax element.

[Ed. transform coefficients...]

sig_flag equal to 1 specifies that the current transform coefficient level is not equal to 0. sig_flag equal to 0 specifies that the current transform coefficient level is equal to 0.

last_flag equal to 1 specifies that the current transform coefficent level is the last nonzero transform coefficient level in the current transform block. last_flag equal to 0 specified that the current transform coefficient level is not the last nonzero transform coefficient level in the current transform block.

abs_greater_one_flag equal to 1 specified that the absolute value of the current transform coefficient level is greater than 1. abs_greater_one_flag equal to 0 specifies that the absolute value of the current transform coefficient level is equal to 1.

coeff_abs_level plus 2 specifies the absolute value of the current transform coefficient level.

sign equal to 1 specifies that the current transform coefficient level is less than zero. sign equal to 1 specifies that the current transform coefficient level is greater than 0.

6 Decoding Process

Outputs of this process are decoded samples of the current picture (sometimes referred to by the variable CurrPic).

This clause describes the decoding process, given syntax elements and upper-case variables from clause 5.

An overview of the decoding process is given as follows:

- The processes in subclauses 6.1, 6.3, 6.4 and 6.5 specify decoding processes using syntax elements in the coding unit layer and above.
  - The intra prediction process for MODE_INTRA prediction unit as specified in subclause 6.1 has intra prediction samples as its output. The outputs are the constructed samples prior to the deblocking filter process.
  - The inter prediction process for MODE_SKIP, MODE_DIRECT and MODE_INTER prediction units is specified in subclause 6.3 with inter prediction samples being the output.
  - The transform coefficient decoding process and picture construction process prior to deblocking filter process are specified in subclause 6.4. The outputs are constructed samples prior to the deblocking filter process.
  - The constructed samples prior to the deblocking filter process that are next to the edges of transform units, prediction units and coding units are processed by a deblocking filter as specified in subclause 6.5.1. The outputs are the constructed samples prior to the adaptive loop filter process.
  - The constructed samples in the current slice prior to the adaptive in-loop filter process are processed by an adaptive loop filter as specified in subclause 6.5.2 with the output being the decoded samples.

6.1 Slice decoding process

6.1.1 Decoding process for picture order count

[Ed: Text to be taken from MPEG-4 AVC/H.264 (section 8.2.1 but without support of field coding)]

6.1.2 Decoding process for reference picture lists construction

[Ed: Text to be taken from MPEG-4 AVC/H.264 (section 8.2.4 but without support of field coding)]

6.1.3 Decoded reference picture marking process

[Ed: Text to be taken from MPEG-4 AVC/H.264 (section 8.2.5 but without support of field coding)]

6.2 Intra prediction process

This process is invoked for MODE_INTRA prediction units.

Inputs to this process are constructed samples prior to the deblocking filter process and the values of IntraPredMode from neighbouring prediction units.

The outputs are constructed luma samples of the prediction unit $pred_L$ and (when ChromaArrayType is not equal to 0) chroma prediction samples of the prediction unit $pred_C$, whether C is equal to Cb and Cr.

The decoding process for intra prediction modes are described for the luma component in subclause 6.2.1.

The decoding process for intra prediction modes are described for the chroma component in subclause 6.2.2.

Samples used in the intra prediction process shall be sample values prior to alteration by any in-loop filter operation.

6.2.1 Intra prediction process for luma samples

This process is invoked for prediction units when PredMode is equal to MODE_INTRA and planar_flag == 0.

Inputs of this process are the values of IntraPredMode (if available) from neighbouring prediction units.

Depending on the value of intra_split_flag, the luma component of prediction unit consists of one or four partitions of luma samples. The variable PartMode is inferred to PART_2Nx2N when intra_split_flag is equal to 0 and PART_NxN when intra_split_flag is equal to 1. These partitions are inverse scanned using the inverse partition scanning process specified in subclause 4.2.4.

For all prediction unit partitions, the derivation process for the IntraPredMode as specified in subclause 6.2.1.1 is invoked with puPartIdx and constructed samples prior (in decoding order) to the deblocking filter process from adjacent luma prediction units as the input and the variable IntraPredMode as the output.

For each prediction unit, the following applies.

– The intra sample prediction process in subclause 6.2.1.2 is invoked with puPartIdx and constructed samples prior (in decoding order) to the deblocking filter process from adjacent luma prediction units as the input and the output are the intra luma prediction samples $predPart_L[x, y]$ with x = 0..PuPartWidth(puPartIdx) and y = 0..PuPartHeight(puPartIdx).

– The position of the upper-left sample of a prediction unit partition with index puPartIdx inside the current prediction unit is derived by invoking the inverse prediction unit partition scanning process in subclause 4.2.4.2 with puPartIdx as the input and the output being assigned to (xO, yO) and x = 0..PuPartWidth(puPartIdx) and y = 0..PuPartHeight(puPartIdx).

$$pred_L[xO + x, yO + y] = predPart_L[x, y]$$

– The transform coefficient decoding process and picture construction process prior to deblocking filter process in subclause 6.4 is invoked with $pred_L$ and puPartIdx as the input and the constructed samples for the current prediction unit partition S'_L as the output.

6.2.1.1 Derivation process for the IntraPredMode

Inputs to this process are the index puPartIdx and variable arrays IntraPredMode (if available) that are previously (in decoding order) derived for adjacent prediction units.

Output of this process is the variable IntraPredMode[puPartIdx].

Table 6-1 specifies the values for IntraPredMode[puPartIdx] and the associated names.

Table 6-1 Specification of IntraPredMode[puPartIdx] and associated names

IntraPredMode [puPartIdx]	IntraPredType [puPartIdx]	IntraPredAngleID [puPartIdx]
0	Intra_Vertical	0
1	Intra_Horizontal	0
2	Intra_DC	-
3	Intra_Vertical	-8
4	Intra_Vertical	-4
5	Intra_Vertical	+4
6	Intra_Vertical	+8
7	Intra_Horizontal	-4
8	Intra_Horizontal	+4
9	Intra_Horizontal	+8
10	Intra_Vertical	-6
11	Intra_Vertical	-2
12	Intra_Vertical	+2
13	Intra_Vertical	+6
14	Intra_Horizontal	-6
15	Intra_Horizontal	-2
16	Intra_Horizontal	+2
17	Intra_Horizontal	+6
18	Intra_Vertical	-7
19	Intra_Vertical	-5
20	Intra_Vertical	-3

21	Intra_Vertical	-1
22	Intra_Vertical	+1
23	Intra_Vertical	+3
24	Intra_Vertical	+5
25	Intra_Vertical	+7
26	Intra_Horizontal	-7
27	Intra_Horizontal	-5
28	Intra_Horizontal	-3
29	Intra_Horizontal	-1
30	Intra_Horizontal	+1
31	Intra_Horizontal	+3
32	Intra_Horizontal	+5
33	Intra_Horizontal	+7

Table 6-2 specifies the values for MappedMostProbable according to IntraPredMode and IntraPredModeNum.

Table 6-2 Specification of MappedMostProbable according to IntraPredMode and IntraPredModeNum

IntraPredModeNum [puPartIdx] / IntraPredMode [puPartIdx]	5	17	34
0	0	0	0
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	0	5	5
6	2	6	6
7	1	7	7
8	1	8	8
9	2	9	9
10	2	10	10
11	0	11	11
12	0	12	12
13	2	13	13
14	2	14	14
15	1	15	15
16	1	16	16
17	2	2	17
18	2	3	18
19	4	10	19
20	4	11	20
21	0	0	21
22	0	0	22
23	0	12	23
24	2	5	24
25	2	13	25
26	2	14	26
27	2	7	27
28	1	15	28
29	1	1	29
30	1	1	30
31	1	16	31

32	2	8	32
33	2	2	33

IntraPredMode[puPartIdx] is derived as follows.

– The derivation process for neighbouring partitions specified in subclause 4.3.4.4 is invoked with puPartIdx given as the input and the output is assigned to lcuAddrA, puIdxA, partIdxA, lcuAddrB, puIdxB and partIdxB.

– IntraPredMode[puPartIdx] is derived by applying the following applies.

  – for N being either replaced by A or B, the variables intraPredModeN are derived as follows.

    – if the largest coding unit with address lcuAddN is not available, intraPredModeN is set equal to -1

    – else if the prediction unit with index puIdxN is not coded in intra prediction mode, intraPredModeN is set equal to Intra_DC

    – Otherwise, intraPredModeN is set equal to IntraPredMode[puPartIdxN], where IntraPredMode is the variable array assigned to the prediction unit puIdxN.

  – The following procedure applies.

```
MostProbable = Min( intraPredModeA, intraPredModeB )
if ( MostProbable >= IntraPredModeNum[ puPartIdx ] )
    MostProbable = MappedMostProbable ( IntraPredModeNum[ puPartIdx ], MostProbable )
if ( MostProbable == -1 )
    MostProbable = 2
if ( prev_intra_luma_pred_flag[ puPartIdx ] )
    IntraPredMode[ puPartIdx ] = MostProbable
else
    if ( rem_intra_luma_pred_mode[ puPartIdx ] < MostProbable )
        IntraPredMode[ puPartIdx ] = rem_intra_luma_pred_mode[ puPartIdx ]
    else
        IntraPredMode[ puPartIdx ] = rem_intra_luma_pred_mode[ puPartIdx ] + 1
```

6.2.1.2 Intra sample prediction

This process is invoked for each prediction unit partition followed by the transform decoding process and picture construction process prior to deblocking filter.

Input to this process are

– the index of the prediction unit partition puPartIdx,

– the intra prediction mode IntraPredMode[puPartIdx] derived as described in 6.2.1.1, and

– the flag intra_luma_filt_flag indicating reference sample filtering .

Outputs of this process are the prediction samples $predPart_L$[x, y], with x = 0..PuPartWidth[puPartIdx] and y = 0..PuPartHeight[puPartIdx] for the prediction unit partition with index puPartIdx.

The position of the upper-left sample of the prediction unit partition with index puPartIdx inside the current prediction unit is derived by invoking the inverse prediction unit partition scanning process in subclause 4.2.4.2 with puPartIdx as the input and the output being assigned to (xO, yO).

Let PuPartSize = max(PuPartWidth, PuPartHeight).

The PuPartSize*4 + 1 neighbouring samples p[x, y] and pf[x, y] are constructed luma samples prior to the deblocking filter process, with x = -1, y = -1..PuPartSize*2 - 1 and x = 0..PuPartSize*2 - 1, y = -1, are derived as follows.

– The luma location (xN, yN) is specified by

  xN = xO + x

  yN = yO + y

– The derivation process for neighbouring locations in 4.3.5 is invoked for luma locations with (xN, yN) as input and lcuAddrN and (xW, yW) as output.

– If lcuAddN is available, the prediction unit partition index in the largest coding unit lcuAddN covering the luma location (xW, yW) is assigned to partIdxN, otherwise, partIdxN is marked as not available.

– Each sample p[x, y] with x = -1, y = -1..PuPartSize*2 – 1 and x = 0..PuPartSize*2 – 1, y = -1 is derived as follows.

  – If any of the following conditions is true, the sample p[x, y] is marked as "not available for intra prediction"

    – lcuAddrN is not available,

    – partIdxN is not available

  – Otherwise, the sample p[x, y] is marked as "available for intra prediction" and the luma sample at luma location (xW, yW) inside the largest coding unit lcuAddrN is assigned to p[x, y].

When samples p[x, -1], with x = PuPartSize..PuPartSize*2 – 1 are marked as "not available for intra prediction," and the sample p[PuPartSize – 1, -1] is marked as "available for intra prediction," the sample value of p[PuPartSize – 1, -1] is substituted for samples values p[x, -1], with x = PuPartSize..PuPartSize*2 – 1 and samples p[x, -1], with x = PuPartSize..PuPartSize*2 – 1 are marked as "available for intra prediction."

When samples p[-1, y], with y = PuPartSize..PuPartSize*2 – 1 are marked as "not available for intra prediction," and the sample p[-1, PuPartSize – 1] is marked as "available for intra prediction," the sample value of p[-1, PuPartSize – 1] is substituted for samples values p[-1, y], with y = PuPartSize..PuPartSize*2 – 1 and samples p[-1, y], with y = PuPartSize..PuPartSize*2 – 1 are marked as "available for intra prediction."

For all remaining samples p[x, y] marked as "not available for intra prediction," the following applies.

  p[x, y] = 1 << (($BitDepth_Y$ + increased_bit_depth_luma) – 1)

If intra_luma_filt_flag == 1, the filtered neighbouring samples pf[x, y] with x = -1, y = -1..PuPartSize*2 - 1 and x = 0..PuPartSize*2 - 1, y = -1 are constructed as follows.

pf[-1, y]	= p[-1, y]	for y = 0 or y=PuPartSize*2 – 1
pf[-1, y]	= (p[-1, y + 1] + 2*p[-1, y] + p[-1, y – 1] + 2) >> 2	otherwise
pf[x, -1]	= p[x, -1]	for x = 0 or x=PuPartSize*2 – 1
pf[x, -1]	= (p[x – 1, -1] + 2*p[x, -1] + p[x + 1, -1] + 2) >> 2	otherwise
pf[-1, -1]	= (p[-1, 0] + 2*p[-1, -1] + p[0, -1] + 2) >> 2	for x = 0 and y = 0

If intra_luma_filt_flag == 0, the filtered neighbouring samples equal the unfiltered neighbouring samples.

  pf[x, y] = p[x, y]

6.2.1.2.1 Specification of intra planar prediction

This intra prediction mode is invoked when planar_flag == 1. The values of the prediction samples $predPart_L$[x, y], with x, y = 0..PuPartSize – 1, are derived by

$predPart_L$[x, y] = ((PuPartSize – (y+1))*TR(x) + (y+1)*BR(x) + (PuPartSize – (x+1))*LC(y) + (x+1)*RC(y) + PuPartSize)/(PuPartSize*2)

where the values of TR pixel array are specified as

– If the samples p[x, -1] with x = 0..PuPartSize – 1 are marked as "available for intra prediction."
TR(i) = p[i,-1] with i = 0..PuPartSize - 1

– Otherwise if the samples p[-1, y] with x = 0..PuPartSize – 1 are marked as "available for intra prediction."
TR(i) = ((PuPartSize – (i+1))*M(-1,0) + (i+1)*BRS + (PuPartSize>>1))/PuPartSize with i = 0..PuPartSize - 1

– Otherwise
TR(i) = 128 with i = 0..PuPartSize - 1

where the values of LC pixel array are specified as

– If the samples p[-1, y] with y = 0..PuPartSize – 1 are marked as "available for intra prediction."
LC(i) = p[-1, i] with i = 0..PuPartSize - 1

– Otherwise if the samples p[x, -1] with x = 0..PuPartSize – 1 are marked as "available for intra prediction."
LC(j) = ((PuPartSize – (j+1))*M(0,-1) + (j+1)*BRS + (PuPartSize>>1))/PuPartSize

– Otherwise
LC(i) = 128 with i = 0..PuPartSize - 1

where the values of BR pixel array are specified as

BR(i) = ((PuPartSize – (i+1)*LC[PuPartSize-1] + (i+1)*BRS + (PuPartSize>>1))/PuPartSize with i = 0..PuPartSize - 1

where the values of RC pixel array are specified as

RC(i) = ((PuPartSize – (i+1))*TR[PuPartSize-1] + (i+1)*BRS + (PuPartSize>>1))/PuPartSize with i = 0..PuPartSize

where the BRS value is specified as
BRS = DC + planar_delta_y
where DC is calculated identically to the DC value in DC prediction as specified in subclause 6.2.1.2.2.2.

6.2.1.2.2 Specification of directional intra prediction

For prediction units with planar_flag == 0 either intra angular prediction mode or DC prediction mode is used depending on the value of IntraPredMode[puPartIdx] variable.

6.2.1.2.2.1 Specification of intra angular prediction mode

This intra prediction mode is invoked when IntraPredType[puPartIdx] is not equal to Intra_DC.

Let intraPredType be equal to IntraPredType[puPartIdx]. intraPredAngle variable is obtained from the table below as a function of IntraPredAngleID[puPartIdx].

IntraPredAngleID[puPartIdx]	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
intraPredAngle	-32	-26	-21	-17	-13	-9	-5	-2	0	2	5	9	13	17	21	26	32

The values of the prediction samples $predPart_L$[x, y], with x, y = 0..PuPartSize – 1, are derived by the following procedure

– For k=0..(PuPartSize – 1)
```
    deltaInt = ((k+1)* intraPredAngle)/32
    deltaFract = ((k+1)*abs(intraPredAngle))%32
    if(intraPredAngle < 0)
        deltaFract = (32 – deltaFract)%32
    for l = 0..(PuPartSize – 1)
        refMainInd = l+deltaInt+1
        if(intraPredAngle >= 0)
            if(deltaFract != 0)
                p(k,l) = ((32-deltaFract)*refMain[refMainInd]+deltaFract*refMain[refMainInd+1]+16) >>
```

```
5
                else
                    p(k,l) = refMain[refMainInd]
            else
                if(refMainInd >= 0)
                    p(k,l) = ((32-deltaFract)*refMain[refMainInd]+deltaFract*refMain[refMainInd+1]+16) >>
5
                else
                    deltaIntSide = (32*32*(l+1)/abs(IntraPredAngle))>>5
                    deltaFractSide = (32*32*(l+1)/abs(IntraPredAngle))%32
                    refSideIndex = k+l-deltaIntSide
                    if(deltaFractSide)
                      p(k,l) = ((32-deltaFractSide)*refSide[refSideIndex]+
                                deltaFractSide*refSide[refSideIndex-1]+16) >> 5
                    else
                      p(k,l) = refSide[refSideIndex]
            if(IntraPredType == Intra_Vertical)
                predPart_L[ x, y ] = p(k,l)
            else
                predPart_L[ y, x ] = p(k,l)
        end for
    end for
```

where the pixel arrays refMain and refSide are specified as

– If intraPredType == Intra_Vertical

  refMain[x] = p[x, -1], with x = 0..PuPartSize – 1
  refSide[x] = p[-1, x], with x = 0..PuPartSize – 1

– Otherwise

  refMain[x] = p[-1, x], with x = 0..PuPartSize – 1
  refSide[x] = p[x, -1], with x = 0..PuPartSize – 1

6.2.1.2.2.2 Specification of Intra_DC prediction mode

This intra prediction mode is invoked when IntraPredMode[puPartIdx] is equal to Intra_DC.
Depending on the variable edge_based_prediction_flag, the following applies.

– If the value of edge_based_prediction_flag is equal to 0, the DC prediction mode process is invoked as specified in subclause 6.2.1.2.2.2.2.
– If the value of edge_based_prediction_flag is equal to 1, the edge detection process is invoked as specified in subclause 6.2.1.2.2.2.1.
  – If the output value edge_detected of the edge detection process is equal to 0, the DC prediction mode process is invoked as specified in subclause 6.2.1.2.2.2.2.
  – If the output value edge_detected of the edge detection process is equal to 1, the edge based prediction process is invoked as specified in subclause 6.2.1.2.2.2.3.

6.2.1.2.2.2.1 Specification of edge detection process

The edge detection process using the Sobel operators shall be performed on the already decoded luma samples. This process is invoked when IntraPredMode[puPartIdx] is equal to Intra_DC and when the value of edge_based_prediction_flag is equal to 1.

Inputs to this process are:
– The index of the prediction unit partition puPartIdx.
– The value of threshold_edge.

Outputs of this process are:
– The value edge_detected equal to 0 or 1 depending on the result of the Sobel operators on the already reconstructed pixels as specified in the following.
– If the value edge_detected is equal to 1, the coordinates dir[i] with i=0,1 in the horizontal and vertical direction of the detected edge as specified in the following.

The position of the upper-left sample of the prediction unit partition with index puPartIdx inside the current prediction unit is derived by invoking the inverse prediction unit partition scanning process in subclause 4.2.4.2 with puPartIdx as the input and the output being assigned to (xO_E, yO_E).

Let PuPartSize be equal to max(PuPartWidth, PuPartHeight).

The 16*PuPartSize + 16 neighbouring decoded luma samples p_E[x, y] prior the deblocking filter process with x = -4..-1, y = -4..PuPartSize*2 - 1 and x = 0..PuPartSize*2 - 1, y = -4..-1, are derived as follows.

– The luma location (xN_E, yN_E) is specified by

$xN_E = xO_E + x$

$yN_E = yO_E + y$

– The derivation process for neighbouring locations in 4.3.5 is invoked for luma locations with (xN_E, yN_E) as input and $lcuAddrN_E$ and (xW_E, yW_E) as output.

– If $lcuAddN_E$ is available, the prediction unit partition index in the largest coding unit $lcuAddN_E$ covering the luma location (xW_E, yW_E) is assigned to $partIdxN_E$, otherwise, $partIdxN_E$ is marked as not available.

– Each sample p_E[x, y] with x = -4..-1, y = -4..PuPartSize*2 – 1 and x = 0..PuPartSize*2 – 1, y = -4..-1 is derived as follows.

  – If any of the following conditions is true, the sample p_E[x, y] is marked as "not available for intra prediction"

    – $lcuAddrN_E$ is not available,

    – $partIdxN_E$ is not available

  – Otherwise, the sample p_E[x, y] is marked as "available for intra prediction" and the luma sample at luma location (xW_E, yW_E) inside the largest coding unit $lcuAddrN_E$ is assigned to p_E[x, y].

– For each sample p_E[x, y] with x = -4..-1, y = -4..PuPartSize*2 – 1 and x = 0..PuPartSize*2 – 1, y = -4..-1 marked as "available for intra prediction", the following applies:

p_E[x, y] = (p_E[x, y] + (1 << (increased_bit_depth_luma – 1))) >> increased_bit_depth_luma

Let norm_max be an integer initialized to 0.

For x = -3, -2 and y = -3..2*PuPartSize-2, and for x = -1..2*PuPartSize-2 and y = -3,-2:

– If the samples p_E[x,y], p_E[x-1,y-1], p_E[x-1,y], p_E[x-1,y+1], p_E[x,y-1], p_E[x,y+1], p_E[x+1,y-1], p_E[x+1,y] and p_E[x+1,y+1] are marked as "available for intra prediction", the values $grad_X$ and $grad_Y$ are calculated as:

$grad_X = – p_E[x-1,y-1] – 2 * p_E[x-1,y] – p_E[x-1,y+1] + p_E[x+1,y-1] + 2 * p_E[x+1,y] + p_E[x+1,y+1]$

$grad_Y = – p_E[x-1,y-1] – 2 * p_E[x,y-1] – p_E[x+1,y-1] + p_E[x-1,y+1] + 2 * p_E[x,y+1] + p_E[x+1,y+1]$

– If $|grad_X|^2+|grad_Y|^2$ > norm_max, the process for extrapolating the edge described below is invoked with the values $grad_X$, $grad_Y$, x, y, PuPartWidth and PuPartHeight as inputs.

– If the process for extrapolating the edge is invoked and the output value cross_block is equal to 1, the value – $grad_Y$ is assigned to dir[0], the value $grad_X$ is assigned to dir[1] and the value $|grad_X|^2+|grad_Y|^2$ is assigned to norm_max.

If the final value of norm_max is superior or equal to the value of (threshold_edge << 8), the value of edge_detected is set equal to 1. Otherwise, the value of edge_detected is set equal to 0 and the values of dir[0] and dir[1] are both set to 0.

<u>Process for extrapolating the edge:</u>

Inputs to the process for extrapolating the edge are

– the gradient values $grad_X$ and $grad_Y$

– the values x and y.

– the width and height of the partition unit PuPartWidth, PuPartHeight

Output of the process for extrapolating the edge is the value cross_block.

The value of cross_block is initialized to 0.

If the value of $grad_X$ is negative, the following applies:
$grad_X = -grad_X$
$grad_Y = -grad_Y$
If the value of $grad_X$ is not equal to 0, the two values $\delta x1$ and $\delta x2$ are calculated as:

$$\delta x1 = (-y) * (-grad_Y)$$

$$\delta x2 = (-y + PuPartHeight - 1) * (-grad_Y)$$

If $x * grad_X + \delta x1 \geq 0$ and $x * grad_X + \delta x1 < PuPartWidth * grad_X$, the value of cross_block is set equal to 1.
If $x * grad_X + \delta x2 \geq 0$ and $x * grad_X + \delta x2 < PuPartWidth * grad_X$, the value of cross_block is set equal to 1;

If the value of $grad_Y$ is positive, the following applies:
$grad_X = -grad_X$
$grad_Y = -grad_Y$
If the value of $grad_Y$ is not equal to 0, the two values $\delta y1$ and $\delta y2$ are calculated as:

$$\delta y1 = (-x) * (grad_X)$$

$$\delta y2 = (-x + PuPartWidth - 1) * (grad_X)$$

If $y * (-grad_Y) + \delta y1 \geq 0$ and $y * (-grad_Y) + \delta y1 < PuPartHeight * (-grad_Y)$, the value of cross_block is set equal to 1.
If $y * (-grad_Y) + \delta y2 \geq 0$ and $y * (-grad_Y) + \delta y2 < PuPartHeight * (-grad_Y)$, the value of cross_block is set equal to 1.

6.2.1.2.2.2.2 Specification of DC prediction mode

This process is invoked

– when IntraPredMode[puPartIdx] is equal to Intra_DC and

– when the value of edge_based_prediction_flag is equal to 0 or when the value of edge_based_prediction_flag is equal to 1 and the ouput value edge_detected of the edge detection process specified in subclause 6.2.1.2.2.2.1 is equal to 0.

The values of the prediction samples $predPart_L$[x, y], with x, y = 0..PuPartSize – 1, are derived as follows.

– If all samples p[x, -1], with x = 0..PuPartSize-1 and p[-1, y], with y = 0..PuPartSize-1 are marked as "available for intra prediction", the values of the prediction samples $predPart_L$[x, y], with x, y = 0..PuPartSize-1, are derived by

$$predPart_L[\,x, y\,] = \left(\sum_{x'=0}^{PuPartSize-1} p[x', -1] + \sum_{y'=0}^{PuPartSize-1} p[-1, y'] + PuPartSize \right) >> (k+1), \text{ with } x, y = 0..PuPartSize - 1$$

where 2^k = PuPartSize

– Otherwise, if any samples p[x, -1], with x = 0..PuPartSize-1 are marked as "not available for intra prediction" and all samples p[-1, y], with y = 0..PuPartSize-1 are marked as "available for intra prediction", the values of the prediction samples $predPart_L$[x, y], with x, y = 0..PuPartSize-1, are derived by

$$predPart_L[\,x, y\,] = \left(\sum_{y'=0}^{PuPartSize-1} p[-1, y'] + PuPartSize/2 \right) >> k, \text{ with } x, y = 0..PuPartSize - 1$$

where 2^k = PuPartSize

– Otherwise, if all samples p[x, -1], with x = 0..PuPartSize-1 are marked as "available for intra prediction" and any samples p[-1, y], with y = 0..PuPartSize-1 are marked as "not available for intra prediction", the values of the prediction samples $predPart_L$[x, y], with x, y = 0..PuPartSize-1, are derived by

$$predPart_L[\,x, y\,] = \left(\sum_{x'=0}^{PuPartSize-1} p[x', -1] + PuPartSize/2 \right) >> k, \text{ with } x, y = 0..PuPartSize - 1$$

where 2^k = PuPartSize

– Otherwise, the values of the prediction samples $predPart_L[\ x, y\ ]$, with x, y = 0..PuPartSize-1, are derived by

$$predPart_L[\ x, y\ ] = 1 << (\ (\ BitDepth_Y + increased_bit_depth_luma\ ) - 1\ )$$

6.2.1.2.2.2.3 Specification of edge based prediction mode

This process is invoked when IntraPredMode[puPartIdx] is equal to Intra_DC, the value of edge_based_prediction_flag is equal to 1 and the ouput value edge_detected of the edge detection process specified in subclause 6.2.1.2.2.2.1 is equal to 1.

Inputs to this process are:
– the index of the prediction unit partition puPartIdx.
– the values dir[0] and dir[1] as calculated in the edge detection process specified in subclause 6.2.1.2.2.2.1.

Outputs of this process are the prediction samples $predPart_L[\ x, y\ ]$, with x = 0..PuPartWidth[puPartIdx] and y = 0..PuPartHeight[puPartIdx] for the prediction unit partition with index puPartIdx.

The position of the upper-left sample of the prediction unit partition with index puPartIdx inside the current prediction unit is derived by invoking the inverse prediction unit partition scanning process specified in subclause 4.2.4.2 with puPartIdx as the input and the output being assigned to (xO_{EP}, yO_{EP}).

Let PuPartSize be equal to max(PuPartWidth, PuPartHeight).

The PuPartSize*4 + 1 neighbouring samples $p_{EP}[\ x, y\ ]$, that are constructed luma samples prior to the deblocking filter process, with x = -1, y = -1..PuPartSize*2 - 1 and x = 0..PuPartSize*2 - 1, y = -1, are derived as follows.

– The luma location (xN_{EP}, yN_{EP}) is specified by

$$xN_{EP} = xO_{EP} + x$$

$$yN_{EP} = yO_{EP} + y$$

– The derivation process for neighbouring locations in 4.3.5 is invoked for luma locations with (xN_{EP}, yN_{EP}) as input and $lcuAddrN_{EP}$ and (xW_{EP}, yW_{EP}) as output.

– If $lcuAddN_{EP}$ is available, the prediction unit partition index in the largest coding unit $lcuAddN_{EP}$ covering the luma location (xW_{EP}, yW_{EP}) is assigned to $partIdxN_{EP}$, otherwise, $partIdxN_{EP}$ is marked as not available.

– Each sample $p_{EP}[\ x, y\ ]$ with x = -1, y = -1..PuPartSize*2 – 1 and x = 0..PuPartSize*2 – 1, y = -1 is derived as follows.

  – If any of the following conditions is true, the sample $p_{EP}[\ x, y\ ]$ is marked as "not available for intra prediction"

    $lcuAddrN_{EP}$ is not available,

    $partIdxN_{EP}$ is not available

  – Otherwise, the sample $p_{EP}[\ x, y\ ]$ is marked as "available for intra prediction" and the luma sample at luma location (xW_{EP}, yW_{EP}) inside the largest coding unit $lcuAddrN_{EP}$ is assigned to $p_{EP}[\ x, y\ ]$.

The values of the prediction samples $predPart_L[\ x, y\ ]$, with x, y = 0..PuPartSize – 1, are derived by linear interpolation of the surrounding samples using the values dir[0] and dir[1] to define the prediction direction. The calculation is performed as follows:

– If the value of dir[0] is not equal to 0 and if at least one sample $p_{EP}[z,-1]$ with z=-1..2*PuPartSize-1 is marked as "available for intra prediction", the value δx is derived by:

$$\delta x = ((y+1) * (dir[0] << 6) + (dir[1] >> 1)) / dir[1]$$

The following four values are calculated:

$$w_a = \delta x \,\&\, (2^6 - 1)$$

$$w_b = 2^6 - w_a$$

$$floor_\delta x = \delta x >> 6$$

$$ceil_\delta x = floor_\delta x \quad \text{if} \quad w_a \quad \text{is equal to 0}$$

$$ceil_\delta x = floor_\delta x + 1 \quad \text{if} \quad w_a \quad \text{is not equal to 0}$$

If both pixels $p_{EP}[x - ceil_\delta x, -1]$ and $p_{EP}[x - floor_\delta x, -1]$ are marked as "available for intra prediction", the value predup[x,y] is marked as "calculated" and is derived by (see Figure 1 for illustration):

$$predup[x, y] = (w_a \times p_{EP}[x - ceil_\delta x, -1] + w_b \times p_{EP}[x - floor_\delta x, -1] + 32) >> 6$$

Otherwise, the value predup[x,y] is marked as "not calculated".

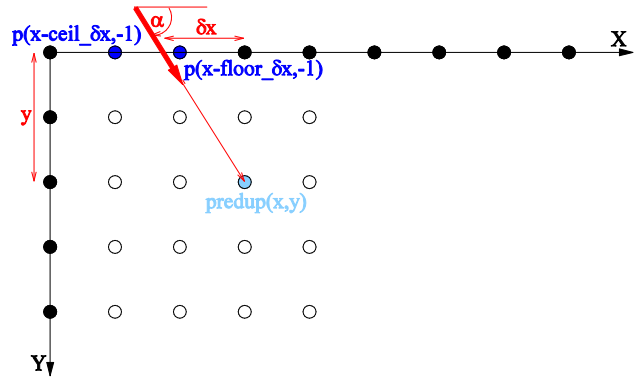


Figure 1: edge based prediction for intra coding.

– If the value of dir[1] is not equal to 0 and if at least one sample p_{EP}[-1,z] with z=-1..2*PuPartSize-1 is marked as "available for intra prediction", the value δy is derived by:

$$\delta y = ((x+1) \times (dir[1] << 6) + (dir[0] >> 1)) / dir[0]$$

The following four values are calculated:

$$w_c = \delta y \,\&\, (2^6 - 1)$$

$$w_d = 2^6 - w_c$$

$$floor_\delta y = \delta y >> 6$$

$$ceil_\delta y = floor_\delta y \quad \text{if } w_c \text{ is equal to 0}$$

$$ceil_\delta y = floor_\delta y + 1 \quad \text{if } w_c \text{ is not equal to 0}$$

If both pixels $p_{EP}[-1, y - ceil_\delta y]$ and $p_{EP}[-1, y - floor_\delta y]$ are marked as "available for intra prediction", the value predleft[x,y] is marked as "calculated" and is derived by:

$$predleft[x, y] = (w_c \times p_{EP}[-1, y - ceil_\delta y] + w_d \times p_{EP}[-1, y - floor_\delta y] + 32) >> 6$$

Otherwise, the value predleft[x,y] is marked as "not calculated".

– If both values predup[x,y] and predleft[x,y] are marked as "calculated", the prediction sample $predPart_L$[x, y] is derived by:
$predPart_L$[x, y] = (predup[x,y] + predleft[x,y]) >> 1

– If predup[x,y] is marked as "calculated" and predleft[x,y] is marked as "not calculated", the prediction sample $predPart_L$[x, y] is derived by:
$predPart_L$[x, y] = predup[x,y]

– If predleft[x,y] is marked as "calculated" and predup[x,y] is marked as "not calculated", the prediction sample $predPart_L$[x, y] is derived by:
$predPart_L$[x, y] = predleft[x,y]

– If both predup[x,y] and predleft[x,y] are marked as "not calculated", the prediction sample $predPart_L$[x, y] is derived by:
$predPart_L$[x, y] = p_{EP}[-1,-1] if x = 0, y = 0 and p_{EP}[-1,-1] is marked as "available for intra prediction"
$predPart_L$[x, y] = p_{EP}[0,-1] if x = 0, y = 0, p_{EP}[-1,-1] is marked "not available for intra prediction" and p_{EP}[0,-1] is marked as "available for intra prediction"
$predPart_L$[x, y] = p_{EP}[-1,0] if x = 0, y = 0, p_{EP}[-1,-1] is marked "not available for intra prediction" and p_{EP}[-1,0] is marked as "available for intra prediction"
$predPart_L$[x, y] = $predPart_L$[x, y-1] if x = 0
$predPart_L$[x, y] = $predPart_L$[x-1, y] if y = 0
$predPart_L$[x, y] = (2*$predPart_L$[x-1, y-1] + $predPart_L$[x, y-1] + $predPart_L$[x-1, y]) >> 2 for all other cases

6.2.2 Intra prediction process for chroma samples

This process is invoked for prediction units when PredMode is equal to MODE_INTRA.

Outputs of this process are intra prediction chroma samples for the current prediction unit partition $pred_{Cb}$[x, y] and $pred_{Cr}$[x, y].

Both chroma partitions (Cb and Cr) of the prediction unit shall use the same prediction mode. In the remainder of this subclause, chroma partition refers to one of the two chroma partitions and the subscript C is used as a replacement of the subscript Cb or Cr.

Table 6-3 specifies the associated meanings of the intra_chroma_pred_mode.

Table 6-3 Associated names of intra_chroma_pred_mode

intra_chroma_pred_mode	Name of intra_chroma_pred_mode
0	Intra_Vertical
1	Intra_Horizontal
2	Intra_DC
3	Intra_Plane
4	Intra_LumaMode

If planar_flag == 1 for the prediction unit, the intra prediction process specified in subclause 6.2.1.2.1 shall be invoked with reconstructed chroma samples as input and the intra chroma prediction samples $predPart_C$[x, y] as output.

Otherwise, if intra_chroma_pred_mode is equal to one of the values from 0 (Intra_Vertical) to 3 (Intra_Plane), the intra prediction processes specified in subclause 1.1.1.1.1.1 to 1.1.1 shall be invoked with intra_chroma_pred_mode and reconstructed chroma samples as input and the intra chroma prediction samples $predPart_C$[x, y] as output. [Ed.: intra sample prediction to be modified to allow the use chroma samples as an input]

Otherwise, if the PuPartSize equals to PU_8x8, the intra prediction processes specified in subclause 6.2.1.2.2 shall be invoked with IntraPredMode and reconstructed chroma samples as input and the intra chroma prediction samples $predPart_C$[x, y] as output.

Otherwise, if the PuPartSize > PU_8x8, the intra prediction processes specified in subclause 1.1.1.1.1.1 shall be invoked with IntraPredMode and reconstructed chroma samples as input and the intra chroma prediction samples $predPart_C$[x, y] as output.

Intra chroma prediction samples for the prediction unit are derived as follows.

– The position of the upper-left sample of a prediction unit partition with index puPartIdx inside the current prediction unit is derived by invoking the inverse prediction unit partition scanning process in subclause 4.2.4.2 with puPartIdx as the input and the output being assigned to (xO, yO).

  xC = xO / SubWidthC and yC = yO / SubHeightC

  $pred_C$[xC + x, yC + y] = $predPart_C$[x, y], x = 0..PuPartWidthC – 1 and y = 0..PuPartHeightC – 1

– The transform coefficient decoding process and picture construction process prior to deblocking filter process in subclause 6.4 is invoked with $pred_C$ and puPartIdx as the input and the constructed samples for the current prediction unit partition S'_C as the output.

6.3 Inter prediction process

This process is invoked when decoding prediction units whose PredMode is not equal to MODE_INTRA.

Outputs of this process are inter prediction samples for the current prediction unit that are a (PuSize)x(PuSize) array $pred_L$ of luma samples and when ChromaArrayType is not equal to 0 two (PuSizeC)x(PuSizeC) arrays $pred_{Cb}$ and $pred_{Cr}$ of chroma samples, one for each of the chroma components Cb and Cr.

The partitioning of a prediction unit is specified by PartMode. Each prediction unit partition is referred to by puPartIdx.

The following steps are specified for each prediction unit partition.

The functions PuPartWidth( ), PuPartHeight( ) describing the width and height of prediction unit partition are specified in Table 5-14.

The prediction unit partition index puPartIdx proceeds over values 0..NumPuParts – 1.

- If PredMode is not equal to MODE_SKIP or MODE_DIRECT, puPartWidth and puPartHeight are derived as

  puPartWidth = PuPartWidth(puPartIdx)

  puPartHeight = PuPartHeight(puPartIdx)

- Otherwise (PredMode is equal to MODE_SKIP or MODE_DIRECT), puPartIdx is set equal to 0, PartMode is set equal to PART_2Nx2N and puPartWidth and puPartHeight are derived as

  puPartWidth = PuPartWidth(0)

  puPartHeight = PuPartHeight(0)

When ChromaArrayType is not equal to 0, the variables puPartWidthC and puPartHeightC are derived as follows.

puPartWidthC = puPartWidth / SubWidthC

puPartHeightC = puPartHeight / SubHeightC

Let the variable MvCnt be initially set equal to 0 before any invocation of subclause 6.3.1 for the prediction unit.

[Ed.: are mvCnt and subMvCnt still needed?]

The inter prediction process for a prediction unit partition puPartIdx consists of the following ordered steps

1. Derivation process for motion vector components and reference indices as specified in subclause 6.3.1.

   Input to this process is a prediction unit partition puPartIdx,

   Outputs of this process are

   – luma motion vectors mvL0 and mvL1 and when ChromaArrayType is not equal to 0, the chroma motion vectors mvCL0 and mvCL1

   – reference indices refIdxL0 and refIdxL1

   – prediction list utilization flags predFlagL0 and predFlagL1

   – the prediction unit partition motion vector count subMvCnt.

2. The variable MvCnt is incremented by subMvCnt.

3. Derivation process for PBIC vector components are specified in subclause 6.3.3

   Inputs to this process are

   – the prediction unit partition index puPartIdx

   – reference indices refIdxL0 and refIdxL1

   – prediction list utilization flags predFlagL0 and predFlagL1

   Output of this process is the PBIC vector ic.

~~3.~~4. Decoding process for inter prediction samples as specified in subclause 6.3.2.

   Inputs to this process are

   – a prediction unit partition puPartIdx,

   – variables specifying partition width and height for luma and chroma (if available), partWidth, partHeight, partWidthC (if available), and partHeightC (if available)

   – luma motion vectors mvL0 and mvL1 and when ChromaArrayType is not equal to 0, the chroma motion vectors mvCL0 and mvCL1

   – PBIC vector ic

   – reference indices refIdxL0 and refIdxL1

– prediction list utilization flags predFlagL0 and predFlagL1

Outputs of this process are

– inter prediction samples (pred); which are a (puPartWidth)x(puPartHeight) array predPartL of prediction luma samples and when ChromaArrayType is not equal to 0 two (puPartWidthC)x(puPartHeightC) arrays predPartCr, and predPartCb of prediction chroma samples, one for each of the chroma components Cb and Cr.

For use in derivation processes of variables invoked later in the decoding process, the following assignments are made:

MvL0[puPartIdx] = mvL0

MvL1[puPartIdx] = mvL1

RefIdxL0[puPartIdx] = refIdxL0

RefIdxL1[puPartIdx] = refIdxL1

PredFlagL0[puPartIdx] = predFlagL0

PredFlagL1[puPartIdx] = predFlagL1

The location of the upper-left sample of the prediction unit partition to the upper-left sample of the prediction unit is derived by invoking the inverse prediction unit partition scanning process as described in subclause 4.2.4.2 with puPartIdx as the input and (xP, yP) as the output.

The prediction unit prediction is formed by placing the prediction unit partition samples in their correct relative positions in the prediction unit, as follows.

The variable $pred_L$[xP + x, yP + y] with x = 0..puPartWidth − 1, y = 0..puPartHeight − 1 is derived by

$pred_L$[xP + x, yP + y] = $predPart_L$[x, y]

When ChromaArrayType is not equal to 0, the variable $pred_C$ with x = 0.. puPartWidthC − 1, y = 0.. puPartHeightC − 1, and C in $pred_C$ and $predPart_C$ being replaced by Cb or Cr is derived by

$pred_C$[xP / SubWidthC + x, yP / SubHeightC + y] = $predPart_C$[x, y]

6.3.1 Derivation process for motion vector components and reference indices

Input to this process is a prediction partition index puPartIdx.

Outputs of this process are

- luma motion vectors mvL0 and mvL1 and when ChromaArrayType is not equal to 0, the chroma motion vectors mvCL0 and mvCL1,
- reference indices refIdxL0 and refIdxL1,
  - prediction list utilization flags predFlagL0 and predFlagL1,
  - a motion vector count variable subMvCnt.

For the derivation of the variables mvL0 and mvL1 as well as refIdxL0 and refIdxL1, the following applies.

- If PredMode is equal to MODE_SKIP or MODE_DIRECT and slice_type is equal to P, the derivation process for luma motion vectors for skipped and direct prediction units in P slices in subclause 6.3.1.1 is invoked with the output being the luma motion vectors mvL0 and reference indices refIdxL0, and predFlagL0 is set equal to 1. mvL1 and refIdxL1 are marked as not available and predFlagL1 is set equal to 0. The motion vector count variable subMvCnt is set equal to 1.
- Otherwise, if PredMode is equal to MODE_SKIP or MODE_DIRECT and slice_type is equal to B, the derivation process for luma motion vectors for skipped and direct PUs in B slices in subclause 6.3.1.2 is invoked with the output being the luma motion vectors mvL0, mvL1, the reference indices refIdxL0, refIdxL1, the motion vector count variable subMvCnt, and the prediction list utilization flags predFlagL0 and predFlagL1.

- Otherwise, if merge_flag is equal to 1, the derivation process for luma motion vectors for merge_flag equal to 1 as specified in subclause 6.3.1.3 is invoked with puPartIdx as input and the outputs being the luma motion vectors mvL0 and mvL1, the reference indices refIdxL0 and refIdxL1, the prediction utilization flags predFlagL0 and predFlagL1, and the motion vector count variable subMvCnt.
- Otherwise, for X being replaced by either 0 or 1 in the variables predFlagLX, mvLX, refIdxLX and in Pred_LX and in the syntax elements ref_idx_lX and mvd_lX, the following applies.
    1. The variables refIdxLX and predFlagLX are derived as follows.
        - If inter_pred_idc[puPartIdx] is equal to Pred_LX or to Pred_BI,

            refIdxLX = ref_idx_lX[puPartIdx]

            predFlagLX = 1
        - Otherwise, the variables refIdxLX and predFlagLX are specified by

            refIdxLX = −1

            predFlagLX = 0
    2. The motion vector count variable subMvCnt is set equal to predFlagL0 + predFlagL1.
    3. The variable mvresLX is derived as follows.

        mvresLX[0] = mvres_lX[puPartIdx][0]

        mvresLX[1] = mvres_lX[puPartIdx][1]
    4. The variable mvdLX is derived as follows.

        mvdLX[0] = mvd_lX[puPartIdx][0]

        mvdLX[1] = mvd_lX[puPartIdx][1]
    5. When predFlagLX is equal to 1, the variable mvpLX is derived as follows.
        - The derivation process for luma motion vector prediction in subclause 6.3.1.3 is invoked with puPartIdx, refIdxLX and mvdLX as the inputs and the output being mvpLX.
    6. When predFlagLX is equal to 1, the horizontal component of luma motion vector is derived as follows.
        - If mvresLX[0] is equal to 1, mvLX[0] = Round(mvpLX[0]) + mvdLX[0]*2
        - Otherwise, mvLX[0] = mvpLX[0] + mvdLX[0]
    7. When predFlagLX is equal to 1, the vertical component of luma motion vector is derived as follows.
        - If mvresLX[1] is equal to 1, mvLX[1] = Round(mvpLX[1]) + mvdLX[1]*2
        - Otherwise, mvLX[1] = mvpLX[1] + mvdLX[1]

    where Round(x) = Sign(x) * Floor(Abs(x) + 0.5).

When ChromaArrayType is not equal to 0 and predFlagLX (with X being either 0 or 1) is equal to 1, the derivation process for chroma motion vectors in subclause - is invoked with mvLX and refIdxLX as input and the output being mvCLX.

6.3.1.1 Derivation process for luma motion vectors for skipped and direct prediction units in P slices

This process is invoked when PredMode is equal to MODE_SKIP or MODE_DIRECT and slice_type is equal to P.

Outputs of this process are the motion vector mvL0 and the reference index refIdxL0.

The reference index refIdxL0 for a skipped or direct prediction unit is derived as

refIdxL0 = 0.

For the derivation of the motion vector mvL0 of a MODE_SKIP or MODE_DIRECT in P, the process specified in subclause 6.3.1.3 is invoked with puPartIdx set equal to 0, listSuffixFlag set equal to 0, the both components of mvdLX set equal to 0 as inputs and the output is assigned to mvpLX. The output is directly assigned to mvL0, since the predictor is equal to the actual motion vector.

6.3.1.2 Derivation process for luma motion vectors for skipped and direct prediction units in B slices

This process is invoked when PredMode is equal to MODE_SKIP or MODE_DIRECT and slice_type is equal to B.

Outputs of this process are the reference indices refIdxL0, refIdxL1, the motion vectors mvL0 and mvL1, the motion vector count variable subMvCnt, and the prediction list utilization flags, predFlagL0 and predFlagL1.

For X being replaced by either 0 or 1 in the variables predFlagLX, mvLX, refIdxLX, and in Pred_LX and in the syntax elements ref_idx_lX and mvd_lX, the following applies.

The variables refIdxLX and predFlagLX are derived as follows.

- If inter_pred_idc[puPartIdx] is equal to Pred_LX or to Pred_BI,

  refIdxLX = 0

  predFlagLX = 1

- Otherwise, the variables refIdxLX and predFlagLX are specified by

  refIdxLX = −1

  predFlagLX = 0

The motion vector count variable subMvCnt is set equal to predFlagL0 + predFlagL1.

When predFlagLX is equal to 1, the derivation process for luma motion vector prediction for rectangular partitions in subclause 6.3.1.3 is invoked with puPartIdx, refIdxLX, and the both components of mvdLX set equal to 0 as the inputs and the output being mvpLX. The output is directly assigned to mvLX, since the predictor is equal to the actual motion vector.

6.3.1.3 Derivation process for luma motion vectors for merge_flag equal to 1

This process is only invoked if merge_flag is equal to 1 for the current partition.

Input to this process is a prediction partition index puPartIdx.

Outputs of this process are

- the luma motion vectors mvL0 and mvL1,
- the reference indices refIdxL0 and refIdxL1,
- the prediction list utilization flags predFlagL0 and predFlagL1,
- a motion vector count variable subMvCnt.

The motion vectors mvLXA and mvLXB, the reference indices refIdxLXA and refIdxLXB, and the prediction utilization flag predFlagLXA and predFlagLXB (with X being 0 and 1) are derived as specified by the following ordered steps:

1. The derivation process for neighbouring partitions in subclause 4.3.4.4 is invoked with lcuAddr, puIdx and puPartIdx as input and the output is is assigned to lcuAddrN, puIdxN and puPartIdxN with N being replaced by A and B.
2. Depending on the partition lcuAddrN/puIdxN/puPartIdxN (with N being A and B), the following applies.
   - If the partition lcuAddrN/puIdxN/puPartIdxN is not available, predFlagL0N and predFlagL1N are set equal to 0.
   - Otherwise, predFlagL0N, predFlagL1N, mvL0N, mvL1N, refIdxL0N, and refIdxL1N are set equal to the variables predFlagL0, predFlagL1, mvL0, mvL1, refIdxL0, and refIdxL1, respectively, of the partition lcuAddrN/puIdxN/puPartIdxN.

The variable mergeLeft is derived as follows:

– If (predFlagL0B is equal to 0 and predFlagL1B is equal to 0) or merge_left_flag is equal to 1, mergeLeft is set equal to 1.

– Otherwise, mergeLeft is set equal to 0.

Depending on mergeLeft, the following applies:

– If mergeLeft is equal to 1, predFlagL0, predFlagL1, mvL0, mvL1, refIdxL0, and refIdxL1 are set equal to predFlagL0B, predFlagL1B, mvL0B, mvL1B, refIdxL0B, and refIdxL1B, respectively.

– Otherwise, predFlagL0, predFlagL1, mvL0, mvL1, refIdxL0, and refIdxL1 are set equal to predFlagL0A, predFlagL1A, mvL0A, mvL1A, refIdxL0A, and refIdxL1A, respectively.

The motion vector count variable subMvCnt is set equal to predFlagL0 + predFlagL1.

6.3.1.4 Derivation process for luma motion vector prediction

Inputs to this process are

- the prediction unit partition index puPartIdx,
- the reference index of the current prediction unit partition refIdxLX (with X being 0 or 1),
- the motion vector difference mvdLX

Output of this process is the prediction mvpLX of the motion vector mvLX (with X being 0 or 1).

Depending on interleaved_motion_vector_predictor_flag, the following applies.

– If interleaved_motion_vector_predictor_flag is equal to 0, the following applies:

  – If mv_competition_flag is equal to 1, the derivation process for luma motion vector prediction in explicit mode in subclause 6.3.1.4.1 is invoked with puPartIdx, refIdxLX and mvdLX as the inputs and the output being mvpLX.

  – Otherwise (mv_competition_flag is equal to 0), the derivation process for luma motion vector prediction in implicit mode in subclause 6.3.1.4.6 is invoked with puPartIdx and refIdxLX as the inputs and the output being mvpLX.

– Otherwise (interleaved_motion_vector_predictor_flag is equal to 1), the following applies:

  – If mv_competition_flag is equal to 1, the derivation process for luma motion vector prediction in explicit mode and interleaved motion vector prediction in subclause 6.3.1.4.7 is invoked with puPartIdx, refIdxLX and mvdLX as the inputs and the output being mvpLX.

  – Otherwise (mv_competition_flag is equal to 0), the derivation process for luma motion vector prediction in implicit mode in subclause 6.3.1.4.6 is invoked with puPartIdx and refIdxLX as the inputs and the output being mvpLX. And the calculation of the horizontal component of mvpLX in subclause 6.3.1.4.9 is invoked with the vertical component of mvpLX, the vertical component of mvdLX as inputs and the output the horizontal component of mvpLX.

6.3.1.4.1 Derivation process for luma motion vector prediction with explicit mode

Inputs to this process are

- the PU partition index puPartIdx,
- the reference index of the current prediction unit partition refIdxLX (with X being 0 or 1),
- the motion vector difference mvdLX

Output of this process is the prediction mvpLX of the motion vector mvLX (with X being 0 or 1).

The motion vector predictor mvpLX is derived in the following ordered steps.

1. The derivation process for motion vector predictor candidates from neighboring prediction unit partitions in subclause 6.3.1.4.2 is invoked with puPartIdx, refIdxLX (with X being 0 or 1) as the inputs and the

availability flags availableFlagLXN and the motion vectors mvLXN with N being replaced by A, B, or C as the output.

2. The derivation process for median luma motion vector prediction in subclause 6.3.1.4.3 is invoked with the motion vectors mvLXN and the availability flags availableFlagLXN with N being replaced by A, B, or C as the inputs and the output is assigned to the median motion vector predictor mvLXMed.
3. The motion vector predictor list, mvpListLX, is constructed of which elements are given as specified order:
   - mvLXMed, median motion vector of available motion vectors
   - mvLXA
   - mvLXB
   - mvLXC
4. If mv_competition_temporal_flag is equal to 1, the derivation process for temporal luma motion vector prediction in subclause 6.3.1.4.4 is invoked with puPartIdx, refIdxLX (with X being 0 or 1 for refIdxLX being refIdxL0 or refIdxL1, respectively) as the inputs and with the output being the availability flag availableFlagLXCol and the temporal motion vector predictor mvLXCol. If availableFlagLXCol is equal to 1, then mvLXCol is inserted at the end of mvpListLX.
5. If one of following conditions is true, mvLXMed is switched with mvLXN in the order of mvpListLX and mvLXN is derived as follows.
   - If PartMode is one of the values among PART_2NxN, PART_2NxnU and PART_2NxnD, the following applies.

     mvLXN = mvLXB for puPartIdx is equal to 0

     mvLXN = mvLXA otherwise
   - Otherwise, If PartMode is one of the values among PART_Nx2N, PART_nLx2N and PART_nRx2N, the following applies.

     mvLXN = mvLXA for puPartIdx is equal to 0

     mvLXN = mvLXC otherwise
6. If several motion vectors have same value, the motion vectors are removed from the list except the motion vector which has the smallest order in the mvpListLX
7. If the number of elements NumMVPCand(LX, puPartIdx) within the mvpListLX is greater than 1, the removal process of motion vector prediction in subclause 6.3.1.4.5 is invoked with mvpListLX and mvdLX as inputs and the output is modified mvpListLX.
8. If the number of elements NumMVPCand(LX, puPartIdx) within the mvpListLX is equal to 1, mvp_idx_lX is set by 0
9. The motion vector of mvListLX[mvp_idx_lX] is assigned to mvpLX

6.3.1.4.2 Derivation process for motion vector predictor candidates

Inputs to this process are

- the prediction unit partition index puPartIdx,
- the reference index of the current prediction unit partition refIdxLX (with X being 0 or 1),

Outputs of this process are (with N being replaced by A, B, or C)

- the motion vectors mvLXN of the neighbouring partitions,
- the availability flags availableFlagLXN of the neighbouring partitions.

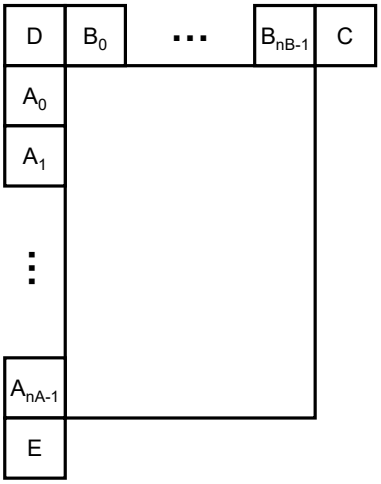


Fig. 6-1 Spatial motion vector neighbours

The motion vector mvLXA and the availability flag availableFlagLXA are derived in the following ordered steps:

1. Let a set of nA sample location (xA_k, yA_k), with k = 0..nA-1, express relative to the upper left corner of prediction unit the partition. The set of sample locations (xA_k, yA_k) represent the sample locations immediately to the left of the left partition boundary with the offset SuSize vertically. nA is set equal to puPartHeight / SuSize.

2. Let the availability flag availableFlagLXA be initially set equal to 0 and the both components of mvLXA are set equal to 0.

3. For (xA_k, yA_k) from (xA_0, yA_0) to (xA_{nN-1}, yA_{nN-1}) where $x_{Ak+1} = x_{Ak}$ and $y_{Ak+1} = y_{Ak}$ + SuSize, the following applies until availableFlagLXA is equal to 1:

   - The derivation process for the neighbouring locations specified in subclause 4.3.5 is invoked with (xA_k, yA_k) as input and the output is assigned to lcuAddrA and (xW, yW)

   - If the lcuAddrA is available,

     - The prediction unit index and the partition index in the largest coding unit lcuAddrA covering the luma location (xW, yW) shall be assigned to puIdxA and puPartIdxA.

     - If the prediction unit partition puPartIdxA is available, PredMode of puIdxA is not MODE_INTRA, predFlagLX of puIdxA is equal to 1, and the reference index refIdxLX of puIdxA is equal to the reference index refIdX of the current partition puPartIdx,

       - availableFlagLXA is set equal to 1 and the motion vector mvLXA is set equal to the motion vector mvLX which has been assigned to the prediction unit partition puPartIdxA

The motion vector mvLXB and the availability flag availableFlagLXB are derived in the following ordered steps:

1. Let a set of nB sample location (xB_k, yB_k), with k = 0..nB-1, express relative to the upper left corner of prediction unit the partition. The set of sample locations (xB_k, yB_k) represent the sample locations immediately to the above of the above partition boundary with the offset SuSize horizontally. nB is set equal to puPartWidth / SuSize.

2. Let the availability flag availableFlagLXB be initially set equal to 0 and the both components of mvLXB are set equal to 0.

3. For (xB_k, yB_k) from (xB_0, yB_0) to (xB_{nN-1}, yB_{nN-1}) where $x_{Bk+1} = x_{Bk}$ + SuSize and $y_{Bk+1} = y_{Bk}$, the following applies until availableFlagLXB is equal to 1:

   - The derivation process for the neighbouring locations specified in subclause 4.3.5 is invoked with (xB_k, yB_k) as input and the output is assigned to lcuAddrB and (xW, yW)

   - If the lcuAddrB is available,

- The prediction unit index and the partition index in the largest coding unit lcuAddrB covering the luma location (xW, yW) shall be assigned to puIdxB and puPartIdxB.
- If the prediction unit partition puPartIdxA is available, PredMode of puIdxB is not MODE_INTRA, predFlagLX of puIdxB is equal to 1, and the reference index refIdxLX of puIdxB is equal to the reference index refIdX of the current partition puPartIdx,
  - availableFlagLXB is set equal to 1 and the motion vector mvLXB is set equal to the motion vector mvLX which has been assigned to the prediction unit partition puPartIdxB

The motion vector mvLXC are derived in the following ordered steps:

3. The derivation process for neighbouring partitions in subclause 4.3.4.4 is invoked with lcuAddr, puIdx and puPartIdx as input and the output is is assigned to lcuAddrN, puIdxN and puPartIdxN with N being replaced by C, D or E.
4. Let the both components of mvLXC are set equal to 0.
5. For the derivation of the motion vectors mvLXC, the following applies:
   - If the prediction unit partition puPartIdxC is available, PredMode of puIdxC is not MODE_INTRA, predFlagLX of puPartIdxC is equal to 1, and the reference index refIdxLX of puPartIdxC is equal to the reference index refIdX of the current partition puPartIdx,
     - availableFlagLXC is set equal to 1 and mvLXC is set equal to the motion vector which has been assigned to the partition puPartIdxC
   - Otherwise, if the prediction unit partition puPartIdxD is available, PredMode of puIdxD is not MODE_INTRA, predFlagLX of puPartIdxD is equal to 1, and the reference index refIdxLX of puPartIdxD is equal to the reference index refIdX of the current partition puPartIdx,
     - availableFlagLXC is set equal to 1 and mvLXC is set equal to the motion vector which has been assigned to the partition puPartIdxD
   - Otherwise, if the prediction unit partition puPartIdxE is available, PredMode of puIdxE is not MODE_INTRA, predFlagLX of puPartIdxE is equal to 1, and the reference index refIdxLX of puPartIdxE is equal to the reference index refIdX of the current partition puPartIdx,
     - availableFlagLXC is set equal to 1 and mvLXC is set equal to the motion vector which has been assigned to the partition puPartIdxE

6.3.1.4.3 Derivation process for median luma motion vector prediction

Inputs to this process are

- the motion vectors mvLXN (with N being replaced by A, B, or C) of the neighbouring partitions,
- the availability flags availableFlagLXN with N being replaced by A, B, or C

Output of this process is the motion vector prediction mvpLXMed

For the derivation of the variables mvpLX, the following applies

- If all of the availability flags availableFlagLXN (with N being replaced by A, B, or C) are equal to 0, the both components of mvLXMed are set equal to 0.
- Otherwise, if one and only one of availableFlagLXA, availableFlagLXB and availableFlagLXC is equal to 1, availableFlagLXN is set equal to 1 and the motion vector mvLXN is assigned to the median motion vector prediction mvpLXMed

  mvLXMed = mvLXN
- Otherwise, each component of the median motion vector prediction mvLXM is given by the median of the corresponding vector components of the motion vector mvLXA, mvLXB, and mvLXC

  mvLXMed [0] = Median(mvLXA[0], mvLXB[0], mvLXC[0])

  mvLXMed [1] = Median(mvLXA[1], mvLXB[1], mvLXC[1])

6.3.1.4.4 Derivation process for temporal luma motion vector prediction

Inputs to this process are

- the prediction unit partition index puPartIdx,
- the reference index of the current prediction unit partition refIdxLX (with X being 0 or 1),

Outputs of this process are

- the motion vector prediction mvLXCol,
- the availability flag availableFlagLXCol

The function RefPicOrderCnt(pic, refidx, LX) is specified by the value of PicOrderCnt of the picture that is the reference picture RefPicListX[refidx] of pic with X being 0 or 1. PicOrderCnt of reference pictures of pic shall be maintained until pic is not marked as "non-exisiting."

Depending on the values of slice_type and collocated_from_l0_flag, the following applies

- If slice_type is equal to B and collocated_from_l0_flag is equal to 1, mvLXCol is specified as follows.
  - The variable colPic specifies the picture that contains the co-located partition as specified by RefPicList0[0]
  - The co-located largest coding unit address lcuAddrCol, prediction unit index puIdxCol and prediction unit partition index puPartIdxCol are specified by

    lcuAddrCol = lcuAddr

    puIdxCol = puIdx

    puPartIdxCol = puPartIdx
  - If the prediction unit puIdxCol is coded in an intra prediction mode, both components of mvLXCol are set qual to 0 and availableFlagLXCol is set equal to 0.
  - Otherwise (the prediction unit puIdxCol is not coded in an intra prediction mode), the prediction utilization flag predFlagL1Col, the motion vector mvCol and the reference index refIdxCol are set equal to PredFlagL1[puPartIdxCol], MvL1[puPartIdxCol] and RefIdxL1[puPartidxCol], respectively, which are the prediction utilization flag, the motion vector mvL1 and the reference index refIdxL1 that have been assigned to the prediction unit partition puPartIdxCol.
    - If predFlagL1Col is equal to 0, both components of mvLXCol are set qual to 0 and availableFlagLXCol is set equal to 0.
    - Otherwise (predFlagL1Col is equal to 1), availableFlagLXCol is set equal to 1 and mvLXCol is derived as follows.
      - If PicOrderCnt(colPic) – RefPicOrderCnt(colPic, refIdxCol, L1)) is equal to PicOrderCnt(currPic) – RefPicOrderCnt(currPic, refIdxCol, LX)),

        mvLXCol = mvCol
      - Otherwise, mvLXCol is derived as scaled version of the motion vector mvCol as specified below

        tx = (16384 + Abs(td / 2)) / td

        DistScaleFactor = Clip3(-1024, 1023, (tb * tx + 32) >> 6)

        mvLXCol = (DistScaleFactor * mvCol + 128) >> 8

        where td and tb are derived as

        td = Clip3(-128, 127, PicOrderCnt(colPic) – RefPicOrderCnt(colPic, refIdxCol, L1))

        tb = Clip3(-128, 127, PicOrderCnt(currPic) – RefPicOrderCnt(currPic, refIdxCol, LX))
- Otherwise, if slice_type is equal to B and collocated_from_l0_flag is equal to 0, mvLXCol is specified as follows.

- The variable colPic specifies the picture that contains the co-located partition as specified by RefPicList1[0]
- The co-located largest coding unit address lcuAddrCol, prediction unit index puIdxCol and prediction unit partition index puPartIdxCol are specified by

  lcuAddrCol = lcuAddr

  puIdxCol = puIdx

  puPartIdxCol = puPartIdx
- If the prediction unit puIdxCol is coded in an intra prediction mode, both components of mvLXCol are set qual to 0 and availableFlagLXCol is set equal to 0.
- Otherwise (the prediction unit puIdxCol is not coded in an intra prediction mode), the prediction utilization flag predFlagL0Col, the motion vector mvCol and the reference index refIdxCol are set equal to PredFlagL0[puPartIdxCol], MvL0[puPartIdxCol] and RefIdxL0[puPartidxCol], respectively, which are the prediction utilization flag, the motion vector mvL0 and the reference index refIdxL0 that have been assigned to the prediction unit partition puPartIdxCol.
  - If predFlagL0Col is equal to 0, both components of mvLXCol are set qual to 0 and availableFlagLXCol is set equal to 0.
  - Otherwise (predFlagL0Col is equal to 1), availableFlagLXCol is set equal to 1 and mvLXCol is derived as follows.
    - If PicOrderCnt(colPic) – RefPicOrderCnt(colPic, refIdxCol, L0)) is equal to PicOrderCnt(currPic) – RefPicOrderCnt(currPic, refIdxCol, LX)),

      mvLXCol = mvCol
    - Otherwise, mvLXCol is derived as scaled version of the motion vector mvCol as specified below

      tx = (16384 + Abs(td / 2)) / td

      DistScaleFactor = Clip3(-1024, 1023, (tb * tx + 32) >> 6)

      mvLXCol = (DistScaleFactor * mvCol + 128) >> 8

      where td and tb are derived as

      td = Clip3(-128, 127, PicOrderCnt(colPic) – RefPicOrderCnt(colPic, refIdxCol, L0))

      tb = Clip3(-128, 127, PicOrderCnt(currPic) – RefPicOrderCnt(currPic, refIdxCol, LX))

- Otherwise (slice_type is equal to P), mvLXCol is specified as follows.
  - The variable colPic specifies the picture that contains the co-located partition as specified by RefPicList0[0]
  - The co-located largest coding unit address lcuAddrCol, prediction unit index puIdxCol and prediction unit partition index puPartIdxCol are specified by

    lcuAddrCol = lcuAddr

    puIdxCol = puIdx

    puPartIdxCol = puPartIdx
  - If the prediction unit puIdxCol is coded in an intra prediction mode, both components of mvLXCol are set qual to 0 and availableFlagLXCol is set equal to 0.
  - Otherwise (the prediction unit puIdxCol is not coded in an intra prediction mode), the prediction utilization flag predFlagL0Col, the motion vector mvCol and the reference index refIdxCol are set equal to PredFlagL0[puPartIdxCol], MvL0[puPartIdxCol] and RefIdxL0[puPartidxCol], respectively, which are the prediction utilization flag, the motion vector mvL0 and the reference index refIdxL0 that have been assigned to the prediction unit partition puPartIdxCol.
    - If predFlagL0Col is equal to 0, both components of mvLXCol are set qual to 0 and availableFlagLXCol is set equal to 0.

– Otherwise (predFlagL0Col is equal to 1), availableFlagLXCol is set equal to 1 and mvLXCol is derived as follows.

  – If PicOrderCnt(colPic) – RefPicOrderCnt(colPic, refIdxCol, L0)) is equal to PicOrderCnt(currPic) – RefPicOrderCnt(currPic, refIdxCol, LX)),

    mvLXCol = mvCol

  – Otherwise, mvLXCol is derived as scaled version of the motion vector mvCol as specified below

    tx = (16 384 + Abs(td / 2)) / td

    DistScaleFactor = Clip3(-1024, 1023, (tb * tx + 32) >> 6)

    mvLXCol = (DistScaleFactor * mvCol + 128) >> 8

  where td and tb are derived as

    td = Clip3(-128, 127, PicOrderCnt(colPic) – RefPicOrderCnt(colPic, refIdxCol, L0))

    tb = Clip3(-128, 127, PicOrderCnt(currPic) – RefPicOrderCnt(currPic, refIdxCol, LX))

6.3.1.4.5 Removal process for motion vector prediction

Inputs to this process are

- the motion vector predictor list mvpListLX,
- the motion resolution mvresLX,
- the motion vector difference mvdLX

Output of this process is the modified motion vector predictor list mvpListLX.

The function EstMvdBits(mvd) of a motion vector difference mvd is specified as follows:

EstMvdBits(mvd) = EstMvdCompBits(mvd [0]) + EstMvdCompBits(mvd [1])

The function EstMvdCompBits(mvd[c]) of a component of a motion vector difference mvd (with c being 0 or 1), used in the above formula is defined as the value of variable estMvdCompBits derived as specified by the following pseudo-code: [Ed.: to be tabularized]

```
estMvdCompBits = 1
uiTemp = ( mvd[ c ] <= 0 ) ? ( -mvd[ c ] << 1 ) + 1 : ( mvd[ c ] << 1 )
while ( 1 != uiTemp ) {
    uiTemp >>= 1
    estMvdCompBits += 2
}
```

The variable currentEstMvdBits is set equal to EstMvdBits(mvdLX).

For each mvpCandidate in mvpListLX, the following applies

- If mvresLX is equal to 0, the variable currentEstMvdBits is set equal to EstMvdBits(mvdLX) and for each mvpCandidate in mvpListLX, the following applies

  - The variable motion vector mvCandidate is derived as

    mvCandidate[0] = Round(mvpCandidate[0])/2 + mvdLX[0]

    mvCandidate[1] = Round(mvpCandidate[1])/2+ mvdLX[1]

  - For each motion vector canndidate mvpOtherCandidate in mvpListLX except mvpCandidate, the variable motion vector difference mvdOtherCandidate is derived as

    mvdOtherCandidate [0] =(mvCandidate [0] - Round(mvpOtherCandidate [0])/2)

    mvdOtherCandidate [1] = (mvCandidate [1] - Round(mvpOtherCandidate [1])/2)

- If any of EstMvdBits(mvdOtherCandidate) in mvpListX is smaller than currentEstMvdBits, mvpCandidate is removed from mvpListLX

- Otherwise, the variable currentEstMvdBits is set equal to EstMvdBits(mvdLX) and for each mvpCandidate in mvpListLX, the following applies
  - The variable motion vector mvCandidate is derived as

    mvCandidate[0] = mvpCandidate[0] + mvdLX[0]

    mvCandidate[1] = mvpCandidate[1] + mvdLX[1]
  - For each motion vector canndidate mvpOtherCandidate in mvpListLX except mvpCandidate, the variable motion vector difference mvdOtherCandidate is derived as

    mvdOtherCandidate [0] = mvCandidate [0] - mvpOtherCandidate [0]

    mvdOtherCandidate [1] = mvCandidate [1] - mvpOtherCandidate [1]
  - If any of EstMvdBits(mvdOtherCandidate) in mvpListX is smaller than currentEstMvdBits, mvpCandidate is removed from mvpListLX

6.3.1.4.6 Derivation process for luma motion vector prediction with implicit mode

[Ed.: motion vector prediction when mv_competition_flag = 0]

6.3.1.4.7 Derivation process for luma motion vector prediction with explicit mode and interleaved motion vector prediction

Inputs to this process are

- the PU partition index puPartIdx,
- the reference index of the current prediction unit partition refIdxLX (with X being 0 or 1),
- the motion vector difference mvdLX

Output of this process is the prediction mvpLX of the motion vector mvLX (with X being 0 or 1).

The motion vector predictor mvpLX is derived in the following ordered steps.

1. The derivation process for motion vector predictor candidates from neighboring prediction unit partitions in subclause 6.3.4.4.5 is invoked with puPartIdx, refIdxLX (with X being 0 or 1) as the inputs and the availability flags availableFlagLXN and the motion vectors mvLXN with N being replaced by A, B, or C as the output.
2. The derivation process for median luma motion vector prediction in subclause 6.3.4.4.6 is invoked with the motion vectors mvLXN and the availability flags availableFlagLXN with N being replaced by A, B, or C as the inputs and the output is assigned to the median motion vector predictor mvLXMed.
3. The motion vector predictor list, mvpListLX, is constructed of which elements are given as specified order:
   - mvLXMed, median motion vector of available motion vectors
   - mvLXA
   - mvLXB
   - mvLXC
4. When mv_competition_temporal_flag is equal to 1, the derivation process for temporal luma motion vector prediction in subclause 6.3.4.4.7 is invoked with puPartIdx, refIdxLX (with X being 0 or 1 for refIdxLX being refIdxL0 or refIdxL1, respectively) as the inputs and with the output being the availability flag availableFlagLXCol and the temporal motion vector predictor mvLXCol. If availableFlagLXCol is equal to 1, then mvLXCol is inserted at the end of mvpListLX.
5. When one of following conditions is true, mvLXMed is switched with mvLXN in the order of mvpListLX and mvLXN is derived as follows.

- If PartMode is one of the values among PART_2NxN, PART_2NxnU and PART_2NxnD, the following applies.

  mvLXN = mvLXB for puPartIdx is equal to 0

  mvLXN = mvLXA otherwise

- Otherwise, If PartMode is one of the values among PART_Nx2N, PART_nLx2N and PART_nRx2N, the following applies.

  mvLXN = mvLXA for puPartIdx is equal to 0

  mvLXN = mvLXC otherwise

6. When several motion vectors have same value, the motion vectors are removed from the list except the motion vector which has the smallest order in the mvpListLX
7. When the number of elements NumMVPCand(LX, puPartIdx) within the mvpListLX is greater than 1, the removal process of vertical component of motion vector prediction in subclause 6.3.1.4.8 is invoked with mvpListLX and mvdLX as inputs and the output is modified mvpListLX.
8. When the number of elements NumMVPCand(LX, puPartIdx) within the mvpListLX is equal to 1, mvp_idx_lX is set by 0
9. The calculation of the horizontal component of mvpLX in subclause 6.3.1.4.9 is invoked with the vertical component of mvpLX, the vertical component of mvdLX as inputs and the output the horizontal component of mvpLX.
10. The motion vector of mvListLX[mvp_idx_lX] is assigned to mvpLX

6.3.1.4.8 Removal process for vertical component of motion vector prediction

Inputs to this process are

- the motion vector predictor list mvpListLX,
- the motion resolution mvresLX,
- the motion vector difference mvdLX

Output of this process is the modified motion vector predictor list mvpListLX.

The function EstMvdCompBits(mvd[c]) of a component of a motion vector difference mvd (with c being 0 or 1), used in the above formula is defined as the value of variable estMvdCompBits derived as specified by the following pseudo-code: [Ed.: to be tabularized]

```
estMvdCompBits = 1
uiTemp = ( mvd[ c ] <= 0 ) ? ( -mvd[ c ] << 1 ) + 1 : ( mvd[ c ] << 1 )
while ( 1 != uiTemp ) {
    uiTemp >>= 1
    estMvdCompBits += 2
}
```

The variable currentEstMvdVerBits is set equal to EstMvdCompBits(mvdLXver).

For each vertical component mvpCandidateVer in mvpListLX, the following applies

- If the vertical component of mvresLX is equal to 0, the variable currentEstMvdVerBits is set equal to EstMvdCompBits (vertical component of mvdLX) and for each mvpCandidate in mvpListLX, the following applies
  - The variable vertical component of motion vector mvCandidateVer is derived as

    mvCandidateVer [0] = Round(mvpCandidateVer [0])/2 + mvdLXver[0]

    mvCandidateVer [1] = Round(mvpCandidateVer [1])/2+ mvdLXver[1]

– For each vertical component of motion vector candidate mvpOtherCandidateVer in mvpListLX except mvCandidateVer, the variable vertical component of motion vector difference mvdOtherCandidateVer is derived as

mvdOtherCandidateVer [0] =(mvCandidateVer [0] - Round(mvpOtherCandidateVer [0])/2)

mvdOtherCandidateVer [1] = (mvCandidateVer [1] - Round(mvpOtherCandidateVer [1])/2)

– When any of EstMvdCompBits(mvpOtherCandidateVer) in mvpListX is smaller than currentEstMvdVerBits, mvpCandidateVer is removed from mvpListLX

– Otherwise, the variable currentEstMvdVerBits is set equal to EstMvdCompBits(mvdLXver) and for each mvpCandidateVer in mvpListLX, the following applies

– The variable vertical component of motion vector mvCandidateVer is derived as

mvCandidateVer [0] = mvCandidateVer [0] + mvdLXver[0]

mvCandidateVer [1] = mvCandidateVer [1] + mvdLXver[1]

– For each vertical component of motion vector candidate mvpOtherCandidateVer in mvpListLX except mvpCandidate, the variable vertical component of motion vector difference mvpOtherCandidateVer is derived as

mvpOtherCandidateVer [0] = mvCandidateVer [0] - mvpOtherCandidateVer [0]

mvpOtherCandidateVer [1] = mvCandidate Ver[1] - mvpOtherCandidateVer [1]

– When any of EstMvdCompBits(mvpOtherCandidateVer) in mvpListX is smaller than currentEstMvdVerBits, mvpCandidate is removed from mvpListLX.

6.3.1.4.9 Derivation process for interleaved motion vector prediction

Inputs to this process are

– the vertical component of motion vector predictor list mvpLXver,

– the vertical component of the motion vector difference mvdLXver.

Output of this process the horizontal component of mvpLXhor.

The location of the top-left luma sample of the prediction block, relative to the top-left luma sample of the picture, is denoted by (x0, y0). The width and height of the prediction block are given by currW and currH, respectively.

Given the predictor mvpLX for the vertical motion vector component, the vertical motion vector component mvpLXver of the current motion vector is reconstructed by setting currMvVer equal to (mvpLXver + mvdLXver). Then, given the reconstructed vertical motion vector component currMvVer, the predictor mvpLXhor for the horizontal motion vector component is derived as follows:

1. Let setOfBlks be the set of neighboring prediction blocks that are contained in the same slice as the current block, precede the current block in coding order, and contain a luma sample at any of the following locations:

   – (x0 − 1, y) with y = 0..currH

   – (x, y0 − 1) with x = −1..currW + 1

2. A list listMv of motion vectors is derived as follows:

   For each block blkX of the set setOfBlks, the following applies with mvX being the motion vector that is associated with blkX:

   The motion vector mvX is scaled as described above and inserted into the list listMv.

3. Let numMv be the number of entries in the list listMv. If numMv is equal to 0, the predictor mvpLXhor for the horizontal motion vector component is set equal to 0; otherwise, mvpLXhor is derived as specified in the following with listMv[k] (k = 0..numMv − 1) representing the k-th entry in the list listMv:

   a. The variable compY is initially set equal to listMv[0][1] and the variable minDelta is set equal to abs(listMv[0][1] − currMvVer), where abs( ) specifies the absolute value of the argument.

   b. For i proceeding over the range of 1 to numMv − 1, inclusive, the following applies:

When abs(listMv[i][1] − currMvVer) is less than minDelta or (abs(listMv[i][1] − currMvVer) is equal to minDelta and listMv[i][1] is less than compY), compY is set equal to listMv[i][1].

c. The list listMvCompX is derived as follows.

For i proceeding over the range of 0 to numMv − 1, inclusive, if listMv[i][1] is equal to compY, the value listMv[i][0] is inserted into the list listMvCompX.

d. Let numCompX be the number of entries in the list listMvCompX and let listMvCompX[k], with k = 0..numCompX − 1, be the entries of the list listMvCompX. Depending on numCompX, the horizontal component mvpLXhor of the motion vector predictor is derived as follows.

– If numCompX is equal to 1, mvpLXhor is set equal to listMvCompX[0].

– Otherwise, if numCompX is equal to 2, mvpLXhor is set equal to (listMvCompX[0] + listMvCompX[1] + 1) >> 1.

– Otherwise (numCompX is greater than 2), the entries in listMvCompX are sorted in increasing order and then mvpLXhor is set equal to listMvCompX[numCompX >> 1].

6.3.1.5 Derivation process chroma motion vectors

This process is only invoked when ChromaArrayType is not equal to 0.

Inputs to this process are a luma motion vector mvLX and a reference index refIdxLX.

Output of this process is a chroma motion vector mvCLX.

A chroma motion vector is derived from the corresponding luma motion vector.

The precision of the chroma motion vector components is 1 ÷ (4 * SubWidthC) horizontally and 1 ÷ (4 * SubHeightC) vertically.

NOTE – For example, when using the 4:2:0 chroma format, since the units of luma motion vectors are one-quarter luma sample units and chroma has half horizontal and vertical resolution compared to luma, the units of chroma motion vectors are one-eighth chroma sample units, i.e., a value of 1 for the chroma motion vector refers to a one-eighth chroma sample displacement. For example, when the luma vector applies to 8x16 luma samples, the corresponding chroma vector in 4:2:0 chroma format applies to 4x8 chroma samples and when the luma vector applies to 4x4 luma samples, the corresponding chroma vector in 4:2:0 chroma format applies to 2x2 chroma samples.

For the derivation of the motion vector mvCLX, the following applies.

mvCLX[0] = mvLX[0]/2

mvCLX[1] = mvLX[1]/2

6.3.2 Decoding process for inter prediction sample

Inputs to this process are

- the prediction unit partition index puPartIdx,
- variables specifyng prediction unit partition width and height for luma and chroma, puPartWidth, puPartHeight, puPartWidthC and puPartHeightC
- luma motion vectors mvL0 and mvL1 and when ChromaArrayType is not equal to 0 chroma motion vectors mvCL0 and mvCL1
- PBIC vector ic
- reference indices refIdxL0 and refIdxL1,
- prediction list utilization flags, predFlagL0 and predFlagL1

Outputs to this process are

- inter prediction samples predPart, which are a (puPartWidth)x(puPartHeight) array $predPart_L$ of prediction luma samples, and when ChromaArrayType is not equal to 0 two (puPartWidthC)x(puPartHeightC) arrays $predPart_{Cb}$, $predPart_{Cr}$ of prediction chroma samples, one for each of the chroma components Cb and Cr.

Let $predPartL0_L$ and $predPartL1_L$ be (puPartWidth)x(puPartHeight) arrays of predicted luma sample values and when ChromaArrayType is not equal to 0 $predPartL0_{Cb}$, $predPartL1_{Cb}$, $predPartL0_{Cr}$, and $predPartL1_{Cr}$ be (puPartWidthC)x(puPartHeightC) arrays of predicted chroma sample values.

When predFlagLX is equal to 1, the following applies.

- The reference picture consisting of an ordered two-dimensional array $refPicLX_L$ of luma samples and when ChromaArrayType is not equal to 0 two ordered two-dimensional arrays $refPicLX_{Cb}$ and $refPicLX_{Cr}$ of chroma samples is derived by invoking the process specified in subclause 6.3.2.1 with refIdxLX and RefPicListX given as input.
- The array $predPartLX_L$ and when ChromaArrayType is not equal to 0 the arrays $predPartLX_{Cb}$ and $predPartLX_{Cr}$ are derived by invoking the process specified in subclause 6.3.2.2 with the current partition specified by puPartIdx, the motion vectors mvLX, mvCLX (if available), and the reference arrays with $refPicLX_L$, $refPicLX_{Cb}$ (if available), and $refPicLX_{Cr}$ (if available) given as input.
- The array $predPartLX_L$ and when ChromaArrayType is not equal to 0 the arrays $predPartLX_{Cb}$ and $predPartLX_{Cr}$ are modified by invoking the process specified in clause 6.3.4 with the current partition specified by puPartIdx, the PBIC vector ic, the prediction list utilization flags predFlagL0 and predFlagL1 given as input.

For C being replaced by L, Cb (if available), or Cr (if available), the array $predPart_C$ of the prediction samples of component C is derived by invoking the process specified in subclause **Error! Reference source not found.** with the current partition specified by puPartIdx, prediction utilization flags predFlagL0 and predFlagL1, the arrays $predPartL0_C$ and $predPartL1_C$ given as input.

6.3.2.1 Reference picture selection process

[Ed.: same as H.264/AVC]

6.3.2.2 Fractional sample interpolation process

Inputs to this process are

- the prediction unit partition index puPartIdx
- the width and height puPartWidth, puPartHeight of this prediction unit partition in luma-sample units
- a luma motion vector mvLX given in one-eighth sample units.
- when ChromaArrayType is not equal to 0, a chroma motion vector mvCLX with a precision of one-(-(4*SubWidthC)-th chroma-sample units horizontally and one-(4*SubHeightC)-th chroma-sample units vertically, and
- the selected reference picture sample arrays $refPicLX_L$, and when ChromaArrayType is not equal to 0, $refPicLX_{Cb}$, and $refPicLX_{Cr}$.

Outputs of this process are

- a puPartWidth*puPartHeight array $predPartLX_L$ of prediction luma sample values
- when ChromaArrayType is not equal to 0, two (puPartWidthC)x(puPartHeightC) arrays $predPartLX_{Cb}$, and $predPartLX_{Cr}$ of prediction chroma sample values

Let (xA_L, yA_L) be the location given in full-sample units of the upper-left luma sample of the current partition given by puPartIdx relative to the upper-left luma sample location of the given two-dimensional array of luma samples.

Let (xIntL, yIntL) be a luma location given in full-sample units and (xFracL, yFracL) be an offset given in one-eighth sample units. These variables are used only inside this subclause for specifying general fractional-sample locations inside the reference sample arrays $refPicLX_L$, $refPicLX_{Cb}$, and $refPicLX_{Cr}$.

For each luma sample location (0<=xL < puPartWidth, 0<=yL < puPartHeight) inside the prediction luma sample array $predPartLX_L$, the corresponding predicted luma sample value $predPartLX_L[x_L, y_L]$ is derived as specified by the following ordered steps.

- The variables $xInt_L$, $yInt_L$, $xFrac_L$, and $yFrac_L$ are derived by

$$xInt_L = xA_L + (mvLX[0] >> 3) + x_L$$

$yInt_L = yA_L + (mvLX[1] >> 3) + y_L$

$xFrac_L = mvLX[0] \& 7$

$yFrac_L = mvLX[1] \& 7$

– The luma sample value $predPartLX_L[x_L, y_L]$ is derived by invoking the process specified in subclause 6.3.2.2.1 with ($xInt_L$, $yInt_L$), ($xFrac_L$, $yFrac_L$) and $refPicLX_L$ given as input.

When ChromaArrayType is not equal to 0, the following applies.

Let ($xInt_CC$, $yInt_CC$) be a chroma location given in full-sample units and ($xFrac_CC$, $yFrac_CC$) be an offset given in one-(-(4*SubWidthC)-th chroma-sample units horizontally and one-(4*SubHeightC)-th chroma-sample units vertically. These variables are used only inside this subclause for specifying general fractional-sample locations inside the reference sample arrays $refPicLX_{Cb}$ and $refPicLX_{Cr}$.

For each chroma sample location ($0 <= x_C < puPartWidthC$, $0 <= y_C < puPartHeightC$) inside the prediction chroma sample arrays $predPartLX_{Cb}$ and $predPartLX_{Cr}$, the corresponding prediction chroma sample values $predPartLX_{Cb}[x_C, y_C]$ and $predPartLX_{Cr}[x_C, y_C]$ are derived as specified by the following ordered steps.

1. Depending on ChromaArrayType, the variables $xInt_C$, $yInt_C$, $xFrac_C$, and $yFrac_C$ are derived as follows

   – If ChromaArrayType is equal to 1,

   $xInt_C = (xA_L / SubWidthC) + (mvCLX[0] >> 3) + x_C$

   $yInt_C = (yA_L / SubHeightC) + (mvCLX[1] >> 3) + y_C$

   $xFrac_C = mvCLX[0] \& 7$

   $yFrac_C = mvCLX[1] \& 7$

   – Otherwise, if ChromaArrayType is equal to 2,

   $xInt_C = (xA_L / SubWidthC) + (mvCLX[0] >> 3) + x_C$

   $yInt_C = (yA_L / SubHeightC) + (mvCLX[1] >> 2) + y_C$

   $xFrac_C = mvCLX[0] \& 7$

   $yFrac_C = (mvCLX[1] \& 3)<<1$

   – Otherwise, if ChromaArrayType is equal to 3,

   $xInt_C = (xA_L / SubWidthC) + (mvCLX[0] >> 2) + x_C$

   $yInt_C = (yA_L / SubHeightC) + (mvCLX[1] >> 2) + y_C$

   $xFrac_C = (mvCLX[0] \& 3)<<1$

   $yFrac_C =(mvCLX[1] \& 3)<<1$

2. Depending on ChromaArrayType, the following applies.

   – If ChromaArrayType is not equal to 3, the following applies

   - The prediction sample value $predPartLX_{Cb}[x_C, y_C]$ is derived by invoking the process specified in subclause 6.3.2.2.2 with ($xInt_C$, $yInt_C$), ($xFrac_C$, $yFrac_C$) and $refPicLX_{Cb}$ given as input.

   - The prediction sample value $predPartLX_{Cr}[x_C, y_C]$ is derived by invoking the process specified in subclause 6.3.2.2.2 with ($xInt_C$, $yInt_C$), ($xFrac_C$, $yFrac_C$) and $refPicLX_{Cr}$ given as input

   – Otherwise (ChromaArrayType is equal to 3), the following applies..

   - The prediction sample value $predPartLX_{Cb}[x_C, y_C]$ is derived by invoking the process specified in subclause 6.3.2.2.1 with ($xInt_C$, $yInt_C$), ($xFrac_C$, $yFrac_C$) and $refPicLX_{Cb}$ given as input.

   - The prediction sample value $predPartLX_{Cr}[x_C, y_C]$ is derived by invoking the process specified in subclause 6.3.2.2.1 with ($xInt_C$, $yInt_C$), ($xFrac_C$, $yFrac_C$) and $refPicLX_{Cr}$ given as input.

6.3.2.2.1 Luma sample interpolation process

Inputs to this process are

– a luma location in full-sample units ($xInt_L$, $yInt_L$),

– a luma location offset in fractional-sample units ($xFrac_L$, $yFracy_L$), and

– the luma sample array of the selected reference picture $refPicLX_L$

Outputs of this process is a predicted luma sample value $predPartLX_L[\ x_L, y_L\ ]$.

6.3.2.2.1.1 Luma sample interpolation process for mc_interpolation_idc equal to 0 and 1

Table 6-4 and Table 6-5 specify the 12-tap filter coefficients and 6-tap filter coefficients for each quarter sample position, respectively.

Table 6-4 12-tap filter coefficients for each quarter sample position

Position (xFracL or yFracL)	filterCoeff[Position][-5...6]
1	-1, 4, -7, 13, -27, 249, 36, -16, 9, -6, 3, -1
2	-1, 5, -12, 20,-40, 229, 76, -32, 16, -8, 4,-1
3	-3, 9, -15, 27,-51, 200,119,-44, 24, -14, 7, -3
4	-1, 8, -16, 24,-48, 161, 161, -48, 24, -16, 8,-1
5	-1,6,-12, 20, -40,119, 195, -44,22,-14, 6, -1
6	-1, 4, -8, 16, -32, 76, 229, -40, 20, -12, 5,-1
7	-1, 3, -6, 9, -16, 36,249, -27, 13,-7, 4, -1

Table 6-5 6-tap filter coefficients for each quarter sample position

Position (xFracL or yFracL)	filterCoeff[Position][-2...3]
1	5, -22, 247, 35, -13, 4
2	8, -32, 224, 72, -24, 8
3	11, -42, 196, 118, -36, 10
4	8, -40, 160, 160, -40, 8
5	10, -36, 196, 118, -42, 11
6	8, -24, 72, 224, -32, 8
7	4, -13, 35,247, -22, 5

If mc_interpolation_idc is equal to 0, the 12-tap filter specified in Table 6-4 shall be used and the variable M is set equal to 6, otherwise if mc_interpolation_idc is equal to 1, the 6-tap filter specified in Table 6-5 shall be used and the variable M is set equal to 3. [Ed.: other values of mc_interpolation_idc to be added]

In the type-1 filtering process in horizontal direction, the predicted value x with quarter sample position ($xFrac_L$, 0) is derived as follows where x_l are full samples aligned with x in horizontal direction.

$$x = \left(\sum_{l=-M+1}^{M} filterCoeff\,[xFrac_L][l] * x_l + 128 \right) >> 8$$

In the type-1 filtering process in vertical direction, the predicted value x with quarter sample position (0, $yFracy_L$) is derived as follows where x_l are full samples aligned with x in vertical direction.

$$x = \left(\sum_{l=-M+1}^{M} filterCoeff\,[yFrac_L][l] * x_l + 128 \right) >> 8$$

In the type-2 filtering process in horizontal direction, the predicted value x with quarter sample position ($xFrac_L$, 0) is derived as follows where x_l are full samples aligned with x in horizontal direction.

$$x = \sum_{l=-M+1}^{M} filterCoeff\,[xFrac_L][l] * x_l$$

In the type-2 filtering process in vertical direction, the predicted value x with quarter sample position ($xFrac_L$, $yFrac_L$) is derived as follows where x_l are input quarter samples with ($xFrac_L$, 0) which are aligned with x in vertical direction.

$$x = \left(\sum_{l=-M+1}^{M} filterCoeff[yFrac_L][l] * x_l + 32768 \right) >> 16$$

Depending on ($xFrac_L$, $yFracy_L$), the following applies.

– If both $xFrac_L$ and $yFracy_L$ are 0, no filtering process is performed.

– Otherwise, if $xFrac_L$ is not 0 and $yFracy_L$ is 0, type-1 filtering process in horizontal direction is performed with full samples aligned with in horizontal direction as inputs.

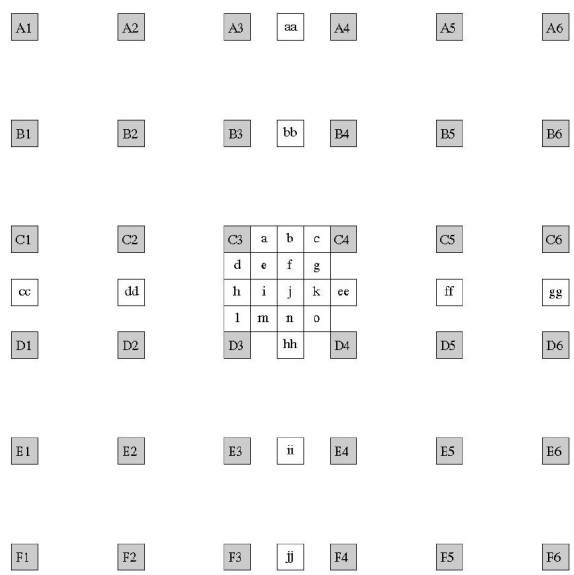
– Otherwise, if $xFrac_L$ is 0 and $yFracy_L$ is not 0, type-1 filtering process in vertical filtering is performed with full samples aligned with in vertical directions as inputs.

– Otherwise, type-2 filtering process in vertical direction is performed using quarter samples with ($xFracy_L$, 0) which were derived by type-2 filtering process in horizontal direction.

– Filtered output x shall be assigned to the prediction unit partition as

$$predPartLX_L[\, x_L, y_L \,] = Clip1_Y(\, x \,)$$

6.3.2.2.1.2 Luma sample interpolation process for mc_interpolation_idc equal to 2



Notation of image samples[Ed.: notations need to be unified between different interpolation filters]

If mc_interpolation_idc is equal to 2, the predicted value x with quarter sample position ($yFrac_L$, $xFrac_L$) is derived as follows:

($yFrac_L$,$xFrac_L$)	predicted value, x
(0,2)	(3*C1 – 15*C2 + 111*C3 + 37*C4 – 10*C5 + 2*C6 + 64)>>7
(0,4)	(3*C1 – 17*C2 + 78*C3 + 78*C4 – 17*C5 + 3*C6 + 64)>>7
(0,6)	(2*C1 – 10*C2 + 37*C3 + 111*C4 – 15*C5 + 3*C6 + 64)>>7
(2,0)	(3*A3 – 15*B3 + 111*C3 + 37*D3 – 10*E3 + 2*F3 + 64)>>7
(2,2)	(3*A1 – 15*B2 + 111*C3 + 37*D4 – 10*E5 + 2*F6 + 64)>>7
(2,4)	(3*(A1+A6) – 15*(B2+B5) + 111*(C3+C4) + 37*(D4+D3) – 10*(E5+E2) + 2*(F6+F1) + 128)>>8

(2,6)	(3*A6 – 15*B5 + 111*C4 + 37*D3 – 10*E2 + 2*F1 + 64)>>7
(4,0)	(3*A3 – 17*B3 + 78*C3 + 78*D3 – 17*E3 + 3* F3 + 64)>>7
(4,2)	(3*(A1+F1) – 15*(B2+E2) + 111*(C3+D3) + 37*(D4+C4) – 10*(E5+B5) + 2*(F6+A6) + 128)>>8
(4,4)	(5*(B3+B4+C2+C5+D2+D5+E3+E4) + 22*(C3+C4+D3+D4) + 64)>>7
(4,6)	(2*(A1+F1) – 10*(B2+E2) + 37*(C3+D3) + 111*(D4+C4) – 15*(E5+B5) + 3*(F6+A6) + 128)>>8
(6,0)	(2*A3 – 10*B3 + 37*C3 + 111*D3 – 15*E3 + 3* F3 + 64)>>7
(6,2)	(2*A6 – 10*B5 + 37*C4 + 111*D3 – 15*E2 + 3*F1 + 64)>>7
(6,4)	(2*(A1+A6) – 10*(B2+B5) + 37*(C3+C4) + 111*(D4+D3) – 15*(E5+E2) + 3*(F6+F1) + 128)>>8
(6,6)	(2*A1 – 10*B2 + 37*C3 + 111*D4 – 15*E5 + 3*F6 + 64)>>7

– Filtered output x shall be assigned to the prediction unit partition as

$$predPartLX_L[\ x_L, y_L\ ] = Clip1_Y(\ x\ )$$

For each one-eighth sample position, refer to 5.2.2.2.1.1.

6.3.2.2.1.3 Luma sample interpolation process for mc_interpolation_idc equal to 3 and 4

Table 5-5, Table 5-6 and Table 5-7 specify 6-tap filter coefficients, 8-tap filter coefficients and 12-tap filter coefficients for each quarter sample position, respectively. For each one-eighth sample position, refer to 5.2.2.2.1.1.

Table 6-5 6-tap filter coefficients for each quarter sample position

filtIdx	Position (xFracL or yFracL)	filterCoeff[Position][-2...3]
0	2	8, -32, 224, 72, -24, 8
	4	8, -40, 160, 160, -40, 8
	6	8, -24, 72, 224, -32, 8
1	2	6, -30, 222, 74, -20, 4
	4	6, -34, 156, 156, -34, 6
	6	4, -20, 74, 222, -30, 6
2	2	-6, 8, 182, 86, -12, -2
	4	-8, -8, 144, 144, -8, -8
	6	-2, -12, 86, 182, 8, -6
3	2	12, -36, 226, 70, -24, 8
	4	14, -46, 160, 160, -46, 14
	6	8, -24, 70, 226, -36, 12

Table 6-6 8-tap filter coefficients for each quarter sample position

filtIdx	Position (xFracL or yFracL)	filterCoeff[Position][-3...4]
4	2	-3, 12, -37, 229, 71, -21, 6, -1
	4	-3, 12, -39, 158, 158, -39, 12, -3
	6	-1, 6, -21, 71, 229, -37, 12, -3
5	2	-4, 16, -32, 228, 68, -28, 12, -4
	4	-1, 9, -40, 160, 160, -40, 9, -1
	6	-4, 12, -28, 68, 228, -32, 16, -4

Table 6-7 12-tap filter coefficients for each quarter sample position

filtIdx	Position (xFracL or yFracL)	filterCoeff[Position][-5...6]
6	2	-1, 5, -12, 20, -40, 229, 76, -32, 16, -8, 4, -1
	4	-1, 8, -16, 24, -48, 161, 161, -48, 24, -16, 8, -1
	6	-1, 4, -8, 16, -32, 76, 229, -40, 20, -12, 5, -1

If mc_interpolation_idc is equal to 3, 12-tap filter specified in Table 5-7 and 8-tap filter specified in Table 5-6 shall be used, otherwise if mc_interpolation_idc is equal to 4, the 6-tap filter specified in Table 5-5 shall be used.

filterCoeff points to the filtIdx according to sifo_filters[i], where i = ($xFrac_L$+($yFracy_L$<<2))>>1.

If mc_interpolation_idc is equal to 4, then filtIdx is derived as follows:

sifo_filter[i]	i=1,2,3,4,8,12	i=5,6,7,9,10,11,13,14,15
	filtIdx	(filtIdxV, filtIdxH)
0	0	0,0
1	1	1,1
2	2	2,2
3	3	3,3
4	-	0,1
5	-	0,2
6	-	0,3
7	-	1,0
8	-	1,2
9	-	1,3
10	-	2,0
11	-	2,1
12	-	2,3
13	-	3,0
14	-	3,1
15	-	3,2

If mc_interpolation_idc is equal to 3, then filtIdx is derived as follows:

sifo_filter[i]	i=1,2,3,4,8,12	i=5,6,7,9,10,11,13,14,15
	filtIdx	(filtIdxV, filtIdxH)
0	6	5,5
1	4	4,4
2	-	5,4
3	-	4,5

If mc_interpolation_idc is equal to 4, the variable M is set to 3. If mc_interpolation_idc is equal to 3 and if filtIdx is equal to 0, the variable M is set to 6, otherwise if filtIdx is greater than 0, the variable M is set to 4.

In the type-1 filtering process in horizontal direction, the predicted value x with quarter sample position ($xFrac_L$, 0) is derived as follows where x_l are full samples aligned with x in horizontal direction.

$$x = \left(\sum_{l=-M+1}^{M} \text{filterCoeff}[\text{filtIdx}][\text{xFrac}_L][l] * x_l + 128 \right) >> 8$$

In the type-1 filtering process in vertical direction, the predicted value x with quarter sample position (0, $yFracy_L$) is derived as follows where x_l are full samples aligned with x in vertical direction.

$$x = \left(\sum_{l=-M+1}^{M} \text{filterCoeff}[\text{filtIdx}][\text{yFrac}_L][l] * x_l + 128 \right) >> 8$$

In the type-2 filtering process in horizontal direction, the predicted value x with quarter sample position ($xFrac_L$, 0) is derived as follows where x_l are full samples aligned with x in horizontal direction.

$$x = \sum_{l=-M+1}^{M} \text{filterCoeff}[\text{filtIdxH}][\text{xFrac}_L][l] * x_l$$

In the type-2 filtering process in vertical direction, the predicted value x with quarter sample position ($xFrac_L$, $yFrac_L$) is derived as follows where x_l are input quarter samples with ($xFrac_L$, 0) which are aligned with x in vertical direction.

$$x = \left(\sum_{l=-M+1}^{M} filterCoeff[filtIdxV][yFrac_L][l] * x_l + 32768 \right) >> 16$$

Depending on ($xFrac_L$, $yFracy_L$), the following applies.

– If both $xFrac_L$ and $yFracy_L$ are 0, no filtering process is performed.

– Otherwise, if $xFrac_L$ is not 0 and $yFracy_L$ is 0, type-1 filtering process in horizontal direction is performed with full samples aligned with in horizontal direction as inputs.

– Otherwise, if $xFrac_L$ is 0 and $yFracy_L$ is not 0, type-1 filtering process in vertical filtering is performed with full samples aligned with in vertical directions as inputs.

– Otherwise, type-2 filtering process in vertical direction is performed using quarter samples with ($xFracy_L$, 0) which were derived by type-2 filtering process in horizontal direction.

– Filtered output x shall be assigned to the variable x0 as

$$x0 = Clip1_Y(x)$$

Depending on zero_offset_flag, the following applies.

– If zero_offset_flag is 0, the variable sifo_offset is set to 0.

– Otherwise, (if zero_offset_flag is not 0), and if predFlagLX is equal to 1, and

- if refIdxLX is equal to 0, the variable sifo_offset is set to sifo_offset_lX[i], where i = ($xFrac_L$+($yFracy_L$<<2))>>1.

- if refIdxLX is greater than 0, the variable sifo_offset is set to img_offset_lX[refIdxLX]

– Final output x0 shall be assigned to the prediction unit partition as

$$predPartLX_L[x_L, y_L] = Clip1_Y(x0 + sifo_offset).$$

6.3.2.2.1.4 Luma sample interpolation process for mc_interpolation_idc equal to 5 and 6

When the mc_interpolation_idc is equal to 5 or 6, the interpolation process consists of an IIR filtering of the reference samples followed by an FIR filtering.

Define PF(z) as a series of sub-stages:

i. F1 in Horizontal direction,
ii. F2 in Horizontal direction,
iii. F1 in Vertical direction,
iv. F2 in Vertical direction,

The sub-stages F1 and F2 are defined as,

Notation	Operation
F1	input[n] + xMult16x16(output[n-1], z), n=0,1…M-1
F2	xMult16x16(output[n+1] - input[n], z), n=M-1,..1,0
xMult16x16	(i16A * i16B + (1<<14)) >> 15

where, M is the total number of samples in the reference picture in the considered direction and z is the pole value. specified below.

When the mc_interpolation_idc is equal to 5, the IIR filtering is PF(z) with z=-12854.

When the mc_interpolation_idc is equal to 6, the IIR filtering is PF(z1) followed by PF(z2) with z1= -19612 and z2=-3067.

Next, the FIR filtering generates the interpolated value required according to the sub-sample position (xFracL, yFracL) pointed to by the motion vector.

Table 6-8 and 6-9 specify 4-tap and 6-tap filter coefficients, for each one-eighth sample position, respectively.

Table 6-8 Coefficients for 4-tap FIR filter for each one-eighth sample position for mc_interpolation_idc=5

Position (xFracL or yFracL)	filterCoeff[Position][-1...2]
0	8192, 24097, 8192, 0
1	5784, 24046, 10457,194
2	3930, 22967, 13117,467
3	2550, 21098, 15935,898
4	1566, 18674, 18674,1566
5	898, 15935, 21098, 2550
6	467, 13117, 22967,3930
7	194, 10457, 24046,5784

Table 6-9 Coefficients for 6-tap FIR filter for each one-eighth sample position for mc_interpolation_idc=6

Position (xFracL or yFracL)	filterCoeff[Position][-2...3]
0	601, 7837, 15892, 7837, 601, 0
1	351, 6418, 15743, 9292, 969, -5
2	189, 5105, 15262, 10746, 1471, -5
3	90, 3940, 14467, 12140, 2125, 6
4	33, 2946, 13405, 13405, 2946, 33
5	6, 2125, 12140, 14467, 3940, 90
6	-5, 1471, 10746, 15262, 5105, 189
7	-5, 969, 9292, 15743, 6418, 351

6.3.2.2.2 Chroma sample interpolation process

[Ed.: same as H.264/AVC]

Depending on mc_interpolation_idc, the following applies:

– If mc_interpolation_idc is equal to 5 or 6, the chroma interpolation process consists of the same steps as described in section 6.3.2.2.1.4 but operating on the chroma reference samples.

– Otherwise, the chroma interpoltaion process as specified in H.264/AVC is applied.

6.3.3 Derivation process for PBIC vector

Inputs to this process are

- the prediction unit partition index puPartIdx
- the prediction list utilization flags of the current prediction unit partition predFlagL0 and predFlagL1
- the reference indices of the current prediction unit partition refIdxL0 and refIdxL1

Output of this process is the PBIC vector ic.

For the derivation of the PBIC vector ic, the following applies:

- If PredMode is equal to MODE_SKIP or MODE_DIRECT, the derivation process for PBIC prediction in subclause 6.3.3.1 is invoked with puPartIdx, refIdxL0, refIdxL1, predFlagL0 and predFlagL1 as the inputs and icp as the output. The output icp is directly assigned to ic, since the predictor is equal to the actual PBIC vector.
- Otherwise, if merge_flag is equal to 1, the derivation process for PBIC vector when merge_flag is equal to 1 as specified in subclause 6.3.3.2 is invoked with puPartIdx as input and the PBIC vector ic as the output.

- Otherwise, the following applies:
    1. The derivation process for PBIC prediction in subclause 6.3.3.1 is invoked with puPartIdx, refIdxL0, refIdxL1, predFlagL0 and predFlagL1 as the inputs and icp as the output.
    2. The vector ic is derived as follows:
        i. ic[0] = icp[0] + icd[puPartIdx][0]
        ii. ic[1] = icp[1] + icd[puPartIdx][1]
        iii. ic[2] = icp[2] + icd[puPartIdx][2]

6.3.3.1 Derivation process for PBIC prediction

Inputs to this process are

- the prediction unit partition index puPartIdx
- the prediction list utilization flags of the current prediction unit partition predFlagL0 and predFlagL1
- the reference indices of the current prediction unit partition refIdxL0 and refIdxL1

Output of this process is the prediction icp of the PBIC vector ic.

The PBIC vector predictor icp is derived in the following ordered steps:

1. The derivation process for PBIC vector predictor candidates from neighboring prediction unit partitions in subclause 6.3.3.1.1 is invoked with puPartIdx, refIdxL0, refIdxL1, predFlagL0 and predFlagL1 as the inputs and the availability flags availableFlagN and the PBIC vectors icN with N being replaced by A, B, or C as the output.
2. A PBIC vector icDefault is constructed such that all of its elements are set to zero.
3. The PBIC vector predictor list, icpList, is constructed of which elements are given as specified order:
    - icDefault
    - icA
    - icB
    - icC
4. If both icA and icB are available and one of the following conditions is true, icA is switched with icB in the order of icpList.
    - If puPartIdx is equal to 0 and PartMode is one of the values among PART_2NxN, PART_2NxnU and PART_2NxnD.
    - If puPartIdx is equal to 1 and PartMode is one of the values among PART_Nx2N, PART_nLx2N and PART_nRx2N.
5. If several PBIC vectors have same value, the PBIC vectors are removed from the list except the PBIC vector which has the smallest order in the icpList
6. If the number of elements NumICPCand(puPartIdx) within the icpList is equal to 1, icp_idx[puPartIdx] is set to 0
7. The PBIC vector of icpList [icp_idx[puPartIdx]] is assigned to icp

6.3.3.1.1 Derivation process for PBIC vector predictor candidates

Inputs to this process are

- the prediction unit partition index puPartIdx
- the prediction list utilization flags of the current prediction unit partition predFlagL0 and predFlagL1
- the reference indices of the current prediction unit partition refIdxL0 and refIdxL1

Outputs of this process are (with N being replaced by A, B, or C)

- the PBIC vectors icN of the neighbouring partitions
- the availability flags availableFlagN of the neighbouring partitions

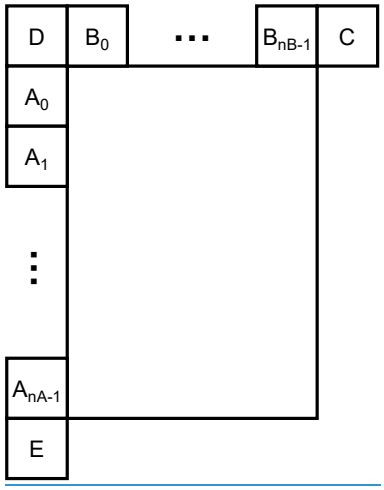


Fig. 6-1 Spatial motion vector neighbours

The PBIC vector icA and the availability flag availableFlagA are derived in the following ordered steps:

1. Let a set of nA sample location (xA_k, yA_k), with k = 0..nA-1, express relative to the upper left corner of the prediction unit partition. The set of sample locations (xA_k, yA_k) represent the sample locations immediately to the left of the left partition boundary with the offset SuSize vertically. nA is set equal to puPartHeight / SuSize.
2. Let the availability flag availableFlagA be initially set equal to 0 and all the components of icA be set equal to 0.
3. For (xA_k, yA_k) from (xA_0, yA_0) to (xA_{nN-1}, yA_{nN-1}) where $x_{Ak+1} = x_{Ak}$ and $y_{Ak+1} = y_{Ak}$ + SuSize, the following applies until availableFlagA is equal to 1:
   - The derivation process for the neighbouring locations specified in subclause 4.3.5 is invoked with (xA_k, yA_k) as input and the output is assigned to lcuAddrA and (xW, yW)
   - If the lcuAddrA is available,
     - The prediction unit index and the partition index in the largest coding unit lcuAddrA covering the luma location (xW, yW) shall be assigned to puIdxA and puPartIdxA.
     - If the prediction unit partition puPartIdxA is available, PredMode of puIdxA is not MODE_INTRA, predFlagL0 of puIdxA is equal to predFlagL0 of the current partition puPartIdx, reference index refIdxL0 of puIdxA is equal to reference index refIdxL0 of the current partition puPartIdx, predFlagL1 of puIdxA is equal to predFlagL1 of the current partition puPartIdx, reference index refIdxL1 of puIdxA is equal to reference index refIdxL1 of the current partition puPartIdx,
       - availableFlagA is set equal to 1 and the PBIC vector icA is set equal to the PBIC vector ic which has been assigned to the prediction unit partition puPartIdxA

The PBIC vector icB and the availability flag availableFlagB are derived in the following ordered steps:

4. Let a set of nB sample location (xB_k, yB_k), with k = 0..nB-1, express relative to the upper left corner of the prediction unit partition. The set of sample locations (xB_k, yB_k) represent the sample locations immediately to the above of the above partition boundary with the offset SuSize horizontally. nB is set equal to puPartWidth / SuSize.
5. Let the availability flag availableFlagB be initially set equal to 0 and all the components of icB be set equal to 0.
6. For (xB_k, yB_k) from (xB_0, yB_0) to (xB_{nN-1}, yB_{nN-1}) where $x_{Bk+1} = x_{Bk}$ + SuSize and $y_{Bk+1} = y_{Bk}$, the following applies until availableFlagLXB is equal to 1:

- The derivation process for the neighbouring locations specified in subclause 4.3.5 is invoked with (xB_k, yB_k) as input and the output is assigned to lcuAddrB and (xW, yW)
- If the lcuAddrB is available,
  - The prediction unit index and the partition index in the largest coding unit lcuAddrB covering the luma location (xW, yW) shall be assigned to puIdxB and puPartIdxB.
  - If the prediction unit partition puPartIdxB is available, PredMode of puIdxB is not MODE_INTRA, predFlagL0 of puIdxB is equal to predFlagL0 of the current partition puPartIdx, reference index refIdxL0 of puIdxB is equal to reference index refIdxL0 of the current partition puPartIdx, predFlagL1 of puIdxB is equal to predFlagL1 of the current partition puPartIdx, reference index refIdxL1 of puIdxB is equal to reference index refIdxL1 of the current partition puPartIdx,
    - availableFlagB is set equal to 1 and the PBIC vector icB is set equal to the PBIC vector ic which has been assigned to the prediction unit partition puPartIdxB

The PBIC vector icC and the availability flag availableFlagC are derived in the following ordered steps:

6. The derivation process for neighbouring partitions in subclause 4.3.4.4 is invoked with lcuAddr, puIdx and puPartIdx as input and the output is is assigned to lcuAddrN, puIdxN and puPartIdxN with N being replaced by C, D or E.
7. Let the availability flag availableFlagC be initially set equal to 0 and all the components of icC be set equal to 0.
8. For the derivation of the availability flag availableFlagC and the PBIC vector icC, the following applies:
   - If the prediction unit partition puPartIdxC is available, PredMode of puIdxC is not MODE_INTRA, predFlagL0 of puIdxC is equal to predFlagL0 of the current partition puPartIdx, reference index refIdxL0 of puIdxC is equal to reference index refIdxL0 of the current partition puPartIdx, predFlagL1 of puIdxC is equal to predFlagL1 of the current partition puPartIdx, reference index refIdxL1 of puIdxC is equal to reference index refIdxL1 of the current partition puPartIdx,
     - availableFlagC is set equal to 1 and the PBIC vector icC is set equal to the PBIC vector ic which has been assigned to the prediction unit partition puPartIdxC
   - Otherwise, if the prediction unit partition puPartIdxE is available, PredMode of puIdxE is not MODE_INTRA, predFlagL0 of puIdxE is equal to predFlagL0 of the current partition puPartIdx, reference index refIdxL0 of puIdxE is equal to reference index refIdxL0 of the current partition puPartIdx, predFlagL1 of puIdxE is equal to predFlagL1 of the current partition puPartIdx, reference index refIdxL1 of puIdxE is equal to reference index refIdxL1 of the current partition puPartIdx,
     - availableFlagC is set equal to 1 and the PBIC vector icC is set equal to the PBIC vector ic which has been assigned to the prediction unit partition puPartIdxE
   - Otherwise, if the prediction unit partition puPartIdxD is available, PredMode of puIdxD is not MODE_INTRA, predFlagL0 of puIdxD is equal to predFlagL0 of the current partition puPartIdx, reference index refIdxL0 of puIdxD is equal to reference index refIdxL0 of the current partition puPartIdx, predFlagL1 of puIdxD is equal to predFlagL1 of the current partition puPartIdx, reference index refIdxL1 of puIdxD is equal to reference index refIdxL1 of the current partition puPartIdx,
     - availableFlagC is set equal to 1 and the PBIC vector icC is set equal to the PBIC vector ic which has been assigned to the prediction unit partition puPartIdxD

6.3.3.2 Derivation process for PBIC vector when merge_flag is equal to 1

This process is only invoked if merge_flag is equal to 1 for the current partition.

Input to this process is the prediction unit partition index puPartIdx.

Output of this process is the PBIC vector ic.

The PBIC vector ic is derived as specified by the following ordered steps:

1. The derivation process for neighbouring partitions in subclause 4.3.4.4 is invoked with lcuAddr, puIdx and puPartIdx as input and the output is is assigned to lcuAddrN, puIdxN and puPartIdxN with N being replaced by A and B.

2. Depending on the partition lcuAddrN/puIdxN/puPartIdxN (with N being A and B), the following applies.

   – If the partition lcuAddrN/puIdxN/puPartIdxN is not available, predFlagL0N and predFlagL1N are set equal to 0.

   – Otherwise, predFlagL0N, predFlagL1N and icN are set equal to the variables predFlagL0, predFlagL1 and ic, respectively, of the partition lcuAddrN/puIdxN/puPartIdxN.

3. The variable mergeLeft is derived as follows:

   – If (predFlagL0B is equal to 0 and predFlagL1B is equal to 0) or merge_left_flag is equal to 1, mergeLeft is set equal to 1.

   – Otherwise, mergeLeft is set equal to 0.

4. Depending on mergeLeft, the following applies:

   – If mergeLeft is equal to 1, icB is assigned to ic.

   – Otherwise, icA is assigned to ic.

6.3.4 Application of PBIC

Inputs to this process are

– the prediction unit partition index puPartIdx

– a PBIC vector ic

– prediction list utilization flags, predFlagL0 and predFlagL1

– a puPartWidth*puPartHeight array $predPartLX_L$ of prediction luma sample values

– when ChromaArrayType is not equal to 0, two (puPartWidthC)x(puPartHeightC) arrays $predPartLX_{Cb}$, and $predPartLX_{Cr}$ of prediction chroma sample values

Outputs of this process are

– modified array $predPartLX_L$ of prediction luma sample values

– when ChromaArrayType is not equal to 0, modified arrays $predPartLX_{Cb}$ and $predPartLX_{Cr}$ of prediction chroma sample values

The application of PBIC is done as specified by the following ordered steps:

1. IC_SCALE_PREC is set to 6

2. The icScaleLX and icOffsetLX are derived as follows:

   – If both predFlagL0 and predFlagL1 are equal to 1, then the following applies:

      o icScaleLX = ((1<< IC_SCALE_PREC) + ic[0]) + (ic[1] << 1), if X = 0

      o icScaleLX = ((1<< IC_SCALE_PREC) + ic[0]) – (ic[1] << 1), if X = 1

      o icOffsetLX = ic[2]

   – Otherwise, the following applies:

      o icScaleLX = ((1<< IC_SCALE_PREC) + ic[0])

      o icOffsetLX = ic[2]

~~1.~~3. For each luma sample location (0 <= xL < puPartWidth, 0 <= yL < puPartHeight) inside the prediction luma sample array $predPartLX_L$, the corresponding predicted luma sample value $predPartLX_L[x_L, y_L]$ is modified as specified by the following ordered steps:

   a. $predPartLX_L[x_L, y_L]$ = (icScaleLX * $predPartLX_L[x_L, y_L]$ + (1 << (IC_SCALE_PREC – 1))) >> IC_SCALE_PREC

b. predPartLX$_L$[x$_L$, y$_L$] = predPartLX$_L$[x$_L$, y$_L$] + icOffsetLX

c. predPartLX$_L$[x$_L$, y$_L$] = Clip1$_Y$(predPartLX$_L$[x$_L$, y$_L$])

4. When ChromaArrayType is not equal to 0, the following applies:

– For each chroma sample location (0 <= x$_C$ < puPartWidthC, 0 <= y$_C$ < puPartHeightC) inside the prediction chroma sample array predPartLX$_N$ (for both N being Cb and Cr), the corresponding prediction chroma sample value predPartLX$_N$[x$_C$, y$_C$] is modified as specified by the following ordered steps:

a. predPartLX$_N$[x$_C$, y$_C$] = predPartLX$_N$[x$_C$, y$_C$] – (1 << (BitDepth$_C$ – 1))

b. predPartLX$_N$[x$_C$, y$_C$] = (icScaleLX * predPartLX$_N$[x$_C$, y$_C$] + (1 << (IC_SCALE_PREC – 1))) >> IC_SCALE_PREC

c. predPartLX$_N$[x$_C$, y$_C$] = predPartLX$_N$[x$_C$, y$_C$] + (1 << (BitDepth$_C$ – 1))

d. predPartLX$_N$[x$_C$, y$_C$] = Clip1$_C$(predPartLX$_N$[x$_C$, y$_C$])

6.4 Transform coefficient decoding process and picture construction process

Inputs to this process are LumaLevel (if available), ChromaLevel (if available), and available inter or intra prediction sample arrays for the current transform unit for the applicable components pred$_L$, pred$_{Cb}$, or pred$_{Cr}$.

Outputs of this process are the constructed sample arrays prior to the deblocking filter process for the applicable components S'$_L$, S'$_{Cb}$, or S'$_{Cr}$.

This subclause specifies transform coefficient decoding and picture construction prior to the deblocking filter process.

When the prediction unit which current transform unit belongs to is coded as MODE_SKIP, all values of LumaLevel and ChromaLevel are set equal to 0 for the current transform unit.

When the prediction unit which current transform unit belongs to is coded as MODE_INTRA and the value of planar_flag equals to 1 for the corresponding prediction unit, all values of LumaLevel and ChromaLevel are set equal to 0 for the current transform unit.

6.4.1 Specification of transform decoding process for luma transform unit

The variable LumaLevel contains the levels for the luma transform coefficients for the luma block with index tuIdx.

For a luma block indexed by tuIdx, the following ordered steps are specified:

1. The inverse scanning process for the luma transform coefficients as described specified in subclause 6.4.3 is invoked with LumaLevel as the input and the two-dimensional array c as the output.
2. The scaling and transformation process for the residual block as specified in subclause 6.4.5 is invoked with c as the input and r as the output.
3. The position of the upper-left luma sample of the current largest coding unit is derived by invoking the inverse largest coding unit scanning process in subclause 4.2.1 with address lcuAddr as input and the output being assigned to (xL, yL).
4. The position of the upper-left luma sample of the current prediction unit puIdx inside the largest coding unit is derived by invoking the inverse prediction unit scanning process in subclause 4.2.4.1 with puIdx as input and the output being assigned to (xP, yP).
5. The position of the upper-left sample of the transform unit with index tuIdx inside the prediction unit is derived by invoking the inverse transform unit scanning process in subclause 4.2.4.3 with tuIdx as the input and the output being assigned to (xO, yO).
6. The NxN array u with elements u$_{ij}$ for i, j = 0..N-1 is derived in raster order as

   – Let xS be xL + xP + xT and yS be yL + yP + yT.

   – If PredMode is equal to MODE_INTRA and combined_intra_pred_flag is equal to 1,

$openPred_{0,0}$=(3*S'$_L$[xS–1, yS] + 3*S'$_L$[xS , yS–1] + 2*S'$_L$[xS–1, yS–1] + 4) >> 3

if i>0, $openPred_{i,0}$ = (3*S'$_L$[xS–1, yS+i] + 3*$u_{i-1,0}$ + 2*S'$_L$[xS–1, yS+i–1] + 4) >> 3

if j>0, $openPred_{0,j}$ = (3*$u_{0,j-1}$ + 3*S'$_L$[xS+j , yS–1] + 2*S'$_L$[xS+j–1, yS–1] + 4) >> 3

if i>0 and j>0, $openPred_{i,j}$ = (3*$u_{i,j-1}$ + 3*$u_{i-1,j}$ + 2*$u_{i-1,j-1}$ + 4) >> 3

[Ed.: availability check of S'$_L$ is needed.]

u_{ij} = Clip1$_Y$((($pred_L$[xO + j, yO + i] + $openPred_{i,j}$ + 1) >> 1) + r_{ij})

- Otherwise

  u_{ij} = Clip1$_Y$($pred_L$[xO + j, yO + i] + r_{ij})

7. The picture construction process prior to deblocking filter process in subclause 6.4.6 is invoked with u and tuIdx as the inputs.

6.4.2 Specification of transform decoding process for chroma transform unit

This process is invoked for each chroma component Cb and Cr separately when ChromaArrayType is not equal to 0.

For each chroma component, the variable ChromaLevel[iCbCr], with iCbCr set equal to 0 for Cb and iCbCr set equal to 1 for Cr, contain the levels for both components of the chroma transform coefficients.

For each chroma component, the transform decoding proceeds separately in the following ordered steps:

1. The inverse scanning process for chroma transform coefficients as described specified in subclause 6.4.3 is invoked with ChromaLevel[iCbCr] as the input and the two-dimensional array c as the output.
2. The scaling and transformation process for residual block as specified in subclause 6.4.5 is invoked with c as the input and r as the output.
3. The position of the upper-left sample of the transform unit with index tuIdx inside the prediction unit is derived by invoking the inverse transform unit scanning process in subclause 4.2.4.3 with tuIdx as the input and the output being assigned to (xO, yO).

   xO_C = xO / SubWidthC

   yO_C = yO / SubHeightC

4. The NxN array u with elements u_{ij} for i, j = 0..N-1 is derived as

   u_{ij} = Clip1$_C$($pred_C$[xO_C + j, yO_C + i] + r_{ij})

5. The picture construction process prior to deblocking filter process in subclause 6.4.6 is invoked with u and tuIdx as the inputs.

6.4.3 Inverse scanning process for transform coefficients

Input to this process is a list of NxN values listTrCoeffs.

Output of this process is a variable c containing a two-dimensional array of NxN values. In the case of transform coefficients, these NxN values represent levels assigned to locations in the transform unit.

The variable c_{ij} which is located in the (j, i) position in the array c is derived as follows.

c_{ij} = ZigzagToBlockPosition(listTrCoeffs, N, idx).

If adaptive coefficient scanning is used, adaptive coefficient scanning order is determined by the mddtIdx parameter. The scan order associated by mddtIdx is used for inverse mapping from scan order to block position.

The variable c_{ij} which is located in the (j, i) position in the array c is derived as follows.

c_{ij} = AdaptScanOrderToBlockPosition(listTrCoeffs, N, mddtIdx, idx).

6.4.4 Adaptive Coefficient Scanning

[Ed: needs more work]

1. At the beginning of each video slice, initialize the coefficient scanning order for each mddtIdx;
2. When a block is entropy-coded, for each non-zero coefficient coded, increment the count at the corresponding position by one;
3. After each macroblock is coded, update the coefficient scanning order according to the statistics collected;
4. Normalize the collected statistics if needed;
5. Use the updated order for coding of future blocks. Go back to 2 until slice is finished.

If no MDDT is used, e.g. for block size larger than 8x8, and entropySymbolMode != 0, an adaptive scan is used for parsing the significance map. The adaptive scan for significance map is further described in 7.5.1.

6.4.5 Scaling and transformation process for transform unit

Input to this process is an NxN array c with elements cij which is either an array relating to the residual block of the luma component or, when ChromaArrayType is equal to 3, an array relating to the residual block of a chroma component.

NOTE 1 – When separate_colour_plane_flag is equal to 1, all residual blocks are considered to be associated with the luma component for purposes of the decoding process of each coded picture (prior to the final assignment of the decoded picture to a particular luma or chroma picture array according to the value of colour_plane_id).

Outputs of this process are residual sample values as NxN array r with elements r_{ij}.

The variables bitDepth and qP are derived as follows.

- If the input array c relates to a luma residual block, bitDepth is set equal to $BitDepth_Y$ and qP is set equal to QP'_Y.
- Otherwise (the input array c relates to a chroma residual block), bitDepth is set equal to $BitDepth_C$ and qP is set equal to QP'_C.

NOTE 2 – When separate_colour_plane_flag is equal to 1, all residual blocks are considered to be associated with the luma component for purposes of the decoding process of each colour component of a picture.

If PredMode is MODE_INTRA and N is equal to 4 or 8, mode depedent directiona transform process as specified in subclause 6.4.5.1 is invoked for luma residual block array c.

Depending on the values of rotational_transform_idx, the following applies.

- If rotational_transform_idx is equal to 1, the following ordered steps are specified:
  1. The rotational transformation process as specified in subclause 6.4.5.2 is invoked with bitDepth, qP, and c as the inputs and the output is assigned to the NxN array d of scaled transform coefficients with elements d_{ij}.
  2. The scaling process for residual blocks as specified in subclause 6.4.5.3 is invoked with bitDepth, qP, and d as the inputs and the output is assigned to the NxN array e of scaled transform coefficients with elements e_{ij}.
  3. The transformation process for residual blocks as specified in subclause 6.4.5.4 is invoked with bitDepth and e as the inputs and the output is assigned to the NxN array r of residual sample values with elements r_{ij}.
- Otherwise (rotational_transform_idx is equal to 0), the following ordered steps are specified:
  1. The scaling process for residual NxN blocks as specified in subclause 6.4.5.3 is invoked with bitDepth, qP, and c as the inputs and the output is assigned to the NxN array d of scaled transform coefficients with elements d_{ij}.
  2. The transformation process for residual blocks as specified in subclause 6.4.5.4 is invoked with bitDepth and d as the inputs and the output is assigned to the NxN array r of residual sample values with elements r_{ij}.

6.4.5.1 Mode dependent directional transformation process for intra prediction residuals

Inputs of this process are

- the variable bitDepth,
- an NxN array of scaled transform coefficients e with elements e_{ij}.
- IntraPredMode
- Prediction unit size PU Size

Outputs of this process are residual sample values as NxN array r with elements r_{ij}.

The transformation process shall convert the block of scaled transform coefficients to a block of output samples in a manner mathematically equivalent to the following.

The final constructed residual samples values are derived as specified in the following ordered steps:

1. Mode dependent directional transform index is derived from IntraPredMode and PU Size according to Table 6-6.
2. If N is equal to 4 block transformation process described in subclause 6.4.5.1.1 is invoked on 4x4 array of scaled transform coefficients e with elements e_{ij}, else block transformation process described in subclause 6.4.5.1.2 is invoked on 8x8 array of scaled transform coefficients e with elements e_{ij}, resulting in residual matrix g_{ij} (i, j = 0…N-1).
3. The residual sample value r_{ij} is derived by

   $r_{ij} = (g_{ij} + 2^{19}) >> 20$ with i, j = 0..N-1

Table 6-6 Specification of IntraPredMode[puPartIdx] and associated mddtIdx

IntraPredMode [puPartIdx]	mddtIdx	
	PU Size != PU_8x8	PU Size == PU_8x8
0	0	0
1	1	1
2	2	2
3	2	4
4	3	5
5	4	7
6	5	3
7	6	6
8	7	8
9	8	3
10	0	4
11	3	0
12	3	0
13	6	3
14	4	4
15	0	1
16	3	1
17	8	3
18	0	4
19	7	5
20	7	5
21	3	0
22	3	0
23	8	7
24	1	7

25	1	3
26	6	4
27	6	6
28	4	6
29	5	1
30	3	1
31	3	8
32	2	8
33	-	3

6.4.5.1.1 Mode dependent directional transform for 4x4 block input

Inputs of this process are 4x4 array e of scaled transform coefficients e_{ij} and mode dependent directional transform index, mddtIdx.

Outputs of this process are residual sample values a 4x4 block array g with elements g_{ij}.

The 4x4 block inverse transform for a given input X is defined as

$$Y = C' X R$$

where C = kltCol4x4[mddtIdx] and R=kltRow4x4[mddtIdx].
The transform matrices kltRow4x4[i], kltCol4x4[i] (i = 0,1,3,4,5,6,7,8) are defined as:

```
kltRow4x4[0]={{40,  64,  78,  68},{ -82, -60,  31,  70},{  76, -52, -56,  69}, {47, -77,  79, -46}}
kltRow4x4[1]={{30,  55,  74,  84},{ -67, -76,  -4,  78},{ -83,  16,  81, -52},{ -64,  85, -66,  25}}
kltRow4x4[3]={{50,  69,  72,  62},{ -89, -43,  42,  70},{  69, -68, -43,  71},{  36, -71,  87, -50}}
kltRow4x4[4]={{26,  59,  81,  76},{ -63, -80,   6,  77},{  86, -15, -72,  60},{  66, -79,  68, -33}}
kltRow4x4[5]={{22,  52,  82,  81},{ -61, -86,   0,  73},{  88, -13, -72,  58},{  67, -78,  67, -36}}
kltRow4x4[6]={{26,  57,  78,  79},{ -65, -77,  -1,  79},{ -87,  15,  75, -56},{ -63,  83, -68,  29}}
kltRow4x4[7]={{50,  70,  72,  62},{ -87, -45,  45,  69},{  69, -67, -44,  72},{  39, -71,  85, -51}}
kltRow4x4[8]={{29,  59,  77,  78},{ -71, -73,   3,  77},{ -85,  25,  72, -58},{ -57,  84, -72,  30}}

kltCol4x4[0]={{32,  56,  74,  82},{ -69, -74,  -3,  79},{ -81,  17,  82, -53},{ -63,  87, -65,  24}}
kltCol4x4[1]={{29,  55,  80,  78},{ -78, -73,  11,  69},{  81, -35, -67,  64},{  55, -82,  73, -37}}
kltCol4x4[3]={{21,  54,  80,  81},{ -64, -82,  -2,  74},{  88, -15, -71,  57},{  64, -80,  70, -32}}
kltCol4x4[4]={{24,  56,  81,  78},{ -62, -81,   0,  77},{  87, -12, -73,  58},{  66, -81,  67, -32}}
kltCol4x4[5]={{25,  56,  79,  80},{ -64, -79,  -3,  78},{ -86,  11,  76, -56},{ -65,  84, -66,  28}}
kltCol4x4[6]={{10,  32,  73, 100},{ -50, -92, -38,  63},{  89,  15, -80,  44},{  77, -82,  57, -24}}
kltCol4x4[7]={{26,  57,  78,  80},{ -64, -78,  -2,  79},{ -85,  13,  77, -55},{ -65,  83, -67,  28}}
kltCol4x4[8]={{40,  38,  60,  99},{ -97, -62,  15,  54},{  65, -80, -63,  43},{  34, -69,  93, -44}}
```

If mmdtIdx = 2, then the transformation process defined in subclause 6.4.5.4 is invoked.

6.4.5.1.2 Mode dependent directional transform for 8x8 block input

Inputs of this process are 4x4 array e of scaled transform coefficients e_{ij} and mode dependent directional transform index, mddtIdx.

Outputs of this process are residual sample values a 8x8 block array g with elements g_{ij}.

The 4x4 block inverse transform for a given input X is defined as

$$Y = C' X R$$

where C = kltCol8x8[mddtIdx] and R=kltRow8x8[mddtIdx].
The transform matrices kltRow8x8[i], kltCol8x8[i] (i = 0,1,3,4,5,6,7,8) are defined as:

```
kltRow8x8[0]={ { 31,  40,  45,  49,  51,  51,  49,  43},{ -52, -59, -47, -23,   6,  35,  54,  57},
               { -58, -42,  10,  57,  60,  21, -30, -56},{  55,   5, -57, -42,  34,  64,   5, -56},
               { -55,  33,  53, -37, -45,  45,  41, -49},{  47, -59,   4,  52, -50, -11,  61, -40},
```

```
                { -31,  60, -57,  21,  25, -57,  59, -28},{ -15,  36, -53,  63, -63,  52, -35,  14}}
kltRow8x8[1]={  { 18,  28,  37,  45,  51,  55,  57,  56},{  42,  58,  57,  41,  14, -19, -46, -61},
                { -56, -53, -11,  41,  61,  38, -16, -56},{  58,  20, -49, -55,  19,  64,  16, -50},
                { -58,  22,  59, -29, -54,  38,  45, -42},{  53, -56,  -3,  54, -44, -18,  63, -36},
                { -37,  62, -53,  15,  28, -57,  59, -26},{  16, -38,  55, -64,  62, -50,  33, -12}
kltRow8x8[3]={  { 37,  45,  49,  51,  50,  47,  43,  38},{  61,  59,  38,   8, -21, -43, -52, -52},
                { -63, -27,  31,  63,  47,   3, -38, -56},{  55, -15, -62, -18,  52,  54,  -8, -57},
                { -48,  49,  34, -56, -26,  58,  28, -51},{  36, -61,  26,  38, -61,   9,  59, -45},
                { -23,  53, -60,  35,   9, -52,  66, -33},{  11, -31,  48, -60,  64, -57,  42, -17}}
kltRow8x8[4]={  { 10,  21,  33,  45,  54,  60,  59,  53},{  25,  49,  61,  54,  24, -17, -49, -59},
                { -40, -60, -36,  22,  61,  45, -16, -59},{  53,  47, -23, -62,  -2,  62,  20, -53},
                { -61,  -9,  63,  -2, -60,  26,  49, -44},{  64, -38, -29,  60, -31, -27,  60, -34},
                { -51,  63, -41,   1,  37, -57,  54, -24},{  27, -46,  58, -61,  57, -46,  31, -12}}
kltRow8x8[5]={  { 11,  22,  34,  45,  53,  59,  59,  54},{  25,  49,  61,  53,  24, -16, -49, -60},
                { -38, -60, -37,  21,  62,  46, -15, -57},{  54,  48, -25, -62,  -1,  61,  20, -51},
                { -65,  -7,  62,  -7, -57,  29,  47, -44},{  64, -43, -22,  58, -35, -23,  59, -35},
                { -49,  64, -48,   9,  31, -55,  54, -25},{  22, -41,  54, -61,  61, -50,  35, -14}}
kltRow8x8[6]={  { 10,  21,  33,  44,  53,  59,  60,  55},{  27,  50,  59,  53,  26, -13, -46, -63},
                { -45, -60, -33,  20,  58,  47, -10, -60},{  59,  42, -28, -60,  -3,  59,  26, -50},
                { -62,   2,  61,  -7, -61,  22,  53, -42},{  62, -48, -21,  61, -32, -29,  58, -30},
                { -43,  64, -49,   7,  36, -59,  53, -22},{  21, -43,  57, -62,  59, -48,  31, -12}}
kltRow8x8[7]={  { 36,  43,  48,  50,  50,  48,  45,  40},{ -58, -60, -42, -13,  16,  41,  53,  52},
                { -60, -33,  23,  63,  53,   8, -37, -54},{  56,  -7, -61, -27,  47,  57,  -6, -57},
                { -52,  44,  41, -49, -31,  55,  31, -51},{  39, -61,  18,  44, -58,   3,  59, -45},
                { -26,  56, -59,  30,  15, -54,  64, -32},{ -13,  33, -50,  61, -63,  55, -40,  17}}
kltRow8x8[8]={  { 10,  21,  34,  44,  53,  58,  59,  55},{  33,  54,  63,  50,  19, -17, -47, -56},
                { -54, -59, -21,  34,  61,  34, -20, -56},{  63,  28, -41, -51,  17,  62,  15, -54},
                { -66,  20,  57, -29, -50,  37,  42, -44},{  52, -58,   3,  54, -47, -14,  60, -37},
                { -33,  59, -53,  19,  27, -59,  60, -28},{  17, -38,  55, -64,  62, -51,  32, -11}}

kltCol8x8[0]={  { 17,  28,  37,  45,  51,  55,  57,  56},{  36,  54,  58,  45,  17, -18, -48, -62},
                { -49, -54, -22,  32,  64,  44, -14, -58},{  63,  29, -40, -57,   7,  60,  24, -50},
                { -62,  15,  58, -17, -55,  29,  52, -45},{  53, -54, -12,  61, -38, -27,  61, -32},
                { -36,  62, -50,   8,  38, -62,  54, -21},{  20, -44,  59, -63,  59, -47,  29, -10}}
kltCol8x8[1]={  { 27,  36,  41,  46,  49,  51,  53,  52},{ -50, -57, -47, -30,  -8,  20,  50,  66},
                { -56, -48,  -3,  47,  64,  36, -17, -55},{  50,  11, -51, -54,  14,  67,  27, -53},
                { -59,  24,  61, -21, -55,  27,  51, -43},{  48, -53, -10,  60, -38, -30,  64, -33},
                { -36,  64, -50,   7,  40, -62,  51, -20},{ -20,  43, -58,  64, -60,  46, -28,  10}}
kltCol8x8[3]={  {  9,  21,  34,  45,  54,  59,  58,  53},{  24,  49,  63,  54,  22, -18, -48, -58},
                { -42, -62, -34,  27,  63,  38, -19, -56},{  58,  44, -30, -56,   9,  61,  17, -55},
                { -66,  -1,  59, -14, -54,  32,  47, -47},{  60, -44, -18,  59, -37, -24,  62, -35},
                { -46,  62, -46,   7,  35, -60,  55, -23},{  24, -44,  57, -62,  59, -48,  31, -11}}
kltCol8x8[4]={  {  9,  20,  33,  45,  55,  60,  59,  51},{  23,  48,  62,  54,  24, -17, -50, -60},
                { -41, -62, -37,  21,  60,  42, -17, -58},{  56,  46, -27, -59,   2,  59,  20, -54},
                { -64,  -5,  61,  -9, -57,  28,  48, -45},{  61, -40, -24,  61, -34, -27,  61, -35},
                { -49,  63, -42,   3,  37, -59,  53, -23},{  27, -46,  57, -61,  57, -47,  31, -12}}
kltCol8x8[5]={  {  9,  19,  30,  42,  52,  59,  61,  57},{  24,  46,  60,  56,  31,  -8, -45, -63},
                { -45, -61, -39,  14,  58,  48,  -8, -57},{  61,  43, -26, -58,  -6,  58,  28, -51},
                { -65,   1,  59,  -5, -59,  19,  55, -43},{  58, -46, -24,  63, -28, -34,  60, -30},
                { -42,  64, -44,  -2,  44, -62,  50, -19},{  25, -48,  61, -63,  56, -43,  26,  -9}}
kltCol8x8[6]={  { 10,  21,  33,  44,  53,  59,  60,  54},{  23,  47,  60,  54,  27, -12, -48, -63},
                { -39, -60, -39,  17,  59,  48,  -9, -59},{  56,  49, -24, -62,  -5,  58,  25, -50},
                { -64,  -6,  63,  -7, -58,  23,  51, -42},{  63, -42, -23,  60, -32, -29,  60, -33},
                { -49,  64, -46,   6,  35, -58,  52, -22},{  24, -42,  55, -62,  60, -49,  31, -12}}
kltCol8x8[7]={  { 10,  22,  34,  44,  53,  58,  59,  56},{  28,  52,  62,  51,  22, -15, -47, -60},
                { -47, -59, -29,  27,  62,  41, -14, -58},{  62,  36, -34, -55,   5,  60,  23, -53},
                { -67,  10,  58, -17, -54,  27,  51, -44},{  55, -50, -13,  62, -39, -26,  60, -33},
                { -38,  62, -50,   8,  37, -62,  53, -21},{  23, -44,  58, -62,  59, -48,  30, -11}}
kltCol8x8[8]={  { 32,  40,  44,  45,  44,  47,  53,  53},{ -69, -67, -39,  -9,  13,  30,  45,  50},
                { -60, -21,  42,  68,  47,   6, -34, -51},{  53, -21, -66,  -5,  62,  51,  -8, -47},
                { -45,  48,  24, -61, -13,  65,  27, -51},{  39, -63,  31,  29, -62,  19,  54, -46},
                { -24,  52, -63,  49,  -9, -39,  63, -34},{  -8,  22, -36,  51, -64,  66, -53,  23}}
```

If mmdtIdx = 2, then the transformation process defined in subclause 6.4.5.4 is invoked.

6.4.5.2 Rotational transformation process

Inputs of this process are

- the variable bitDepth and qP,
- an NxN array of transform coefficients c with elements c_{ij}

Outputs of this process are transform coefficients as NxN array d with elements d_{ij}.

The transform process shall convert the block of scaled transform coefficients to a block of output samples in a manner mathematically equivalent to the following.

Depending on the values of N, the following applies.

- If N is equal to 4, the following ordered steps are specified:
  1. The scaled transform coefficients s with elements s_{ij} is derived as

     $s_{ij} = c_{ij} * (1<< (qP / 6))$ with i, j = 0…3.
  2. The rotational transformation process for 4x4 transform unit as specified in subclause 6.4.5.2.1 is invoked with bitDepth, qP, and s as the inputs and the output is assigned to the 4x4 array d of transform coefficients with elements d_{ij}.
- Otherwise (N is larget than 4), the following ordered steps are specified:
  1. The scaled transform coefficients s with element s_{ij} is derived as

     $s_{ij} = c_{ij} * (1<< (qP / 6))$ with i, j = 0…7.
  2. The rotational transformation process for 8x8 transform unit as specified in subclause 6.4.5.2.2 is invoked with bitDepth and s_{ij} as the inputs and the output is assigned to the 8x8 array d8x8 of transform coefficients with elements $d8x8_{ij}$.
  3. The NxN array d of transform coefficients with element d_{ij} is derived by

     $d_{ij} = d8x8_{ij}$ with i, j = 0..7,

     $d_{ij} = s_{ij}$ otherwise

6.4.5.2.1 Rotational transformation process for 4x4 transform coefficients

Inputs of this process is a 4x4 array of transform coefficients s with elements s_{ij}

Outputs of this process are transform coefficients as a 4x4 array d with elements d_{ij}.

The variable addShift and addOffset is derived as follows.

shift = Min(Max(0, 4 – increased_bit_depth_luma), 8)

if (shift > 0) offset = 1 << (shift – 1), otherwise offset = 0

When the value of variable idx is set to rotational_transform_idx – 1, output element d_{ij} is specified as follows.

- For j=0..3, a set of intermediate values t_{ij} is derived by

  $t_{ij} = INV_ROT_4[idx][9]*s_{ij} + INV_ROT_4[idx][12]*s_{i+1,j} + INV_ROT_4[idx][15]*s_{i+2,j}$

  $t_{i+1,j} = INV_ROT_4[idx][10]*s_{ij}+ INV_ROT_ 4[idx][13]*s_{i+1,j}+ INV_ROT_4[idx][16]*s_{i+2,j}$

  $t_{i+2,j} = INV_ROT_ 4[idx][11]*s_{ij}+ INV_ROT_4[idx][14]*s_{i+1,j}+ INV_ROT_4[idx][17]*s_{i+2,j}$

  $t_{ij} = Sign(t_{ij})*(Abs(t_{ij}) >> (8-Shift))$

  $t_{i+1,j} = Sign(t_{i+1,j})*(Abs(t_{i+1,j}) >> (8-shift))$

  $t_{i+2,j} = Sign(t_{i+2,j})*(Abs(t_{i+2,j}) >> (8-shift))$

  $t_{i+3,j} = t_{i+3,j} << shift$
- For i=0..3, the transformed result d_{ij} is computed from these intermediate values t_{ij} as

  $d_{ij} = INV_ROT_4[idx][0]*t_{ij} + INV_ROT_4[idx][3]*t_{i,j+1}+ INV_ROT_4[idx][6]*t_{i,j+2}$

  $d_{i,j+1} = INV_ROT_4[idx][1]*t_{ij} + INV_ROT_4[idx][4]*t_{i,j+1}+ INV_ROT_4[idx][7]*t_{i,j+2}$

  $d_{i,j+2} = INV_ROT_4[idx][2]*t_{ij} + INV_ROT_4[idx][5]*t_{i,j+1} + INV_ROT_4[idx][8]*t_{i,j+2}$

  $d_{i,j+3} = t_{i, j+3}$

  $d_{ij} = Sign(d_{ij})*((Abs(d_{ij}) + offset) >> (8+shift))$

$d_{i,j+1}$ = Sign($d_{i,j+1}$)*((Abs($d_{i,j+1}$) + (offset << 8)) >> (8+shift))

$d_{i,j+2}$ = Sign($d_{i,j+2}$)*((Abs($d_{i,j+2}$) + (offset << 8)) >> (8+shift))

$d_{i,j+3}$ = Sign($d_{i,j+3}$)*((Abs($d_{i,j+3}$) + offset) >> shift)

The matrix INV_ROT_4 is specified in Table 6-7.

Table 6-7 Specification of transpose of NV_ROT_4 matrix

	idx = 0	idx = 1	idx = 2	idx = 3
0	248	255	237	250
1	-55	22	-96	-18
2	-28	-8	-9	-54
3	-60	-22	90	-13
4	-244	254	229	220
5	-52	-17	-73	-131
6	-16	6	35	55
7	57	17	64	130
8	-249	255	245	213
9	250	241	243	212
10	-49	-84	-80	-143
11	-26	-18	-6	9
12	-54	69	70	134
13	-240	221	222	192
14	-71	-110	-107	-103
15	-11	52	38	51
16	75	98	100	90
17	-245	231	233	234

6.4.5.2.2 Rotational transformation process for 8x8 transform coefficients

Inputs of this process is a 8x8 array of transform coefficients s with elements s_{ij}

Outputs of this process are transform coefficients as a 8x8 array d with elements d_{ij}.

The variable addShift and addOffset is derived as follows.

shift = Min(Max(0, 4 – increased_bit_depth_luma), 8)

if (shift > 0) offset = 1 << (shift – 1), otherwise offset = 0

When the value of variable idx is set to rotational_transform_idx – 1, output element d_{ij} is specified as follows.

- For j=0..7, a set of intermediate values t_{ij} is derived by

t_{ij} = INV_ROT_8[idx][9]*s_{ij} + INV_ROT_8[idx][12]*$s_{i+1,j}$+ INV_ROT_8[idx][15]*$s_{i+2,j}$

$t_{i+1,j}$ = INV_ROT_8[idx][10]*s_{ij} + INV_ROT_8[idx][13]*$s_{i+1,j}$+ INV_ROT_8[idx][16]* $s_{i+2,j}$

$t_{i+2,j}$ = INV_ROT_8[idx][11]*s_{ij} + INV_ROT_8[idx][14]*$s_{i+1,j}$+ INV_ROT_8[idx][17]* $s_{i+2,j}$

$t_{i+3,j}$ = INV_ROT_8[idx][27]*$s_{i+3,j}$ + INV_ROT_8[idx][30]*$s_{i+4,j}$ + INV_ROT_8[idx][33]*$s_{i+5,j}$

$t_{i+4,j}$ = INV_ROT_8[idx][28]*$s_{i+3,j}$ + INV_ROT_8[idx][31]*$s_{i+4,j}$ + INV_ROT_8[idx][34]*$s_{i+5,j}$

$t_{i+5,j}$ = INV_ROT_8[idx][29]*$s_{i+3,j}$ + INV_ROT_8[idx][32]*$s_{i+4,j}$ + INV_ROT_8[idx][35]*$s_{i+5,j}$

t_{ij} = Sign(t_{ij})*(Abs(t_{ij}) >> (8-shift))

$t_{i+1,j}$ = Sign($t_{i+1,j}$)*(Abs($t_{i+1,j}$) >> (8-shift))

$t_{i+2,j}$ = Sign($t_{i+2,j}$)*(Abs($t_{i+2,j}$) >> (8-shift))

$t_{i+3,j}$ = Sign($t_{i+3,j}$)*(Abs($t_{i+3,j}$) >> (8-shift))

$t_{i+4,j}$ = Sign($t_{i+4,j}$)*(Abs($t_{i+4,j}$) >> (8-shift))

$t_{i+5,j}$ = Sign($t_{i+5,j}$)*(Abs($t_{i+5,j}$) >> (8-shift))

$t_{i+6,j}$ = $s_{i+6,j}$ << shift

$t_{i+7,j}$ = $s_{i+7,j}$ << shift

- For i=0..7, the transformed result d_{ij} is computed from these intermediate values t_{ij} as

d_{ij} = INV_ROT_8[idx][0] * t_{ij} + INV_ROT_8[index][3] * $t_{i,j+1}$ + INV_ROT_8[idx][6] * $t_{i,j+2}$

$d_{i,j+1}$ = INV_ROT_8[idx][1] * t_{ij} + INV_ROT_8[index][4] * $t_{i,j+1}$ + INV_ROT_8[idx][7] * $t_{i,j+2}$

$d_{i,j+2}$ = INV_ROT_8[idx][2] * t_{ij} + INV_ROT_8[index][5] * $t_{i,j+1}$ + INV_ROT_8[idx][8] * $t_{i,j+2}$

$d_{i,j+3}$ = INV_ROT_8[idx][18] * $t_{i,j+3}$ + INV_ROT_8[idx][21] * $t_{i,j+4}$ + INV_ROT_8[idx][24] * $t_{i,j+5}$

$d_{i,j+4}$ = INV_ROT_8[idx][19] * $t_{i,j+3}$ + INV_ROT_8[idx][22] * $t_{i,j+4}$ + INV_ROT_8[idx][25] * $t_{i,j+5}$

$d_{i,j+5}$ = INV_ROT_8[idx][20] * $t_{i,j+3}$ + INV_ROT_8[idx][23] * $t_{i,j+4}$ + INV_ROT_8[idx][26] * $t_{i,j+5}$

$d_{i,j+6}$ = $t_{i,j+6}$

$d_{i,j+7}$ = $t_{i,j+7}$

d_{ij} = Sign(d_{ij})*((Abs(d_{ij}) + (offset << 8)) >> (8+shift))

$d_{i,j+1}$ = Sign($d_{i,j+1}$)*((Abs($d_{i,j+1}$) + (offset << 8)) >> (8+shift))

$d_{i,j+2}$ = Sign($d_{i,j+2}$)*((Abs($d_{i,j+2}$) + (offset << 8)) >> (8+shift))

$d_{i,j+3}$ = Sign($d_{i,j+3}$)*((Abs($d_{i,j+3}$) + (offset << 8)) >> (8+shift))

$d_{i,j+4}$ = Sign($d_{i,j+4}$)*((Abs($d_{i,j+4}$) + (offset << 8)) >> (8+shift))

$d_{i,j+5}$ = Sign($d_{i,j+5}$)*((Abs($d_{i,j+5}$) + (offset << 8)) >> (8+shift))

$d_{i,j+6}$ = Sign($d_{i,j+6}$)*((Abs($d_{i,j+6}$) + offset) >> shift)

$d_{i,j+7}$ = Sign($d_{i,j+7}$)*((Abs($d_{i,j+7}$) + offset) >> shift)

The matrix INV_ROT_8 is specified in Table 6-8.

Table 6-8 Specification of transpose of INV_ROT_8 matrix

	idx = 0	idx = 1	idx = 2	idx = 3
0	251	243	243	174
1	-36	-61	-81	-186
2	-31	-50	12	23
3	23	-75	81	181
4	237	-230	232	158
5	-94	-83	-70	-87
6	42	-25	11	49
7	90	94	71	75
8	236	-237	246	240
9	236	254	252	236
10	-100	-27	-41	-99
11	3	-18	-9	-10
12	100	22	-42	-99
13	234	249	-251	-235
14	-25	-56	-28	-25
15	7	24	-4	1
16	24	54	29	27
17	255	249	-254	-255
18	251	243	243	174
19	-36	-61	-81	-186
20	-31	-50	12	23
21	23	-75	81	181
22	237	-230	232	158
23	-94	-83	-70	-87
24	42	-25	11	49

25	90	94	71	75
26	236	-237	246	240
27	236	254	252	236
28	-100	-27	-41	-99
29	3	-18	-9	-10
30	100	22	-42	-99
31	234	249	-251	-235
32	-25	-56	-28	-25
33	7	24	-4	1
34	24	54	29	27
35	255	249	-254	-255

6.4.5.3 Scaling process for residual blocks

Inputs of this process are

- the variables bitDepth and qP,
- an NxN array d with elements d_{ij} which is either an array relating to a residual block of luma component or an array relating to a residual block of a chroma component.

Output of this process is an NxN array of scaled transform coefficients e with elements e_{ij}.

The scaling process for NxN block transform coefficient levels d_{ij} proceeds as follows.

- If rotational_transform_idx is not equal to 0, the scaled result is derived as

  e_{ij} = (d_{ij} * LevelScaleNxN[qP % 6][i][j]) , with i, j = 0..N-1

  where N in the LevelScaleNxN is replaced with 4, 8, 16, 32 and 64 depending on the value of N.

- Otherwise (rotational_transform_idx is equal to 0), the scaled result is derived as

  e_{ij} = (d_{ij} * LevelScaleNxN[qP % 6][i][j]) << (qP / 6), with i, j = 0..N-1

  where N in the LevelScaleNxN is replaced with 4, 8, 16, 32 and 64 depending on the value of N.

If mode dependent directional transform is invoked, LevelScaleNxN[m][i][j] = w[m] for m=0..5 and i, j = 0..N-1 where w = [40 45 50 57 63 71].

6.4.5.4 Transformation process for residual blocks

Inputs of this process are

- the variable bitDepth,
- an NxN array of scaled transform coefficients e with elements e_{ij}.

Outputs of this process are residual sample values as NxN array r with elements r_{ij}.

The transformation process shall convert the block of scaled transform coefficients to a block of output samples in a manner mathematically equivalent to the following.

The final constructed residual samples values are derived as specified in the following ordered steps:

4. Each (horizontal) row of scaled transform coefficients e_{ij} (i, j = 0…N-1) is transformed to f_{ij} (i, j = 0…N-1) by invoking the one-dimensional transformation process as specified in subclause 6.4.5.4.1.
5. Each (vertical) column of the resulting matrix f_{ij} (i, j = 0…N-1) is transformed by invoking the one-dimensional transformation process as specified in subclause 6.4.5.4.1 where resulting matrix is g_{ij} (i, j = 0…N-1).
6. Depending on the value of N, following is applied.
   - If N is equal to 4 or 8 or 64, the residual sample value r_{ij} is derived by

     $r_{ij} = (g_{ij} + 2^8) >> 9$ with i, j = 0..N-1

- Otherwise (N is equal to 16 or 32), the residual sample value r_{ij} is derived by

$$r_{ij} = (g_{ij} + 2^9) >> 10 \qquad \text{with } i, j = 0..N-1$$

6.4.5.4.1 Transformation process for N-point input

Inputs of this process are an N-point array of scaled transform coefficients X with elements Xi.

Outputs of this process are residual sample values as N-point array Y with elements Yi.

Depending on the values of N, the following applies.

- If N is equal to 4, the transformation process for 4-point input as specified in subclause 6.4.5.4.2 is invoked with X as the input and Y as the output.
- Otherwise, if N is equal to 8, the transformation process for 8-point input as specified in subclause 6.4.5.4.3 is invoked with X as the input and Y as the output.
- Otherwise, if N is equal to 16, the transformation process for 16-point input as specified in subclause 6.4.5.4.4 is invoked with X as the input and Y as the output.
- Otherwise, if N is equal to 32, the transformation process for 32-point input as specified in subclause 6.4.5.4.5 is invoked with X as the input and Y as the output.
- Otherwise, if N is equal to 64, the transformation process for 64-point input as specified in subclause 6.4.5.4.6 is invoked with X as the input and Y as the output.

6.4.5.4.2 Transformation process for 4-point input

[Ed.: same as H.264/AVC]

6.4.5.4.3 Transformation process for 8-point input

[Ed.: same as H.264/AVC]

6.4.5.4.4 Transformation process for 16-point input

Inputs of this process are a 16-point array of scaled transform coefficients X with elements Xi.

Outputs of this process are residual sample values as a 16-point array Y with elements Yi.

16-point one-dimensional inverse transform process is defined as following 6 stages. Xi (i = 0...15) are elements of input vector and Yi (i=0...15) are elements of output vector. In each stage, sets of intermediate values Fi, Ei, Di, Ci, Bi (i = 0...15) are derived and fed into the next stage.

Stage 1	Stage 2	Stage 3
F8 = (6 * X1 - 63 * X15) >> 6	E4 = (12 * X2 - 62 * X14) >> 6	D0 = (45 * (X0 + X8)) >> 6
F9 = (49 * X9 - 40 * X7) >> 6	E5 = (53 * X10 - 35 * X6) >> 6	D1 = (45 * (X0 - X8)) >> 6
F10 = (30 * X5 - 56 * X11) >> 6	E6 = (53 * X6 + 35 * X10) >> 6	D2 = (24 * X4 - 59 * X12) >> 6
F11 = (61 * X13 - 18 * X3) >> 6	E7 = (12 * X14 + 62 * X2) >> 6	D3 = (59 * X4 + 24 * X12) >> 6
F12 = (61 * X3 + 18 * X13) >> 6	E8 = F8 + F9	D4 = E4 + E5
F13 = (30 * X11 + 56 * X5) >> 6	E9 = F8 - F9	D5 = E4 - E5
F14 = (49 * X7 + 40 * X9) >> 6	E10 = F11 - F10	D6 = E7 - E6
F15 = (6 * X15 + 63 * X1) >> 6	E11 = F11 + F10	D7 = E7 + E6
	E12 = F12 + F13	D9 = (24 * E14 - 59 * E9) >> 6
	E13 = F12 - F13	D10 = (- 59 * E13 - 24 * E10) >> 6
	E14 = F15 - F14	D13 = (24 * E13 - 59 * E10) >> 6
	E15 = F15 + F14	D14 = (59 * E14 + 24 * E9) >> 6

Stage 4	Stage 5	Stage 6
C0 = D0 + D3	B0 = C0 + D7	Y0 = B0 + C15
C3 = D0 - D3,	B7 = C0 - D7	Y15 = B0 - C15
C8 = E8 + E11	B1 = C1 + C6	Y1 = B1 + C14
C11 = E8 - E11	B6 = C1 - C6	Y14 = B1 - C14
C12 = E15 - E12	B2 = C2 + C5	Y2 = B2 + B13
C15 = E15 + E12	B5 = C2 - C5	Y13 = B2 - B13
C1 = D1 + D2	B3 = C3 + D4	Y3 = B3 + B12
C2 = D1 - D2	B4 = C3 - D4	Y12 = B3 - B12

C9 = D9 + D10 C10 = D9 - D10 C13 = D14 - D13 C14 = D14 + D13 C5 = (45 * (D6 - D5)) >> 6 C6 = (45 * (D6 + D5)) >> 6	B10 = (45 * (C13 - C10)) >> 6 B13 = (45 * (C13 + C10)) >> 6 B11 = (45 * (C12 - C11)) >> 6 B12 = (45 * (C12 + C11)) >> 6	Y4 = B4 + B11 Y11 = B4 - B11 Y5 = B5 + B10 Y10 = B5 - B10 Y6 = B6 + C9 Y9 = B6 - C9 Y7 = B7 + C8 Y8 = B7 - C8

6.4.5.4.5 Transformation process for 32-point input

Inputs of this process are a 32-point array of scaled transform coefficients X with elements Xi.

Outputs of this process are residual sample values as a 32-point array Y with elements Yi.

32-point one-dimensional inverse transform process is defined as following 8 stages. Xi (i = 0...31) are elements of input vector and Yi (i=0...31) are elements of output vector. In each stage, sets of intermediate values Gi, Fi, Ei, Di, Ci, Bi, Ai (i = 0...31) are derived and fed into next stage.

Stage 1	Stage 2	Stage 3
G16 = (12 * X1 - 255 * X31) >> 8 G17 = (189 * X17 - 171 * X15) >> 8 G18 = (109 * X9 - 231 * X23) >> 8 G19 = (241 * X25 - 86 * X7) >> 8 G20 = (62 * X5 - 248 * X27) >> 8 G21 = (219 * X21 - 131 * X11) >> 8 G22 = (152 * X13 - 205 * X19) >> 8 G23 = (253 * X29 - 37 * X3) >> 8 G24 = (253 * X3 + 37 * X29) >> 8 G25 = (152 * X19 + 205 * X13) >> 8 G26 = (219 * X11 + 131 * X21) >> 8 G27 = (62 * X27 + 248 * X5) >> 8 G28 = (241 * X7 + 86 * X25) >> 8 G29 = (109 * X23 + 231 * X9) >> 8 G30 = (189 * X15 + 171 * X17) >> 8 G31 = (12 * X31 + 255 * X1) >> 8	F8 = (25 * X2 - 254 * X30) >> 8 F9 = (197 * X18 - 162 * X14) >> 8 F10 = (120 * X10 - 225 * X22) >> 8 F11 = (244 * X26 - 74 * X6) >> 8 F12 = (244 * X6 + 74 * X26) >> 8 F13 = (120 * X22 + 225 * X10) >> 8 F14 = (197 * X14 + 162 * X18) >> 8 F15 = (25 * X30 + 254 * X2) >> 8 F16 = G16 + G17 F17 = G16 - G17 F18 = G19 - G18 F19 = G19 + G18 F20 = G20 + G21 F21 = G20 - G21 F22 = G23 - G22 F23 = G23 + G22 F24 = G24 + G25 F25 = G24 - G25 F26 = G27 - G26 F27 = G27 + G26 F28 = G28 + G29 F29 = G28 - G29 F30 = G31 - G30 F31 = G31 + G30	E4 = (49 * X4 - 251 * X28) >> 8 E5 = (212 * X20 - 142 * X12) >> 8 E6 = (212 * X12 + 142 * X20) >> 8 E7 = (49 * X28 + 251 * X4) >> 8 E8 = F8 + F9 E9 = F8 - F9 E10 = F11 - F10 E11 = F11 + F10 E12 = F12 + F13 E13 = F12 - F13 E14 = F15 - F14 E15 = F15 + F14 E17 = (49 * F30 - 251 * F17) >> 8 E18 = (- 251 * F29 - 49 * F18) >> 8 E21 = (212 * F26 - 142 * F21) >> 8 E22 = (- 142 * F25 - 212 * F22) >> 8 E25 = (212 * F25 - 142 * F22) >> 8 E26 = (142 * F26 + 212 * F21) >> 8 E29 = (49 * F29 - 251 * F18) >> 8 E30 = (251 * F30 + 49 * F17) >> 8

Stage 4	Stage 5	Stage 6
D0 = (181 * (X0 + X16)) >> 8 D1 = (181 * (X0 - X16)) >> 8 D2 = (97 * X8 - 236 * X24) >> 8 D3 = (236 * X8 + 97 * X24) >> 8 D4 = E4 + E5 D5 = E4 - E5 D6 = E7 - E6 D7 = E7 + E6 D9 = (97 * E14 - 236 * E9) >> 8 D10 = (- 236 * E13 - 97 * E10) >> 8 D13 = (97 * E13 - 236 * E10) >> 8 D14 = (236 * E14 + 97 * E9) >> 8 D16 = F16 + F19 D19 = F16 - F19 D20 = F23 - F20 D23 = F23 + F20 D24 = F24 + F27 D27 = F24 - F27 D28 = F31 - F28 D31 = F31 + F28 D17 = E17 + E18 D18 = E17 - E18 D21 = E22 - E21 D22 = E22 + E21 D25 = E25 + E26 D26 = E25 - E26 D29 = E30 - E29	C0 = D0 + D3 C3 = D0 - D3 C8 = E8 + E11 C11 = E8 - E11 C12 = E15 - E12 C15 = E15 + E12 C1 = D1 + D2 C2 = D1 - D2 C9 = D9 + D10 C10 = D9 - D10 C13 = D14 - D13 C14 = D14 + D13 C5 = (181 * (D6 - D5)) >> 8 C6 = (181 * (D6 + D5)) >> 8 C18 = (97 * D29 - 236 * D18) >> 8 C20 = (- 236 * D27 - 97 * D20) >> 8 C26 = (- 236 * D21 + 97 * D26) >> 8 C28 = (97 * D19 + 236 * D28) >> 8 C19 = (97 * D28 - 236 * D19) >> 8 C21 = (- 236 * D26 - 97 * D21) >> 8 C27 = (- 236 * D20 + 97 * D27) >> 8 C29 = (97 * D18 + 236 * D29) >> 8	B7 = C0 - D7 B1 = C1 + C6 B6 = C1 - C6 B2 = C2 + C5 B5 = C2 - C5 B3 = C3 + D4 B4 = C3 - D4 B10 = (181 * (C13 - C10)) >> 8 B13 = (181 * (C13 + C10)) >> 8 B11 = (181 * (C12 - C11)) >> 8 B12 = (181 * (C12 + C11)) >> 8 B16 = D16 + D23 B23 = D16 - D23 B24 = D31 - D24 B31 = D31 + D24 B17 = D17 + D22 B22 = D17 - D22 B25 = D30 - D25 B30 = D30 + D25 B18 = C18 + C21 B21 = C18 - C21 B26 = C29 - C26 B29 = C29 + C26 B19 = C19 + C20 B20 = C19 - C20 B27 = C28 - C27 B28 = C28 + C27

D30 = E30 + E29		

Stage 7	Stage 8	
A0 = B0 + C15 A15 = B0 - C15 A1 = B1 + C14 A14 = B1 - C14 A2 = B2 + B13 A13 = B2 - B13 A3 = B3 + B12 A12 = B3 - B12 A4 = B4 + B11 A11 = B4 - B11 A5 = B5 + B10 A10 = B5 - B10 A6 = B6 + C9 A9 = B6 - C9 A7 = B7 + C8 A8 = B7 - C8 A20 = (181 * (B27 - B20)) >> 8 A27 = (181 * (B27 + B20)) >> 8 A21 = (181 * (B26 - B21)) >> 8 A26 = (181 * (B26 + B21)) >> 8 A22 = (181 * (B25 - B22)) >> 8 A25 = (181 * (B25 + B22)) >> 8 A23 = (181 * (B24 - B23)) >> 8 A24 = (181 * (B24 + B23)) >> 8	Y0 = (A0 + B31) Y31 = (A0 - B31) Y1 = (A1 + B30) Y30 = (A1 - B30) Y2 = (A2 + B29) Y29 = (A2 - B29) Y3 = (A3 + B28) Y28 = (A3 - B28) Y4 = (A4 + A27) Y27 = (A4 - A27) Y5 = (A5 + A26) Y26 = (A5 - A26) Y6 = (A6 + A25) Y25 = (A6 - A25) Y7 = (A7 + A24) Y24 = (A7 - A24) Y8 = (A8 + A23) Y23 = (A8 - A23) Y9 = (A9 + A22) Y22 = (A9 - A22) Y10 = (A10 + A21) Y21 = (A10 - A21) Y11 = (A11 + A20) Y20 = (A11 - A20) Y12 = (A12 + B19) Y19 = (A12 - B19) Y13 = (A13 + B18) Y18 = (A13 - B18) Y14 = (A14 + B17) Y17 = (A14 - B17) Y15 = (A15 + B16) Y16 = (A15 - B16)	

6.4.5.4.6 Transformation process for 64-point input

Inputs of this process are a 64-point array of scaled transform coefficients X with elements Xi.

Outputs of this process are residual sample values as a 64-point array Y with elements Yi.

64-point one-dimensional inverse transform process is defined as following 10 stages. Xi (i = 0...63) are elements of input vector and Yi (i=0...63) are elements of output vector. In each stage, sets of intermediate values Hi,Gi, Fi, Ei, Di, Ci, Bi, Ai, Oi (i = 0...63) are derived and fed into next stage.

Stage 1	Stage 2	Stage 3
H32 = (25*X1-1024*X63) >> 10 H33 = (742*X33-706*X31) >> 10 H34 = (415*X17-936*X47) >> 10 H35 = (955*X49-369*X15) >> 10 H36 = (224*X9-999*X55) >> 10 H37 = (865*X41-548*X23) >> 10 H38 = (590*X25-837*X39) >> 10 H39 = (1009*X57-175*X7) >> 10 H40 = (125*X5-1016*X59) >> 10 H41 = (807*X37-630*X27) >> 10 H42 = (505*X21-891*X43) >> 10 H43 = (987*X53-273*X11) >> 10 H44 = (321*X13-972*X51) >> 10 H45 = (915*X45-460*X19) >> 10 H46 = (669*X29-775*X35) >> 10 H47 = (1021*X61-75*X3) >> 10 H48 = (1021*X3+75*X61) >> 10 H49 = (669*X35+775*X29) >> 10 H50 = (915*X19+460*X45) >> 10 H51 = (321*X51+972*X13) >> 10 H52 = (987*X11+273*X53) >> 10 H53 = (505*X43+891*X21) >> 10 H54 = (807*X27+630*X37) >> 10 H55 = (125*X59+1016*X5) >> 10 H56 = (1009*X7+175*X57) >> 10 H57 = (590*X39+837*X25) >> 10	G16 = (50*X2-1023*X62) >> 10 G17 = (759*X34-688*X30) >> 10 G18 = (438*X18-926*X46) >> 10 G19 = (964*X50-345*X14) >> 10 G20 = (249*X10-993*X54) >> 10 G21 = (878*X42-526*X22) >> 10 G22 = (610*X26-822*X38) >> 10 G23 = (1013*X58-150*X6) >> 10 G24 = (1013*X6+150*X58) >> 10 G25 = (610*X38+822*X26) >> 10 G26 = (878*X22+526*X42) >> 10 G27 = (249*X54+993*X10) >> 10 G28 = (964*X14+345*X50) >> 10 G29 = (438*X46+926*X18) >> 10 G30 = (759*X30+688*X34) >> 10 G31 = (50*X62+1023*X2) >> 10 G32 = H32+H33 G33 = H32-H33 G34 = H35-H34 G35 = H35+H34 G36 = H36+H37 G37 = H36-H37 G38 = H39-H38 G39 = H39+H38 G40 = H40+H41 G41 = H40-H41	F8 = (100*X4-1019*X60) >> 10 F9 = (792*X36-650*X28) >> 10 F10 = (483*X20-903*X44) >> 10 F11 = (980*X52-297*X12) >> 10 F12 = (980*X12+297*X52) >> 10 F13 = (483*X44+903*X20) >> 10 F14 = (792*X28+650*X36) >> 10 F15 = (100*X60+1019*X4) >> 10 F16 = G16+G17 F17 = G16-G17 F18 = G19-G18 F19 = G19+G18 F20 = G20+G21 F21 = G20-G21 F22 = G23-G22 F23 = G23+G22 F24 = G24+G25 F25 = G24-G25 F26 = G27-G26 F27 = G27+G26 F28 = G28+G29 F29 = G28-G29 F30 = G31-G30 F31 = G31+G30 F33 = (100*G62-1019*G33) >> 10 F34 = (-1019*G61-100*G34) >> 10

H58 = (865*X23+548*X41) >> 10 H59 = (224*X55+999*X9) >> 10 H60 = (955*X15+369*X49) >> 10 H61 = (415*X47+936*X17) >> 10 H62 = (742*X31+706*X33) >> 10 H63 = (25*X63+1024*X1) >> 10	G42 = H43-H42 G43 = H43+H42 G44 = H44+H45 G45 = H44-H45 G46 = H47-H46 G47 = H47+H46 G48 = H48+H49 G49 = H48-H49 G50 = H51-H50 G51 = H51+H50 G52 = H52+H53 G53 = H52-H53 G54 = H55-H54 G55 = H55+H54 G56 = H56+H57 G57 = H56-H57 G58 = H59-H58 G59 = H59+H58 G60 = H60+H61 G61 = H60-H61 G62 = H63-H62 G63 = H63+H62	F37 = (792*G58-650*G37) >> 10 F38 = (-650*G57-792*G38) >> 10 F41 = (483*G54-903*G41) >> 10 F42 = (-903*G53-483*G42) >> 10 F45 = (980*G50-297*G45) >> 10 F46 = (-297*G49-980*G46) >> 10 F49 = (980*G49-297*G46) >> 10 F50 = (297*G50+980*G45) >> 10 F53 = (483*G53-903*G42) >> 10 F54 = (903*G54+483*G41) >> 10 F57 = (792*G57-650*G38) >> 10 F58 = (650*G58+792*G37) >> 10 F61 = (100*G61-1019*G34) >> 10 F62 = (1019*G62+100*G33) >> 10

Stage 4	Stage 5	Stage 6
E4 = (200*X8-1004*X56) >> 10 E5 = (851*X40-569*X24) >> 10 E6 = (851*X24+569*X40) >> 10 E7 = (200*X56+1004*X8) >> 10 E8 = F8+F9 E9 = F8-F9 E10 = F11-F10 E11 = F11+F10 E12 = F12+F13 E13 = F12-F13 E14 = F15-F14 E15 = F15+F14 E17 = (200*F30-1004*F17) >> 10 E18 = (-1004*F29-200*F18) >> 10 E21 = (851*F26-569*F21) >> 10 E22 = (-569*F25-851*F22) >> 10 E25 = (851*F25-569*F22) >> 10 E26 = (569*F26+851*F21) >> 10 E29 = (200*F29-1004*F18) >> 10 E30 = (1004*F30+200*F17) >> 10 E32 = G32+G35 E33 = F33+F34 E34 = F33-F34 E35 = G32-G35 E36 = G39-G36 E37 = F38-F37 E38 = F38+F37 E39 = G39+G36 E40 = G40+G43 E41 = F41+F42 E42 = F41-F42 E43 = G40-G43 E44 = G47-G44 E45 = F46-F45 E46 = F46+F45 E47 = G47+G44 E48 = G48+G51 E49 = F49+F50 E50 = F49-F50 E51 = G48-G51 E52 = G55-G52 E53 = F54-F53 E54 = F54+F53 E55 = G55+G52 E56 = G56+G59 E57 = F57+F58 E58 = F57-F58 E59 = G56-G59 E60 = G63-G60 E61 = F62-F61	D0 = (724*(X0+X32)) >> 10 D1 = (724*(X0-X32)) >> 10 D2 = (392*X16-946*X48) >> 10 D3 = (946*X16+392*X48) >> 10 D4 = E4+E5 D5 = E4-E5 D6 = E7-E6 D7 = E7+E6 D9 = (392*E14-946*E9) >> 10 D10 = (-946*E13-392*E10) >> 10 D13 = (392*E13-946*E10) >> 10 D14 = (946*E14+392*E9) >> 10 D16 = F16+F19 D19 = F16-F19 D20 = F23-F20 D23 = F23+F20 D24 = F24+F27 D27 = F24-F27 D28 = F31-F28 D31 = F31+F28 D17 = E17+E18 D18 = E17-E18 D21 = E22-E21 D22 = E22+E21 D25 = E25+E26 D26 = E25-E26 D29 = E30-E29 D30 = E30+E29 D34 = (200*E61-1004*E34) >> 10 D35 = (200*E60-1004*E35) >> 10 D36 = (-1004*E59-200*E36) >> 10 D37 = (-1004*E58-200*E37) >> 10 D42 = (851*E53-569*E42) >> 10 D43 = (851*E52-569*E43) >> 10 D44 = (-569*E51-851*E44) >> 10 D45 = (-569*E50-851*E45) >> 10 D50 = (851*E50-569*E45) >> 10 D51 = (851*E51-569*E44) >> 10 D52 = (569*E52+851*E43) >> 10 D53 = (569*E53+851*E42) >> 10 D58 = (200*E58-1004*E37) >> 10 D59 = (200*E59-1004*E36) >> 10 D60 = (1004*E60+200*E35) >> 10 D61 = (1004*E61+200*E34) >> 10	C0 = D0+D3 C3 = D0-D3 C8 = E8+E11 C11 = E8-E11 C12 = E15-E12 C15 = E15+E12 C1 = D1+D2 C2 = D1-D2 C9 = D9+D10 C10 = D9-D10 C13 = D14-D13 C14 = D14+D13 C5 = (724*(D6-D5)) >> 10 C6 = (724*(D6+D5)) >> 10 C18 = (392*D29-946*D18) >> 10 C20 = (-946*D27-392*D20) >> 10 C26 = (-946*D21+392*D26) >> 10 C28 = (392*D19+946*D28) >> 10 C19 = (392*D28-946*D19) >> 10 C21 = (-946*D26-392*D21) >> 10 C27 = (-946*D20+392*D27) >> 10 C29 = (392*D18+946*D29) >> 10 C32 = E32+E39 C39 = E32-E39 C40 = E47-E40 C47 = E47+E40 C48 = E48+E55 C55 = E48-E55 C56 = E63-E56 C63 = E63+E56 C33 = E33+E38 C38 = E33-E38 C41 = E46-E41 C46 = E46+E41 C49 = E49+E54 C54 = E49-E54 C57 = E62-E57 C62 = E62+E57 C34 = D34+D37 C37 = D34-D37 C42 = D45-D42 C45 = D45+D42 C50 = D50+D53 C53 = D50-D53 C58 = D61-D58 C61 = D61+D58 C35 = D35+D36 C36 = D35-D36 C43 = D44-D43 C44 = D44+D43

E62 = F62+F61 E63 = G63+G60		C51 = D51+D52 C52 = D51-D52 C59 = D60-D59 C60 = D60+D59

Stage 7	Stage 8	Stage 9
B0 = C0+D7 B7 = C0-D7 B1 = C1+C6 B6 = C1-C6 B2 = C2+C5 B5 = C2-C5 B3 = C3+D4 B4 = C3-D4 B10 = (724*(C13-C10)) >> 10 B13 = (724*(C13+C10)) >> 10 B11 = (724*(C12-C11)) >> 10 B12 = (724*(C12+C11)) >> 10 B16 = D16+D23 B23 = D16-D23 B24 = D31-D24 B31 = D31+D24 B17 = D17+D22 B22 = D17-D22 B25 = D30-D25 B30 = D30+D25 B18 = C18+C21 B21 = C18-C21 B26 = C29-C26 B29 = C29+C26 B19 = C19+C20 B20 = C19-C20 B27 = C28-C27 B28 = C28+C27 B36 = (392*C59-946*C36) >> 10 B40 = (-946*C55-392*C40) >> 10 B52 = (-946*C43+392*C52) >> 10 B56 = (392*C39+946*C56) >> 10 B37 = (392*C58-946*C37) >> 10 B41 = (-946*C54-392*C41) >> 10 B53 = (-946*C42+392*C53) >> 10 B57 = (392*C38+946*C57) >> 10 B38 = (392*C57-946*C38) >> 10 B42 = (-946*C53-392*C42) >> 10 B54 = (-946*C41+392*C54) >> 10 B58 = (392*C37+946*C58) >> 10 B39 = (392*C56-946*C39) >> 10 B43 = (-946*C52-392*C43) >> 10 B55 = (-946*C40+392*C55) >> 10 B59 = (392*C36+946*C59) >> 10	A0 = B0+C15 A15 = B0-C15 A1 = B1+C14 A14 = B1-C14 A2 = B2+B13 A13 = B2-B13 A3 = B3+B12 A12 = B3-B12 A4 = B4+B11 A11 = B4-B11 A5 = B5+B10 A10 = B5-B10 A6 = B6+C9 A9 = B6-C9 A7 = B7+C8 A8 = B7-C8 A20 = (724*(B27-B20)) >> 10 A27 = (724*(B27+B20)) >> 10 A21 = (724*(B26-B21)) >> 10 A26 = (724*(B26+B21)) >> 10 A22 = (724*(B25-B22)) >> 10 A25 = (724*(B25+B22)) >> 10 A23 = (724*(B24-B23)) >> 10 A24 = (724*(B24+B23)) >> 10 A32 = C32+C47 A47 = C32-C47 A48 = C63-C48 A63 = C63+C48 A33 = C33+C46 A46 = C33-C46 A49 = C62-C49 A62 = C62+C49 A34 = C34+C45 A45 = C34-C45 A50 = C61-C50 A61 = C61+C50 A35 = C35+C44 A44 = C35-C44 A51 = C60-C51 A60 = C60+C51 A36 = B36+B43 A43 = B36-B43 A52 = B59-B52 A59 = B59+B52 A37 = B37+B42 A42 = B37-B42 A53 = B58-B53 A58 = B58+B53 A38 = B38+B41 A41 = B38-B41 A54 = B57-B54 A57 = B57+B54 A39 = B39+B40 A40 = B39-B40 A55 = B56-B55 A56 = B56+B55	O0 = A0+B31 O31 = A0-B31 O1 = A1+B30 O30 = A1-B30 O2 = A2+B29 O29 = A2-B29 O3 = A3+B28 O28 = A3-B28 O4 = A4+A27 O27 = A4-A27 O5 = A5+A26 O26 = A5-A26 O6 = A6+A25 O25 = A6-A25 O7 = A7+A24 O24 = A7-A24 O8 = A8+A23 O23 = A8-A23 O9 = A9+A22 O22 = A9-A22 O10 = A10+A21 O21 = A10-A21 O11 = A11+A20 O20 = A11-A20 O12 = A12+B19 O19 = A12-B19 O13 = A13+B18 O18 = A13-B18 O14 = A14+B17 O17 = A14-B17 O15 = A15+B16 O16 = A15-B16 O40 = (724*(A55-A40)) >> 10 O55 = (724*(A55+A40)) >> 10 O41 = (724*(A54-A41)) >> 10 O54 = (724*(A54+A41)) >> 10 O42 = (724*(A53-A42)) >> 10 O53 = (724*(A53+A42)) >> 10 O43 = (724*(A52-A43)) >> 10 O52 = (724*(A52+A43)) >> 10 O44 = (724*(A51-A44)) >> 10 O51 = (724*(A51+A44)) >> 10 O45 = (724*(A50-A45)) >> 10 O50 = (724*(A50+A45)) >> 10 O46 = (724*(A49-A46)) >> 10 O49 = (724*(A49+A46)) >> 10 O47 = (724*(A48-A47)) >> 10 O48 = (724*(A48+A47)) >> 10

Stage 10

Y0 = O0+A63 Y63 = O0-A63 Y1 = O1+A62 Y62 = O1-A62 Y2 = O2+A61 Y61 = O2-A61 Y3 = O3+A60 Y60 = O3-A60 Y4 = O4+A59 Y59 = O4-A59 Y5 = O5+A58 Y58 = O5-A58 Y6 = O6+A57 Y57 = O6-A57 Y7 = O7+A56 Y56 = O7-A56 Y8 = O8+O55 Y55 = O8-O55 Y9 = O9+O54 Y54 = O9-O54 Y10 = O10+O53 Y53 = O10-O53	Y11 = O11+O52 Y52 = O11-O52 Y12 = O12+O51 Y51 = O12-O51 Y13 = O13+O50 Y50 = O13-O50 Y14 = O14+O49 Y49 = O14-O49 Y15 = O15+O48 Y48 = O15-O48 Y16 = O16+O47 Y47 = O16-O47 Y17 = O17+O46 Y46 = O17-O46 Y18 = O18+O45 Y45 = O18-O45 Y19 = O19+O44 Y20 = O20+O43 Y43 = O20-O43 Y21 = O21+O42 Y42 = O21-O42 Y22 = O22+O41	Y41 = O22-O41 Y23 = O23+O40 Y40 = O23-O40 Y24 = O24+A39 Y39 = O24-A39 Y25 = O25+A38 Y38 = O25-A38 Y26 = O26+A37 Y37 = O26-A37 Y27 = O27+A36 Y36 = O27-A36 Y28 = O28+A35 Y35 = O28-A35 Y29 = O29+A34 Y34 = O29-A34 Y30 = O30+A33 Y33 = O30-A33 Y31 = O31+A32 Y32 = O31-A32

6.4.6 Picture construction process prior to deblocking filter process

Inputs to this process are

- a sample array u with elements u_{ij} which is either a NxN luma block or NxN chroma block.
- largest coding unit address lcuAddr, prediction unit index puIdx and transform unit index tuIdx.

The position of the upper-left luma sample of the current largest coding unit is derived by invoking the inverse largest coding unit scanning process in subclause 4.2.1 with address lcuAddr as input and the output being assigned to (xL, yL).

The position of the upper-left luma sample of the current prediction unit puIdx inside the largest coding unit is derived by invoking the inverse prediction unit scanning process in subclause 4.2.4.1 with puIdx as input and the output being assigned to (xP, yP).

The position of the upper-left luma sample of the current transform unit tuIdx inside the prediction unit is derived by invoking the inverse transform unit scanning process in subclause 4.2.4.3 with tuIdx as input and the output being assigned to (xO, yO).

Let xS be xL + xP + xO and yS be yL + yP + yO.

When u is a luma block, for each sample u_{ij} of the luma block, the following applies.

$$S'_L[\ xS + j, yS + i\ ] = u_{ij} \quad \text{with } i, j = 0..N-1$$

When u is a chroma block, for each sample u_{ij} of the chroma block, the following ordered steps are specified:

1. The subscript C in the variable S'C is replaced with Cb for the Cb chroma component and with Cr for the Cr chroma component.

   $xS_C = xS / SubWidthC$

   $yS_C = yS / SubHeightC$

2. Then, the following applies.

   $S'_C[\ xS_C + j, yS_C + i\ ] = u_{ij}$ with i, j = 0..N-1

6.5 In-loop filter process

6.5.1 Deblocking filter process

The deblocking filter process shall be applied to all prediction unit partition edges and transform unit edges of a picture, except edges at the boundary of the picture, and edges of prediction unit partitions and transform unit partitions smaller than 8 pixels in either vertical or horizontal direction. For the transform units and prediction units with edges smaller than 8 pixels, only the edges lying on the 8x8 grid are filtered.

The deblocking filter process is invoked for the luma and chroma components separately. The filter process is in LCU order. Each LCU is processed in CU order. For each CU, vertical edges are filtered first, starting with the edge on the left-hand side of the prediction unit proceeding through the edges towards the right-hand side of the prediction unit in their geometrical order. Then, horizontal edges are filtered starting with the edge on the top of the CU proceeding through the edges towards the bottom of the CU in their geometrical order.

The variables filterInternalEdgesFlag, filterLeftPuEdgeFlag, filterTopPuEdgeFlag are derived as specified by the following ordered steps.

1. The derivation process for neighbouring largest coding units specified in subclause 4.3.4.1 is invoked and the output is assigned to lcuAddrA and lcuAddrB
2. The variables filterInternalEdgesFlag, filterLeftPuEdgeFlag and filterTopPuEdgeFlag are derived as specified by the following ordered steps:
   a. The variable filterInternalEdgesFlag is derived as follows.
      – the variable filterInternalEdgesFlag is set equal to 1
   b. The variable filterLeftPuEdgeFlag is derived as follows.
      – If any of the following conditions is true, the variable filterLeftPuEdgeFlag is set equal to 0:
        – CurrLcuAddr % PicWidthInLCUs is equal to 0
        – the largest coding unit lcuAddA is not available
      – Otherwise, the variable filterLeftPuEdgeFlag is set equal to 1
   c. The variable filterTopPuEdgeFlag is derived as follows.
      – If any of the following conditions is true, the variable filterTopPuEdgeFlag is set equal to 0:
        – CurrLcuAddr is less than PicWidthInLCUs
        – the largest coding unit lcuAddB is not available
      – Otherwise, the variable filterTopPuEdgeFlag is set equal to 1

Fig. 6-2 shows the possible edges from the partition boundaries inside the prediction unit which can be interpreted as luma or chroma edges.

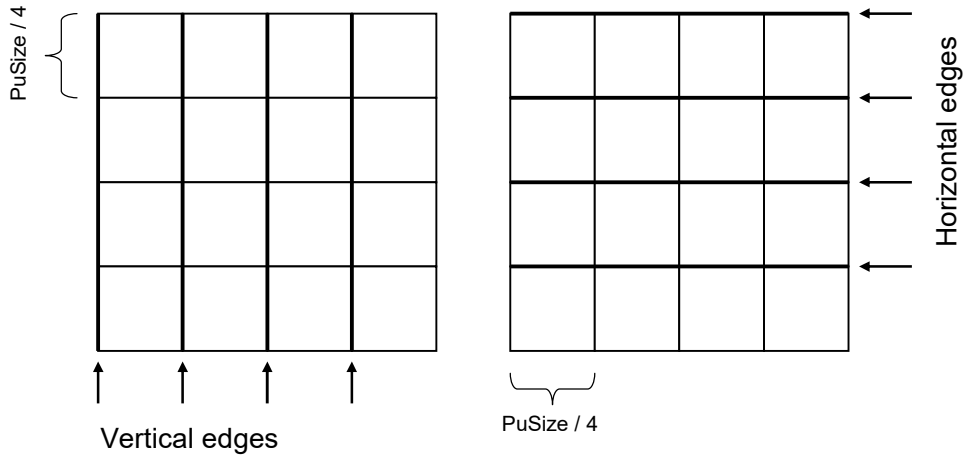


Fig. 6-2 Partition boundaries in a prediction unit to be filtered

When interpreting the edges in Fig. 6-2 as luma edges and chroma edges, the partition mode PartMode is considered as well as the value of the variables filterInternalEdgesFlag, filterLeftPUEdgeFlag and filterTopPUEdgeFlag.

The vertical edge interpretation depending on the partition mode is specified as follows:

- The first vertical edge can be filtered when filterLeftPuEdgeFlag is equal to 1 and the width of the prediction unit is equal or larger than 8 pixels.

- If PartMode is PART_nLx2N, the second vertical edge can be filtered when filterInternalEdgesFlag is equal to 1 and the distance between the first and the second vertical edges is equal or larger than 8 pixels.
- Otherwise, if PartMode is PART_Nx2N or PART_NxN, the third vertical edge can be filtered when filterInternalEdgesFlag is equal to 1 and the distance between the first and the third vertical edges is equal or larger than 8 pixels.
- Otherwise, if PartMode is PART_nRx2N, the fourth vertical edge can be filtered when filterInternalEdgesFlag is equal to 1 and the distance between the fourth vertical edges and the next PU or the picture boundary is equal or larger than 8 pixels.

The horizontal edge interpretation depending on the partition mode is specified as follows:

- The first horizontal edge can be filtered when filterTopPuEdgeFlag is equal to 1 and the height of the prediction unit is equal or larger than 8 pixels.
- If PartMode is PART_2NxnU, the second horizontal edge can be filtered when filterInternalEdgesFlag is equal to 1 and the distance between the first and the second horizontal edges is equal or larger than 8 pixels.
- Otherwise, if PartMode is PART_2NxN or PART_NxN, the third horizontal edge can be filtered when filterInternalEdgesFlag is equal to 1 and the distance between the first and the third horizontal edges is equal or larger than 8 pixels.
- Otherwise, if PartMode is PART_2NxnD, the fourth horizontal edge can filtered when filterInternalEdgesFlag is equal to 1 and the distance between the fourth horizontal edges and the next PU or the picture boundary is equal or larger than 8 pixels.

The vertical and horizontal edges interpretation depending on transform unit size is specified as follows:

Fig. 5-3 shows the possible edges from the partition boundaries inside the transform unit which can be interpreted as luma or chroma edges.

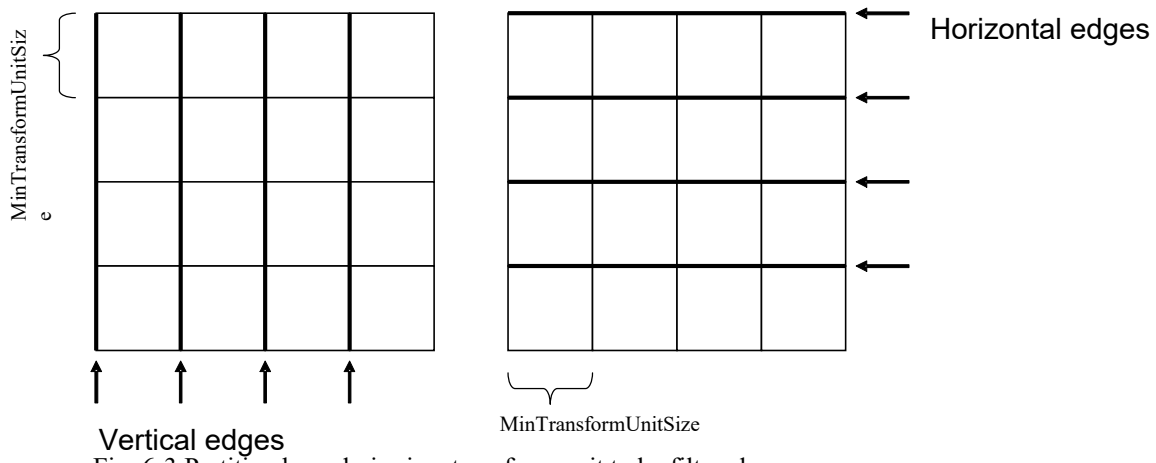


Fig. 6-3 Partition boundaries in a transform unit to be filtered

Only vertical edges in the transform unit with a distance equal to 8 or larger can be filtered. This means that if MinTransformUnitSize=4 only every second vertical edge can be filtered. Only horizontal edges in the transform unit with a distance equal to 8 or larger can be filtered. This means that if MinTransformUnitSize=4 only every second horizontal edge can be filtered.

When a horizontal or vertical edge from either partitions of a prediction unit or from partitions of a transform unit can be filtered according to above processes, another process follows to check if parts of respective edge can be filtered. The deblocking filter operates on k parts, where k ranges 0 to K-1, of edges for luma as well as for chroma, where K is the width or height of the current CU divided by 8 for horisontal edges and vertical edges respectively. The size of each part is 8 pixel. The pixels on respective side of parts of the edges are in the following denoted A and B where B corresponds to a part of the partition at largest coding unit address lcuAddr, prediction unit index

puIdx and transform unit index tuIdx. In the following, A corresponds to the left neighbouring partition to B for vertical edges and to the above neighbouring partition to B for horizontal edges.

$p3_0$ $p2_0$ $p1_0$ $p0_0$	$q0_0$ $q1_0$ $q2_0$ $q3_0$
$p3_1$ $p2_1$ $p1_1$ $p0_1$	$q0_1$ $q1_1$ $q2_1$ $q3_1$
$p3_2$ $p2_2$ $p1_2$ $p0_2$	$q0_2$ $q1_2$ $q2_2$ $q3_2$
A $p3_3$ $p2_3$ $p1_3$ $p0_3$	$q0_3$ $q1_3$ $q2_3$ $q3_3$ **B**
$P3_4$ $p2_4$ $p1_4$ $p0_4$	$q0_4$ $q1_4$ $q2_4$ $q3_4$
$P3_5$ $p2_5$ $p1_5$ $p0_5$	$q0_5$ $q1_5$ $q2_5$ $q3_5$
$P3_6$ $p2_6$ $p1_6$ $p0_6$	$q0_6$ $q1_6$ $q2_6$ $q3_6$
$P3_7$ $p2_7$ $p1_7$ $p0_7$	$q0_7$ $q1_7$ $q2_7$ $q3_7$

Notation of an 8 pixel part of a vertical edge for deblocking

The k:th part of a vertical edge in luma the pixels in partition A and B have following correspondance with reconstructed pixel values in luma:
$qj_i = S'_L[\ xS + j, yS + i + k*8]$
$pj_i = S'_L[\ xS - j - 1, yS + i + k*8]$
with j=0..3 and i=0..7
where S'_L , xS and yS are defined in 5.3.5.

The k:th part of a horizontal edge in luma the pixels in partition A and B have following correspondance with reconstructed pixel values in luma:
$qj_i = S'_L[\ xS + j + k*8, yS + i\ ]$
$pj_i = S'_L[\ xS + j + k*8, yS - i - 1\ ]$
with j=0..7 and i=0..3

The k:th part of a vertical edge in chroma the pixels in partition A and B have following correspondance with reconstructed pixel values in chroma:
$qj_i = S'_C[\ xS_C + j, yS_C + i + k*8]$
$pj_i = S'_C[\ xS_C - j - 1, yS_C + i+ k*8\ ]$
with j=0..3 and i=0..7
where S'_C , xS_C and yS_C are defined in 5.3.5.

The k:th part of a horizontal edge in chroma the pixels in partition A and B have following correspondance with reconstructed pixel values in chroma:
$qj_i = S'_C[\ xS_C + j+ k*8, yS_C + i\ ]$
$pj_i = S'_C[\ xS_C + j+ k*8, yS_C - i - 1]$
with j=0..7 and i=0..3

Luma filtering

A part of the luma edge between A and B can be filtered if one of the following conditions is true

- A or B has PredMode==MODE_INTRA
- ***or*** A or B has nonzero transform coefficients
- ***or*** A and B use different reference frames or different number of motion vectors
- ***or*** one motion vector is used to predict partition A and one motion vector is used to predict the partition B and the absolute difference between the horizontal or vertical component of the motion vectors used is greater than or equal to 4 in units of quarter luma frame samples,
- ***or*** two motion vectors and two different reference pictures are used to predict the partition A and two motion vectors for the same two reference pictures are used to predict the partition B and the absolute difference between the horizontal or vertical component of the two motion vectors used in the prediction of the two partitions for the same reference picture is greater than or equal to 4 in units of quarter luma frame samples,
- ***or*** two motion vectors for the same reference picture are used to predict the partition A and two motion vectors for the same reference picture are used to predict the partition B and the absolute difference between the horizontal or vertical component of the corresponding motion vectors used in the prediction of the two partitions is greater than or equal to 4 in units of quarter luma frame samples.
- ***or*** a PBIC value (icScale or icOffset) of partition A used for a reference picture differs from the corresponding value of partition B

- ***and*** $|p2_2 - 2*p1_2 + p0_2| + |q2_2 - 2*q1_2 + q0_2| + |p2_5 - 2*p1_5 + p0_5| + |q2_5 - 2*q1_5 + q0_5| < \beta$

The filtering is also performed on the 8 pixel edge if the conditions described above are fulfilled for any pair of the smaller partitions or transform units on the different sides of the edge. For example, if A consists of two 4x4 partitions (A_1 and A_2) then the above process except the last item is done for both partition pairs A_1 - B and A_2 – B , and the last item is applied for the pair A-B. If pairs A_1 - B ***or*** pair A_2 - B need to be filtered then the whole 8 pixel edge between A and B is filtered.

A part of the luma edge between A and B is ***not*** filtered if one of the following conditions is true.

- A and B belong to the same transform unit partition and the same prediction unit partition
- ***or*** the edge is a prediction unit border ***and*** both A and B have planar_flag ==1.

If the edge between A and B is filtered, one of two types of filtering (weak or strong filtering) is performed. The choice between the strong and the weak filtering is done separately for each line depending on the following conditions. For each line i = 0,7, the strong filtering is performed if all the following conditions are true, otherwise, weak filtering is performed.

- $d < (\beta >> 2)$
- ***and*** $(|p3_i - p0_i| + |q0_i - q3_i|) < (\beta >> 3)$
- ***and*** $|p0_i - q0_i| < ((5*t_C + 1) >> 1)$,

where t_C and β depends on qp their relations are shown in the table below. The t_C is calculated as t_C (qp+4) when A ***or*** B has PredMode==MODE_INTRA.

Relation between qp, tc and β

qp	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
t_c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
β	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	7
qp	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
tc	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4
β	8	9	10	11	12	13	14	15	16	17	18	20	22	24	26	28	30	32
qp	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
tc	4	4	5	5	6	6	7	8	9	9	10	10	11	11	12	12	13	13
β	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64		
qp	54	55																
tc	14	14																
β																		

Weak filtering

Weak filtering mode filtering is performed based on the above conditions,

$\Delta = Clip(-t_C, t_C, (13*(q0_i - p0_i) + 4*(q1_i - p1_i) - 5*(q2_i - p2_i) + 16) >> 5))$ i = 0,7

$p0_i = Clip_{0\text{-}255}(p0_i + \Delta)$ i = 0,7

$q0_i = Clip_{0\text{-}255}(q0_i - \Delta)$ i = 0,7

$p1_i = Clip_{0\text{-}255}(p1_i + \Delta/2)$ i = 0,7

$q1_i = Clip_{0\text{-}255}(q1_i - \Delta/2)$ i = 0,7

Strong filtering

Strong filtering mode is performed with the following set of operations.

$p0_0 = Clip_{0\text{-}255}((p2_i + 2*p1_i + 2*p0_i + 2*q0_i + q1_i + 4) >> 3)$; i = 0,7

$q0_0 = Clip_{0\text{-}255}((p1_i + 2*p0_i + 2*q0_i + 2*q1_i + q2_i + 4) >> 3)$; i = 0,7

$p1_0 = Clip_{0\text{-}255}((p2_i + p1_i + p0_i + q0_i + 2) >> 2)$; i = 0,7

$q1_0 = Clip_{0\text{-}255}((p0_i + q0_i + q1_i + q2_i + 2) >> 2)$; i = 0,7

$p2_0 = Clip_{0\text{-}255}((2*p3_i + 3*p2_i + p1_i + p0_i + q0_i + 4) >> 3)$; i = 0,7

$q2_0 = Clip_{0\text{-}255}((p0_i + q0_i + q1_i + 3*q2_i + 2*q3_i + 4) >> 3)$; i = 0,7

Chroma filtering

The chroma edge between A and B can be filtered if the following condition is true.

- A or B has PredMode==MODE_INTRA

The filtering is not applied if both following conditions are true.

- The edge is a prediction unit edge

and both A and B have planar_flag==1.

If filtering is performed based on the above condition,

$\Delta = Clip(-t_C, t_C, ((((q0_i - p0_i) << 2) + p1_i - q1_i + 4) >> 3))$ $\quad i = 0,7$

$p0_i = Clip_{0\text{-}255}(p0_i + \Delta)$ $\quad i = 0,7$

$q0_i = Clip_{0\text{-}255}(q0_i - \Delta)$ $\quad i = 0,7$

t_C depend on qp and their relations are shown in the table above. For chroma filtering t_C is calculated as t_C (qp+4).

Planar mode filtering

There is a special filtering mode which is applied to the prediction unit edge when both prediction units are encoded in intra planar mode. Luma and chroma edges between A and B are filtered with *planar filtering* if all of the following conditions are true, otherwise normal filtering described in Luma and Chroma filtering are performed.

- Edge between A and B is a prediction unit edge
- Both A ***and*** B have planar_flag==1
- The prediction units for both A and B have the same size.

Let variable blkSize equals to width (or height) of prediction unit, blkSizeHalf= blkSize>>1 and blkSizeQuarter = blkSize>>2 and bitShift = log_2(blkSize) - 1. If luma edges are filtered, let S = S'_L , xPos = xS, yPos = yS, otherwise let S = S'_C , xPos = xS_C, yPos = yS_C

The horizontal planar mode filtering is performed with the following set of operations.

```
for(k=0;k<blkSize;k++) {
    a1 = S [xPos - blkSizeQuarter][yPos+k];
    a2 = S [xPos + blkSizeQuarter][yPos+k];
    for(l=1;l<blkSizeHalf;l++)
        S[xPos-blkSizeQuarter+l] [yPos+k] = (a1*(blkSizeHalf-l) + a2*l + blkSizeQuarter) >> bitShift;
}
```

The vertical planar mode filtering for luma component is performed with the following set of operations.

```
for(k=0; k<blkSize; k++) {
    a1 = S[xPos +k] [yPos-blkSizeQuarter];
    a2 = S[xPos +k] [yPos+blkSizeQuarter];
    for(l=1; l<blkSizeHalf; l++)
        S[xPos +k][ yPos -blkSizeQuarter+l] = (a1*(blkSizeHalf-l) + a2*l + blkSizeQuarter) >> bitShift;
}
```

6.5.2 Adaptive loop filter process

This process is invoked when adaptive_loop_filter_flag is equal to 1.

This process is performed on a coding unit basis after the completion of the slice construction process prior to adaptive loop filter process for the entire decoded slice, with all coding units in a slice processed in order of coding unit scan order.

~~The following filter~~Filter coefficients c_L for luma samples and c_C for chroma samples are derived by invoking the process specified in subclause 6.5.2.1.

- ~~Filter coefficients c_{L_hor} for horizontal filtering of the samples of the reconstructed signal of the luma component~~
- ~~Filter coefficients c_{L_ver} for vertical filtering of the luma samples of the reconstructed signal of the luma component~~

- ~~Filter coefficients $c_{L_pred_hor}$ for horizontal filtering of the samples of the prediction signal of the luma component~~
- ~~Filter coefficients $c_{L_pred_ver}$ for vertical filtering of the samples of the prediction signal of the luma component~~
- ~~Filter coefficients $c_{L_qpe_hor}$ for horizontal filtering of the samples of the quantized prediction error signal of the luma component~~
- ~~Filter coefficients $c_{L_qpe_ver}$ for vertical filtering of the samples of the quantized prediction error signal of the luma component~~
- ~~Filter coefficients c_{C_hor} for horizontal filtering of the samples of the reconstructed signal of the chroma components~~
- ~~Filter coefficients c_{C_ver} for vertical filtering of the samples of the reconstructed signal of the chroma components~~
- ~~Filter coefficients $c_{C_pred_hor}$ for horizontal filtering of the samples of the prediction signal of the chroma components~~
- ~~Filter coefficients $c_{C_pred_ver}$ for vertical filtering of the samples of the prediction signal of the chroma components~~
- ~~Filter coefficients $c_{C_qpe_hor}$ for horizontal filtering of the samples of the quantized prediction error signal of the chroma components~~
- ~~Filter coefficients $c_{C_qpe_ver}$ for vertical filtering of the samples of the quantized prediction error signal of the chroma components~~

When interpreting the luma samples of the coding unit as to be filtered, depending on alf_cu_control_flag and alf_flag, the following applies.

- If alf_cu_control_flag is equal to 0, the luma samples are filtered,
- Otherwise (alf_cu_control_flag is equal to 1), if alf_flag is equal to 1, the luma samples are filtered.
- Otherwise, the luma samples are not filtered.

When interpreting the chroma samples of the coding unit as to be filtered, depending on alf_chroma_idc, the following applies.

- If alf_chroma_idc is equal to 1, the Cr samples are filtered.
- Otherwise, if alf_chroma_idc is equal to 2, the Cb samples are filtered.
- Otherwise, if alf_chroma_idc is equal to 3, both chroma samples are filtered.
- Otherwise (alf_chroma_idc is equal to 0), both chroma samples are not filtered.

For the luma samples of the coding unit interpreted as to be filtered, the following ordered steps are specified:

1. The position of the upper-left sample of the largest coding unit with address lcuAddr is derived by invoking the inverse largest coding unit scanning process in subclause 4.2.1 with lcuAddr as the input and the output being assigned to (xL, yL).
2. The relative position of the upper-left sample of the current coding unit with index cuIdx is derived by invoking the inverse coding unit scanning process in subclause 4.2.3 with cuIdx as the input and the output being assigned to (xP, yP).
3. The filtering process for luma samples specified in subclause 6.5.2.2 is invoked with the position (xL+xP,yL+yP), the samples of the reconstructed signal (after deblocking) of the luma component $S'_L[\ x, y\ ]$, the samples of the prediction signal of the luma component $S_{L_pred}[\ x, y\ ]$, and the samples of the quantized prediction error signal of the luma component $S_{L_qpe}[\ x, y\ ]$, with x = 0..$PicWidthInSamples_L$, y = 0..$PicHeightInSamples_L$ as input and the output being assigned to pf[x, y], with x, y = 0..CuSize-1 as output.
4. The reconstructed samples in the current slice are updated as follows.

$$S''_L[\ xL + xP + x, yL + yP + y\ ] = pf[\ x, y\ ], \text{ with } x, y = 0..CuSize - 1$$

For the chroma samples of the coding unit interpreted as to be filtered, the following ordered steps are specified (with C being Cb or Cr):

1. The position of the upper-left sample of the largest codint unit with address lcuAddr is derived by invoking the inverse largest coding unit scanning process in subclause 4.2.1 with lcuAddr as the input and the output being assigned to (xL, yL).

$xL_C = xL$ / SubWidthC

$yL_C = yL$ / SubHeightC

2. The relative position of the upper-left sample of the current codint unit with index cuIdx is derived by invoking the inverse coding unit scanning process in subclause 4.2.3 with cuIdx as the input and the output being assigned to (xP, yP).

$xP_C = xP$ / SubWidthC

$yP_C = yP$ / SubHeightC

3. The filtering process for luma samples specified in subclause 6.5.2.3 is invoked with the position ($xL_C + xP_C$, $yL_C + yP_C$), the samples of the reconstructed signal (after deblocking) of the chroma component S'_C[x, y], the samples of the prediction signal of the chroma component S_{C_pred}[x, y], and the samples of the quantized prediction error signal of the chroma component S_{C_qpe}[x, y], with x = 0..$PicWidthInSamples_C$, y = 0..$PicHeightInSamples_C$ as input and the output being assigned to pf[x, y], with x, y = 0..CuSizeC-1 as output.

4. The reconstructed samples in the current slice are updated as follows.

$S''_C[\ xL_C + xP_C + x,\ yL_C + yP_C + y\ ]$ = pf[x, y], with x, y = 0..CuSizeC – 1

6.5.2.1 Derivation process for filter coefficients

Outputs of this process are the filter coefficients c_L for the luma samples and the filter coefficients c_C for the chroma samples.

- ~~Filter coefficients c_{L_hor} for horizontal filtering of the samples of the reconstructed signal of the luma component~~
- ~~Filter coefficients c_{L_ver} for vertical filtering of the luma samples of the reconstructed signal of the luma component~~
- ~~Filter coefficients $c_{L_pred_hor}$ for horizontal filtering of the samples of the prediction signal of the luma component~~
- ~~Filter coefficients $c_{L_pred_ver}$ for vertical filtering of the samples of the prediction signal of the luma component~~
- ~~Filter coefficients $c_{L_qpe_hor}$ for horizontal filtering of the samples of the quantized prediction error signal of the luma component~~
- ~~Filter coefficients $c_{L_qpe_ver}$ for vertical filtering of the samples of the quantized prediction error signal of the luma component~~
- ~~Filter coefficients c_{C_hor} for horizontal filtering of the samples of the reconstructed signal of the chroma components~~
- ~~Filter coefficients c_{C_ver} for vertical filtering of the samples of the reconstructed signal of the chroma components~~
- ~~Filter coefficients $c_{C_pred_hor}$ for horizontal filtering of the samples of the prediction signal of the chroma components~~
- ~~Filter coefficients $c_{C_pred_ver}$ for vertical filtering of the samples of the prediction signal of the chroma components~~
- ~~Filter coefficients $c_{C_qpe_hor}$ for horizontal filtering of the samples of the quantized prediction error signal of the chroma components~~
- ~~Filter coefficients $c_{C_qpe_ver}$ for vertical filtering of the samples of the quantized prediction error signal of the chroma components~~

~~Derivation of the coefficients of the horizontal filters:~~

~~c_{L_hor}~~ [i][j] with i=0...AlfNumFilters-1, j = 0..~~AlfLengthLuma_hor~~AlfNumCoeffLuma – 1 shall be derived as follows.

The first luma filter c_{L_hor}[0] 's coefficients with elements c_{L_hor}[0][j], j = 0..~~AlfLengthLuma_hor~~AlfNumCoeffLuma – 1 shall be derived as,

c_{L_hor}[0][j] = alf_coeff_luma~~_hor~~[0][j]

~~for j = 0..(AlfLengthLuma_hor – 1)/2-1~~

~~c_{L_hor}[0][j] = (1<<alf_quant_step_size_luma_hor) + alf_coeff_luma_hor[0][j]~~

~~for j = (AlfLengthLuma_hor – 1)/2~~

~~c_{L_hor}[0][j] = alf_coeff_luma_hor[0][j]~~

~~for j = (AlfLengthLuma_hor – 1)/2+1.. AlfLengthLuma_hor~~AlfNumCoeffLuma – 1.

The other luma filter c_{L_hor}[i]'s coefficients with elements c_{L_hor}[i][j], i=1...AlfNumFilters-1, j = 0.. ~~AlfLengthLuma_hor~~AlfNumCoeffLuma – 1 shall be derived as follows.

If Alf_PredMethod is equal to 1,

c_{L_hor}[i][j] = alf_coeff_luma~~_hor~~[i][j] + c_{L_hor}[i-1][j] for j = 0.. ~~AlfLengthLuma_hor~~AlfNumCoeffLuma – 1

otherwise,

c_{L_hor}[i][j] = alf_coeff_luma~~_hor~~[i][j] for j = 0.. ~~AlfLengthLuma_hor~~AlfNumCoeffLuma – 1

~~$c_{L_pred_hor}$ [i][j] with i=0...AlfNumFilters-1, j = 0..AlfLengthLuma_pred_hor – 1 shall be derived as follows.~~

~~The first luma filter $c_{L_pred_hor}$[0] 's coefficients with elements $c_{L_pred_hor}$[0][j], j = 0.. AlfLengthLuma_pred_hor – 1 shall be derived as,~~

~~$c_{L_pred_hor}$ [0][j] = alf_coeff_luma_pred_hor[0][j] for j = 0.. (AlfLengthLuma_pred_hor – 1)/2-1~~

~~$c_{L_pred_hor}$ [0][j] = alf_coeff_luma_pred_hor[0][j] - alf_coeff_luma_hor[0][AlfLengthLuma_hor – 1)/2]~~

~~for j = (AlfLengthLuma_pred_hor – 1)/2~~

~~$c_{L_pred_hor}$ [0][j] = alf_coeff_luma_pred_hor[0][j]~~

~~for j = (AlfLengthLuma_pred_hor – 1)/2+1.. AlfLengthLuma_pred_hor – 1~~

~~The other luma filter $c_{L_pred_hor}$[i]'s coefficients with elements $c_{L_pred_hor}$[i][j], i=1...AlfNumFilters-1, j = 0.. AlfLengthLuma_pred_hor – 1 shall be derived as follows.~~

~~If Alf_PredMethod is equal to 1,~~

~~$c_{L_pred_hor}$[i][j] = alf_coeff_luma_pred_hor[i][j] + $c_{L_pred_hor}$[i-1][j]~~

~~for j = 0.. AlfLengthLuma_pred_hor – 1~~

~~otherwise,~~

~~$c_{L_pred_hor}$[i][j] = alf_coeff_luma_pred_hor[i][j] for j = 0.. AlfLengthLuma_pred_hor – 1~~

~~The first luma filter $c_{L_qpe_hor}$[0] 's coefficients with elements $c_{L_qpe_hor}$[0][j], j = 0.. AlfLengthLuma_qpe_hor – 1 shall be derived as,~~

~~$c_{L_qpe_hor}$[0][j] = alf_coeff_luma_qpe_hor[0][j] for j = 0.. (AlfLengthLuma_qpe_hor – 1)/2-1~~

~~$c_{L_qpe_hor}$[0][j] =~~

~~$c_{L_pred_hor}$ [0][(AlfLengthLuma_pred_hor – 1)/2] + alf_coeff_luma_qpe_hor[0][j]~~

~~for j = (AlfLengthLuma_qpe_hor – 1)/2~~

~~$c_{L_qpe_hor}$[0][j] = alf_coeff_luma_qpe_hor[0][j]~~

~~for j = (AlfLengthLuma_qpe_hor – 1)/2+1.. AlfLengthLuma_qpe_hor – 1~~

~~The other luma filter $c_{L_qpe_hor}$[i]'s coefficients with elements $c_{L_qpe_hor}$[i][j], i=1...AlfNumFilters-1, j = 0.. AlfLengthLuma_qpe_hor – 1 shall be derived as follows.~~

~~If Alf_PredMethod is equal to 1,~~

~~$c_{L_qpe_hor}$[i][j] = alf_coeff_luma_qpe_hor[i][j] + $c_{L_qpe_hor}$[i-1][j]~~

~~for j = 0.. AlfLengthLuma_qpe_hor – 1~~

~~otherwise,~~

~~$c_{L_qpe_hor}$[i][j] = alf_coeff_luma_qpe_hor[i][j] for j = 0.. AlfLengthLuma_qpe_hor – 1~~

The chroma filter coefficients c_{C_hor} with elements $c_{C_hor}[i]$, i = 0..~~AlfLengthChroma_hor~~AlfNumCoeffChroma – 1 ~~are~~is derived as follows.

$c_{C_hor}[i]$ = alf_coeff_chroma~~_hor~~[i] for i = 0..~~AlfLengthChroma_hor~~AlfNumCoeffChroma – 2

$c_{C_hor}[i]$ = ~~(1<<alf_quant_step_size_chroma_hor)~~255 – sum – alf_coeff_chroma~~_hor~~[i], otherwise

where

sum = ∑(m_i * alf_coeff_chroma~~_hor~~[i]) with i = 0..~~AlfLengthChroma_hor~~AlfNumCoeffChroma - 2

m_i = 2 with i = 0⋯ ~~AlfLengthChroma_hor~~AlfNumCoeffChroma – 3

= 1 with i = ~~AlfLengthChroma_hor~~AlfNumCoeffChroma – 2

~~The chroma filter coefficients $c_{C_pred_hor}$ with elements $c_{C_pred_hor}[i]$, i = 0.. AlfLengthChroma_pred_hor – 1 are derived as follows.~~

~~$c_{C_pred_hor}[i]$ = alf_coeff_chroma_pred_hor [i]~~

~~for i = 0.. (AlfLengthChroma_pred_hor – 1)/2-1~~

~~$c_{C_pred_hor}[i]$ = alf_coeff_chroma_pred_hor[i] - alf_coeff_chroma_hor[(AlfLengthChroma_hor – 1)/2]~~

~~for i = (AlfLengthChroma_pred_hor – 1)/2~~

~~$c_{C_pred_hor}[i]$ = alf_coeff_chroma_pred_hor[i]~~

~~for i = (AlfLengthChroma_pred_hor – 1)/2+1.. AlfLengthChroma_pred_hor – 1~~

~~The chroma filter coefficients $c_{C_qpe_hor}$ with elements $c_{C_qpe_hor}[i]$, i = 0.. AlfLengthChroma_qpe_hor – 1 are derived as follows.~~

~~$c_{C_qpe_hor}[i]$ = alf_coeff_chroma_qpe_hor [i]~~

~~for i = 0.. (AlfLengthChroma_qpe_hor – 1)/2-1~~

~~$c_{C_qpe_hor}[i]$ = alf_coeff_chroma_qpe_hor[i] + $c_{C_pred_hor}$[(AlfLengthChroma_pred_hor – 1)/2]~~

~~for i = (AlfLengthChroma_qpe_hor – 1)/2~~

~~$c_{C_qpe_hor}[i]$ = alf_coeff_chroma_qpe_hor[i]~~

~~for i = (AlfLengthChroma_qpe_hor – 1)/2+1.. AlfLengthChroma_qpe_hor – 1~~

~~The derivation of the coefficients of the vertical filters follows the one of the vertical filters as specified above. The subscript "hor" need to be replaced by the subscript "ver".~~

6.5.2.2 Filter process for luma samples

Inputs to this process are:

- Position (ox, oy)
- Samples of the reconstructed signal of the luma component S'_L[x, y] ,

  with x = 0..$PicWidthInSamples_L$, y = 0..$PicHeightInSamples_L$
- Samples of the prediction signal of the luma component S_{L_pred}[x, y] ,

  with x = 0..$PicWidthInSamples_L$, y = 0..$PicHeightInSamples_L$
- Samples of the quantized prediction error signal of the luma component S_{L_qpe}[x, y],

  with x = 0..$PicWidthInSamples_L$, y = 0..$PicHeightInSamples_L$

Output of this process are:

– Filtered samples pf[x, y], with x, y = 0..CuSize-1 as output

In a first step, the vertical filter process is performed as follows:

pf~~_tmp~~[x, y] =[~~∑ (~~∑ ∑ (c$_{L_ver}$[i,j] * S'$_L$[x+ox~~, y+oy~~+i-((AlfLengthLuma~~_ver~~-1)>>1~~)].)~~

~~+∑ (c$_{L_pred_ver}$[j] * S$_{L_pred}$ [x+ox,~~), y+~~-~~oy+j-((AlfLengthLuma~~_pred_ver~~-1)>>1)] ~~))~~]

~~+∑ (c$_{L_qpe_ver}$[k] * S$_{L_qpe}$ [x+ox, y+ oy+k-((AlfLengthLuma_qpe_ver-1)>>1)].)]~~

>> Alf_filter_precision_Luma~~_ver~~

with i = 0.. AlfLengthLuma~~_ver~~-1, j = 0.. AlfLengthLuma~~_pred_ver -1, k = 0.. AlfLengthLuma_qpe_ver~~ -1.

~~In a second step, the horizontal filter process is performed as follows:~~

~~pf[x, y] =[∑ (c$_{L_hor}$[i] * pf_tmp')~~

~~+∑ (c$_{L_pred_hor}$[j] * S$_{L_pred}$ [x+ox +j-((AlfLengthLuma_pred_hor-1)>>1), y+ oy].)~~

~~+∑ (c$_{L_qpe_hor}$[k] * S$_{L_qpe}$ [x+ox +k-((AlfLengthLuma_qpe_hor-1)>>1), y+ oy].)]~~

~~>> Alf_filter_precision_Luma_hor~~

~~with i = 0.. AlfLengthLuma_hor -1, j = 0.. AlfLengthLuma_pred_hor -1, k = 0.. AlfLengthLuma_qpe_hor -1.~~

~~The variable pf_tmp' is derived as follows:~~

- ~~If pf_tmp [x +j-((AlfLengthLuma_hor-1)>>1), y] is the result of the vertical filter process, then pf_tmp' is set to pf_tmp[x +j-((AlfLengthLuma_hor-1)>>1), y]~~
- ~~Otherwise (if pf_tmp[x +j-((AlfLengthLuma_hor-1)>>1), y] is not the result of the vertical filter process), then pf_tmp' is set to S'$_L$ [x +xo+j-((AlfLengthLuma_hor-1)>>1), y+yo]~~

6.5.2.3 Filter process for chroma samples

Inputs to this process are:

- Position (ox, oy)
- Samples of the reconstructed signal of the chroma component S'$_C$[x, y] ,

  with x = 0..PicWidthInSamples$_C$, y = 0..PicHeightInSamples$_C$
- Samples of the prediction signal of the chroma component S$_{C_pred}$[x, y] ,

  with x = 0..PicWidthInSamples$_C$, y = 0..PicHeightInSamples$_C$
- Samples of the quantized prediction error signal of the chroma component S$_{C_qpe}$[x, y],

  with x = 0..PicWidthInSamples$_C$, y = 0..PicHeightInSamples$_C$

Output of this process is:

- Filtered samples pf[x, y], with x, y = 0..CuSizeC-1 as output

In a first step, the vertical filter process is performed as follows:

pf_tmp[x, y] =[~~∑ (~~∑ ∑ (c$_{C_ver}$[i,j] * S'$_C$[x+ox~~, y+oy~~+i-((AlfLengthChroma~~_ver~~-1)>>1~~)].)~~

~~+∑ (c$_{C_pred_ver}$[j] * S$_{C_pred}$ [x+ox,~~), y+~~-~~oy+j-((AlfLengthChroma~~_pred_ver~~-1)>>1)] ~~))~~]

~~+∑ (c$_{C_qpe_ver}$[k] * S$_{C_qpe}$ [x+ox, y+ oy+k-((AlfLengthChroma_qpe_ver-1)>>1)].)]~~

>> Alf_filter_precision_Chroma~~_ver~~

with i = 0.. AlfLengthChroma~~_ver~~-1, j = 0.. AlfLengthChroma~~_pred_ver -1, k = 0.. AlfLengthChroma_qpe_ver~~ -1.

~~In a second step, the horizontal filter process is performed as follows:~~

~~pf[x, y] =[∑ (c$_{C_hor}$[i] * pf_tmp')~~

~~+∑ (c$_{C_pred_hor}$[j] * S$_{C_pred}$ [x+ox+j-((AlfLengthChroma_pred_hor-1)>>1), y+oy].)~~

~~+∑ ($e_{C_qpe_hor}$[k] * S_{C_qpe} [x+ ox+k -((AlfLengthChroma_qpe_hor-1)>>1), y+oy].)]~~

~~>> Alf_filter_precision_Chroma_hor~~

~~with i = 0.. AlfLengthChroma_hor -1, j = 0.. AlfLengthChroma_pred_hor-1, k = 0.. AlfLengthChroma_qpe_hor-1.~~

~~The variable pf_tmp' is derived as follows:~~

- ~~If pf_tmp [x +j -((AlfLengthChroma_hor-1)>>1), y] is the result of the vertical filter process, then pf_tmp' is set to pf_tmp[x +j -((AlfLengthChroma_hor-1)>>1), y]~~
- ~~Otherwise (if pf_tmp[x +j-((AlfLengthChroma _hor-1)>>1), y] is not the result of the vertical filter process), then pf_tmp' is set to S'$_C$ [x +xo+j -((AlfLengthChroma _hor-1)>>1), y+yo]~~

_[Ed.: the indices may need some refinement]

[Ed.: clipping to be added]

[3-Input-ALF is still missing]

7 Parsing Process

Inputs to this process are bits from the RBSP.
Outputs of this process are syntax element values.

7.1 VLC Parsing process for side information

[Ed.: first draft from A119]
Following ordered steps are specified:

1. The context variable, ctxID is derived (subclause 7.1.1).
2. The modeIdx variable is decoded and the variables related to prediction unit transform unit are computed (subclause 7.1.2).
3. For each one of the transform unit within the coding unit, the coded block pattern information is computed (subclause 7.1.3).

7.1.1 Derivation of ctxID for prediction unit mode

Input to this process is the slice tpye specified by slice_type. Output of this process is the context identification variable ctxID.

The ctxID variable is given as:

ctxID = 0 for slice_type == I_SLICE
ctxID = 1 for slice_type == P_SLICE
ctxID = 2 for slice_type == B_SLICE

7.1.2 VLC Parsing process for prediction unit mode

This process is invoked when entropy_coding_mode_flag is equal to 0.

The syntax element **mode_table_idx** is decoded using subclause 7.1.2.1. The variable modeIdx is decoded using subclause 7.1.2.2.

The modeIdx variable is used to decode the values of the following:

- pred_mode
- intra_split_flag
- inter_partitioning_idc
- ref_idx_l0
- inter_pred_idc
- split_transform_unit_flag

– PU_dQP_idx

[Ed.: more details to be further edited]

7.1.2.1 Parsing process for the mode_table_idx

Input to this process is context variable array modeTableVLC_idx.
The **mode_table_idx** syntax element is decoded from the bitstream using VLC table given by modeTableVLCTable[modeTableVLC_idx[ctxID]]. The values of VLC table array modeTableVLCTable is given in the below table

VLC table numbers for mode table

ctxID	modeTableVLCTable
0	0,0,5,5,5,5,2
1	5,5,5,5,5,5,2
2	5,5,5,5,5,5,2

After the **mode_table_idx** syntax element is decoded, modeTableVLC_idx [ctxID] is updated according to the following:

If (modeTableVLCTable [ctxID] < **mode_table_idx**)
    modeTableVLC_idx [ctxID] = modeTableVLCTable [ctxID] + 1
else if (modeTableVLCTable [ctxID] > **mode_table_idx**)
    modeTableVLC_idx [ctxID] = modeTableVLCTable [ctxID] – 1
if(modeTableVLCTable [ctxID] < 0)
    modeTableVLCTable [ctxID] = 0
else if(modeTableVLCTable [ctxID] > 6)
    modeTableVLCTable [ctxID] = 6

7.1.2.2 Derivation of modeIdx

The inputs to this process are context identification information ctxID and the two dimensional context list array modeTableIdxCtxList.
The modeIdx variable is derived from the **mode_table_idx** syntax element as follows:

modeTableIdx = modeTableIdxCtxList [idx][mode_table_idx]

The entries of the modeTableIdxCtxList are updated as follows:

modeTableIdx2 = max(0, mode_table_idx-1);
modeIdx2 = modeTableIdxCtxList [idx][modeTableIdx2]
modeTableIdxCtxList [ctxID][modeTableIdx2] = modeTableIdx
modeTableIdxCtxList [ctxID][mode _table_idx] = modeTableIdx2

The initial values of the modeTableIdxCtxList are defined as

[Ed.: size of context list array to be further defined]

modeTableIdxCtxList [idx][n] = n; n=0..127, idx = 0..2

7.1.3 VLC Parsing process for coded block pattern

[Ed: Initial draft]

This process is invoked when entropy_coding_mode_flag is equal to 0.

The syntax element **cbp_table_idx** is decoded using sublcause XX. The variable cbpIdx is decoded using subclause XX.

7.1.3.1 Parsing process for the cbp_table_idx

Input to this process is variable array cbpTableVLC_idx.

The **cbp_table_idx** syntax element is decoded from the bitstream using VLC table given by cbpTableVLCTable[cbpTableVLC_idx[ctxID]]. The values of the VLC table array cbpTableVLCTable is given in the below table.

VLC table numbers for cbp

ctxID	modeTableVLCTable
0	10,10,10,2,2,2,2,7
1	10,10, 6,6,6,6,7,7
2	10,10, 6,6,6,6,7,7

After the **cbp_table_idx** syntax element is decoded, cbpTableVLC_idx[ctxID] is updated according to the following:

If (cbpTableVLCTable [ctxID] < **cbp_table_idx**)
    cbpTableVLCTable _idx [ctxID] = cbpTableVLCTable [ctxID] + 1
else if (cbpTableVLCTable [ctxID] > **cbp_table_idx**)
    cbpTableVLCTable _idx [ctxID] = cbpTableVLCTable [ctxID] – 1
if(cbpTableVLCTable [ctxID] < 0)
    cbpTableVLCTable [ctxID] = 0
else if(cbpTableVLCTable [ctxID] > 7)
    cbpTableVLCTable [ctxID] = 7

7.1.3.1 Derivation of modeIdx

The inputs to this process are context identification information ctxID and the two dimensional context list array cbpTableIdxCtxList.
The cbpIdx variable is derived from the **cbp_table_idx** syntax element as follows:

cbpTableIdx = cbpTableIdxCtxList [idx][cbp_table_idx]

The entries of the cbpTableIdxCtxList are updated as follows:

cbpTableIdx2 = max(0, cbp_table_idx-1);
cbpIdx2 = modeTableIdxCtxList [idx][modeTableIdx2]
cbpTableIdxCtxList [ctxID][modeTableIdx2] = cbpTableIdx
cbpTableIdxCtxList [ctxID][mode _table_idx] = cbpTableIdx2

The initial values of the cbpTableIdxCtxList are defined as

```
cbpTableIdxCtxList[0] =
{14,7,3,11,1,0,4,2,9,12,6,10,13,5,8,30,31,62,15,46,28,34,22,35,41,33,39,17,18,
20,36,47,16,26,44,23,25,43,29,27,19,32,42,38,56,45,50,52,24,57,60,49,61,54,51,
58,55,40,59,37,21,48,53}

cbpTableIdxCtxList[1] =
{14,11,2,12,4,6,10,9,13,1,3,5,8,0,7,15,31,46,30,62,38,42,44,20,45,36,18,22,34,
27,41,25,43,28,29,26,47,40,21,19,52,16,60,37,61,32,23,58,17,24,54,39,33,35,59,
57,50,53,56,51,49,48,55}
```

```
cbpTableIdxCtxList[2] =
{14,11,2,12,4,6,10,9,13,1,3,5,8,0,7,15,31,46,30,62,38,42,44,20,45,36,18,22,34,
27,41,25,43,28,29,26,47,40,21,19,52,16,60,37,61,32,23,58,17,24,54,39,33,35,59,
57,50,53,56,51,49,48,55}
```

7.2 VLC Parsing process for transform coefficients

[Ed.: more editorial work needed in this section]
This process is invoked when entropy_coding_mode_flag is equal to 0.

Inputs to this process are bits from slice data, the index of the current transform unit tuIdx, the size of the current transform unit tuSize.

Output of this process is the list coeffLevel containing transform coefficient levels of the transform block with index tuIdx.

Let W,H equal to width and height of the transform unit indicated with tuIdx. The variable numTotalCoeff specifies the total coefficients in the transform unit block and it is set to WxH. The variable numCodedCoeffs specifies the number of coded coefficients and it is equal to 16 if tuSize equals to TU_4x4, otherwise the variable numCodedCoeffs is set to 64.

Let codedCoeffLevel is a one dimensional array with size equal to numCodedCoeffs.

Following ordered steps are specified:

1. All transform coefficient levels, with indices from 0 to numTotalCoeff - 1, in the list coeffLevel are set equal to 0.
2. All transform coefficient levels, with indices from 0 to numCodedCoeffs - 1, in the list codedCoeffLevel are set equal to 0.
3. The context variable, ctxID is derived (subclause 7.2.1).
4. The position and the level of the last non-zero transform coefficient in zigzag scan order are derived and the list codedCoeffLevel is updated (subclause 7.2.2).
5. The combined run and level information are derived in run mode coding and the list codedCoeffLevel is updated (see subclause in 7.2.3).
6. The remaining coefficient levels are calculated and the list codedCoeffLevel is updated (see subclause in 0)
7. The coeffLevel array is updated using codedCoeffLevel array as follows (see subclause in 7.2.1).

If tuSize > TU_ 16x16 and PredMode == MODE_INTRA, a single 8x8 coefficient block uvCoeffLevel is decoded for both of the chroma components. The decoded uvCoeffLevel are deinterleaved to uCoeffLevel and vCoeffLevel as follows:

```
for(i = 0; i<32;i++) {
        uCoeffLevel[i] = uvCoeffLevel[i*2];
        vCoeffLevel[i] = uvCoeffLevel[i*2+1];
}

for(i = 32; i<64;i++) {
        uCoeffLevel[i] = 0;
        vCoeffLevel[i] = 0;
 }
```

7.2.1 Derivation of ctxID for transform coefficients

Input to this process are prediction unit specified by the prediction unit index puIdx, transform unit size specified by tuSize. Output of this process is the context identification variable ctxID.

The ctxID variable is given where for tuSize = TU_4x4:
ctxID = 0 for tuSize == TU_4x4 and PredMode == MODE_INTRA

ctxID = 1 for tuSize == TU_4x4 and PredMode == MODE_INTER and slice_type == P_SLICE
ctxID = 2 for tuSize == TU_4x4 and PredMode == MODE_INTER and slice_type == B_SLICE

for other values of tuSize:
ctxID = 0 for U and UV blocks
ctxID = 1 for V blocks
ctxID = 2 for tuSize == TU_8x8 and PredMode == MODE_INTRA
ctxID = 3 for tuSize == TU_8x8 and PredMode == MODE_INTER and slice_type == P_SLICE
ctxID = 4 for tuSize == TU_8x8 and PredMode == MODE_INTER and slice_type == B_SLICE
ctxID = 5 for tuSize == TU_16x16 and PredMode == MODE_INTRA
ctxID = 6 for tuSize == TU_16x16 and PredMode == MODE_INTER and slice_type == P_SLICE
ctxID = 7 for tuSize == TU_16x16 and PredMode == MODE_INTER and slice_type == B_SLICE
ctxID = 8 for tuSize > TU_16x16 and PredMode == MODE_INTRA
ctxID = 9 for tuSize > TU_16x16 and PredMode == MODE_INTER and slice_type == P_SLICE
ctxID = 10 for tuSize> TU_16x16 and PredMode == MODE_INTER and slice_type == B_SLICE

7.2.2 Parsing process for the level and position of last non-zero coefficient

Inputs to this process are bits from slice data.
Output of this process is the updated list codedCoeffLevel containing transform coefficient levels of the last non-zero coefficient in zig-zag scan within the transform block, and the variable lastPos, indicating the position of the last non-zero coefficient.

The syntax element **last_pos_table_idx** is decoded using subclause 7.2.2.1. The variable lastPosIdx is derived using subclause 7.2.2.2. The variables lastPos and levelMagnitudeGreaterThanOneFlag are calculated as follows:

– If the variable tuSize is equal to TU_4x4, the variable lastPos is set to lastPosIdx%16 and the variable levelMagnitudeGreaterThanOneFlag is set to lastPosIdx>>4
– Otherwise, the variable lastPos is set to lastPosIdx%64 and the variable levelMagnitudeGreaterThanOneFlag is set to lastPosIdx>>6

The magnitude of the last non-zero coefficient, lastPosMag is calculated as follows:

– If levelMagnitudeGreaterThanOneFlag is set to 1, the last_pos_level syntax element is decoded from the bitstream and lastPosMag = last_pos_level
– If levelMagnitudeGreaterThanOneFlag is set to 0, lastPosMag variable is set to 1
– last_pos_sign syntax element is decoded from the bitstream. If the value of last_pos_sign is equal to 1, lastPosMag is set to -1* lastPosMag

The codedCoeffLevel array is updated as codedCoeffLevel[lastPos] = lastPosMag. The currPos variable is updated as currPos = lastPos

7.2.2.1 Parsing process for the position of last non-zero coefficient

Input to this process is context variable array lastPosVLC_idx.
The **last_pos_table_idx** syntax element is decoded from the bitstream using VLC table given by lpVLCTable[lastPosVLC_idx[ctxID]]. The values of VLC table array lpVLCTable is given in the below table

VLC table numbers for last non-zero coefficient

ctxID	lpVLCTable
0	[10,10,10,10, 2,2,2,7,9,9,9,9,9,4,4,4,4]
1	[10,10,10,10,10,2,9,9,9,9,9,9,9,4,4,4,4]
2	[2, 2, 2, 2, 2,7,7,7,7,7,7,7,7,7,4,4,4]
3	[2, 2, 2, 2, 7,7,7,7,7,7,7,7,7,7,7,7,4]
4	[2, 2, 2, 2, 7,7,7,7,7,7,7,7,7,7,7,7,4]
5	[10, 1, 2, 2, 2,2,7,7,7,7,9,9,9,4,4,4,4]
6	[10,10, 2, 2, 7,7,7,7,7,7,7,7,4,4,4,4,4]
7	[10,10, 2, 2, 7,7,7,7,7,7,7,7,4,4,4,4,4]
8	[2, 2, 2, 2, 7,7,7,7,7,7,7,7,7,7,7,7,4]
9	[2, 2, 2, 2, 7,7,7,7,7,7,7,7,7,7,7,7,4]

After the **last_pos_table_idx** syntax element is decoded, lastPosVLC_idx[ctxID] is updated according to the following:

If (lpVLCTable [ctxID] < **last_pos_table_idx**)

```
            lastPosVLC_idx[ ctxID ] = lpVLCTable [ ctxID ] + 1
    else if (lpVLCTable [ ctxID ] > last_pos_table_idx)
            lastPosVLC_idx[ ctxID ] = lpVLCTable [ctxID] – 1
    if( lpVLCTable[ ctxID ] < 0)
             lpVLCTable[ ctxID ] = 0
    else if( lpVLCTable[ ctxID ] > 16 )
            lpVLCTable[ ctxID ] = 16
```

7.2.2.2 Derivation of lastPosIdx

The input to this process are context identification information ctxID and the two dimensional context list array lastPosCtxList.
The lastPosIdx variable is derived from the **last_pos_table_idx** syntax element as follows:

```
lastPosIdx = lastPosCtxList[idx][ last_pos _table_idx]
```

The entries of the lastPosCtxList are updated as follows:

```
lastPosTableIdx2  =  max(0, last_pos _table_idx-1);
lastPosIdx2 = lastPosCtxList [idx][ lastPosTableIdx2]
lastPosCtxList[ctxID][ lastPosTableIdx2] = lastPosIdx
lastPosCtxList [ctxID][ last_pos _table_idx] = lastPosIdx2
```

Initial values of the lastPosCtxList are defined as:

for tuSize = TU_4x4:
    lastPosCtxList[idx][n] = n; n=0,31
for other tuSize values:

For idx = 5,6,7: lastPosCtxList[idx][n] = n; n=0,127

For idx = 0,1:
lastPosCtxList =
{0,2,1,4,7,3,6,11,13,9,18,22,19,17,8,10,20,24,28,27,21,26,38,42,37,31,23,12,16,33,30,44,45,49,46,36,57,50,55,47,39,43,35,75,66,56,60,58,54,70,63,29,77,87,69,48,51,64,71,65,80,85,76,94,5,15,14,34,52,25,41,72,74,53,59,81,82,68,40,62,95,127,89,84,67,73,126,79,125,93,90,61,32,124,123,83,86,122,88,78,121,92,91,120,119,118,117,116,115,114,113,112,111,110,109,108,107,106,105,104,103,102,101,100,99,98,97,96}

For idx=2:
lastPosCtxList =
{0,1,2,9,14,3,5,17,15,6,8,16,23,18,4,11,24,27,25,20,10,26,50,40,34,31,21,12,13,28,33,32,35,43,57,46,76,65,55,45,38,36,22,39,47,49,53,60,75,95,70,61,59,51,64,63,68,101,111,69,67,74,99,97,7,30,19,42,66,41,54,83,72,29,37,71,81,86,52,58,79,85,84,77,48,62,104,92,89,80,78,56,44,88,93,87,94,96,105,82,127,114,110,109,100,91,73,90,106,103,126,118,125,124,113,117,107,98,112,116,115,123,122,102,108,121,120,119}

For idx=3,4,8,9:
lastPosCtxList =
{0,3,1,4,6,5,12,16,7,2,10,14,15,17,8,13,22,21,18,20,19,37,35,30,26,24,23,11,9,27,29,28,31,38,45,57,71,50,41,36,34,32,25,33,39,40,44,55,79,90,62,46,49,42,54,53,63,87,94,60,64,74,86,95,43,58,52,51,65,66,67,76,59,47,56,61,73,81,69,72,88,84,78,75,70,77,98,85,83,82,92,68,48,91,97,93,100,102,106,112,127,110,107,104,96,101,80,89,103,109,117,113,126,125,124,116,105,99,108,115,114,123,122,121,111,120,119,118}

7.2.3 Parsing process for run mode decoding

Inputs to this process are bits from slice data, current coefficient position currPos, number of coded coefficients numCodedCoeff.
Output of this process is the updated list codedCoeffLevel.

While the variable runMode is equal to 1 and variable pos < numCodedCoeff, the codedCoeffLevel array is updated as follows:

– Variable vlcIdx is determined as follows:

```
if( (numCodedCoeff - 1) - i > 27 )
    vlcIdx = 3
else
    vlcIdx = runsVLCTable[ 63 - (maxNumCoeff-1)]
```

where runsVLCTable is a one dimensional array with values given as:

runsVLCTable = {8,0,0,5,5,5,5,5,5,5,6,6,6,6,6,6,6,6,6,6,6,6,6,6,6,6,6,7,7,7...}

– The syntax element is_level_one_run is decoded and variables run and isLevelOne are calculated using the below table.

Mapping from k, level, and run into codeNumber

		isLevelOne_run
currPos	isLevelOne	run = 0,1...
0	1	1,0
	0	2
1	1	2,1,0
	0	4,3
2	1	1,3,2,0
	0	4,6,5
3	1	2,1,3,4,0
	0	6,5,7,8
4	1	1,5,3,2,4,0
	0	6,10,8,7,9
5	1	1,2,6,5,3,4,0
	0	7,8,11,10,9,12
6	1	2,1,3,5,4,7,6,0
	0	9,8,10,12,11,13,14
7	1	1,5,4,2,3,6,8,7,0
	0	9,13,12,10,11,14,15,16
8	1	1,3,8,7,5,2,4,9,6,0
	0	10,12,16,15,14,11,13,18,17
9	1	1,2,5,10,9,7,3,4,11,6,0
	0	8,12,15,17,18,16,13,14,20,19
10	1	2,1,3,4,7,8,5,6,9,11,10,0
	0	13,12,14,15,17,18,16,19,20,22,21
11	1	1,4,3,2,5,7,6,8,10,11,12,9,0
	0	13,17,15,14,16,19,18,20,22,23,24,21
12	1	1,2,6,7,5,3,4,8,9,13,11,12,10,0
	0	14,16,18,21,19,15,17,20,22,26,23,24,25
13	1	1,2,4,8,9,7,6,3,5,12,14,13,11,10,0
	0	15,16,19,21,23,22,20,17,18,26,28,27,24,25
14	1	1,2,3,5,9,10,8,7,4,6,13,16,15,14,12,0
	0	11,17,18,20,22,24,23,26,19,21,27,30,29,25,28
15	1	1,2,3,4,5,8,10,7,6,9,11,13,18,15,16,12,0
	0	14,17,19,20,21,23,25,24,22,26,27,29,31,28,32,30
16	1	1,3,4,2,5,6,10,9,7,8,11,12,13,16,17,18,14,0
	0	15,19,22,20,21,24,26,25,23,27,32,29,28,30,33,34,31
17	1	1,2,4,7,6,3,5,8,9,10,11,18,15,13,14,17,19,12,0
	0	16,21,24,25,26,20,22,27,23,28,30,35,31,29,34,33,36,32
18	1	1,2,5,7,9,10,6,3,4,8,11,17,20,18,15,13,14,19,12,0
	0	16,21,24,25,29,28,27,23,22,26,31,36,34,37,33,32,30,38,35
19	1	1,3,5,7,9,14,12,8,6,2,4,15,18,21,20,16,10,11,22,13,0

	0	17,23,25,27,29,31,33,30,26,19,24,35,37,39,40,36,32,28,38,34
20	1	0,2,4,7,10,9,16,15,14,8,3,5,17,19,22,20,18,11,13,21,12
	0	6,23,25,29,27,31,30,34,38,32,24,26,36,82,39,37,83,28,33,84,35
21	1	2,1,3,4,5,8,9,11,13,10,6,7,12,14,21,24,23,18,15,19,22,16,0
	0	20,17,25,26,27,28,31,34,35,30,29,32,33,36,37,43,44,38,39,40,41,42
22	1	1,5,4,2,3,6,8,7,11,12,9,10,13,14,15,18,22,21,17,19,20,25,16,0
	0	26,28,27,23,24,29,31,32,38,34,30,33,35,37,36,43,44,40,41,85,42,86,39
23	1	1,4,8,6,5,2,3,7,9,12,10,11,13,16,15,14,18,20,21,19,23,22,25,17,0
	0	24,28,33,29,31,26,27,34,35,36,32,30,37,40,38,42,45,47,39,43,46,41,87,44
24	1	0,3,7,12,10,6,5,2,4,8,9,11,13,17,24,21,16,15,19,20,22,25,26,23,18,1
	0	14,28,34,36,33,35,31,27,30,29,32,37,40,46,38,44,39,47,48,49,45,41,42,50,43
25	1	0,2,5,9,13,11,10,8,6,3,4,7,12,15,19,26,23,20,16,14,18,22,27,24,25,21,1
	0	17,28,31,36,35,39,37,34,33,30,29,32,38,43,86,87,45,46,44,41,40,88,48,89,47,42
26	1	1,2,4,7,11,15,12,9,10,8,5,3,6,14,16,23,24,25,21,20,13,19,27,28,26,22,17,0
	0	18,29,31,33,39,36,35,38,41,40,34,30,32,43,48,53,90,49,42,50,37,44,51,47,52,45,46
27	1	0,2,3,5,7,11,15,14,12,10,13,8,4,9,17,19,22,24,26,21,23,16,20,29,30,28,25,18,1
	0	6,27,31,33,34,38,39,37,40,42,41,35,32,36,44,45,87,48,88,49,46,89,43,47,90,50,51,91
>=28	1	0,1,2,3,4,5,7,9,10,13,8,12,11,6,14,15,18,20,24,31,32,30,28,26,22,25,33,37,38,17,19,21,23,29,36,34,45,40, 43,42,44,39,35,46,48,53,54,51,61,62,67,66,68,65,73,74,71,69,86,82,90,88,98,94
	0	16,27,41,47,50,57,58,60,59,55,52,63,56,49,64,70,72,77,76,80,84,81,79,78,75,83,85,87,91,95,92,104,89,93,96,99,100,102,101,97,105,103,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126

- The magnitude of non-zero coefficient is given as level and is calculated as follows:
  - If the variable isLevelOne is equal to 1, the level_sign is decoded from the bitstream. If the value of level_sign is equal to 1, the variable level is set to -1. If the value of level_sign is equal to 0, the variable level is set to 1.
  - Otherwise, if the variable isLevelOne is equal to 0, the level_magnitude_minus2 and level_sign syntax elements are decoded from the bitstream. If the value of level_sign is equal to 0, the value of level is set to level_magnitude_minus2 + 2. Otherwise, the value of level is set to -1*(level_magnitude_minus2+2)
- The codedCoeffLevel array is updated as codedCoeffLevel [currPos] = level
- The variable currPos is updated as currPos = currPos - run
- The variable runMode is calculated as follows:

```
runMode = 1
if (tuSize == TU_4x4 || PredMode == MODE_INTRA)
    runMode == (isLevelOne)
else if(currPos < 14 || sumBigCoef > 2)
    runMode = 0
```

where the variable sumBigCoef is calculated as:

```
for(i = currPos; i < 64; i++) {
    sumBigCoef += ( Abs(codedCoeffLevel [ i ] ) > 1 ? Abs(codedCoeffLevel [ i ] ) : 0 );
```

7.2.4 Parsing process for level mode decoding

Inputs to this process are bits from slice data, a maximum number of non-zero transform coefficient levels, maxCoeff, current coefficient position currPos.

Output of this process is the updated list codedCoeffLevel.

The variable vlcMagIdx is initialized to 0.

While the variable currPos is larger than -1, the codedCoeffLevel array is updated as follows:

- The level_magnitude syntax element is decoded from the bitstream
- The codedCoeffLevel [currPos] is updated as follows:
  - If the level_magnitude is not equal to 0, the level_sign is decoded from the bitstream. If the value of level_sign is equal to 1, the variable codedCoeffLevel [currPos] is set to -1*level_magnitude. If the value of level_sign is equal to 0, the variable codedCoeffLevel [0] is set to level_magnitude.
- The variable currPos is updated as currPos - 1.
- The variable vlcMagIdx is updated as follows:

```
if (level_magnitude > vlc_level_table [ vlcMagIdx ] )
    vlcMagIdx++;
```

The one dimensional vlc_level_table array is given as

VLC Table Index for Decoding Level

x	vlc_level_table[x]
0	4
1	6
2	14
3	28
4	∞

The codedCoeffLevel [0] is updates as follows:

– If the PredMode == MODE_INTRA and none of the prediction samples are available for prediction (subclause 6.2.1.2) the level_magnitude syntax element is decoded from the bitstream using the VLC table given with the variable dcVLC_id. The variable dcVLC_id is equal to 3 if the decoded block is a luminance block, otherwise dcVLC_id is equal to 1.
– If the level_magnitude is not equal to 0, the level_sign is decoded from the bitstream. If the value of level_sign is equal to 1, the variable codedCoeffLevel [0] is set to -1*level_magnitude. If the value of level_sign is equal to 0, the variable codedCoeffLevel [0] is set to level_magnitude.

7.2.1 Update process for coeffLevel array

Inputs to this process are one dimensional coded coefficient levels array codedCoeffLevel, one dimensional transform coefficient levels array coeffLevel, number of total coefficients numTotalCoeff and number of total coded coefficients, numCodedCoeffs.

If the tuSize is larger than TU_8x8 the following ordered steps are specified

1. The inverse scanning process for the transform coefficients as described specified in subclause 6.4.3 is invoked with codedCoeffLevel as the input and the two-dimensional array ccl as the output.
2. The inverse scanning process for the transform coefficients as described specified in subclause 6.4.3 is invoked with coeffLevel as the input and the two-dimensional array cl as the output.
3. The two dimensional array cl is updated as follows
   cl[i, j] = ccl[i,j], with i = 0..7, j = 0..7
4. The forward scanning process for the transform coefficients as described in subclause 7.2.2 is invoked with cl as input and coeffLevel as output

Otherwise, if tuSize is smaller than or equal to TU_4x4 the coefficient level array is updated as follows

coeffLevel[i] = codedCoeffLevel[i] , with i = 0.. numCodedCoeffs-1

7.2.2 Forward scanning process for transform coefficients

Input to this process is a list of N values listTrCoeffs.

Output of this process is a variable c containing a one dimensional array of N values.

The variable c_{ij} which is located in the (j, i) position in the array c is derived as follows.

c_{ij} = BlocktoZigzagPosition(listTrCoeffs, N, idx).

7.3 VLC Tables

n = 0	n = 1	n = 2	n = 3	n = 4	n = 5	n = 6	n = 7	n = 8	n = 9	n = 10
1	1x	1xx	1xxx	1xxxx	1x	1xx	1xxx	1	100	1
01	01x	01xx	01xxx	01xxxx	01x	01xx	01xxx	01	1010	01x
001	001x	001xx	001xxx	001xxxx	001x	001xx	001xxx	00	1011	001xx

0001	0001x	0001xx	0001xxx	0001xxxx	..	..	..		11xxx	0001xxx
00001	00001x	00001xx	00001xxx	00001xxxx					01xxxx	..
0000001	0000001x	0000001xx	0000001xxx	0000001xxxx					001xxxx	
00000001	00000001x	00000001xx	00000001xxx	00000001xxxx					..	
000000001x	000000001xx	000000001xxx	000000001xxxx	000000001xxxxx						
0000000001xx	0000000001xxx	0000000001xxxx	0000000001xxxxx	0000000001xxxxxx						
..	..	..	..	..						

The tables list the codes for code number 0,1,2,3..etc. However, for a more compact description most of the entries in the table ends with a number of "x" -es. As an example 1xx in VLC table 2 represents 4 codes with code numbers 0-3:

100

101

110

111

Generally the code numbers increase in the same way as the natural number representation of the codes increase. The symbol ".." in the tables indicate that the tables continue in the obvious way.

7.4 Parsing process for Exp-Golomb codes of order k

This process is invoked when the descriptor of a syntax element in the syntax tables is equal to ge(v).
Inputs to this process are bits from the RBSP.
Outputs of this process are syntax element values.
Syntax elements coded as ge(v) are Exp-Golomb-coded of order k. The parsing process for these syntax elements begins with reading the bits starting at the current location in the bitstream up to and including the first non-zero bit, counting k bits, and sign bit if available. This process is specified as follows:

```
q = -1, nr = 0, m = pow(2.0, k)
uiSymbol = 1;
while (uiSymbol)
{
   uiSymbol    = read_bits (uiSymbol)
   q++;
}
for(a = 0; a < k; ++a)
{
   uiSymbol    = read_bits (uiSymbol)
   if(uiSymbol) nr += 1 << a
}
nr += q * m
if (nr != 0){
   uiSymbol    = read_bits (uiSymbol)
   codeNum = (uiSymbol)? nr: -nr;
}
```

7.5 PIPE parsing process

[Ed. Need more details.]

The parsing process specified in this subclause is used when entropy_coding_mode_flag is equal to 1.

The PIPE entropy coding consists of three stages:

– binarization,

– context modelling,

– binary entropy coding.

The stages of binarization and context modelling are the same as in H.264/AVC and are specified in clause 9 of ITU-T Rec. H.264 | ISO/IEC 14496-10. [Ed. Need to specify binarization and context determination for all syntax elements]

The decoding of the binary decisions (bins) proceeds as follows:

– If pipe_multi_codeword_flag is equal to 1 and balanced_cpus is equal to 1, the multi-partition parsing process as specified in subclause 7.5.1 is invoked.

– Otherwise, if pipe-multi_codeword_flag is equal to 1 and balanced_cpus >1, the multi-partition parsing process with load balancing as specified in subclause 7.5.2 is invoked.

– Otherwise, if pipe_max_delay_in_bits_shift_6 is equal to 0, the interleaved parsing process for binary decisions as specified in subclause ~~7.5.2~~7.5.3 is invoked.

– Otherwise, the interleaved parsing process for binary decisions with a delay constraint as specified in subclause 7.5.4~~7.5.3~~7.5.4 is invoked.

The decoded syntax elements are determined based on the binarization schemes and the decoded binary decisions as specified in clause 9 of ITU-T Rec. H.264 | ISO/IEC 14496-10. [Ed. Need more details.]

The PIPE parsing process for transform coefficient levels is specified in subclause 7.6.

7.5.1 Multi-partition parsing process for binary decisions

The V2V codewords for each probability partition, given by probPartIdx, are coded in separate NAL unit partitions.

The first bit for each partition, with partition index probPartIxd, is given by the variable pipe_partition_start[probPartIdx] as specified in subclause 5.1.12 and the size of each partition is given by the variable pipe_partition_size[probPartIdx] as specified in subclause 5.1.12.

The binary decisions are decoded as follows.

Let binDecisions[probPartIdx] be 12 bin buffers, with probPartIdx 0..11, inclusive, which are empty at the beginning of the parsing process for a slices.

With probPartIdx proceeding over 0..11, inclusive, the following applies.

– The variable bitCounter is set equal to pipe_partition_start[probPartIdx].

– The variable numBitsRead is set equal to 0.

– While numBitsRead is less than pipe_partition_size[probPartIdx], the following applies.

  – The next codeword is read from the bitstream at position bitCounter. The ~~VLC~~ V2V table that is used is specified in subclause 7.7 given the value of probPartIdx.

  – The variable bitCounter is incremented by the number of bits in the read codeword.

  – The codeword is converted into a bin sequence as specified in the V2V table of subclause 7.7 that is given the value of probPartIdx.

  – The bin sequence is inserted at the end of the bin buffer binDecisions[probPartIdx]

A requested binary decision (given by the binarization scheme and the context modelling) with a context (pStateIdx, pMPSval) is decoded as follows:

– The variable probPartIdx is determined as specified in Table 7-1~~Table 7-1~~~~Table 7-1~~ given the value of pStateIdx.

– The first bin pBin is removed from the bit buffer binDecisions[probPartIdx].

– The value of the decoded bin is set equal to pBin ^ pMPSval, where "^" specifies the xor operator.

7.5.2 Multi-partition parsing process with load balancing for binary decision

To make use of multiple bin decoders for parallel entropy decoding, the starting posititions balancedPartStart[blancedPartIdx], balancedPartIdx=0, 1, …, balanced_cpus-1, of individually decodeable partial bitstreams of the encoded bitstream is first determined as follows.

Step 1: Calculate uiNumOverallBits = variable pipe_partition_size[0]+ variable pipe_partition_size[1]+…+ variable pipe_partition_size[11];
Step 2: Set balancedPartStart[0] = 0. The following loop determines the remaining starting positions and the size balancedPartSize[balancedPartIdx] of each partial bitstream.

```
for (balancedPartIdx =0; balancedPartIdx < balanced_cpus-1; balancedPartIdx++)
{
        balancedPartSize[balancedPartIdx] = uiNumOverallBits/balanced_cpus;
        balancedPartSize[balancedPartIdx] += balanced_offsets[balancedPartIdx];
        balancedPartStart[balancedPartIdx+1] = balancedPartStart[balancedPartIdx]+balancedPartSize[balancedPartIdx];
}
balancedPartSize[balancedPartIdx] = unNumOverallBits – balancedPartStart[balancedPartIdx];
```

In parallel to the decoding of the other partial bitstreams, the partial bitstream starting at balancedPartStart[balancedPartIdx], where 0 ≤ balancedPartIdx < balanced_cpus can be decoded follows.

Let partBinDecisions[balancedPartIdx] be 12 bin buffers which are empty at the beginning of the parsing process for a slice. For probPartIdx=0,..., 11, do the following.

- If pipe_partition_start[probPartIdx] >= balancedPartStart[balancedPartIdx]+ balancedPartSize[balancedPartIdx], stop.
- Otherwise, if pipe_partition_start[probPartIdx] < balancedPartStart[balancedPartIdx]- pipe_partition_size[probPartIdx], continue to the next probPartIdx.
- Otherwise, do the following
  - set the variable bitCounter to max(pipe_partition_start[probPartIdx], balancedPartStart[balancedPartIdx]).
  - set the variable numBitsRead to bitCounter- pipe_partition_start[probPartIdx].
  - While numBitsRead is less than pipe_partition_size [probPartIdx], the following applies.
    - The next codeword is read from the bitstream at position bitCounter. The V2V table that is used is specified in subclause 7.7 given the value of probPartIdx.
    - The variable bitCounter is incremented by the number of bits in the read codeword. The codeword is converted into a bin sequence as specified in the V2V table of subclause 7.7 that is given the value of probPartIdx.
    - The bin sequence is inserted at the end of the bin buffer partBinDecisions[balancedPartIdx][probPartIdx].

After all partBinDecisions are decoded, they are concatenated to form binDecisions as follows.
For probPartIdx=0, …, 11, do the following.

- Initialize binDecisions[probPartIdx] as empty.
- For balancedPartIdx=0,…,balanced_cpus, do the following.
  - Insert partBinDecisions[balancedPartIdx][probPartIdx] at the end of binDecisions[probPartIdx].

With binDecisions, a requested binary decision (given by the binarization scheme and the context modelling) with a context (pStateIdx, pMPSval) is decoded as described at the end of subclause 7.5.1 above.

~~7.5.2~~7.5.3 Interleaved parsing process for binary decisions

The V2V codewords for the 12 probability partitions are interleaved in a single NAL unit partition.

Let binBuffer[probPartIdx] be 12 bin buffers, with probPartIdx 0..11, inclusive, which are empty at the beginning of the parsing process for a slices.

A requested binary decision (given by the binarization scheme and the context modelling) with a context (pStateIdx, pMPSval) is decoded as follows:

- The variable probPartIdx is determined as specified in Table 7-1~~Table 7-1Table 7-1~~ given the value of pStateIdx.
- When the binBuffer[probPartIdx] is empty, the following applies.
  - The next codeword is read from the bitstream. The ~~VLC~~ V2V table that is used is specified in subclause 7.7 given the value of probPartIdx.
  - The codeword is converted into a bin sequence as specified in the V2V table of subclause 7.7 that is given the value of probPartIdx.
  - The bin sequence is inserted in the bin buffer binBuffer[probPartIdx].
- The first bin pBin is removed from the bit buffer binBuffer[probPartIdx].
- The value of the decoded bin is set equal to pBin ^ pMPSval, where "^" specifies the xor operator.

~~7.5.3~~7.5.4 Interleaved parsing process for binary decisions with a delay constraint

The V2V codewords for the 12 probability partitions are interleaved in a single NAL unit partition. In addition, the decoding process takes into account a delay constraint. The maximum delay in bits is specified by the syntax element pipe_max_delay_in_bits_shift_6.

Let binBuffer[probPartIdx] be 12 bin buffers, with probPartIdx 0..11, inclusive, which are empty at the beginning of the parsing process for a slices.

Let maxDelayCountSum be a variable that is initially set equal to 0. Let maxDelayCount[probPartIdx] be 12 variables, with probPartIdx 0..11, inclusive, that are initially set equal to 0.

A requested binary decision (given by the binarization scheme and the context modelling) with a context (pStateIdx, pMPSval) is decoded as follows:

- The variable probPartIdx is determined as specified in Table 7-1~~Table 7-1Table 7-1~~ given the value of pStateIdx.
- When maxDelayCountSum − maxDelayCount[probPartIdx] is greater than pipe_max_delay_in_bits_shift_6 * 32, the bin buffer binBuffer[probPartIdx] is emptied (i.e., all bins are removed).
- When the binBuffer[probPartIdx] is empty, the following applies.
  - The next codeword is read from the bitstream. The ~~VLC~~ V2V table that is used is specified in subclause 7.7 given the value of probPartIdx.
  - The codeword is converted into a bin sequence as specified in the V2V table of subclause 7.7 that is given the value of probPartIdx.
  - The bin sequence is inserted in the bin buffer binBuffer[probPartIdx].
  - Let maxNumBits the number of bits of the longest codeword in the codeword tables given by pStateIdx as specified in subclause 7.7.
  - The counter maxDelayCountSum is increased by maxNumBits.
  - The counter maxDelayCount[probPartIdx] is set equal to maxDelayCountSum.
- The first bin pBin is removed from the bit buffer binBuffer[probPartIdx].
- The value of the decoded bin is set equal to pBin ^ pMPSval, where "^" specifies the xor operator.

7.6 PIPE Parsing process for transform coefficients

[Ed. Needs better specification. The current specification is unsuitable for a standard.]

Transform coefficient levels are parsed in two steps like in CABAC of H.264/AVC. In the first step, the significance map specifies the locations of significant coefficient levels are parsed. The second step parsed the absolute coefficient levels (minus one) and the sign for each significant coefficient position.

7.6.1 Parsing process for significant coefficient positions

The parsing process of significance map based on an adaptive scan and context modeling depends on already parsed neighbours. The scanning order for coding the significance map is adapted by switching between two predefined scan patterns as illustrated in Fig. 2. For the first scanning pattern, the diagonal sub-scans are scanned from bottom-left to top-right (left illustration of Fig. 2), and for the second scanning pattern, the diagonal sub-scans are scanned from top-right to bottom-left (right illustration of Fig. 2).

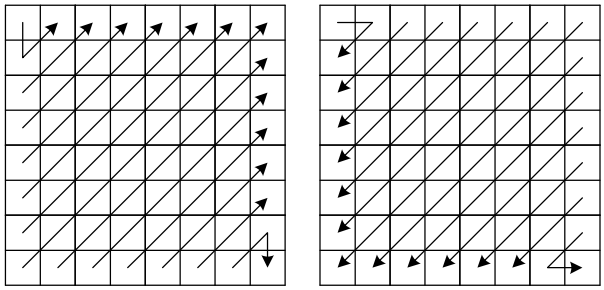


Figure 2: Scanning patterns for significance map

The parsing of the significance map starts with the second scanning pattern. While parsing the syntax elements, the number of significant transform coefficient values is counted by two counters c_1 and c_2. The first counter c_1 counts the number of significant transform coefficients that are located in the bottom-left part of the transform block; i.e., this counter is incremented by one when a significant transform coefficient level is parsed for which the horizontal coordinate x inside the transform block is less than the vertical coordinate y. The second counter c_2 counts the number of significant transform coefficients that are located in the top-right part of the transform block; i.e., this counter is incremented by one when a significant transform coefficient level is parsed for which the horizontal coordinate x inside the transform block is greater than the vertical coordinate y. At the end of each diagonal sub-scan, it is decided whether the first or the second of the predefined scanning patterns is used for the next diagonal sub-scan. This decision is based on the values of the counters c_1 and c_2. When the counter for the bottom-left part of the transform block is greater than the counter for the bottom-left part, the scanning pattern that scans the diagonal sub-scans from bottom-left to top-right is used; otherwise (the counter for the bottom-left part of the transform block is less than or equal to the counter for the bottom-left part), the scanning pattern that scans the diagonal sub-scans from topright to bottom-left is used.

For 4x4 blocks, the context modeling for the syntax elements significant_coeff_flag is done as specified in AVC. For 8x8 blocks, the transform block is decomposed into 16 sub-blocks of 2x2 samples, and each of these sub-blocks is associated with a separate context. The context model selection for larger transform blocks (e.g., for blocks greater than 8x8) is based on the number of already parsed significant transform coefficients in a predefined neighborhood (inside the transform block). Following evaluation is made for this case, where ctxIdx specifies the context model index for the syntax element significant_coeff_flag, and ctxInc is a temporal counter init by zero:

- Scan position lies inside first 2x2 sub-block
  - ctxIdx = (posY << 1) + posX
- Scan position lies on the top border
  - ctxInc += significant_coeff_flag[x-1, y] ? 1 : 0

- ctxInc += significant_coeff_flag[x-2, y] ? 1 : 0
- ctxInc += significant_coeff_flag[x-2,y+1] ? 1 : 0
- if selected scanPattern=0 (fist scan pattern)
  - ctxInc += significant_coeff_flag[x-1,y+1] ? 1 : 0
- ctxIdx = 4 + ((ctxInc + 1) >> 1)

- Scan position lies on the left border
  - ctxInc += significant_coeff_flag[x, y-1] ? 1 : 0
  - ctxInc += significant_coeff_flag[x, y-2] ? 1 : 0
  - ctxInc += significant_coeff_flag[x+1, y-2] ? 1 : 0
  - if selected scanPattern=1
    - ctxInc += significant_coeff_flag[x+1, y-1] ? 1 : 0
  - uiIdx = 7 + ((ctxInc + 1) >> 1)
- Scan position lies inside the transform block
  - ctxInc += significant_coeff_flag[x, y-1] ? 1 : 0
  - ctxInc += significant_coeff_flag[x-1, y] ? 1 : 0
  - ctxInc += significant_coeff_flag[x-1, y-1] ? 1 : 0
  - if x > 1
    - ctxInc += significant_coeff_flag[x-2, y] ? 1 : 0
    - ctxInc += significant_coeff_flag[x-2, y-1] ? 1 : 0
    - if y < tuSize – 1
      - ctxInc += significant_coeff_flag[x-2, y+1] ? 1 : 0
  - if y > 1
    - ctxInc += significant_coeff_flag[x, y-2] ? 1 : 0
    - ctxInc += significant_coeff_flag[x-1, y-2] ? 1 : 0
    - if x < tuSize – 1
      - ctxInc += significant_coeff_flag[x+1, y-2] ? 1 : 0
    - if scanPattern = 1
      - if x < tuSize – 1
        - ctxInc += significant_coeff_flag[x+1, y-1] ? 1 : 0
    - else
      - if y < tuSize – 1
        - ctxInc += significant_coeff_flag[x-1, y+1] ? 1 : 0
  - ctxIdx = 10 + min(4, (ctxInc + 1) >> 1)

For coding of the last_significant_coeff_flag, the context modeling has been designed that depends on a distance measure of the current scan position to the top-left corner of the given transform block. The context model for coding the last_significant_coeff_flag is chosen based on the scan diagonal on which the current scan position lies. The distance measure x + y is mapped on a reduced set of context models. Given x, y and the block size, the ctxIdx is derived by following formula:

- Blocksize is 4x4
  - Same context selection like in AVC CABAC
- Blocksize is larger than 4x4
  - ctxIdx = (x + y) >> (Log2(tuSize) - 3)

7.6.2 Parsing process for the absolute level and sign

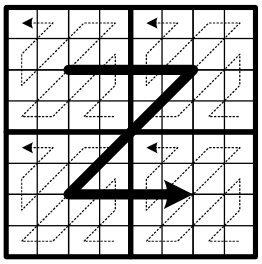


Figure 3: Scan pattern for coefficient levels

For 4x4 blocks, the context modeling process for coefficient levels is done as specified in AVC. For blocks larger than 4x4, the coding process for absolute transform coefficient levels maps each quadratic (or rectangular) block onto an ordered set (vector) of 4x4 sub-blocks by using a forward zig-zag scan; while the transform coefficient levels inside a sub-block are processed in a reverse zig-zag scan as illustrated in Fig. 3. The handling of context model selection for 4x4 blocks is the same like in AVC CABAC. In AVC CABAC, five context models are used for the syntax element coeff_abs_greater_one and another five context models for the syntax element coeff_abs_level_m2. The syntax element coeff_level_sign is bypassed. Following, the context selection of AVC CABAC for a 4x4 is summarized:

- coeff_abs_greater_one
  - if first scan position
    - ctxIdx = 1
  - if previous coeff_abs_greater_one = 0
    - if ctxIdx > 0
      - ctxIdx = min(ctxIdx++, 4)
  - else
    - ctxIdx = 0
- coeff_abs_level_m2
  - ctxIdx = 0
  - if coeff_abs_greater_one = 1
    - ctxIdx++

The number context models is extended resulting in 30 context models for coeff_abs_greater_one and another 30 context models for coeff_abs_level_m2. An offset is selected for each sub-blocks, while the context model selection inside a sub-block is the same like 4x4 blocks in AVC CABAC resulting in a limitation of context selection to [offset, offset+5]. The choice of the offset for both syntax elements for a sub-block depends on the number of absolute coefficient levels greater than one in the previous sub-block, where empty sub-blocks are skipped. For the first sub-block, the the offset is 20. For 4x4 blocks, the offset is zero. For all other sub-blocks, following offset mapping is used, where the index of the array is the number of coefficient levels greater than one in the previous sub-block (where empty sub-blocks are skipped):

- offset = [5, 5, 5, 5, 10, 10, 10, 10, 15, 15, 15, 15, 20, 20, 20, 20, 25]

7.7 PIPE tables

Table 7-1~~Table 7-1Table 7-1~~ specifies that mapping of a context state (given by a variable pStateIdx) to a probability partition index probPartIdx.

Table 7-2~~Table 7-2Table 7-2~~ to Table 7-13~~Table 7-13Table 7-13~~ specify the V2V codes for the probability partition indices 0 to 11, inclusive. The tables show a mapping from a bin sequence with a variable number of bins to variable-length codewords and vice versa.

Table 7-1 Mapping of the variable pStateIdx to the variable probPartIdx

probPartIdx	pStateIdx
0	0..1
1	2
2	3..4
3	5..6
4	7..9
5	10..12
6	13..16
7	17..20
8	21..28
9	29..39

10	40..55
11	56..63

Table 7-2 V2V mapping for probPartIdx = 0

bin sequence	codeword
0	0
1	1

Table 7-3 V2V mapping for probPartIdx = 1

bin sequence	codeword
10	10
01	11
001	010
110	011
000 11	001 01
000 000	001 10
111 00	001 11
000 011	000 100
000 101	000 101
111 11	000 110
000 010 0	000 111
000 001 0	001 000
000 100 0	001 001
000 010 1	000 000 1
000 100 1	000 001 0
000 001 1	000 001 1
111 011	000 010 0
111 101	000 010 1
111 010 0	000 011 0
111 100 0	000 011 1
111 010 1	000 000 00
111 100 1	000 000 01

Table 7-4 V2V mapping for probPartIdx = 2

bin sequence	codeword
10	10
01	11
001	011
000 00	010 0
110 0	010 1
000 11	000 11
111 1	001 00
000 100	001 01
000 010	001 10
111 00	001 11
000 101	000 010
110 11	000 011
111 01	000 100
110 100	000 101
000 011 1	000 000 1
000 011 00	000 001 0
110 101 0	000 001 1
000 011 01	000 000 00
110 101 1	000 000 01

Table 7-5 V2V mapping for probPartIdx = 3

bin sequence	codeword
10	10

01	11
001	010
000 0	011
111	001 0
110 0	001 1
000 11	000 10
000 100	000 11
110 11	000 010
110 100	000 011
000 101 1	000 001 0
000 101 00	000 001 1
110 101 1	000 000 10
110 101 00	000 000 11
000 101 011	000 000 010
000 101 010 0	000 000 011
110 101 011	000 000 000 1
110 101 010 0	000 000 001 0
000 101 010 10	000 000 001 1
110 101 010 1	000 000 000 00
000 101 010 11	000 000 000 01

Table 7-6 V2V mapping for probPartIdx = 4

bin sequence	codeword
000 00	110
11	111
000 10	011 0
000 01	011 1
100 00	100 0
010 00	100 1
001 00	101 0
101 0	101 1
000 11	000 10
011 00	000 11
001 10	001 00
001 01	001 01
010 01	001 10
010 10	001 11
100 01	010 00
100 10	010 01
011 1	010 10
101 1	010 11
011 01	000 000
001 11	000 001
010 11	000 010
100 11	000 011

Table 7-7 V2V mapping for probPartIdx = 5

bin sequence	codeword
00	1
010 00	001 1
100 00	010 0
011	010 1
101	011 0
110	011 1
010 10	000 01
010 01	000 10
100 01	000 10
100 10	001 00

111	001 01
010 11	000 000
100 11	000 001

Table 7-8 V2V mapping for probPartIdx = 6

bin sequence	codeword
1	11
010	100
000 000 0	101
001 000	010 0
000 010	101 1
000 100	011 0
000 001	011 1
011 0	000 11
000 000 10	001 00
001 10	001 01
001 01	001 10
000 11	001 11
001 001 0	000 010
000 101 0	000 011
000 011 0	000 100
011 1	001 101
001 11	000 001 0
000 000 110	000 001 1
001 001 1	000 000 00
000 101 1	000 000 01
000 011 1	000 000 10
000 000 111	000 000 11

Table 7-9 V2V mapping for probPartIdx = 7

bin sequence	codeword
000	1
010	001
100	010
001	011
110 0	000 10
011 0	000 11
101 000 0	000 011
111 0	000 001 0
011 1	000 001 1
110 1	000 010 0
101 1	000 010 1
101 001	000 000 01
101 000 1	000 000 10
101 010 0	000 000 11
111 1	000 000 001
101 011	000 000 000 0
101 010 1	000 000 000 1

Table 7-10 V2V mapping for probPartIdx = 8

bin sequence	codeword
000 0	1
10	010
010	011
000 100	001 0
001 000	001 1
000 11	000 011
001 01	000 100

001 10	000 101
011 00	000 110
110 00	000 111
000 101 00	000 010 0
001 001 00	000 010 1
111	000 000 10
011 1	000 000 11
110 1	000 001 00
001 11	000 001 01
011 01	000 001 10
110 01	000 001 11
000 101 1	000 000 000
001 001 1	000 000 001
000 101 01	000 000 010
001 001 01	000 000 011

Table 7-11 V2V mapping for probPartIdx = 9

bin sequence	codeword
000 000 00	1
100	001 0
010	001 1
001 0	010 0
000 1	010 1
000 01	011 0
000 001	011 1
000 000 100 00	000 10
000 000 010 000	000 11
11	000 010 0
011	000 010 1
101	000 011 0
001 1	000 011 1
000 000 11	000 000 00
000 000 101	000 000 01
000 000 011	000 000 10
000 000 100 1	000 000 11
000 000 010 1	000 001 00
000 000 100 01	000 001 01
000 000 010 01	000 001 10
000 000 010 001	000 001 11

Table 7-12 V2V mapping for probPartIdx = 10

bin sequence	codeword
000 000 000 000 000 00	1
1	000 01
01	000 10
001	000 11
000 1	001 00
000 01	001 01
000 001	001 10
000 000 1	001 11
000 000 01	010 00
000 000 001	010 01
000 000 000 1	010 10
000 000 000 01	010 11
000 000 000 001	011 00
000 000 000 000 1	011 01
000 000 000 000 01	011 10
000 000 000 000 001	011 11

000 000 000 000 000 1	000 000
000 000 000 000 000 01	000 001

Table 7-13 V2V mapping for probPartIdx = 11

bin sequence	codeword
000 000 000 000 000 000 000 000 000 000 00	1
000 000 000 000 000 000 000 000 000 000 01	000 000
000 000 000 000 000 000 000 000 000 000 1	000 001
000 000 000 000 000 000 000 000 000 001	000 010
000 000 000 000 000 000 000 000 000 01	000 011
000 000 000 000 000 000 000 000 000 1	000 100
000 000 000 000 000 000 000 000 001	000 101
000 000 000 000 000 000 000 000 01	000 110
000 000 000 000 000 000 000 000 1	000 111
000 000 000 000 000 000 000 001	001 000
000 000 000 000 000 000 000 01	001 001
000 000 000 000 000 000 000 1	001 010
000 000 000 000 000 000 001	001 011
000 000 000 000 000 000 01	001 100
000 000 000 000 000 000 1	001 101
000 000 000 000 000 001	001 110
000 000 000 000 000 01	001 111
000 000 000 000 000 1	010 000
000 000 000 000 001	010 001
000 000 000 000 01	010 010
000 000 000 000 1	010 011
000 000 000 001	010 100
000 000 000 01	010 101
000 000 000 1	010 110
000 000 001	010 111
000 000 01	011 000
000 000 1	011 001
000 001	011 010
000 01	011 011
000 1	011 100
001	011 101
01	011 110
1	011 111

[Ed. In our understanding, clauses 8 to 14 should be removed, when the decoding process description stabalizes]

8 Unit definition

8.1 Coding Tree Block (CTB)

The coding unit (CTB) is defined as a basic unit which has a square shape. Although it has a similar role to the macroblock and sub-macroblock in AVC, the main difference lies in the fact that CTB can have various sizes, with no distinction corresponding to its size. All processing except frame-based loop filtering is performed on a CTB basis, including intra/inter prediction, transform, quantization and entropy coding. Two special terms are defined: the largest coding unit (LCTB) and the smallest coding unit (SCTB). For convenient implementation, LCTB size and SCTB size are limited to values which are a power of 2 and which are greater than or equal to 8.

It is assumed that a picture consists of non-overlapped LCTBs. Since the CTB is restricted to be a square shape, the CTB structure within a LCTB can be expressed in a recursive tree representation adapted to the picture. That is, CTB is characterized by LCTB size and the hierarchical depth in the LCTB that the CTB belongs to.

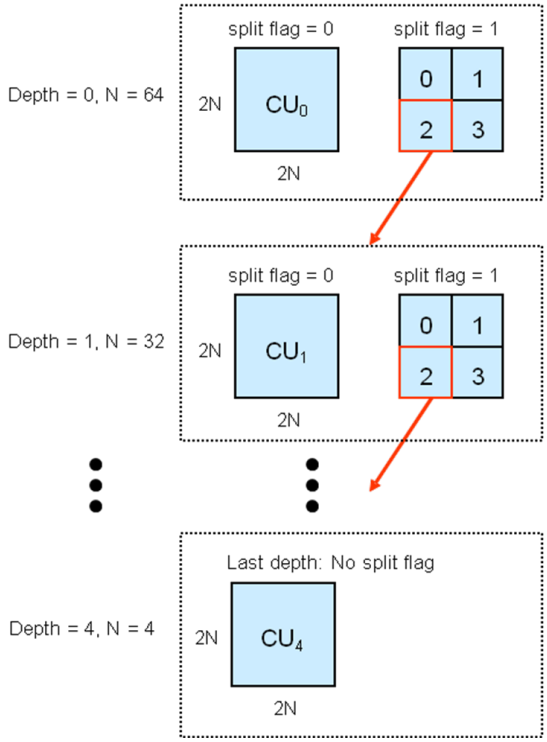


Fig. 1: Illustration of recursive CTB structure (LCTB size = 128, maximum hierarchical depth = 5)

Figure 1 shows an example where LCTB size is 128 and the maximum hierarchical depth is 5. The recursive structure is represented by a series of split flags. For CTB_d, which has depth d and size 2Nx2N, the coding of CTB is performed in the current depth when split flag is set to zero. When the split flag is set to 1, CTB_d is split into 4 independent CTB_{d+1} which have depth (d+1) and size NxN. In this case, CTB_{d+1} is called a sub-CTB of CTB_d similar to a sub-macroblock in AVC. Unless the depth of sub-CTB (d+1) is equal to the maximum allowed depth (4 in this case), each CTB_{d+1} is processed in a recursive manner. If the depth of sub-CTB (d+1) is equal to the maximum allowed depth, further splitting is not allowed. Note that a CTB can be further split into PUs.

The sizes of LCTB and SCTB are specified in the Sequence Parameter Set (SPS). The embedded information in the SPS is LCTB size (s) and the maximum hierarchical depth (h) in a LCTB. For example, if s = 128 and h = 5, then 5 kinds of CTB sizes are possible: 128x128 (LCTB), 64x64, 32x32, 16x16 and 8x8 (SCTB). If s = 16 and h = 2, then 16x16 (LCTB) and 8x8 (SCTB) are possible; this is a similar block structure to AVC. Therefore, if the LCTB size and maximum hierarchical depth are given, this defines the possible CTB sizes which are allowed.

This kind of arbitrary unit representation provides several major benefits. The first benefit comes from the support of CTB sizes greater than the conventional 16x16 macroblock. When the region of interest is homogeneous, a large CTB can represent the region in a smaller number of symbols than is possible in the case of several small blocks.

Furthermore, supporting arbitrary LCTB sizes enables the codec to be readily optimized for various content, applications and devices. Compared to the use of fixed size macroblock, support of various LCTB sizes is one of the major properties. It is especially useful for low resolution video services, which is still commonly used in the market. By choosing LCTB size and maximum hierarchical depth appropriately, the hierarchical block structure can be optimized in a better way for the targeted application. In the later stage of the standardization, the range of LCTB sizes could be specified in the Profiles and Levels section to match the requirements more specifically.

Finally, by eliminating the distinction between macroblock and sub-macroblock and using only one unit type, CTB, the multi-level hierarchical structure can be specified in a very simple and elegant way: LCTB size, maximum hierarchical depth and a series of split flags. Together with the proposed size-independent syntax representation, it's sufficient to specify syntax items of one general size for the remaining coding tools. This kind of consistency can greatly simplify the specification effort as well as the actual parsing process.

The maximum depth for CTB hierarchy is arbitrary and potentially larger than the maximum depth allowed in the AVC block hierarchy. Therefore, the text includes a size-independent syntax representation which specifies all syntax elements in a consistent way independent of the CTB size. By contrast, in AVC block level syntax elements

such as transform_8x8_mode_flag, coded_block_flag and intra_pred_modes are coded differently depending on whether the block size is 16, 8 or 4. The splitting process for the CTB can be specified recursively and all other syntax elements for the leaf CTB are defined in the same way independent on the CTB size. This kind of representation is very useful in terms of reduced parsing complexity and improved clarity if a large hierarchical depth is allowed.

For the purpose of mode decision, transmission of the data associated with each block etc. all CTBs are traversed in raster scan order (left-to-right, top-down), and within each CTB, the subblocks are traversed in depth-first order.

8.2 Prediction unit (PU)

Once the splitting process is done, prediction methods are specified for every CTB which is not further split i.e. the leaf nodes of the CTB hierarchical tree.

Coupled with CTB, a basic unit for the prediction mode is introduced: the prediction unit (PU). It should be noted that the PU is defined only for the last-depth CTB, i.e., the leaf nodes of the CTB-related quadtree and its size is limited to that of the CTB.

Similar to conventional standards, we define two different terms to specify the prediction method: the prediction type and the PU splitting. The prediction type is one of the values among intra or inter, which roughly describe the nature of the prediction method. After that, possible PU splittings are defined according to the prediction type.

The PU for intra has 2 different possible splittings: 2Nx2N (i.e. no split) and NxN (quarter split). The PU for inter has 8 different possible splittings: 4 symmetric splittings (2Nx2N, 2NxN, Nx2N, NxN) and 4 asymmetric splittings (2NxnU, 2NxnD, nLx2N and nRx2N). The number N is derived from the size of the CTB which the PU belongs to. For example, if the size of CTB is 128x128, then both 128x128 and 64x64 PUs for intra are possible. For inter prediction, 128x128, 128x64, 64x128, 64x64, 128x32 (for 2NxnU and 2NxnD), 128x96 (for 2NxnU and 2NxnD), 32x128 (for nRx2N and nLx2N) and 96x128 (for nRx2N and nLx2N) are possible.

Figure 1a shows an example where a 64x64 block is asymmetrically partitioned into 64x16, 64x48, 16x64, or 48x16 blocks, instead of two 64x32 or 32x64 blocks. Note that the motion partitions shown in the figure correspond to 2NxnU, 2NxnD, nLx2N, and nRx2N, respectively.

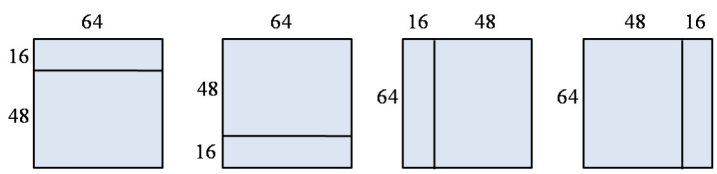


Figure 1a: Example of asymmetric motion partitions for 64x64 block

In addition, we have geometrical shapes for partitioning of inter PUs that are described as follows.

For each CTB, one type of PU splittings is defined by an arbitrary straight line across the CTB that divides the CTB into two regions. The boundary of the PU partition is defined by an angle subtended by a line perpendicular to the boundary with the X axis and the distance of the partition line from the origin . The equation of the line defining the partition boundary is specified as

$$y = \frac{-1}{\tan\theta}x + \frac{\rho}{\sin\theta} = mx + c.$$

Two 32 bit lookup tables are used, one to store the slope, $m = -1/\tan\theta$, and the other to store the Y-intercept, $c = \rho/\sin\theta$. The region to which each pixel belongs is calculated on the fly.

At each level CTB, 32 different values of are defined (from 0 to in steps of). The number of values that ρ can take depends on the CTB size. For example, for CTB size of 16×16, takes 8 possible values (from 0 to 7 in steps of 1). For block sizes of 32×32 and 64×64, takes 16 and 32 possible values, respectively.

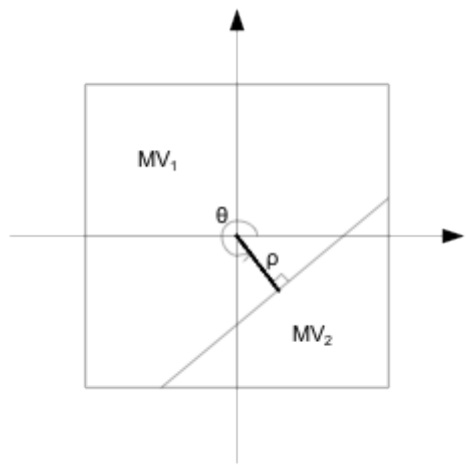


Figure 2: Parameters defining a geometry motion partition

For a CTB that is predicted in a manner described above, overlapped block motion compensation (OBMC) is applied. Let the two regions created by a geometry partition be denoted by region 1 and region 2. Let the corresponding motion vectors be denoted by MV_1 and MV_2, respectively. A pixel from region 1 (2) is defined to be a boundary pixel if any of its four connected neighbors (left, top, right, and bottom) belongs to region 2 (1). Fig. 2 shows an example where light blue pixels belong to the boundary of region 1 and white pixels belong to the boundary of region2. If a pixel is not a boundary pixel, normal motion compensation is performed using the appropriate motion vector. If a pixel is a boundary pixel, the motion compensation is performed using a weighted sum of the motion predictions from the two motion vectors, MV_1 and MV_2. The weights are $2/3$ for the region containing the boundary pixel and $1/3$ f for the other region.

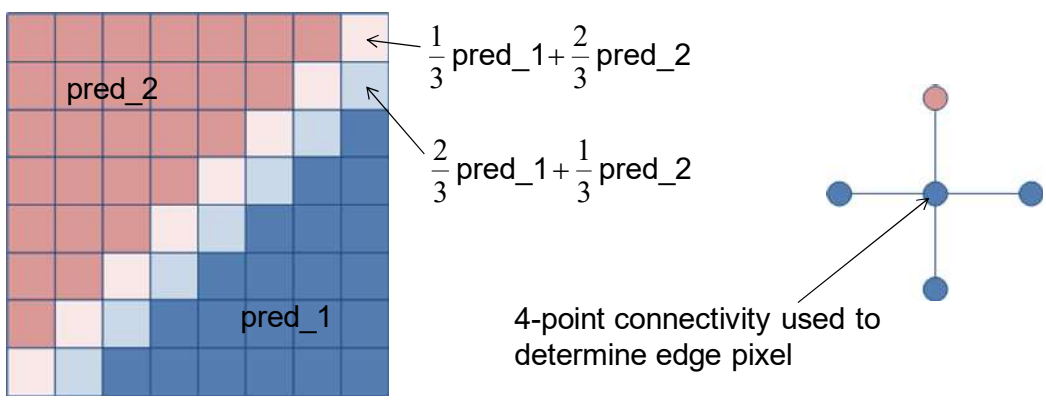


Figure 3: Overlapped motion compensation for geometry partitions

All information related to prediction is signaled on a PU basis, for instance, the direction of intra prediction for intra or the motion vector difference and reference index for inter. Motion vector prediction and motion compensation are also performed on a PU basis.

For each inter predicted blocks, individual motion parameters are transmitted. In order to achieve an improved coding efficiency, the block merging process enables to merge neighbouring blocks into so-called regions. By doing so, the motion parameters do not need to be transmitted for each block of the region individually, but instead the parameters are transmitted only for once for the whole region.

For each inter prediction block, the set of all prediction blocks that are coded before that block in processing order is called the "set of causal blocks". The set of blocks that is admissible for merging with a particular block is called the "set of available blocks" and is always a subset of the set of causal blocks. If a particular block is encoded and its set of available blocks is not empty, it is signaled whether this block is to be merged with one block out of this set and if so, with which of them. Otherwise, merging cannot be used for this block.

The set of available blocks is formed as follows. Starting from the top-left sample position of the current block, its left neighbouring sample position and its top neighbouring sample position is derived. The set of available blocks can have only up to two elements, namely those blocks out of the set of causal blocks that contain one of the two sample positions. Thus the set of available blocks can only have the two direct neighbouring blocks of the top-left sample position of the current block as its elements. Note that only inter predicted blocks can be members of the set of available blocks.

If the set of available blocks is not empty, one flag called merge_flag is signaled, specifying whether the current block is merged with any of the available blocks. Otherwise, or if the merge_flag is equal to 0 (for "false"), this block is not merged with one of its causal blocks and all parameters are transmitted ordinarily. If the merge_flag is equal to 1 (for "true"), the following applies. If the set of available blocks contains one and only one block, this block is used for merging. Otherwise the set of available blocks contains exactly two blocks. If the motion parameters of these two blocks are identical, these motion parameters are used for the current block. Otherwise (the two blocks have different motion parameters), a flag called merge_left_flag is signaled. If merge_left_flag is equal to 1 (for "true"), the block containing the left neighbouring sample position of the top-left sample position of the current block is selected out of the set of available blocks. If merge_left_flag is equal to 0 (for "false"), the other (i.e., top neighbouring) block out of the set of available blocks is selected. The motion parameters of the selected block are used for the current block.

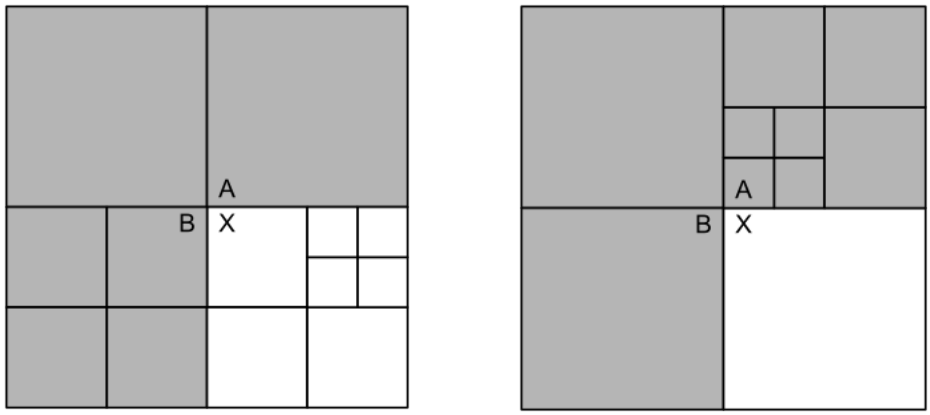


Fig. 3: Two examples illustrating the set of causal blocks (grey) and the set of available blocks (A, B).

Fig. 3 shows two examples for a quadtree-based division of a picture into prediction blocks. On the left side of Fig. 4, the top two blocks of the biggest size are so-called macroblocks, i.e., they are prediction blocks of the maximum possible size. The other blocks in this left figure are obtained as a subdivision of their corresponding macroblock. The current block is marked with an "X". All the grey-shaded blocks are encoded before the current block, so they form the set of causal blocks. As explicated in the description of the derivation of the set of available blocks, only the blocks containing the direct (i.e. top or left) neighbouring samples of the top-left sample position of the current block can be members of the set of available blocks. Thus the current block can be merged with either block "A" or block "B". If merge_flag is equal to 0 (for "false"), the current block "X" is not merged with any of the two blocks. If blocks "A" and "B" have identical motion parameters, no distinction needs to be made, since merging with any of the two blocks will lead to the same result. So, in this case, the merge_left_flag is not transmitted. Otherwise, if blocks "A" and "B" have different prediction parameters, merge_left_flag equal to 1 (for "true") will merge blocks "X" and "B", whereas merge_left_flag equal to 0 (for "false") will merge blocks "X" and "A".

In Fig. 4 (right) another example is shown. Here the current block "X" and the left neighbour block "B" are macroblocks, i.e., they have the maximum allowed block size. The size of the top neighbour block "A" is one quarter of the macroblock size. The blocks which are element of the set of causal blocks are grey-shaded. Note that the current block "X" can only be merged with the two blocks "A" or "B", not with any of the other top neighbouring blocks.

8.3 Transform unit (TU)

In addition to the CTB and PU definitions, the transform unit (TU) for transform and quantization is defined separately. It should be noted that the size of the TU may be as large as the size of the CTB. Like the partitioning used for prediction, the partitioning of a single prediction error block into transform blocks is represented by quad

trees. The greatest applicable transform size and the maximum depth of such quad trees (giving the minimum applicable size) are variable and are signaled in the bit stream. Transform blocks with an edge length of any positive power of two can be employed. Transform block sizes are constrained to the range 4x4 to 64x64 (for chroma, also 2x2 transforms may be used).

9 Motion representation

9.1 Motion vector prediction for rectangular partitions

A new method to form motion vector prediction is introduced. Unlike in AVC, this method takes the temporal distance of the reference frames into account for motion vector prediction. The neighboring blocks that are used for the prediction of the vertical components are illustrated in Figure 2.

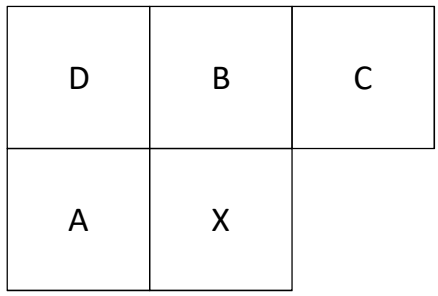


Figure 2: Neighboring blocks used for motion vector prediction

But the motion vectors of neighboring blocks A, B, and C may point to different reference frames in the buffer. Therefore, the motion vectors are normalized based on their temporal distance from the current frame, before taking the median. This is illustrated in Figure 3 for an IPPP configuration. In the figure, blue colored frames are the reference frames stored in the buffer. Let A_r, B_r, C_r, and X_r refer to the reference frames corresponding to blocks A, B, C, and X, respectively. Let their temporal distances from the current frame be denoted by $d(A_r), d(B_r), d(C_r)$, and $d(X_r)$, respectively. Then, each of the neighboring motion vectors, $MV^Y, Y \in \{A, B, C\}$ is scaled as follows:

$$\text{scaled_}MV^Y = MV^Y \frac{d(X_r)}{d(Y_r)}.$$

This scheme is applied to both P and B frames.

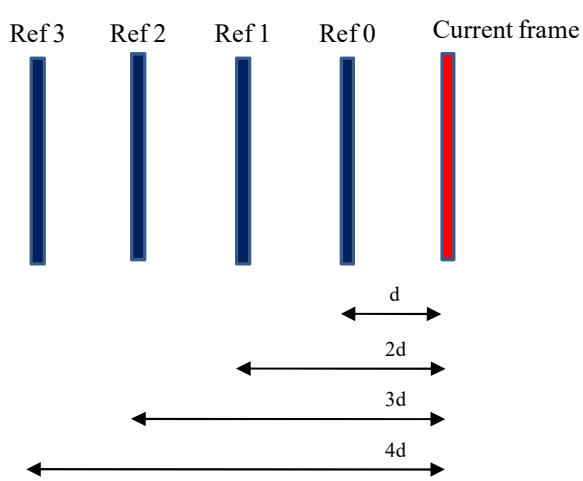


Figure 3: Reference frames and their temporal distances from the current frame

Depending on the settings of interleaved_motion_predictor_flag and mv_competition_flag, the derivation process of motion vector predictor is determined in one of the following ways as shown in 6.3.1.4:

interleaved_motion_predictor_flag	mv_competition_flag	normative section
0	1	6.3.1.4.1
0	0	6.3.1.4.6
1	1	6.3.1.4.7
1	0	6.3.1.4.6 and 6.3.1.4.9

9.2 Motion vector prediction for geometric block partitions

The process of forming motion vector prediction for a geometric block partition is shown Figure 2. Motion vectors of neighboring blocks are used to form the motion vector prediction. Depending on the partition, a subset of blocks from {A, B, C, E, F} are used to form motion vector prediction. The choice of block for motion vector prediction depends upon whether they lie on the same side or opposite side of the geometry partition boundary.

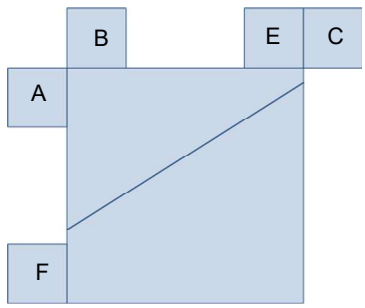


Figure2: Motion vector prediction for a block having geometry partition

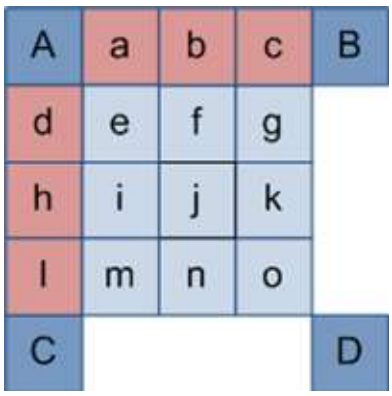
Let blkA, blkB, blkC, blkD, blkE and blkF be the prediction blocks that contain the luma samples at locations (x0 − 1, y0), (x0, y0 − 1), (x0 + currW, y0 − 1), (x0 − 1, y0 − 1), (x0 + currW − 1, y0 − 1), and (x0 − 1, y0 + currW − 1), respectively. For each partition, if blkX (X being replaced A, B, C, D, E and F) is sharing a boundary with the partition, blkX is used to derive the prediction motion vector.

The prediction motion vector mvPred is derived as specified by the folowing ordered steps:

1. If blkA, blkB and blkC are all connected to the current partition, median filter is used to derive mvPred.
2. Otherwise, if blkA is connected to the current partition, mvPred = mvA
3. Otherwise, if blkB is connected to the current partition, mvPred = mvB
4. Otherwise, if blkE is connected to the current partition, mvPred = mvE
5. Otherwise, if blkF is connected to the current partition, mvPred = mvF
6. Otherwise, if blkC is connected to the current partition, mvPred = mvC
7. Otherwise mvPred = (0,0)

9.3 Interpolation Methods

This text uses single pass switched interpolation filters with offsets (single pass SIFO). The 1/4th pixel motion positions are shown in the figure.



9.3.1 Single pass switched Interpolation Filters with offsets (single pass SIFO)

In this text, 7 different filter sets are defined. Each filter set consists of 15 filters, one for each fractional pixel position.

- Filter set 0: This filter set uses high precision filtering with the filters shown in the following table with the exception of position 'g', where a non-separable filter is used.

Table 9-1: 6-tap separable filters

1/4	{ 8, -32, 224, 72, -24, 8 } (8 additions, 4 shifts)
1/2	{ 8, -40, 160, 160, -40, 8 } (6 additions, 3 shifts)
3/4	{ 8, -24, 72, 224, -32, 8 } (8 additions, 4 shifts)

The filter coefficients are scaled by 256 and the intermediate data is kept in higher precision. For position 'g', the following filter is used (followed by right shift by 7 bits):

0	5	5	0
5	22	22	5
5	22	22	5
0	5	5	0

- Filter set 1: This filter set uses 12 tap filters for both horizontal and vertical filtering. The filter coefficients are scaled by 256. A higher bit depth of filter coefficients leads to more accurate interpolation; for comparison, AVC uses 5 bits for filter coefficients. Also, the intermediate values are maintained at higher bit precision.

Table 9-2: 12-tap separable filters

¼	{-1, 5, -12, 20,-40, 229, 76, -32, 16, -8, 4,-1 } (18 additions, 6 shifts)
½	{-1, 8, -16, 24,-48, 161, 161, -48, 24, -16, 8,-1 } (15 additions, 4 shifts)
¾	{-1, 4, -8, 16, -32, 76, 229, -40, 20, -12, 5,-1 } (18 additions, 6 shifts)

- Filter set 2: This set of interpolation filter is referred to as the Directional Interpolation Filter (DIF) and is used for all 15 quarter-pixel positions. For each of the three horizontal positions and the three vertical positions which are aligned with full pixel positions, a single 6-tap filter is used. For the 9 innermost quarter-pixel positions two 6-tap filters at +45 degree and -45 degree angles are used.

The filter coefficients for DIF are
[3 -15 111 37 -10 2]/128 for ¼ displacement (and mirrored for ¾ displacement)
[3 -17 78 78 -17 3]/128 for ½ displacement

- Filter set 3: The third set of interpolation filters consists of Separable Filters (SF) where interpolated samples are calculated by first applying a 6-tap filter horizontally and then vertically.

  The filter coefficients for SF are
  [3 -15 111 37 -10 2]/128 for ¼ displacement (and mirrored for ¾ displacement)
  [3 -17 78 78 -17 3]/128 for ½ displacement

- Filter set 4: Consists of a combination of a 2-tap pre-filter and a 4-tap interpolation filter.
  - The pre-filter is a 1D IIR filter in horizontal and vertical directions. The coefficients are given below:
    - Left-to-right filtering: [1] / [1, c]
    - Right-to-left filtering: [c] / [1, c]

    where, the constant c = -11276. The pre-filter produces the same number of samples as the input to it. The filtering can be performed on the picture region to be interpolated.

  - The interpolation filter is implemented as a sequence of 1D horizontal and vertical filtering step. The FIR filters consist of 4-taps. The filter coefficients are the same for both horizontal and vertical directions. The filters used for different sub-pel positions are given below:
    - Full-pel: [6242, 20284, 6242, 0] / 32768
    - 1/4 pel : [2888, 19078, 10520, 280] / 32768
    - 1/2 pel : [1073, 15311, 15311, 1073] / 32768
    - 3/4 pel : [280, 10520, 19078, 2888] / 32768

- Filter set 5 and 6: For each set, positions *a*, *b*, and *c* use a six-tap horizontal filters. Positions *d*, *h*, and *l* use six-tap vertical filters. For the remaining fractional pixel positions, 4×4 non-separable filters are used. Each of the non-separable filters has horizontal, vertical or diagonal symmetry.

9.3.2 Choice of filter set and offsets

The choice of the filter and offset is signalled to the decoder for each slice. For each of the 15 fractional pixel positions, the choice of the filter is signalled using 3 bits. Before encoding a frame, the encoder selects a filter for each fractional pixel position based on statistics gathered from previously encoded frames. In this text, the filter that minimizes prediction error for the previously encoded frames is selected. For each fractional pixel position, the minimization is performed only on blocks whose motion vector points to that fractional pixel location. The choice of filter remains the same irrespective of the reference frame in which the motion search is being performed.

For reference frame 0 from each list, offsets are sent to the decoder for each of the 15 fractional pixel positions as well as the full pixel position For other reference frames only one frame offset is sent. The offsets are encoded using exponential Golomb codes.

9.3.3 Partition based Illumination Compensation (PBIC)

Illumination-compensation parameters are signaled at each partition using scale and offset parameters.

For single-list prediction, one transformed scale t0 and one offset o are transmitted. Scale s is derived from t0 as s = (64+t0).

For bi-prediction, two transformed scales t0 and t1, and one offset o are transmitted. Scales s0 and s1 are derived from t0 and t1 as s0 = (64 + t0)/2+t1 and s1 = (64+t0) – s0.

The scales are applied to all components, whereas the offsets are applied only to the luma component. In addition, for chroma components, the value '128' (chroma value corresponding to a gray pixel without color) is removed before the application of scale and this value '128' is added after the application of scale.

In the case of luma component, illumination compensation is applied to motion-compensated samples as follows:

- Single-list Prediction

- w = (s*v)/64+o
- w is illumination-compensated sample
- v is motion-compensated sample

- Bi-prediction
  - w = (w0+w1)/2
  - w0 = (2*s0*v0/64)+o
  - w1 = (2*s1*v1/64)+o
  - w is illumination-compensated sample
  - w0 and w1 are illumination-compensated samples for each list
  - v0 and v1 are motion-compensated samples for each list

Note that the implementation is done such that w0 and w1 are obtained first to be inline with the TMuC implementation of motion compensation for bi-prediction. The samples w0 and w1 are later averaged to obtain w.

In the case of chroma components, illumination compensation is applied to motion-compensated samples as follows (the terms v, v0, v1, w, w0, w1 have the same meaning as above, but represent chroma samples instead of luma samples):

- Single-list Prediction
  - w = (s*(v-128))/64+128
- Bi-prediction
  - w = (w0+w1)/2
  - w0 = (2*s0*(v0-128)/64)+128
  - w1 = (2*s1*(v1-128)/64)+128

Note that the above equations (for both luma and chroma) assume that the motion-compensated values are represented using an unsigned 8-bit notation. When IBDI is used, appropriate scaling modifications are used to do the operations at higher bit-depth.

The applicable PBIC parameters ({t0, o} or {t0, t1, o}) are coded differentially in combination with motion vector differences. A list of predictors is constructed using a default predictor (all parameters being 0) and predictors using PBIC parameters of neighboring PUs. A predictor index is signaled to indicate the predictor to be used. A zero-tree is used to indicate which of the PBIC parameter differences and motion vector differences are zero. For single-list prediction, the zero-tree deals with 4 parameters (mvdx, mvdy, t0 and o). For bi-prediction, the zero-tree deals with 7 parameters (mvd0x, mvd0y, mvd1x, mvd1y, t0, t1 and o). The non-zero PBIC parameter differences are coded similar to non-zero motion vector differences.

In the deblocking filter, edges between blocks with different PBIC parameters are treated similar to the edges between blocks with MV differences.~~Intensity compensation parameters are signaled at each partition using scale and offset parameters.~~

~~In the single list prediction case, one scale s and one offset o are transmitted. For bi-prediction, two transformed scales t0 and t1, and one offset o are transmitted. Scales s0 and s1 are derived from t0 and t1 as s0 = (64 + t0)/2+t1 and s1 = (64+t0) – s0.~~

~~The scales are applied to all components, whereas the offsets are applied only to the luma component (in the following the offset o is considered to be 0 for chroma components).~~

~~In the single list prediction case, a predicted, illumination compensated, sample w is set to ((64+s)*v)/64+o, where v is a motion compensated sample. For bi-prediction, a predicted sample w is obtained by the weighted average (s0*v0+s1*v1)/64+o where v0 and v1 are the motion compensated samples from each list.~~

~~The parameters s, t0, t1 and o are coded differentially in combination with motion vector differences.~~

~~This feature is enabled by a flag on slice level.~~

9.4 Adaptive Motion Vector Resolution

For each region in a motion partition, the motion accuracy can be adaptively chosen to be 1/4th pixel or 1/8th pixel. We will refer to this as adaptive motion vector resolution. The choice of motion vector resolution is signaled to the decoder. For each motion vector, a motion vector resolution flag is encoded. If the flag is zero, the motion vector

precision is 1/4th otherwise 1/8th. If the flag is 1 and motion vector is nonzero, refinement information for this motion vector is sent which specifies 1/8th pel precision.

The encoder always maintains the motion vector (MV) and MVD information at 1/8th pixel resolution. Then, the MV prediction for the current block is formed with 1/8th pixel accuracy. If the current block has only 1/4th pixel motion accuracy, the MV prediction is converted to 1/4th pixel accuracy. On the other hand if the current block has 1/8th pixel motion accuracy, the MVD is formed directly by subtracting the MV prediction from the motion vector for the current block. Once MVD is formed, if the current block has 1/4th pixel accuracy, for all the neighboring blocks used for determining the MVD contexts, the MVDs are converted to 1/4th pixel accuracy. Similar procedure is followed for 1/8th pixel accuracy.

10 Intra-frame prediction

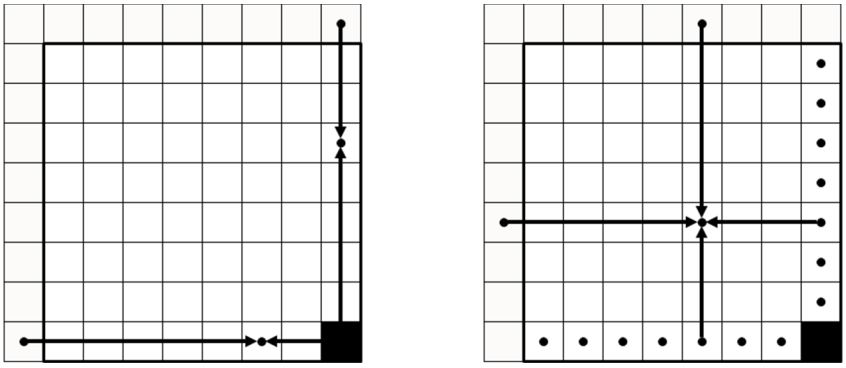
For blocks of size 64x64 : 33 Directions (ADI+Planar)
For blocks of size 32x32 : 33 Directions (ADI+Planar)
For blocks of size 16x16 : 33 Directions (ADI+Planar)
For blocks of size 8x8 : 33 directions (Angular+Planar)
For blocks of size 4x4: 9 directions (AVC)

10.1 Adaptive reference sample smoothing

In addition, a smoothing operation can be applied to the reference samples as a pre-processing step before calculating the prediction. This smoothing operation corresponds to applying an FIR-filter (1,2,1)>>2 with low-pass characteristics to the samples along the two reference rays. Whether this smoothing operation is used is determined by the encoder and signaled in the bit stream.

10.2 Planar prediction

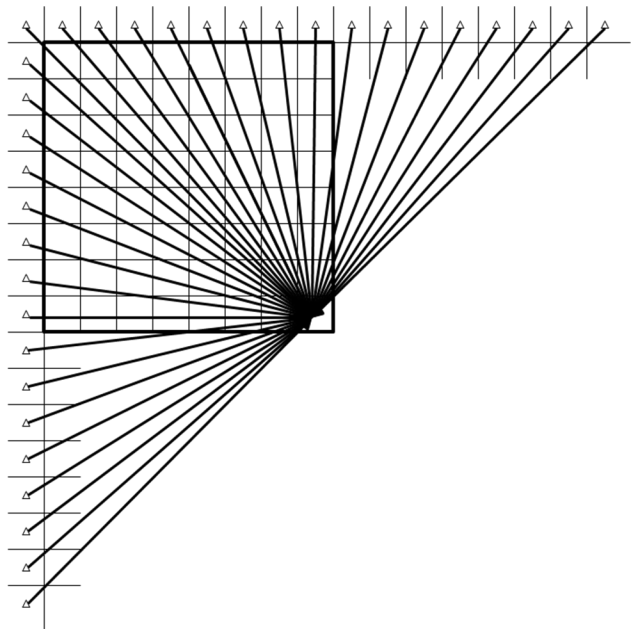
The planar prediction is designed to be able to reconstruct smooth image segments in a visually pleasing way. It provides maximal continuity of the image plane at the macroblock borders and is able to follow gradual changes of the pixel values by signalling a planar gradient for each macroblock coded in this mode. When a macroblock is coded in planar mode its bottom-right sample is signalled in the bitstream, the rightmost and bottom samples of the macroblock are linearly interpolated, and the middle samples are bilinearly interpolated from the border samples. When planar mode is signalled, the same algorithm is applied to luminance and both chrominance components separately with individual signalling of the bottom-right samples (16x16 based operation for luminance and 8x8 based for chrominance). The process is illustrated in the picture below.



Planar prediction of an 8x8 (chrominance) block. Bottom-right sample is signalled in the bitstream, rightmost and bottom samples are interpolated linearly, and the middle samples are interpolated bi-linearly.

10.3 Angular prediction

In order to be able to accurately represent directional structures the Intra 8x8 coding mode provides a possibility to predict the blocks at any direction shown below.



Available prediction directions in the angular mode of Intra 8x8 macroblocks.

In the angular mode the prediction direction is given by the displacement of the bottom row of the block and the reference row above the block in the case of vertical prediction or displacement of the rightmost column of the block and reference column left from the block in the case of the horizontal prediction. The displacement is signalled at 1 pixel accuracy. When projection of the predicted pixel falls inbetween reference samples, the predicted value for the pixel is linearly interpolated from the reference samples (at 1/8th pel accuracy). The process is illustrated in the picture below for the sixth row of the block when building vertical prediction at +1 pixel displacement.

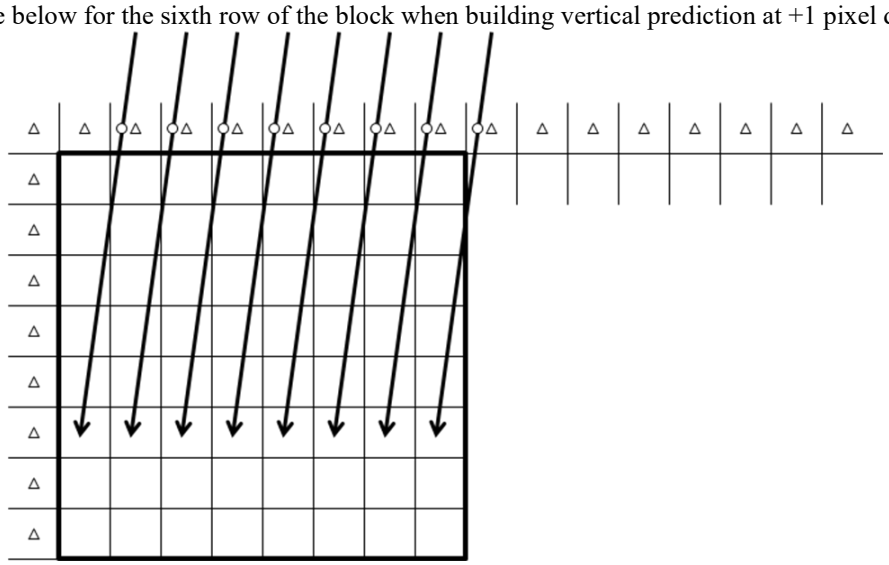
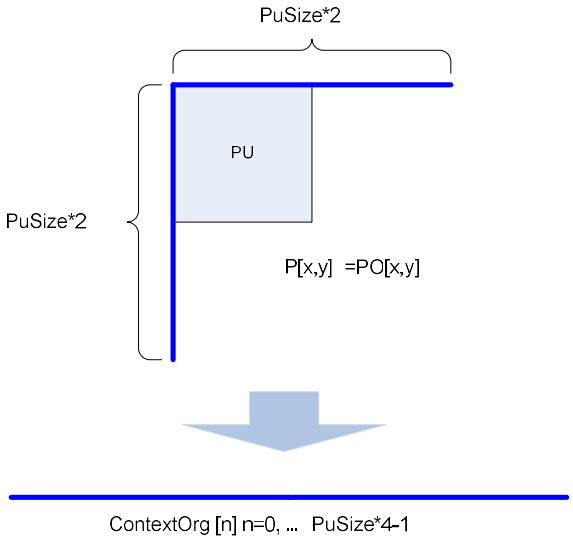


Figure 4 An example of angular prediction when operating the sixth row of the block with +1 pixel displacement. Projections of the pixels now fall at the 6/8 sub-pixel location (circles) in the reference row of pixels.

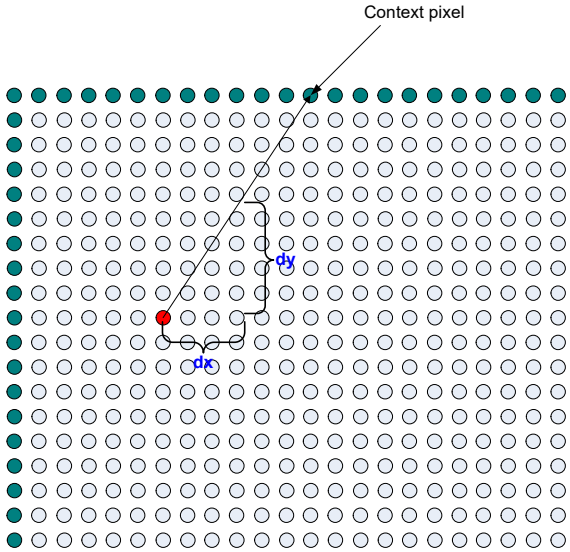
10.4 Arbitrary Directional Intra (ADI)

Arbitrary Directional Intra (ADI) generates prediction pixels by directional extrapolation or calculation using the nearest boundary pixels of the already decoded area. But in ADI, even boundary pixels from the left down region may be used as context pixels for prediction as depicted in below



Example of context pixels for ADI

Whilst the 9 prediction modes are defined separately as Vertical, Horizontal, DC, Diagonal Down-Left, Diagonal Down-Right, Vertical-Right, Horizontal-Down, Vertical-Left, and Horizontal-Up in AVC, most of prediction modes in ADI are defined by integer pair information (dx, dy). The (dx, dy) pair represents the direction which each mode uses for context pixel extrapolation



prediction methods defined by (dx, dy)

10.5 Edge based prediction

If the edge based prediction mode is switched on, the DC prediction mode can be replaced by an adaptive directional prediction mode depending on the presence of an edge in the neighboring reconstructed pixels.
The edge-based prediction mode consists of two steps:

- edge detection based on the Sobel operators to determine if an edge is present and if an edge is present, its direction
- extrapolation of the reference pixels along the direction of the detected edge

If an edge intersecting with the block to be predicted is detected, the reference pixels are extrapolated along the direction of the detected edge as showed in Figure 5.

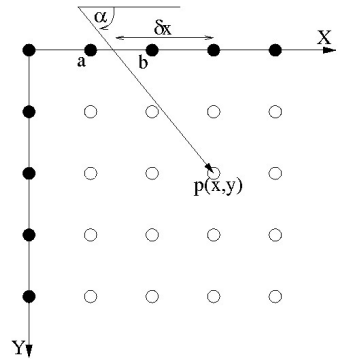


Figure 5: Computation of the edge based prediction for intra coding

The prediction of the pixel p(x,y) is:

$$w_a = \delta x - floor(\delta x)$$
$$w_b = ceil(\delta x) - \delta x$$
$$p = w_a \times a + w_b \times b$$

10.6 Combined Intra Prediction (CIP)

The CIP is a low-complexity tool for providing improved prediction, especially in large blocks where a directional linear prediction may not work well, even with the large range of angles available to ADI. CIP predictions comprise a weighted combination of an ADI prediction together with a pixel-by-pixel mean prediction. It provides pixel-by-pixel adaptation but is a simpler tool than, for example, local template matching approaches.

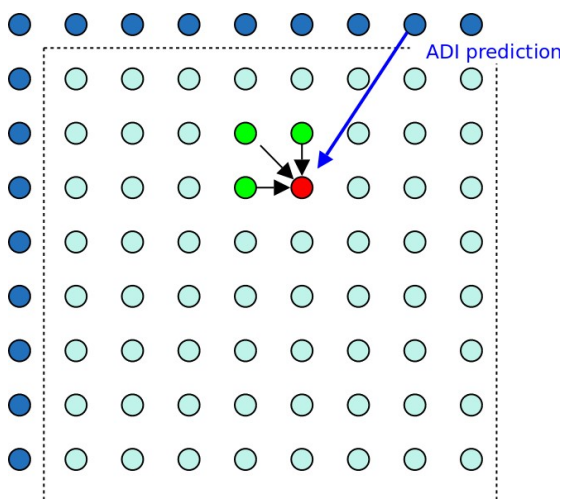


Figure 4-12 Example of Combined Intra Prediction utilizing a local mean and ADI prediction

The local mean is constructed as the average of pixel values to the left, top-left and above the current picture. In the decoder and within the local decoder in the encoder, these values are the reconstructed values after inverse quantization and transform. In the encoder, the reconstructed values are not available because quantization and transform of the prediction residue have not yet been performed, so original values are used This local mean prediction is therefore different between forward prediction (encoder only) and reconstruction (encoder and decoder).

The combination factor is a 5-bit number between 0 and 31/32 which determines the proportion of local mean in the prediction. Since this number is less than 1, the prediction/reconstruction difference noise is damped, and pixel-by-pixel prediction adaptation is possible without noise blow-up. The ADI component provides an overall prediction direction and the local mean prediction provides local adaptation.

For each CTB, a single CIP flag is sent for all PUs. If set, the flag indicates that CIP prediction is used, otherwise ADI prediction is used. The use of CIP is signaled in the SPS.

11 Spatial transforms

11.1 Large transform (16x16, 32x32, 64x64)

For smooth data, a large transform has several advantages such as better energy compaction and reduced quantization error. In HD sequences, most image patterns in a macroblock represent a small part of objects or backgrounds which can be described as homogeneous texture patterns with little variation. Therefore, the coding efficiency of high resolution video can be improved by the use of large transforms as well as large block sizes. By contrast, AVC supports only 4x4 and 8x8 transform sizes. Larger transform sizes can also be chosen (or set) for each coding unit (blocks or partitions). Transform sizes larger than the prediction unit can also be supported.

3 additional sizes of transform are included: 16x16, 32x32 and 64x64. In a large transform design, it is very important to minimise complexity. The transforms in this text are based on Chen's fast DCT algorithm [10]. Chen's algorithm is not the fastest one, but it has reduced implementation complexity due to the regular butterfly structure. Moreover, it is readily extensible to larger transform sizes.

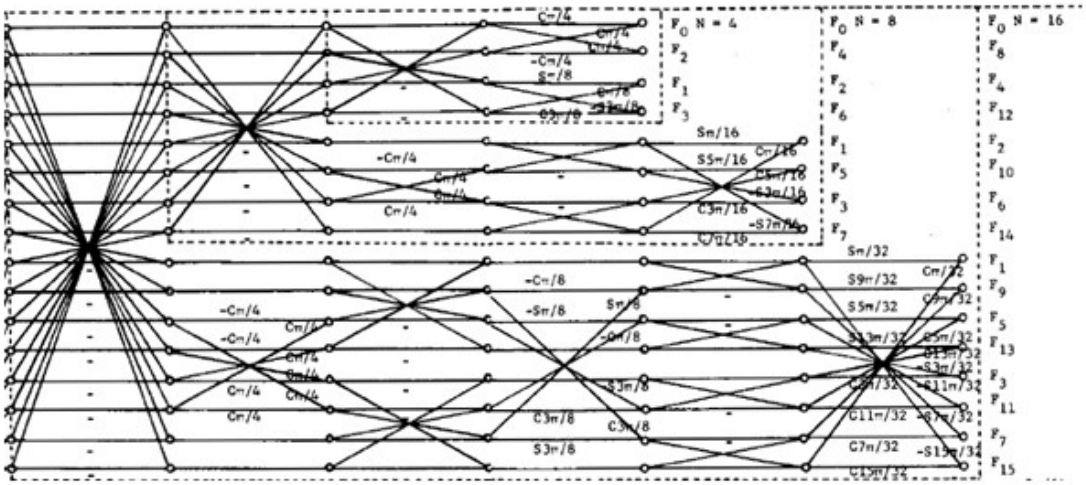


Figure 5-1 Signal flow graph of Chen's fast 16-point DCT transform

Figure 5-1 shows the signal flow graph of Chen's fast factorization of a 16 point DCT transform. In this figure, multiplication constants are represented by sinusoidal functions of specific angles, requiring floating point operations. To solve this problem, we scale and approximate the factors by fixed precision using pre-defined values, which can be calculated by cost effective shift operations. The approximated constants are shown in Table 0., with pre-defined precision value 64 in this case. Here, the ak's are approximated values of cos(k*pi/32) for k =1,2,…,15.

Table 0 Approximated constants for 16 point transform

a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15
63/64	62/64	61/64	59/64	56/64	53/64	49/64	45/64	40/64	35/64	30/64	24/64	18/64	12/64	6/64

When the constant is approximated by the dyadic rational, the transform is no longer truly orthogonal. However, this minor non-orthogonality does not result in any perceptible negative effects on the compression performance, whilst the complexity can be significantly reduced.

11.2 Rotational transform (ROT)

DCT is the most widely used transform in block based video and image codecs. The input to the transform is the residual, i.e. the difference between the prediction and the original signal. But it is well-known that the DCT basis functions are not optimal for some types of residual signal. For example, the residual signal having strong diagonal components cannot be represented efficiently with the DCT basis vectors.

Typically, directional transform schemes are exploited to solve this problem since spatial domain rotation makes it dificult to maintain the original square shape of the block and generally requires many floating point operations. However, it's hard to develop directional transform cores, especially since many transforms of different sizes are

needed. This text uses mode dependent directional transforms (MDDT) for block sizes of 4×4 and 8×8, and uses ROT for the higher block sizes. ROT can be applied as a 2nd transform after the DCT operation for block sizes of 16×16 or higher.

The main idea of ROT is to change the coordination system of the transform basis, instead of direct rotation of the input source. For this purpose, the following matrices are defined as

$$R_{vertical}(\alpha_1,\alpha_2,\alpha_3) =$$
$$= \begin{pmatrix} \cos\alpha_1\cos\alpha_3 - \sin\alpha_1\cos\alpha_2\sin\alpha_3 & -\sin\alpha_1\cos\alpha_3 - \cos\alpha_1\cos\alpha_2\sin\alpha_3 & \sin\alpha_2\sin\alpha_3 & 0 \\ \cos\alpha_1\sin\alpha_3 + \sin\alpha_1\cos\alpha_2\cos\alpha_3 & -\sin\alpha_1\sin\alpha_3 + \cos\alpha_1\cos\alpha_2\cos\alpha_3 & -\sin\alpha_2\cos\alpha_3 & 0 \\ \sin\alpha_1\sin\alpha_2 & \cos\alpha_1\sin\alpha_2 & \cos\alpha_2 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_{horizontall}(\alpha_4,\alpha_5,\alpha_6) =$$
$$= \begin{pmatrix} \cos\alpha_4\cos\alpha_6 - \sin\alpha_4\cos\alpha_5\sin\alpha_6 & -\sin\alpha_4\cos\alpha_6 - \cos\alpha_4\cos\alpha_5\sin\alpha_6 & \sin\alpha_5\sin\alpha_6 & 0 \\ \cos\alpha_4\sin\alpha_6 + \sin\alpha_4\cos\alpha_5\cos\alpha_6 & -\sin\alpha_4\sin\alpha_6 + \cos\alpha_4\cos\alpha_5\cos\alpha_6 & -\sin\alpha_5\cos\alpha_6 & 0 \\ \sin\alpha_4\sin\alpha_5 & \cos\alpha_4\sin\alpha_5 & \cos\alpha_5 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

where $R_{vertical}$ and $R_{horizontal}$ represent the rotation matrices for horizontal and vertical directions with the rotation angles of (α1, α2, α3) and (α4, α5, α6), respectively. In this text, only four out of all possible rotation angles are quantized and used, in order to minimize the encoder-side complexity. The chosen transform is signalled to the decoder using the chosen intra prediction direction as the context.

Furthermore, since ROT is a second transform, not all of the DCT coefficients are processed. For the TUs larger than 8×8, only 8x8 low-frequency areas are rotated by multiplying by the ROT matrix since most coefficients are already compacted into these low-frequency areas.

11.3 Mode dependent directional transforms for intra-prediction residuals

In this text, nine directional intra prediction modes are used for block size of 4×4 and 33 directional intra prediction modes are used for block sizes of 8×8 (INTRA4x4 and INTRA8x8). For each directional prediction mode, the prediction residual exhibits a different directionality. In addition, the magnitude of the error increases for predicted pixels farther away from the boundary pixels used for prediction. To take advantage of this, mode dependent directional transforms (MDDT) are used to encode 4×4 and 8×8 intra prediction residuals. The type of MDDT is coupled with the selected intra prediction direction, so is not explicitly signaled. We briefly describe design and implementation of the MDDT.

For the 8×8 block size, the 33 intra prediction directions are clustered into nine separate directions. Thus, for both 4×4 and 8×8 blocks, nine separate MDDT transforms are designed. The Karhunen-Loève transform (KLT) derived from the statistics of the intra prediction residuals for that mode, would be the optimal transform choice from a rate-distortion perspective. However, KLT is a non-separable transform. For a residual block of size $N \times N$, the size of the KLT matrix is $N^2 \times N^2$. Thus, KLT is prohibitively expensive in term of storage and computational requirement. A separable directional transform is used, which can be described as

$$Y = C_i X R_i ,$$

where *X, Y, C*, and *R* are all of size $N \times N$ and *i* is the prediction mode. Singular Value Decomposition (SVD) is applied to the training set of residuals first in the row direction and then, in the column direction. A fixed-point approximation of the transform matrices to reduce computational cost is used.

Adaptive coefficient scanning

After applying separable directional transform, the 2-D transform coefficient matrix is converted to 1-D. In AVC, zigzag scanning order is used for this purpose. In the case of MDDT, even after separable directional transforms are applied, the resulting 2-D transform coefficient matrix still carries some directionality. For example, consider

vertical prediction (mode 0). After prediction, transform and quantization, the nonzero coefficients tend to exist along the horizontal direction. By using coefficient scanning oriented in the horizontal direction instead of the zigzag scanning, the non-zero coefficients in the 2D matrix can be further compacted toward the beginning of the 1-D vector. This in turn improves entropy coding efficiency. Quantized transform coefficients of different prediction modes carry different statistics. Therefore, for each mode, adaptive coefficient scanning is used. This is accomplished as follows:

6. At the beginning of each video slice, initialize the coefficient scanning order for each prediction mode;
7. When a block is entropy-coded, for each non-zero coefficient coded, increment the count at the corresponding position by one;
8. After each macroblock is coded, update the coefficient scanning order according to the statistics collected;
9. Normalize the collected statistics if needed;
10. Use the updated order for coding of future blocks. Go back to 2 until slice is finished.

11.4 Transform Selection

For the luma component of the inter residual signal, two switchable transforms can be adaptively selected for each block size. Therefore, the selected transform can better fit the residue data. The selection is between the DCT and a KLT using a rate-distortion criterion. For transform sizes smaller than 16x16, no explicit flag is sent to indicate which transform is used for each block. Instead, the flag is incorporated within the transform coefficients themselves to reduce overhead. At the decoder, the transform coefficients are first recovered and the parity of their sum is computed. If the parity is even, the inverse DCT is applied. If the parity is odd, the inverse KLT is applied. When the transform size is 16x16 and above, an explicit flag is used to indicate which transform to apply.

For a residual block of size NxN, a separable KLT transform is used, which can be described as:

$$Y = C_{\text{inter}} X C^{T}_{\text{inter}},$$

where X, Y, C_{inter}, are of size NxN.

The KLT basis functions are derived from the statistics of the inter prediction residuals from a representative set of sequences. The offline training is done so that the KLT complements the DCT. The transform is implemented in integer arithmetic and the norms are forced to be the same as those of the DCT. In this way, the quantization tables and entropy coding of the DCT can be reused. Also, the first basis vector of the KLT is forced to be constant, so it is consistent with the first basis vector of the DCT, which improves subjective quality at low bit-rates.

The scanning order of the KLT coefficients is the same as for the DCT coefficients.

11.5 Quantization

The basic principle for quantization and de-quantization of coefficients for large transforms is the same as that used in AVC, i.e. a scalar quantizer with dead-zone.

12 Deblocking filter

Deblocking filter operates across 8x8 block edges for luma as well as for chroma blocks.

$p3_0$ $p2_0$ $p1_0$ $p0_0$	$q0_0$ $q1_0$ $q2_0$ $q3_0$
$p3_1$ $p2_1$ $p1_1$ $p0_1$	$q0_1$ $q1_1$ $q2_1$ $q3_1$
$p3_2$ $p2_2$ $p1_2$ $p0_2$	$q0_2$ $q1_2$ $q2_2$ $q3_2$
A $p3_3$ $p2_3$ $p1_3$ $p0_3$	$q0_3$ $q1_3$ $q2_3$ $q3_3$ **B**
$P3_4$ $p2_4$ $p1_4$ $p0_4$	$q0_4$ $q1_4$ $q2_4$ $q3_4$
$P3_5$ $p2_5$ $p1_5$ $p0_5$	$q0_5$ $q1_5$ $q2_5$ $q3_5$
$P3_6$ $p2_6$ $p1_6$ $p0_6$	$q0_6$ $q1_6$ $q2_6$ $q3_6$
$P3_7$ $p2_7$ $p1_7$ $p0_7$	$q0_7$ $q1_7$ $q2_7$ $q3_7$

Notation of Block Edge for Deblocking

Luma filtering

The luma edge between blocks A and B can be filtered if one of the following conditions is true

- Block A or Block B has mbMode==INTRA
- ***or*** Block A or block B has nonzero transform coefficients
- ***or*** The absolute difference between the horizontal or vertical component of the motion vectors used for Block A and Block B is greater than or equal to 4 in units of quarter luma samples**,**
- ***or*** a PBIC value (icScale or icOffset) of Block A differs from the corresponding value of Block B
- ***and*** $|p2_2 - 2*p1_2 + p0_2| + |q2_2 - 2*q1_2 + q0_2| + |p2_5 - 2*p1_5 + p0_5| + |q2_5 - 2*q1_5 + q0_5| < \beta$

The luma edge between blocks A and B is ***not*** filtered if one of the following conditions is true.

- Block A and Block B belong to the same macroblock ***and*** mb_svt_flag==1
- ***or*** Block A and Block B belong to the same macroblock ***and*** (mbMode==INTER_16x16 or mbMode==INTRA) ***and*** transform 16x16 is used
- ***or*** the edge is an internal edge of a large macroblock LMB32
- ***or*** the edge is an internal edge of a large macroblock LMB64
- ***or*** the edge is a macroblock border ***and*** both Block A and Block B have planar_flag ==1.

If the edge between Block A and Block B is filtered, one of two types of filtering (weak or strong filtering) is performed. The choice between the strong and the weak filtering is done separately for each line depending on the following conditions. For each line i = 0,7, the strong filtering is performed if all the following conditions are true, otherwise, weak filtering is performed.

- $d < (\beta>>2)$
- ***and*** $(|p3_i - p0_i| + |q0_i - q3_i|) < (\beta>>3)$
- ***and*** $|p0_i - q0_i| < ((5*t_C + 1)>>1)$,

where t_C and β depends on qp their relations are shown in Table 1. t_C is increased by 4 when one of Block A or Block B has mbMode==INTRA.

Table 1 Corr_qpc, tc and β

qp	0	1	2	3	4	5	6	7	8	9	10	11	13	13	14	15	16	17
Corr_qpc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
t_c	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2
B	0	0	0	0	0	0	6	7	8	9	10	11	12	13	14	15	16	17
qp	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Corr_qpc	0	0	1	1	1	1	2	2	2	3	3	4	4	5	5	6	6	6
tc	2	2	2	3	3	3	3	4	4	4	5	5	6	6	7	8	9	9
B	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
qp	36	37	38	39	40	41	42	43	44	45								
Corr_qpc	7	7	7	8	8	8												
tc	10	10	11	11	12	12	13	13	14	14								
B	54	56	58	60	62	64												

Weak filtering
Weak filtering mode filtering is performed based on the above conditions,

$\Delta = Clip(-t_C, t_C, (13*(q0_i - p0_i) + 4*(q1_i - p1_i) - 5*(q2_i - p2_i) + 16)>>5))$ $i = 0,7$
$p0_i = Clip_{0\text{-}255}(p0_i + \Delta)$ $i = 0,7$
$q0_i = Clip_{0\text{-}255}(q0_i - \Delta)$ $i = 0,7$
$p1_i = Clip_{0\text{-}255}(p1_i + \Delta/2)$ $i = 0,7$
$q1_i = Clip_{0\text{-}255}(q1_i - \Delta/2)$ $i = 0,7$

Strong filtering
Strong filtering mode is performed with the following set of operations.

$p0_i = Clip_{0\text{-}255}((p2_i + 2*p1_i + 2*p0_i + 2*q0_i + q1_i + 4)>>3);$ $i = 0,7$
$q0_i = Clip_{0\text{-}255}((p1_i + 2*p0_i + 2*q0_i + 2*q1_i + q2_i + 4)>>3);$ $i = 0,7$
$p1_i = Clip_{0\text{-}255}((p2_i + p1_i + p0_i + q0_i + 2)>>2);$ $i = 0,7$
$q1_i = Clip_{0\text{-}255}((p0_i + q0_i + q1_i + q2_i + 2)>>2);$ $i = 0,7$
$p2_i = Clip_{0\text{-}255}((2*p3_i + 3*p2_i + p1_i + p0_i + q0_i + 4)>>3);$ $i = 0,7$
$q2_i = Clip_{0\text{-}255}((p0_i + q0_i + q1_i + 3*q2_i + 2*q3_i + 4)>>3);$ $i = 0,7$

Chroma filtering

The chroma edge between blocks A and B can be filtered if the following condition is true.

- Block A or Block B has mbMode==INTRA

The filtering is not applied if both following conditions are true.

- The edge is a macroblock edge

and both Block A and Block B have planar_flag==1.

If filtering is performed based on the above condition,

$\Delta = Clip(-t_C, t_C, ((((q0_i - p0_i) << 2) + p1_i - q1_i + 4) >> 3))$ $i = 0,7$
$p0_i = Clip_{0\text{-}255}(p0_i + \Delta)$ $i = 0,7$
$q0_i = Clip_{0\text{-}255}(q0_i - \Delta)$ $i = 0,7$

t_C depend on qp and their relations are shown in Table 1. For chroma filtering t_C is increased by 4.

Planar mode filtering

There is a special filtering mode which is applied to the macroblock edge when both macroblocks are encoded in intra planar mode. Luma and chroma edges between blocks A and B are filtered with *planar filtering* if all of the following conditions are true, otherwise normal filtering described in 0 and 0 are performed.

- Edge between Macroblock A and Macroblock B is a macroblock edge
- Both Macroblock A ***and*** Macroblock B have planar_flag==1

Planar luma filtering
The planar mode filtering for luma component is performed with the following set of operations.

$p3_i = (7*p3_i + 3)/7$ $i = 0,15$
$p2_i = (6*p3_i + q3_i + 3)/7$ $i = 0,15$
$p1_i = (5*p3_i + 2*q3_i + 3)/7$ $i = 0,15$
$p0_i = (4*p3_i + 3*q3_i + 3)/7$ $i = 0,15$
$q0_i = (3*p3_i + 4*q3_i + 3)/7$ $i = 0,15$
$q1_i = (2*p3_i + 5*q3_i + 3)/7$ $i = 0,15$
$q2_i = (p3_i + 6*q3_i + 3)/7$ $i = 0,15$
$q3_i = (7*q3_i + 3)/7$ $i = 0,15$

Planar chroma filtering
The planar mode filtering for chroma component is performed with the following set of operations.

$p1_i = (4*p1_i + 2)/4$ i = 0,7
$p0_i = (3*p1_i + q1_i + 2)/4$ i = 0,7
q0i = (2*p1i + 2q1i + 2)/4 i = 0,7
q1i = (p1i + 3*q1i + 2)/4 i = 0,7

13 In-loop filtering

The purpose of the adaptive loop filtering (ALF) process is to further reduce the distortion between the original picture and the reconstructed picture caused by complex lossy coding. Filters minimizing the distortion for both luma and chroma components are calculated using the Wiener filter approach. Based on the prediction signal $\hat{s}$, the quantized prediction error e', and the reconstructed filter signal s'', the following adaptive loop filter operation is performed:

$$s''' = \sum_{i=1}^{M} w_i \cdot s''_i + \sum_{i=1}^{N} w_{M+i} \cdot \hat{s}_i + \sum_{i=1}^{O} w_{M+N+i} \cdot e'_i + c$$

After filters are applied in a frame or coding units, filter coefficients are explicitly sent in the bitstream. This adaptive loop filter increases reconstructed picture quality as well as reference picture quality for the next picture coding. The filtering control basis is usually obtained independently from the prediction structure, which results in a large amount of information being sent to the decoder and its inability to access prediction information in its process.

In this text, Coding Block Tree (CBT) synchronized ALF is presented. By utilizing the coding unit structure, the amount of control information to be sent is reduced. Due to the flexible coding unit structure from large to small block, coding unit boundary provides great flexibility to be used as control basis in the adaptive loop filter process. Since the optimal coding unit boundary obtained from previous coding stages reflects objects' boundaries having similar properties, like prediction and quantization error, a simple control scheme which infers filter control structure from the coding unit structure and the optimal control depth reduces the complexity of the optimal control map while achieving similar performance.

The filter control information is signaled in the slice header in order to avoid re-multiplexing of the information at the CU level coded data.

Once the control units for filtering are determined, a control flag indicating whether filtering is applied is sent to maximize filter performance and reduce complexity of filter application. Depending on the largest block size, the maximum depth, sequence property and coding parameters, the number of coding units can be too many to be used as filter control units itself. Thus the optimal control depth is sent to indicate the maximum depth (i.e., the smallest size) of a coding unit boundary to be used as filter control map.

The text uses M set of non-separable/separable filters. The M sets of non-separable/separable filters is transmitted to the decoder for each frame. Whenever the ALF segmentation map indicates that a block should be filtered, for each pixel, a specific set of filters is chosen based on a measure of local characteristic of an image, called activity measure. The text uses the sum-modified Laplacian measure. The sum-modified Laplacian for pixel is calculated as follows:

$$\mathrm{var}(i,j) = \sum_{k=-K}^{K} \sum_{l=-L}^{L} \left|2R(i+k,j+l) - R(i+k-1,j+l) - R(i+k+1,j+l)\right| + \left|2R(i+k,j+l) - R(i+k,j+l-1) - R(i+k,j+l+1)\right| .$$

14 Entropy Coding

14.1 Low-Complexity Entropy Coding

General

All syntax elements are encoded using either FLC or "UVLC-like" VLC tables. Each syntax element use one out of 10 pre-determined VLC tables that are designed for different probability distributions. All VLC tables are organized in the conventional way with the shortest binary codeword at the beginning.

Encoding of a parameter/event using a VLC table is typically done in three steps:

1) Convert the parameter/event value to a *table index* by using some enumeration scheme.
2) Use the *table index* to generate a *code number* through lookup in a *sorting table.* The purpose of the *sorting table* is to assign *code numbers* according to increasing probability so that parameters/events with the high probability are assigned a code number with a low value.
3) Use the *code number* to generate a *binary codeword* by lookup in the pre-determined VLC table.

The VLC encoding process is illustrated in Figure 5, while the VLC decoding process is illustrated in Figure 6.

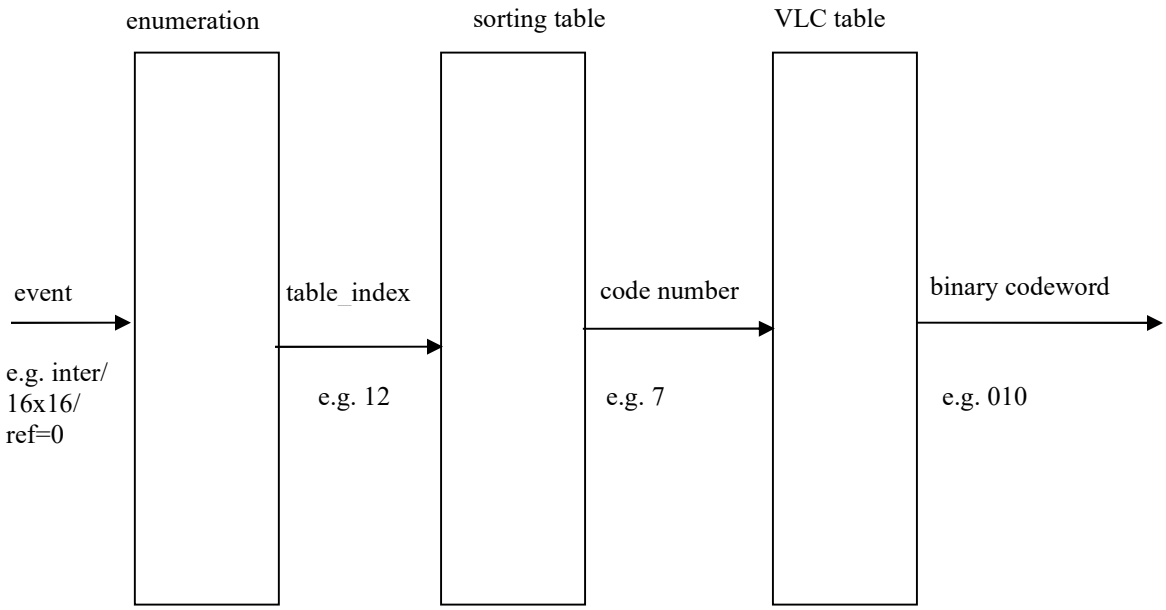


Figure 9 VLC encoding process

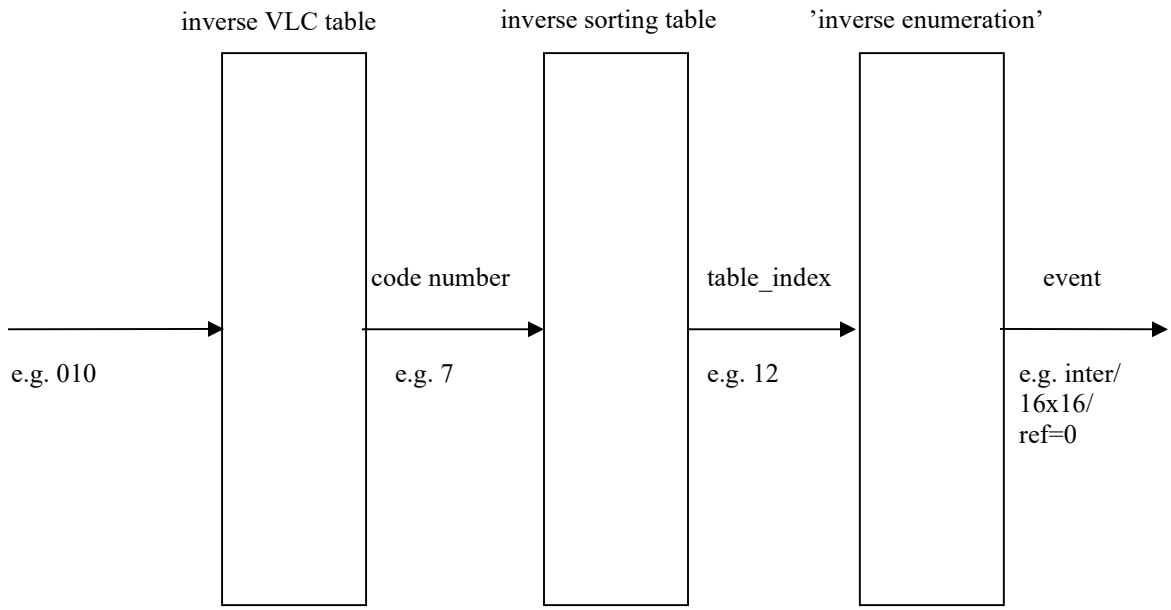


Figure 10 VLC decoding process

Adaptivity

Two different forms of adaptivity are applied to VLC encoding:

1) For some parameters/events, the particular VLC table to be used depends on the value of previously encoded parameters/events. A context variable is maintained that indicates expected probability distribution of the events. This variable is updated as the events are encoded and it is used to look-up VLC table number.

2) For some parameters/events, the *sorting table* is made adaptive. This process is most easily described in terms of *decoder* operations as follows: For each binary codeword that is decoded into a *code number*, determine the corresponding *table index* by lookup into an *inverse sorting table*. Next, swap that entry in the inverse *sorting table* with the entry immediately above. This mechanism ensures that a *table index* value that occurs frequently eventually propagates towards the top of the inverse sorting *table*, corresponding to the most likely value and the shortest *binary codeword*. On the encoder side, both a sorting table and the corresponding inverse sorting table need to be updated simultaneously. Updating the inverse sorting table on the decoder side is illustrated in Figure 7.

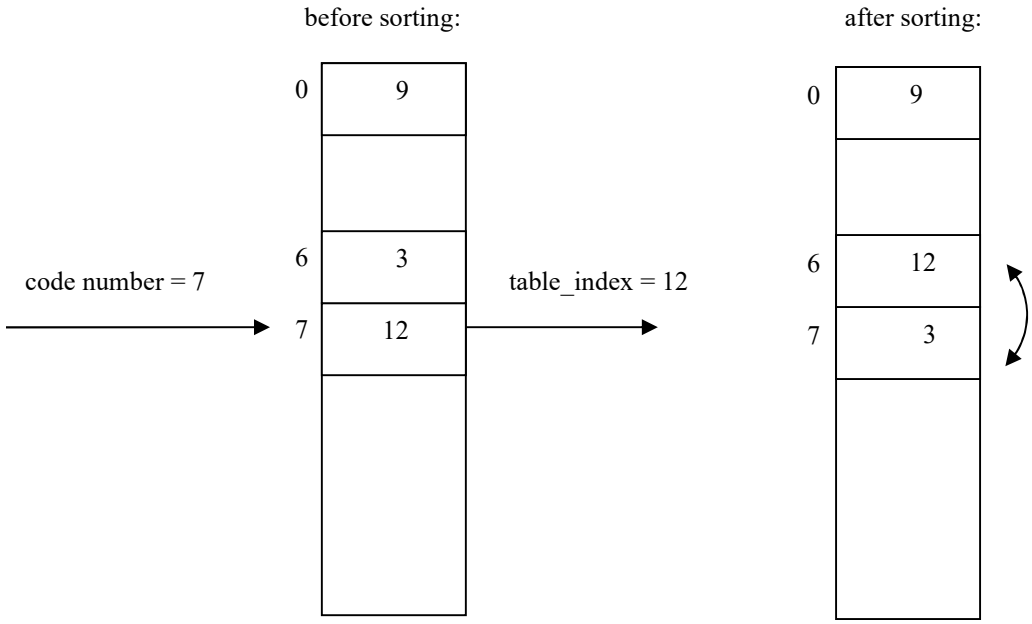


Figure 11 Update of inverse sorting table - example

Transform coefficients

Entropy coding of transform coefficients is performed by an improved version of CAVLC as follows:

1) Organize the quantized transform coefficients, each represented by a level and sign in a 1D array using the conventional zig-zag scan.

2) Coefficients are encoded backwards along the 1D array from the most high frequency coefficient towards the DC coefficients.

3) Each event (to be described below) is encoded using an "UVLC-like" table. Different VLC tables are used for different events.

4) First, the last significant coefficient (last_coeff) is coded in two steps:

i. Code the position (in backward scan order) of last_coeff (last_pos) and a flag (levelFlag = level>1) as a combined event.

ii. If level>1 code the value of level as a single event

iii. Code the sign as one bit

5) If level==1, continue encoding non-zero levels in run-mode.

6) If level>1, switch to level-mode if any of the following is true:

i. Cumulative sum of all level of coefficients coded so far >1 (excluding the level of last_coeff), is bigger than a threshold

ii. The position of the current level is bigger than the threshold position

7) In *run-mode*, encode each non-zero coefficient using the preceding run and levelFlag as a combined event. Then encode the sign and level (if levelFlag==1).

8) In level-mode, encode each coefficient (including zero coefficients) as level and sign.

For the combined last_coeff/levelFlag event, an *adaptive sorting table* is used.

Side information

The following parameters are coded as a combined event for each macroblock:

- macroblock mode
- motion vector partition
- transform size
- macroblock level CBP information

- reference frame index for P frames
- dqp flag (indicating whether or not dqp is signalled for that MB)

For this combined event, an *adaptive sorting table* is used.

The following side information parameters are encoded separately as single events:

- block level CBP
- motion vector differences
- reference frame index for B frames
- intra prediction modes

Block level CBP is encoded using an *adaptive sorting table*.

14.2 High Coding Efficiency Entropy Coding

For entropy coding, a variation of CABAC (as found in AVC) is employed. The binarization and context modeling are basically the same as in CABAC of AVC, except from a few modifications and additions as further explained below. However, the actual coding of the bins is based on a novel concept that has been introduced in order to support parallelized implementations of entropy encoding and decoding with load balancing.

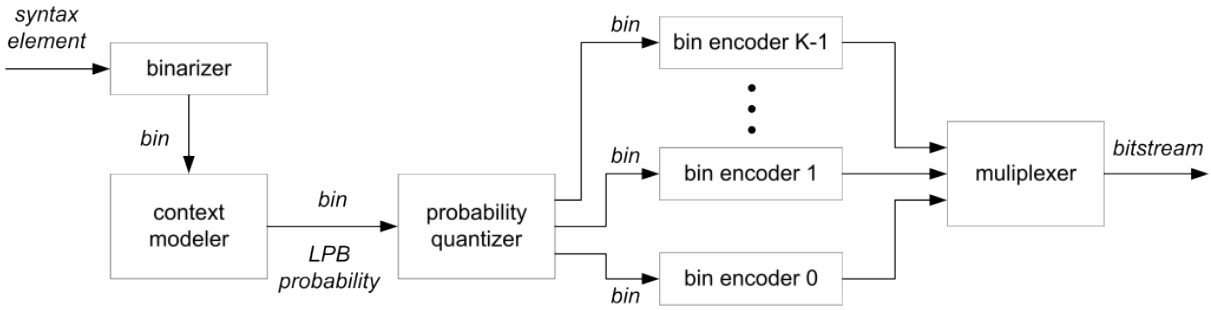


Figure 10: Parallel V2V entropy coding

14.2.1 Novel entropy coding concept

In Fig. 9, the basic entropy coding concept is illustrated. If a syntax element does not already represent a binary syntax element, it is first binarized, i.e., it is mapped onto a sequence of binary decisions (bins). For each bin a context is selected. A context represents a (binary) probability model for a class of bins; it is characterized by the probability and the value of the less probable bin (LPB). As in AVC, the LPB probability is represented by one out of 64 states. At the beginning of the encoding/decoding of a slice, the probability models are initialized using fixed values (as in CABAC of AVC). And after encoding/decoding a bin with a particular model, the model (i.e., the corresponding probability and value of the LPB) is updated. The probability model update, i.e., the probability estimation process is the same as in CABAC of AVC. The association of a bin with a context model is also similar as in CABAC of AVC. It depends on the syntax element, the bin number, and, for some bins, the values of neighboring syntax elements.

The above described binarization and association of the bins with context models is basically the same as in CABAC of AVC. The main difference is the next step. Instead of arithmetically coding the bins with the associated probability models using a single arithmetic coding engine as in CABAC of AVC, the estimated LPB probabilities are quantized, i.e., they are mapped onto a small number of LPB probability intervals and for each of these probability intervals a separate bin encoder/decoder is operated. In one implementation, we used 12 probability intervals and thus 12 different bin encoders/decoders. Each bin encoder/decoder operates at a fixed LPB probability, which can be considered as the representative probability for an LPB interval. The selection of a bin encoder/decoder is implemented via a look-up table that associates a bin encoder with each of the 64 state indices for the LPB probability. Hence, the 64 states that are used for estimating the LPB probability of a context model are mapped onto the selected (e.g. 12 in one of the proposed implementation) probability classes, for each of which a separate bin encoder/decoder is operated. The partial bitstreams that are generated by the bin encoders can be written to different partitions of a NAL unit (with the partitioning of the NAL unit being indicated in the slice header) or they can be interleaved into a single bitstream.

The bin encoders and decoders represent simple variable length bin to variable length (V2V) codes, by which a variable number of bins is mapped onto variable length codewords and vice versa.

In the case where parallel processing at the decoder is desired, a load balancing scheme is provided to distribute the computational load onto multiple bin decoders evenly.

14.2.2 V2V codes

For the bin encoders (cf. 9), V2V codes are employed. It should be again noted that each bin encoder operates at a fixed LPB probability. And for a fixed LPB probability, we can simply construct a code that maps a variable number of bins onto a variable length codeword and vice versa. As a particular example, the following table shows an example for such a mapping. In the example the bins "0" represent the more probable bin values and the bins "1" represent the less probable bin values. The example code has been designed for a LPB probability of 0.15 and it yields a redundancy of only 0.25 % relative to the entropy limit for this probability. Generally, it is possible to get closer to the entropy limit when the table size is increased.

Table 1: Example for a mapping between a variable number of bins and variable length codewords

Sequence of bins (bin order is from left to right)	codewords (bits order is from left to right)
0000	1
01	001
10	010
001	011
0001 00	0001
11	0000 1
0001 1	0000 00
0001 01	0000 01

At the end of a slice or due to a flush event (e.g. buffer full), it is possible that a bin sequence does not represent any bin sequence that is associated with a codeword, that is the bin sequence sits at an internal node of the V2V tree. In order to terminate the codeword, the shortest codeword for a bin sequence that contains the current bin sequence as prefix is written. At the decoder side, the additionally decoded bins are discarded. As an example, we could use the mapping in the above table and have a bin sequence "00" at the end of a slice. Then we would write the codeword "1" (corresponding to the bin sequence "0000"). At the decoder side, the codeword "1" would be translated into the bin sequence "0000", but the decoder would discard (ignore) the last two decoded bins.

The partial bitstreams can be written to different partitions of the slice data NAL unit (with transmitting the partitioning information in the slice header). It is also possible to combine the partial bitstreams into one single bitstream. Let L_k be the encoded length of the kth partial bitstream, where $0 <= k < N$, where N=StateCount. We define a prefix code C the following way:

If $n < 128$, then $C(n) = n << 1$;
Else if $n < 16512$, then $C(n) = ((n - 128) << 2) | 1$;
Else if $n < 2113664$, then $C(n) = ((n - 16512) << 3) | 3$;
Else $C(n) = ((n - 2113664) << 3) | 7$;

where "<<" is a right shift, and "|" is a bit-wise OR.

The output of the parallel framework is the concatenation of the following:

1. [Header] $C(L_k)$ for $0 <= k < N$,
2. [Payload] The encoded sequence for bitstream k ($0 <= k < N$).

The decoder first decodes the L_k values from the header, and uses these values to find the starting point of the encoded sequence k within the payload. After this, the N bitstreams can be decoded independently of each other from the payload, hence parallel decoding is feasible.

It is also possible to interleave the codewords from different partial bitstreams. This is in particular beneficial for small slice data NAL units, for which parallelized bin decoding is not required. In order to realize such an interleaving, a first-in-first-out codeword buffer for variable-length codewords can be introduced at the encoder side. When a particular bin encoder starts the encoding of a new bin sequence (i.e., the bin encoder receives the first bin

after having written the previous codeword), it reserves the next variable-length codeword entry in the codeword buffer. When the received bins represent a bin sequence that corresponds to a codeword, this codeword is written to the previously reserved codeword entry, that is, output in a first-in-first-out order. Examples for the codeword buffer status are illustrated in Fig. 8. At the decoder side, the codewords can be directly read from the bitstream in decoding order.

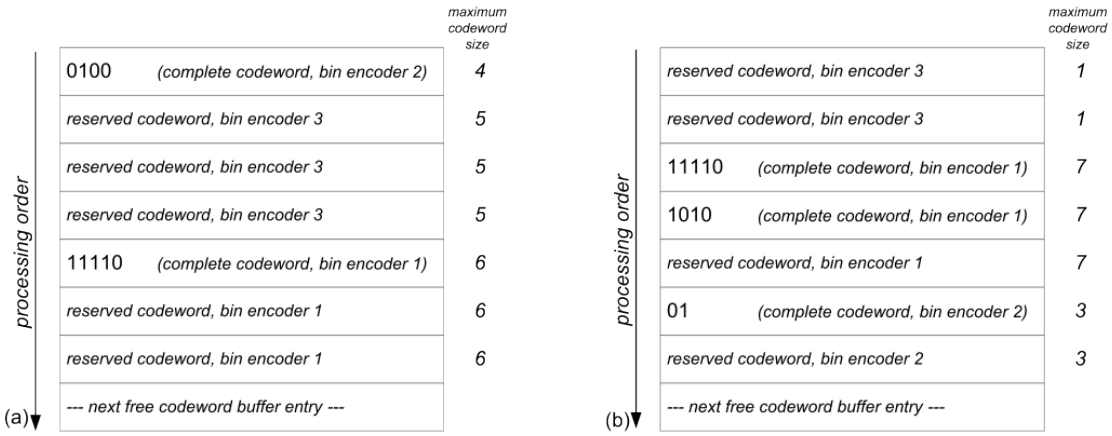


Figure 11: Interleaving codewords by using a first-in-first-out codeword buffer

It is also possible to combine the codeword interleaving with a low-delay buffer control. That means, we can suitably restrict the buffer delay that is introduced by the codeword interleaving. With such a low-delay control, a particular codeword is terminated when the maximum number of bits (this maximum number of bits represents the maximum codeword length for a particular bin encoder and is given by the corresponding mapping table) that are associated with the reserved or completed buffer entries following the buffer entry for the particular codeword is greater than a particular threshold. At the decoder side, the extra decoded bins must be discarded; this can be done by using the same measure of the maximum number of bits as at the encoder side.

~~14.2.3Encoding process for load balancing in parallel V2V (Informative)~~

~~[Ed.: Would this section be better to be moved to an Informative Annex?]~~

~~This section describes the load balancing of bins for an arbitrary (possibly unknown) number of bin decoders available in the parallel framework described in Figure 9 above. In this section all length values are expressed in bits, unless stated otherwise.~~

~~The parallel V2V encoding process creates the encoded bit streams S'_k of length M'_k for each of the input bin symbol sequence S_k, k=0,…,N, with the given entropy coder, where N=mergeStateCount.~~

~~The output of the load balancing extension to the parallel framework is the concatenation of the following:~~

- ~~[First part of the header] $C(M'_k)$ for k = 0,…,N,~~
- ~~[Second part of the header,] auxiliary offset information~~
- ~~[Payload] S'_k (k=0,…,63)~~

~~The byte-align prefix code C() is the same as defined in Section 5.1.16.1.~~

~~The format and content of the second part of the header depends on the V2V codes used to encode the S_k sequences, and a distributor function. This part is a self-delimiting sequence.~~

~~Let D(a, b) be the set of all $(v_1,\ldots,v_b)$ vectors, for which v_k is a positive integer (k=1,…,b), and $v_1 + v_2 + \ldots + v_b = a$. Let $S' = S'_0 + \ldots + S'_N$. Then, using the notations above, the distributor function is a function of the form F : {0,1}^K -> D(K, b). The distributor partitions the concatenated encoded sequences into b units, such that decoding each unit would take approximately the same time.~~

~~In this form, the distribution function gives the lengths of the decodable segments. The starting positions of these segments are given by the associated function F'(x), where for F(x)= $(v_1,\ldots,v_b)$, F'(x)=$(0, v_1, v_1+v_2, v_1+v_2+v_3, \ldots, v_1+\ldots+v_b)$. Obviously, the functions F and F' mutually determine each other.~~

~~Example: the uniform distributor assumes that the decoding complexity of any S'_k depends only on M'_k, that is, the length of S'_k. Then, for the concatenated encoded bit stream x of length S', F(x) = (S'/b, S'/b, …, S'/b) (the division may be rounded up or down to meet the final sum $M'_0+\ldots+M'_N$). Example: the weighted distributor assumes that the decoding complexity of any S'_k is uniform within S'_k, but may vary according to k. Let w_k be this complexity for S'_k, and $W=w_0*M'_0 + \ldots + w_{63}*M'_{63}$. Then the distributor assigns the values F'(x) = $(v_1,\ldots,v_b)$ such that for any k < b: the decoding complexity of the segment $x[v_k,\ldots,v_{k+1}-1]$ is W/b.~~

~~The format of the second part of the header is as follow:~~

~~Consider a V2V bin encoder. For all k=1,…,b-1, let B_k be the number of bits, which we have to read ahead from F'(x)[k] to arrive at the start of the next codeword. That is, B_k=0 if a codeword starts right at F'(x)[k], B_k=1 if the next codeword starts at F'(x)[k+1], and so on. Then Part 2 of the header is the concatenation of the values $C(B_k)$ for k=1,…,b-1.~~

~~It is possible to achieve load balancing for any specific set of b segments and d bin decoders; however, some sets obviously perform better than others. The best performance among all (b, d) values is reached when b is a multiple of d.~~

~~Example: If d divides b, then the load balancing algorithm simplifies to G_k=b/d for all k=1,…,d.~~

~~The general method works with the case when the encoder has no information about the number d of bin decoders at the side of the decoder. In the case that the encoder has a knowledge of some potential candidates $d_1, d_2, \ldots, d_k$ for the number of bin decoders, we present the following improvement: let b be a number which is a multiple of all of $d_1, \ldots, d_k$ (the least common multiple of the numbers $d_1, \ldots, d_k$ is adequate). In this case, for all the candidates the load distribution algorithm simplifies to the previous example, while for all other bin decoder numbers it resorts to the general algorithm.~~

~~Example: Suppose that the encoder knows that target decoders may be equipped with any one of 1, 2, 3, 4, 6, 8, 10, 12 or 16 bin decoders. The least common multiple of these numbers is 240, so the encoder should set b=240.~~

~~Example: If the encoder sets $b=2^t$, then optimal load balancing is achieved for each of 1, 2, 4, 8, …, 2^t bin decoders.~~

~~14.2.4~~14.2.3 Binarization and context modeling

[Ed. put into parsing process of context adaptive entropy coding]
As already mentioned above, we have reused the binarization and context modeling schemes of AVC CABAC for most syntax elements in this video coding algorithm, especially for those which have already been present in AVC like, e.g., syntax elements related to intra prediction modes or motion parameters. For entropy coding of novel syntax elements like, e.g., flags indicating the quadtree structure, suitable context models have been designed. In addition, for coding of syntax elements related to transform coefficients of larger block sizes, an improved context modeling scheme has been employed.

~~14.2.5~~14.2.4 Improved context modeling scheme for coding of transform coefficients

The novel context modeling scheme applies to the syntax elements significant_coeff_flag, last_significant_coeff_flag, and coeff_abs_level_minus_one of blocks of size 8x8 and larger, and it is complemented by an adaptive switching of the scan during encoding/decoding of the significance map (specifying the locations of non-zero transform coefficient levels).

Coding of the significance map

Coding of the syntax elements significant_coeff_flag and the last_significant_coeff_flag, as constituting the significance map, is improved by an adaptive scan and a new context modeling based on a defined neighborhood of already coded scan positions. This turned out to be beneficial especially for large block sizes.

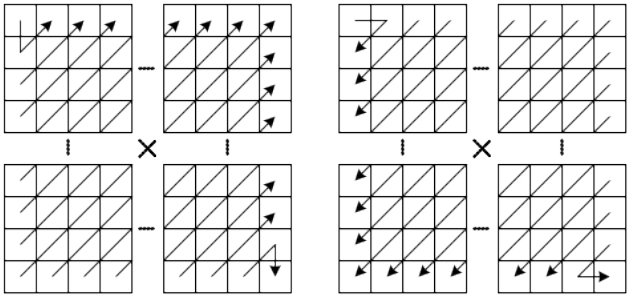


Fig. 9 Illustration of the two scanning patterns for the significance map

Scanning order

The scanning order for coding the significance map is adapted by switching between two predefined scan patterns. For the first scanning pattern, the diagonal sub-scans are scanned from bottomleft to topright (left illustration of Fig. 9), and for the second scanning pattern, the diagonal subscans are scanned from topright to bottomleft (right illustration of Fig. 9). The coding of the significance map starts with the second scanning pattern. While coding the syntax elements, the number of significant transform coefficient values is counted by two counters c_1 and c_2. The first counter c_1 counts the number of significant transform coefficients that are located in the bottom-left part of the transform block; i.e., this counter is incremented by one when a significant transform coefficient level is coded/decoded for which the horizontal coordinate x inside the transform block is less than the vertical coordinate y. The second counter c_2 counts the number of significant transform coefficients that are located in the top-right part of the transform block; i.e., this counter is incremented by one when a significant transform coefficient level is coded/decoded for which the horizontal coordinate x inside the transform block is greater than the vertical coordinate y. At the end of each diagonal sub-scan, it is decided whether the first or the second of the predefined scanning patterns is used for the next diagonal sub-scan. This decision is based on the values of the counters c_1 and c_2. When the counter for the bottom-left part of the transform block is greater than the counter for the bottom-left part, the scanning pattern that scans the diagonal sub-scans from bottom-left to top-right is used; otherwise (the counter for the bottom-left part of the transform block is less than or equal to the counter for the bottom-left part), the scanning pattern that scans the diagonal sub-scans from topright to bottom-left is used.

Context modeling

For 4x4 blocks, the context modeling for the syntax elements significant_coeff_flag is done as specified in AVC. For 8x8 blocks, the transform block is decomposed into 16 sub-blocks of 2x2 samples, and each of these sub-blocks is associated with a separate context. The context model selection for larger transform blocks (e.g., for blocks greater than 8x8) is based on the number of already coded significant transform coefficients in a predefined neighborhood (inside the transform block). For coding of the last_significant_coeff_flag, a context modeling has been designed that depends on a distance measure of the current scan position to the top-left corner of the given transform block. To be more specific, the context model for coding the last_significant_coeff_flag is chosen based on the scan diagonal on which the current scan position lies (i.e., it is chosen based on x + y, where x and y represent the horizontal and vertical location of a scan position inside the transform block, respectively). To avoid overfitting, the distance measure x + y is mapped on a reduced set of context models in a certain way (e.g. by quantizing x + y).

Coding of absolute values of transform coefficient levels

The coding process for absolute transform coefficient levels maps each quadratic (or rectangular) block of size 8x8 and larger onto an ordered set (vector) of 4x4 sub-blocks by using a forward zig-zag scan; while the transform coefficient levels inside a sub-block are processed in a reverse zig-zag scan. Following the handling of 4x4 blocks in AVC CABAC, the context model set for each sub-block consists of two times five context models with five models for both the first bin and all remaining bins (up to and including the 14. bin) of the coeff_abs_level_minus_one syntax element, where the selection of context models is done exactly as in the original CABAC. However, as a novel feature, different sub-blocks may select different sets of context models, where the choice of the context model set for a sub-block depends on certain statistics of one or more already coded sub-blocks.

AAnnex B
Byte stream format

This annex specifies syntax and semantics of a byte stream format specified for use by applications that deliver some or all of the NAL unit stream as an ordered stream of bytes or bits within which the locations of NAL unit boundaries need to be identifiable from patterns in the data, such as ITU-T Rec. H.222.0 | ISO/IEC 13818-1 systems or ITU-T Rec. H.320 systems. For bit-oriented delivery, the bit order for the byte stream format is specified to start with the MSB of the first byte, proceed to the LSB of the first byte, followed by the MSB of the second byte, etc.

The byte stream format consists of a sequence of byte stream NAL unit syntax structures. Each byte stream NAL unit syntax structure contains one start code prefix followed by one nal_unit(NumBytesInNALunit) syntax structure. It may (and under some circumstances, it shall) also contain an additional zero_byte syntax element. It may also contain one or more additional trailing_zero_8bits syntax elements. When it is the first byte stream NAL unit in the bitstream, it may also contain one or more additional leading_zero_8bits syntax elements.

A.1 Byte stream NAL unit syntax and semantics

A.1.1 Byte stream NAL unit syntax

byte_stream_nal_unit(NumBytesInNALunit) {	C	Descriptor
while(next_bits(24) != 0x000001 && next_bits(32) != 0x00000001)		
leading_zero_8bits /* equal to 0x00 */		f(8)
if(next_bits(24) != 0x000001)		
zero_byte /* equal to 0x00 */		f(8)
start_code_prefix_one_3bytes /* equal to 0x000001 */		f(24)
nal_unit(NumBytesInNALunit)		
while(more_data_in_byte_stream( ) && next_bits(24) != 0x000001 && next_bits(32) != 0x00000001)		
trailing_zero_8bits /* equal to 0x00 */		f(8)
}		

A.1.2 Byte stream NAL unit semantics

The order of byte stream NAL units in the byte stream shall follow the decoding order of the NAL units contained in the byte stream NAL units. The content of each byte stream NAL unit is associated with the same access unit as the NAL unit contained in the byte stream NAL unit.

leading_zero_8bits is a byte equal to 0x00.

zero_byte is a single byte equal to 0x00.

When any of the following conditions are fulfilled, the zero_byte syntax element shall be present:

– the nal_unit_type within the nal_unit( ) is equal to 7 (sequence parameter set) or 8 (picture parameter set),

– the byte stream NAL unit syntax structure contains the first NAL unit of an access unit in decoding order.

start_code_prefix_one_3bytes is a fixed-value sequence of 3 bytes equal to 0x000001. This syntax element is called a start code prefix.

trailing_zero_8bits is a byte equal to 0x00.

A.2 Byte stream NAL unit decoding process

Input to this process consists of an ordered stream of bytes consisting of a sequence of byte stream NAL unit syntax structures.

Output of this process consists of a sequence of NAL unit syntax structures.

At the beginning of the decoding process, the decoder initialises its current position in the byte stream to the beginning of the byte stream. It then extracts and discards each leading_zero_8bits syntax element (if present), moving the current position in the byte stream forward one byte at a time, until the current position in the byte stream is such that the next four bytes in the bitstream form the four-byte sequence 0x00000001.

The decoder then performs the following step-wise process repeatedly to extract and decode each NAL unit syntax structure in the byte stream until the end of the byte stream has been encountered (as determined by unspecified means) and the last NAL unit in the byte stream has been decoded:

1. When the next four bytes in the bitstream form the four-byte sequence 0x00000001, the next byte in the byte stream (which is a zero_byte syntax element) is extracted and discarded and the current position in the byte stream is set equal to the position of the byte following this discarded byte.

2. The next three-byte sequence in the byte stream (which is a start_code_prefix_one_3bytes) is extracted and discarded and the current position in the byte stream is set equal to the position of the byte following this three byte sequence.

3. NumBytesInNALunit is set equal to the number of bytes starting with the byte at the current position in the byte stream up to and including the last byte that precedes the location of any of the following conditions:

   – A subsequent byte-aligned three-byte sequence equal to 0x000000,

   – A subsequent byte-aligned three-byte sequence equal to 0x000001,

   – The end of the byte stream, as determined by unspecified means.

4. NumBytesInNALunit bytes are removed from the bitstream and the current position in the byte stream is advanced by NumBytesInNALunit bytes. This sequence of bytes is nal_unit(NumBytesInNALunit) and is decoded using the NAL unit decoding process.

5. When the current position in the byte stream is not at the end of the byte stream (as determined by unspecified means) and the next bytes in the byte stream do not start with a three-byte sequence equal to 0x000001 and the next bytes in the byte stream do not start with a four byte sequence equal to 0x00000001, the decoder extracts and discards each trailing_zero_8bits syntax element, moving the current position in the byte stream forward one byte at a time, until the current position in the byte stream is such that the next bytes in the byte stream form the four-byte sequence 0x00000001 or the end of the byte stream has been encountered (as determined by unspecified means).

A.3 Decoder byte-alignment recovery (informative)

Many applications provide data to a decoder in a manner that is inherently byte aligned, and thus have no need for the bit-oriented byte alignment detection procedure described in this subclause.

A decoder is said to have byte-alignment with a bitstream when the decoder is able to determine whether or not the positions of data in the bitstream are byte-aligned. When a decoder does not have byte alignment with the encoder's byte stream, the decoder may examine the incoming bitstream for the binary pattern ‘00000000 00000000 00000000 00000001’ (31 consecutive bits equal to 0 followed by a bit equal to 1). The bit immediately following this pattern is the first bit of an aligned byte following a start code prefix. Upon detecting this pattern, the decoder will be byte aligned with the encoder and positioned at the start of a NAL unit in the byte stream.

Once byte aligned with the encoder, the decoder can examine the incoming byte stream for subsequent three-byte sequences 0x000001 and 0x000003.

When the three-byte sequence 0x000001 is detected, this is a start code prefix.

When the three-byte sequence 0x000003 is detected, the third byte (0x03) is an emulation_prevention_three_byte to be discarded as specified in subclause XX.

When an error in the bitstream syntax is detected (e.g., a non-zero value of the forbidden_zero_bit or one of the three byte or four-byte sequences that are prohibited in subclause XX), the decoder may consider the detected condition as an indication that byte alignment may have been lost and may discard all bitstream data until the detection of byte alignment at a later position in the bitstream as described in this subclause.

BAnnex C
Hypothetical reference decoder

[Ed: Text describing the HRD and the bumping process to be taken from MPEG-4 AVC/H.264 as a starting point for this test model under consideration]

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

B.1 Operation of coded picture buffer (CPB)

B.2 Operation of the decoded picture buffer (DPB)

B.3 Bitstream conformance

B.4 Decoder conformance