DECLARATION OF JUNE ANN MUNFORD

1. My name is June Ann Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.

2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix CV.

3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog

search performance and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as "MARC") code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item's MARC record indicates the date of an item's public availability.

5. Typically, in creating a MARC record, a librarian would gather various bits of metadata such as book title, publisher and subject headings among others and assign each value to a relevant numerical field. For example, a book's physical description is tracked in field 300 while title/attribution is tracked in field 245. The 008 field of the MARC record is reserved for denoting the creation of the library record itself. As this is the only date reflecting the inclusion of said materials within the library's collection, it is my experience

that an item's 008 field accurately indicates the date of an item's public availability.

6. I am familiar with the Internet Archive, a digital library accessible to the general public. Among other services that the Internet Archive makes available to the general public is the Wayback Machine, an online archive of the web. The Internet Archive's Wayback Machine service archives webpages as of a certain capture date to track changes in the web over time. The Internet Archive has been in operation as a nonprofit library since 1996 and has hosted the Wayback Machine service since its inception in 2001. During my time as a librarian, I frequently used the Internet Archive's Wayback Machine for research and instruction purposes. This includes teaching instructional classes on using the Wayback Machine to library patrons and using the Wayback Machine to research reference inquiries that require hard-to-find online resources. I consider the Internet Archive's recordskeeping to be as rigorous and detailed as other formal library recordskeeping practices such as MARC records, OCLC records and Dublin Core.

7. I have reviewed Exhibit 1009 a document entitled *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication (02/98).*

8. Attached hereto as Appendix ITU01 are screen captures of a web page entitled "H.263: Video Coding for Low Bit Rate Communication" hosted on the ITU (International Telecommunications Union) website. I secured these screen captures from https://www.itu.int/rec/T-REC-H.263-199802-S/en.

9. Appendix ITU01 is a web page describing the February 1998 revision of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication*. This page indicates the February 1998 revision of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* was approved as of February 6, 1998 and posted to the ITU web page as of October 22, 1998.

10. Appendix ITU01 also contains a full PDF copy of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* downloaded from the ITU page. In comparing this copy of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* found in Appendix ITU01 to Exhibit 1009, it is my determination that Exhibit 1009 is a true and correct copy of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication.*

11. Attached hereto as Appendix IA01 is a screen capture of the Internet Archive Wayback Machine entry for http://www.itu.int/itudoc/itu-t/rec/h.html. I secured these screen captures myself from https://web.archive.org/web/19991001000000*/http://www.itu.int/itudoc/itu-t/rec/h.html.

12. Appendix IA01 is a web page entitled "Series H Recommendations – Line Transmission of Non-Telephone Signals" hosted on the ITU website. This page was captured by the Internet Archive as of January 28, 1999.

13. Appendix IA01 is a list of all active ITU-T Series H Recommendations as of January 28, 1999. A notice visible on page 2 of this Appendix reads "Publications tagged with Bookshop can be ordered and downloaded from the ITU Electronic Bookshop". An entry for the February 1998 revision of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* can be found on page 3 of this Appendix. This entry contains the 'Bookshop' marker indicating *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* could be ordered and downloaded from the ITU Electronic Bookshop as of January 28, 1999.

14. Attached hereto as Appendix IA02 is a screen capture of the Internet Archive Wayback Machine entry for http://www.itu.int/itudoc/itu-t/rec/h/h263.html. I secured these screen captures myself from https://web.archive.org/web/19991101000000*/http://www.itu.int/itudoc/itu-t/rec/h/h263.html.

15. Appendix IA02 is a web page entitled "[H.263] Recommendation H.263 (02/98) – Video Coding for low bit rate communication" hosted on the ITU website. This page was captured by the Internet Archive as of November 4, 1999.

16. Appendix IA02 is a web page describing the February 1998 revision of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication.* This web page contains a Table of Contents for *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* that is functionally identical to the table of contents found in Exhibit 1009. This page offers ITU customers the ability to purchase and download a copy of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* as of November 4, 1999. This page also indicates that *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* is accessible at the time via the ITU's subscriptions service.

17. Attached hereto as Appendix TAMU01 is a true and correct copy of the MARC record for *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* as held by the Texas A&M University library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix TAMU01 accurately describes the title, author, publisher, and ITU-T recommendation number of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication.*

18. The 008 field of the MARC record in Appendix TAMU01 indicates the date of record creation. The 008 field of Appendix TAMU01 indicates Texas A&M University library first acquired this book as of May 11, 2000.

19. Appendix IA02 clearly indicates the ITU web page was offering PDF copies of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* for purchase to the public as of November 4, 1999. Appendix TAMU01 clearly indicates that Texas A&M University library first acquired *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* as of May 11, 2000. Therefore, it is my determination that *ITU-T Recommendation H.263: Video Coding for Low Bit Rate*

Communication was first made available to the public as of November 4, 1999 and certainly no later than May 11, 2000.

20. As Appendix ITU01 indicates a PDF version of *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* was uploaded to the ITU website as of October 22, 1998 and Appendix IA01 indicates *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* was on a list of materials for sale as of January 28, 1999, it is likely that *ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication* was available to the public prior to November 1999.

21. I have reviewed Exhibit 1008, *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s* by ISO/IEC.

22. Attached hereto as Appendix ISO01 is a true and correct copy of the MARC record for *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s* as held by the University of Wisconsin-Madison Library. I secured this record myself from the library's public catalog. The MARC record contained within Appendix ISO01 accurately describes the title,

author, publisher, and ISBN number of *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s*.

23. Attached hereto as Appendix ISO02 is a true and correct copy of *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s* as held by the University of Wisconsin-Madison Library. These scans were secured from the library's collection. In comparing Exhibit 1008 to Appendix ISO02, it is my determination that Exhibit 1008 is a true and correct copy of *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s* by ISO/IEC.

24. The 008 field of the MARC record in Appendix ISO01 indicates the date of record creation. The 008 field of Appendix ISO01 indicates the University of Wisconsin-Madison Library first acquired *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s* as of October 21, 1993. Considering this information, it is my determination that *ISO/IEC Standard 11172: Information Technology -- Coding of Moving Pictures and*

Associated Audio for Digital Storage Media at Up to About 1.5 Mbit/s was made available to the public shortly after its initial acquisition as of October 21, 1993.

25. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of $200.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

26. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of 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 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.

Dated: 6/6/2025

June Ann Munford

APPENDIX CV

June A. Munford
Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy, cataloging and public administration.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance ● Pittsburgh, Pennsylvania & Grand Rapids, Michigan

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Experienced with appeals and deposition process.

- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.

- Past clients include Alston & Bird, Arnold & Porter, Baker Botts, Fish & Richardson, Erise IP, Irell & Manella, O'Melveny & Myers, Perkins-Coie, Pillsbury Winthrop Shaw Pittman and Slayden Grubert Beard.

Library Director, February 2013 - March 2015
Dowagiac District Library ● Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over $400,000 and total assets of approximately $1,300,000.

● Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years while being audited.

● Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.

● Led the organization and digitization of the library's archival records.

● Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.

● Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013
Librarian & Branch Manager, Anchorage Public Library ● Anchorage, Alaska

● Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.

● Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.

● Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013
Library Assistant, Hart Area Public Library
Hart, MI

● Responsible for verifying imported MARC records and original MARC cataloging for the local-level collection as well as the Michigan Electronic Library.

● Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter

● Treasurer, 2012

Library Of Michigan
● Level VII Certification, 2008
● Level II Certification, 2013

Michigan Library Association Annual Conference 2014
● New Directors Conference Panel Member

Southwest Michigan Library Cooperative
● Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008
Petoskey, MI
● Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011
Nashville, TN
● Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012
Fairbanks, AK
● Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Depositions

2019 ● Fish & Richardson

Apple v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282 and 39521-00421IP2)

2019 ● Erise IP

Implicit, LLC v. Netscout Systems, Inc (Case No. 2:18-cv-53-JRG)

2019 ● Perkins-Coie

Adobe Inc. v. RAH Color Technologies LLC (Case No. IPR2019-00627, IPR2019-00628, IPR2019-00629 and IPR2019-00646)

2020 ● O'Melveny & Myers

Maxell, Ltd. v. Apple Inc. (Case No. 5:19-cv-00036-RWS)

2021 ● Pillsbury Winthrop Shaw Pittman LLP

Intel v. SRC (Case No. IPR2020-1449)

2022 ● Perkins-Coie

Realtek v. Future Link (Case No. IPR2021-01182)

2023 ● Fish & Richardson

Neuroderm Ltd. v. Abbvie, Inc (Case No. PGR2022-00040)

2023 ● Fish & Richardson

Nearmap US Inc. v. Pictometry International Corp. (Case No. IPR2022-00735)

2023 ● Fish & Richardson

Samsung Electronics v. MemoryWeb LLC (Case No. 39843-0136PS1)

2023 ● Pillsbury Winthrop Shaw Whitman LLP

Gravel Rating Systems v. Costco Wholesale Corp. (Case No. 4:21-cv-149-ALM)

2024 ● Willkie-Farr

Netflix, Inc. v. VideoLabs. Inc. (Case No. IPR2023-00628)

2024 ● Quinn Emanuel Urquhart & Sullivan

Purdue University v. Wolfspeed (Case No. 1:21-CV-840)

2024 ● Fish & Richardson

Dish Network v. Entropic Communications (Case No. IPR2024-00393)

2025 ● Perkins Coie

Amazon.com, Inc. v. Nokia Technologies Oy (Case No. IPR2024-00572)

2025 ● Fish & Richardson

Dish Network v. Entropic Communications (Case No. IPR2024-00373)

Limited Case and Clientele History

Alston & Bird

● Ericsson

v. Collision Communications (Case No. IPR2022-01233)

● Nokia

v. Neptune Subsea, Xtera (Case No. 1:17-cv-01876)

● Universal Electronics Inc

v. Roku Inc (Case No. IPR2022-00818)

Alavi & Anaipakos PLLC

● Stingray Group Inc. and Stingray Music USA, Inc.

v. Edwin A. Hernandez-Mondragon and Egla Corp. (Case No. 1:24-cv-21226-RAR)

Arnold & Porter

● Ivantis

v. Glaukos (Case No. 8:18-cv-00620)

● Samsung

v. Jawbone (Case No. 2:21-cv-00186)

Benesch Friedlander Coplan & Aronoff

- Voyis

  v. Cathx (Case No. 5:21-cv-00077-RWS)

Buchanan, Ingersoll & Rooney PC

- Google LLC, AT&T Service Inc., T Mobile USA Inc., Cellco Partnership, Ericsson Inc. & Nokia of America Corp.

  v. KT Corp & Pegasus Wireless Innovation LLC (Case No. IPR2025-00293)

Deschert LLP

- Smaxtec Animal Care

  v. ST Reproductive Technologies, LLC (Case No. IPR2024-00885)

Duane Morris

- Kangxi Communication Technologies

  v. Skyworks Solutions Inc. (Case No. IPR2025-00373)

- Microsoft

  v. Edge Networking Systems LLC (Case No. 1:24-cv-00215)

Erise I.P.

- Apple

  v. Ericsson Inc. (Case No. IPR2022-00715)

  v. Future Link Systems (Case No. IPRs 6317804, 6622108, 6807505, and 7917680)

  v. INVT (Case No. 20-1881)

  v. Navblazer LLC (Case No. IPR2020-01253)

  v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

v. Quest Nettech Corp (Case No. 2:19-cv-00118-JRG)

v. Telefonaktiebolaget LM Ericsson (Case No. IPR2022-00275)

v. Theta IP, LLC (Case No. IPR2024-00818)

v. THL Holding Company LLC (Case No. 1:23-cv-00548)

- Fanduel

  v. CGT (Case No. 19-1393)

- Garmin

  v. Phillips North America LLC (Case No. 2:19-cv-6301-AB-KS)

- Netscout

  v. Longhorn HD LLC (Case No. 2:20-cv-00349)

  v. Implicit, LLC (Case No. 2:18-cv-53-JRG)

- Sony Interactive Entertainment LLC

  v. Bot M8 LLC (Case No. IPR2020-01288)

  v. Infernal Technology LLC (Case No. 2:19-CV-00248-JRG)

- Tesla

  v. Charge Fusion Technologies LLC (Case No. IPR2025-00032)

- Unified Patents

  v. GE Video Compression (Case No. 2:19-cv-248)

Fish & Richardson

- Apple

  v. AliveCor (Case No. 3:21-cv-03958)

  v. LBS Innovations (Case No. 2:19-cv-00119-JRG-RSP)

  v. Koss Corporation (Case No. IPR2021-00305)

v. Masimo (Case No. IPR 50095-0012IP1, 50095-0012IP2, 50095-0013IP1, 50095-0013IP2, 50095-0006IP1, 50095-0135IP1)

v. Neonode (Case No. 21-cv-08872-EMC)

v. Qualcomm (Case No. IPR2018-001281, 39521-00421IP, IPR2018-01282, 39521-00421IP2)

v. Resonant Sys. (Case No. 7:23-cv-00077-ADA)

- AsusTek Computer Inc.
  v. Videolabs, Inc. (Case No. 22-CV-00720-ADA)

- Dell
  v. Neo Wireless (Case No. IPR2022-00616)

- Dish Network

  v. Entropic Communications, LLC (Case No. 2:2023-CV-01043)

  v. Entropic Communications LLC (Case No. IPR2024-00393)

  v. Realtime Adaptive Streaming (Case No. 1:17-CV-02097-RBJ)

  v. TQ Delta LLC (Case No. 18-1798)

- Evapco Dry Cooling

  v. SPG Dry Cooling (Case No. IPR2021-00688)

- Genetec

  v. Sensormatic Electronics (Case No. 1:20-CV-00760)

- Huawei

  v. Bell Northern Research LLC (Case No. IPR2019-01174)

- Kianxis

  v. Blue Yonder (Case No. 3:20-cv-03636)

- LG Electronics

  v. Bell Northern Research LLC (Case No. 3:18-cv-2864-CAB-BLM)

- MediaTek

  v. MOSAID (Case No. IPR2024-00718)

- Metaswitch

  v. Sonus Networks (Case No. IPR2018-01719)

- Microsoft

  v. Throughputer Inc (Case No. IPR2022-00757)

- Mom Enterprises

  v. Ddrops Company (Case No. 1:22-cv-00332)

- MLC Intellectual Property

  v. MicronTech (Case No. 3:14-cv-03657-SI)

- Nearmap Inc

  v. EagleView Technologies (Case No. IPR2022-01009)

- Neuroderm Ltd.

  v. Abbvie, Inc (Case No. PGR2022-00040)

- Posco Co Ltd.

  v. Pascal Drillet et al. (Case No. IPR2025-00370)

- Realtek Semiconductor

  v. Future Link (Case No. IPR2021-01182)

- Quectel
  - v. Koninklijke Philips (Case No. 1:20-cv-01710)

- Samsung
  - v. Aire Technology (Case No. IPR2022-00877)
  - v. Bell Northern Research (Case No. 2:19-cv-00286-JRG)
  - v. Communication Technologies Inc (Case No. IPR2022-01221)
  - v. Jawbone Innovations (Case No. IPR2022-00865)
  - v. MemoryWeb LLC (Case No. IPR2022-00885)
  - v. Dodots Licensing Solutions (Case No. IPR2023-00701)
  - v. Telefonaktiebolaget LM Ericsson (Case No. IPR2021-00615)

- Texas Instruments
  - v. Vantage Micro LLC (Case No. IPR2020-01261)

- Xilinx
  - v. Sentient Sensors LCC (Case No. 1:22-cv-00173)

Goodwin Proctor

- Intel
  - v. Proxense, LLC (Case No. 6:24-cv-00283)

- Samsung Electronics
  - v. Mobile Data Technologies (Case No. 2:24-cv-00435)

- Taiwan Semiconductor Manufacturing Company Ltd.
  - v. Advanced Integrated Circuit Process LLC (Case No. 2:24-cv-00623)

Groombridge Wu

- Nearmap

  v. Eagle View Technologies Inc. and Pictometry International Corp. (Case No. 2:21-cv-00283-TS-DAO)

Irell & Manella

- Curium

Latham & Watkins LLP

- Apple

  v. Advanced Coding Research LLC

Leydig, Voit & Mayer, Ltd.

- Public Availability Consultancy

O'Melveny & Myers

- Apple

  v. Maxell (Case No. 5:19-cv-00036-RWS)

- Disney Media & Entertainment Distribution LLC

  v. Digital Media Technology Holdings, LLC (Case No. 2:22-cv-01642)

- Micron Technology Inc.

  v. Besang Inc (Case No. IPR2023-00900)

- Samsung

  v. Daedalus Prime LLC (1335 Investigation)

Perkins-Coie

- Amazon

  v. Nokia (Case No. IPR2024-00847 and IPR2024-00848)

  v. Nokia Technologies Oy (Case No. IPR2024-00572)

- Heru Industries

  v. The UAB Research Foundation (Case No. IPR2022-01148)

- Intel Corporation

  v. BeSang Inc. (Case No. IPR2023-00991)

  v. BitMICRO (Case No. 5:23-cv-00625)

  v. Telefonaktiebolaget L M Ericsson (Case No. IPR2024-00610)

- Realtek Semiconductor

  v. Future Link (Case No. IPR2021-01182)

- r-pac

  v. Adasa, Inc. (Case No. 1:2024cv06102)

- Twitter Inc

  v. VOIP-Pal.com (Case No. 3:20-cv-02397-JD)

- TCL Industries

  v. Koninklijke Philips NV (Case No. IPR2021-00495, IPR2021-00496 and IPR2021-00497)

- VusionGroup

  v. Hanshow (Case No. IPR2024-00857)

Pillsbury Winthrop Shaw Pittman

- Intel

  v. FG SRC LLC (Case No. 6:20-cv-00315)

- Gravel Rating Systems

  v. Costco (Case No. 4:21-cv-149)
  v. Lowe's Home Centers (Case No. 4:21-cv-150)
  v. T-Mobile USA (Case No. 4:21-cv-152)
  v. Kohl's Inc. (Case No. 4:21-cv-258)
  v. Under Armor (Case No. 4:21-cv-356)

Quinn Emanuel

- Exact Sciences Corporation

  v. Geneoscopy, Inc. (Case No. IPR2024-00459 and IPR2024-1330)

- ServiceNow, Inc.

  v. InQuisient, Inc. (Case No. 22-900-CJB)

- Wolfspeed

  v. The Trustees of Purdue University (Case No. 1:2021-cv-00840)

Sheppard, Mullin, Richter & Hampton LLP

- Advanced Micro Devices, Inc and Pensando Systems, Inc.

  v. Concurrent Ventures LLC and Xtreamedge, Inc. (Case No. IPR2025-00478)

- Cadence Design Systems Inc.

  v. Semiconductor Design Technologies (Case No. 3:23-cv-01001)

Shook, Hardy & Bacon LLP

- HP Inc.

  v. Universal Connectivity Technologies (Case No. 1:23-cv-01177)

Stern, Kessler, Goldstein & Fox

- Preliminary Research

Wilmer, Cutler, Pickering, Hale and Dorr

- Apple

  v. Shunock (Case No. 1:23-cv-08598)

- Quest Diagnostics Inc., Haystack Oncology Inc. and Haystack Oncology GmbH

  v. Natera, Inc. (Case No. 1:23-cv-08598)

- Roche Diabetes, Inc.

  v. Trividia Health, Inc. (Case No. 1:24-cv-00668)

Willkie, Farr & Gallagher LLP

- Lenovo, Dell, HP

  v. Universal Connectivity Technologies Inc. (Case No. 2:2023cv00449)

- Neurent

  v. The Foundry, LLC (Case No. IPR2024-00669)

- Netflix, Inc.

  v. VideoLabs, Inc. (Case No. IPR2023-00628)

APPENDIX IA01

https://web.archive.org/web/19991001000000*/http://www.itu.int/itudoc/itu-t/rec/h.html May 4, 2024

INTERNET ARCHIVE

SIGN UP | LOG IN UPLOAD Search

ABOUT BLOG PROJECTS HELP DONATE CONTACT JOBS VOLUNTEER PEOPLE

DONATE

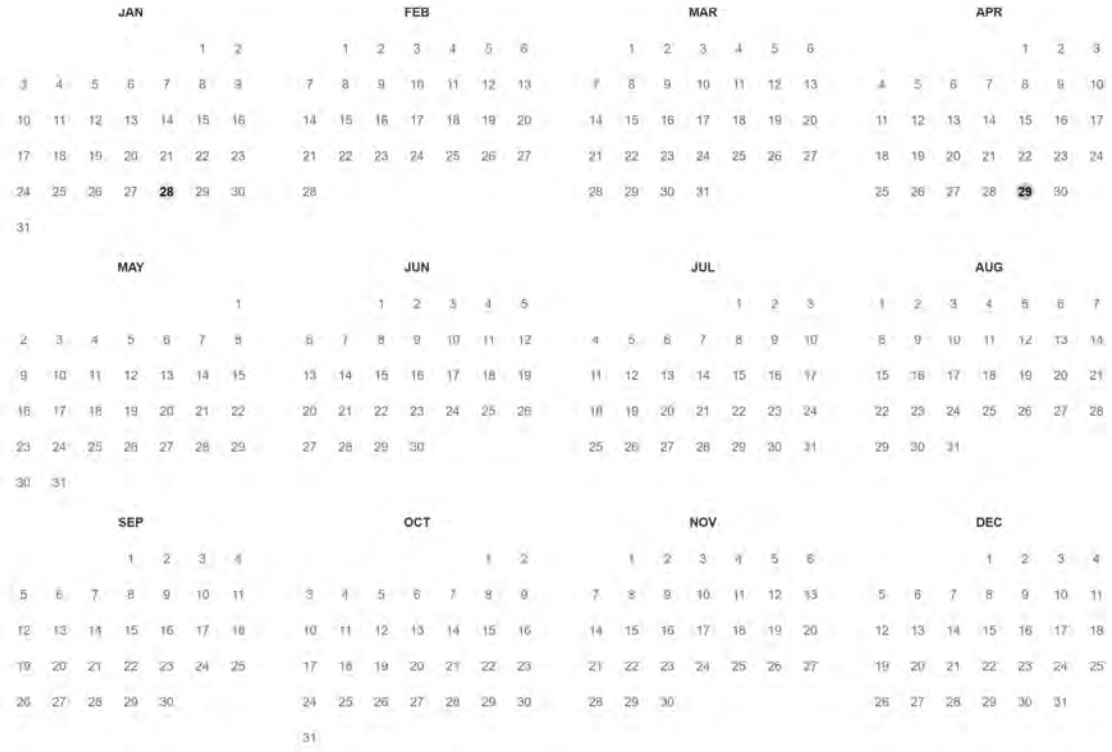
INTERNET ARCHIVE WaybackMachine

Explore more than 866 billion web pages saved over time

http://www.itu.int/itudoc/itu-t/rec/h.html

Calendar · Collections · Changes · Summary · Site Map · URLs

Saved **24 times** between February 7, 1997 and December 29, 2006.



Note

This calendar view maps the number of times **http://www.itu.int/itudoc/itu-t/rec/h.html** was crawled by the Wayback Machine, *not* how many times the site was actually updated. More info in the FAQ. Green indicates redirects (3xx).

FAQ | Contact Us | Terms of Service (Dec 31, 2014)

The Wayback Machine is an initiative of the Internet Archive, a 501(c)(3) non-profit building a digital library of Internet sites and other cultural artifacts in digital form. Other projects include Open Library & archive-it.org

Your use of the Wayback Machine is subject to the Internet Archive's Terms of Use

https://web.archive.org/web/19990128213243/http://www.itu.int/itudoc/itu-t/rec/h.html May 4, 2024

INTERNET ARCHIVE WaybackMachine http://www.itu.int/itudoc/itu-t/rec/h.html Go JUN JAN 28 APR 1997 1999 2000 About this capture
24 captures
7 Feb 1997 - 29 Dec 2006

International Telecommunication Union

TELECOMMUNICATION STANDARDIZATION SECTOR

Series H Recommendations - Line transmission of non-telephone signals

Parent

Publications tagged with BOOKSHOP can be ordered and downloaded from the ITU Electronic Bookshop

- **Implementor's Guides (1)**

- List of ITU-T H-Series Recommendations in force (1)
- [H.100] Recommendation H.100 (1988) - Visual telephone systems (11) BOOKSHOP
- [H.110] Recommendation H.110 (1988) - Hypothetical reference connections for videoconferencing using primary digital group transmission (11) BOOKSHOP
- [H.120] Recommendation H.120 (03/93) - Codecs for videoconferencing using primary digital group transmission (11) BOOKSHOP
- [H.130] Recommendation H.130 (1988) - Frame structures for use in the international interconnection of digital codecs for videoconferencing or visual telephony (11)
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- [H.200] Recommendation H.200 (03/93) - Framework for Recommendations for audiovisual services (8) BOOKSHOP
- [H.221] Recommendation H.221 (07/97) - Frame structure for a 64 to 1920 kbit/s channel in audiovisual teleservices (10) BOOKSHOP
- Table of Contents and Summary of Recommendation H.221 (07/97) (2)
- [H.222.0] Recommendation H.222.0 (07/95) - Information technology - Generic coding of moving pictures and associated audio information: Systems (11) BOOKSHOP
- Summary of Recommendation H.222.0 (07/95) (2)
- [H.222.0 Corr.1] Corrigendum 1 (02/98) Recommendation H.222.0 - Information technology - Generic coding of moving pictures and associated audio information: Systems Technical Corrigendum 1 (1)
- [H.222.0 Amd1-2] Amendments 1 and 2 (11/96) to Recommendation H.222.0 - Information Technology - Generic coding of moving pictures and associated audio information: Systems (8) BOOKSHOP
- [H.222.0 Amd.3] Amendment 3 (02/98) Recommendation H.222.0 - Information technology - Generic coding of moving pictures and associated audio information: Systems Amendment 3 (4) BOOKSHOP
- Table of Contents and Summary of Amendment 3 (02/98) Recommendation H.222.0 (1)
- [H.222.0 Amd.4] Amendment 4 (02/98) Recommendation H.222.0 - Information technology - Generic coding of moving pictures and associated audio information: Systems Amendment 4 (4) BOOKSHOP
- Table of Contents and Summary of Amendment 4 (02/98) Recommendation H.222.0 (1)
- [H.222.1] Recommendation H.222.1 (03/96) - Multimedia multiplex and synchronization for audiovisual communication in ATM environments (8) BOOKSHOP
- Summary of Recommendation H.222.1 (03/96) (2)
- [H.223] Recommendation H.223 (03/96) - Multiplexing protocol for low bit rate multimedia communication (7) BOOKSHOP
- Summary of Recommendation H.223 (03/96) (2)
- [H.223 Annex A] Recommendation H.223 Annex A (02/98) - Multiplexing protocol for low bit rate multimedia mobile communication over low error-prone channels (6) BOOKSHOP
- [H.223 Annex B] Recommendation H.223 Annex B (02/98) - Multiplexing protocol for low bit rate multimedia mobile communication over moderatore error-prone channels (6) BOOKSHOP
- [H.223 Annex C] Recommendation H.223 Annex C (02/98) - Multiplexing protocol for low bit rate multimedia communication over highly error-phone channels (9) BOOKSHOP
- [H.224] Recommendation H.224 (11/94) - A real time control protocol for simplex application using the H.221 LSD/HSD/MLP channels (8) BOOKSHOP
- Summary of Recommendation H.224 (11/94) (2)
- [H.225.0] Recommendation H.225.0 (02/98) - Call signalling protocols and media stream packetization for packet-based multimedia communication systems (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.225.0 (02/98)) (1)
- [H.225.0 Anx.I] Annex I (09/98) to Recommendation H.225.0 - Call signalling protocols and media stream packetization for packet-based multimedia communication systems Annex I: H.263 + video packetization (6) BOOKSHOP
- [H.226] Recommendation H.226 (09/98) - Channel aggregation protocol for multilink operation on circuit-switched networks (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.226 (09/98) (1)
- [H.230] Recommendation H.230 (07/97) - Frame-synchronous control and indication signals for audiovisual systems (6) BOOKSHOP
- Table of Contents and Summary of Recommendation H.230 (07/97) (2)
- [H.231] Recommendation H.231 (07/97) - Multipoint control units for audiovisual systems using digital channels up to 1920 kbit/s (6) BOOKSHOP
- Table of Contents and Summary of Recommendation H.231 (07/97) (2)
- [H.233] Recommendation H.233 (07/95) - Confidentiality system for audiovisual services (8) BOOKSHOP
- [H.234] Recommendation H.234 (11/94) - Encryption key management and authentication system for audiovisual services (8) BOOKSHOP
- Summary of Recommendation H.234 (11/94) (2)
- [H.235] Recommendation H.235 (02/98) - Security and encryption for H-Series (H.323 and other H.245-based) multimedia terminals (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.235 (02/98) (1)
- [H.242] Recommendation H.242 (07/97) - System for establishing communication between audiovisual terminals using digital channels up to 2 Mbit/s (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.242 (07/97) (2)
- [H.243] Recommendation H.243 (07/97) - Procedures for establishing communication between three or more audiovisual terminals using digital channels up to 1920 kbit/s (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.243 (07/07) (2)
- [H.244] Recommendation H.244 (07/95) - Synchronized aggregation of multiple 64 or 56 kbit/s channels (11) BOOKSHOP
- [H.245] Recommendation H.245 (02/98) - Control protocol for multimedia communication (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.245 (02/98) (1)
- [H.246] Recommendation H.246 (02/98) - Interworking of H-Series multimedia terminals with H-Series multimedia terminals and voice/voiceband terminals on GSTN and ISDN (6) BOOKSHOP
- Table of Contents and Summary of Recommendation H.246 (02/98) (1)
- [H.247] Recommendation H.247 (09/98) - Multipoint extension for broadband audiovisual communication systems and terminals (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.247 (09/98) (1)
- [H.261] Recommendation H.261 (03/93) - Video codec for audiovisual services at p x 64 kbit/s (10) BOOKSHOP
- [H.262] Recommendation H.262 (07/95) - Information technology - Generic coding of moving pictures and associated audio information: Video (10) BOOKSHOP
- Summary of Recommendation H.262 (07/95) (2)
- [H.262 Amend.1] Amendment 1 (11/96) to Recommendation H.262 - Information Technology - Generic coding of moving pictures and associated audio information: Video (8) BOOKSHOP
- [H.262 Corr.1] Corrigendum 1 (11/96) to Recommendation H.262 - Information Technology - Generic coding of moving pictures and associated audio information: Video (8)

- [H.262 Amend.2] Amendment 2 (11/96) to Recommendation H.262 - Information Technology - Generic coding of moving pictures and associated audio information: Video (10) BOOKSHOP
- [H.262 Corr.2] Corrigendum 2 (11/96) to Recommendation H.262 - Information Technology - Generic coding of moving pictures and associated audio information: Video (8)
- [H.262 Amend.3] Amendment 3 (02/98) Recommendation H.262 - Information technology - Generic coding of moving pictures and associated audio information: Video Amendment 3 (3) BOOKSHOP
- Table of Contents and Summary of Amendment 3 (02/98) Recommendation H.262 (1)
- [H.262 Amend.4] Amendment 4 (02/98) Recommendation H.262 - Information technology - Generic coding of moving pictures and associated audio information: Video Amendment 4 (4) BOOKSHOP
- Table of Contents and Summary of Amendment 4 (02/98) Recommendation H.262 (1)
- [H.263] Recommendation H.263 (02/98) - Video coding for low bit rate communication (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.263 (02/98) (1)
- [H.263 Append.I] Appendix I (03/97) to Recommendation H.263 - Video coding for low bit rate communication - Appendix I: Error tracking (8) BOOKSHOP
- [H.281] Recommendation H.281 (11/94) - A far end camera control protocol for videoconferences using H.224 (8) BOOKSHOP
- Summary of Recommendation H.281 (11/94) (2)
- [H.310] Recommendation H.310 (09/98) - Broadband audiovisual communication systems and terminals (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.310 (09/98) (1)
- [H.310 Corr.1] Corrigendum 1 (02/98) to Recommendation H.310 - Broadband audiovisual communication systems and terminals (6)
- [H.320] Recommendation H.320 (07/97) - Narrow-band visual telephone systems and terminal equipment (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.320 (07/97) (2)
- [H.321] Recommendation H.321 (02/98) - Adaptation of H.320 visual telephone terminals to B-ISDN environments (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.321 (02/98) (1)
- [H.322] Recommendation H.322 (03/96) - Visual telephone systems and terminal equipment for local area networks which provide a guaranteed quality of service (8) BOOKSHOP
- Summary of Recommendation H.322 (03/96) (2)
- [H.323] Recommendation H.323 (02/98) - Packet-based multimedia communications systems (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.323 (02/98) (1)
- [H.323 Annex D] Annex D (09/98) to Recommendation H.323 - Packet-based multimedia communications systems Annex D: Real-time facsimile over H.323 systems (6) BOOKSHOP
- [H.324] Recommendation H.324 (02/98) - Terminal for low bit rate Multimedia Communication (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.324 (02/98) (1)
- [H.324 Annex F] Annex F (09/98) to Recommendation H.324 - Terminal for low bit-rate multimedia communication Annex F: Multilink operation (6) BOOKSHOP
- Table of Contents of Annex F (09/98) to Recommendation H.324 (1)
- [H.331] Recommendation H.331 (03/93) - Broadcasting type audiovisual multipoint systems and terminal equipment (8) BOOKSHOP
- [H.332] Recommendation H.332 (09/98) - H.323 extended for loosely coupled conferences (6) BOOKSHOP
- Table of Contents and Summary of Recommendation H.332 (09/98) (1)
- [H.450.1] Recommendation H.450.1 (02/98) - Generic functional protocol for the support of supplementary services in H.323 (6) BOOKSHOP
- Table of Contents and Summary of Recommendation H.450.1 (02/98) (1)
- [H.450.2] Recommendation H.450.2 (02/98) - Call transfer supplementary service for H.323 (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.450-2 (02/98) (1)
- [H.450.3] Recommendation H.450.3 (02/98) - Call diversion supplementary service for H.323 (9) BOOKSHOP
- Table of Contents and Summary of Recommendation H.450.3 (02/98) (1)

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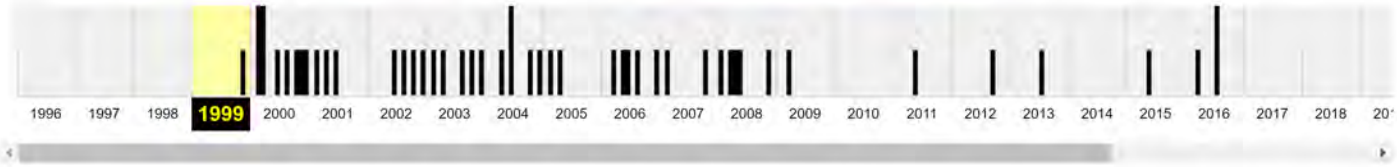

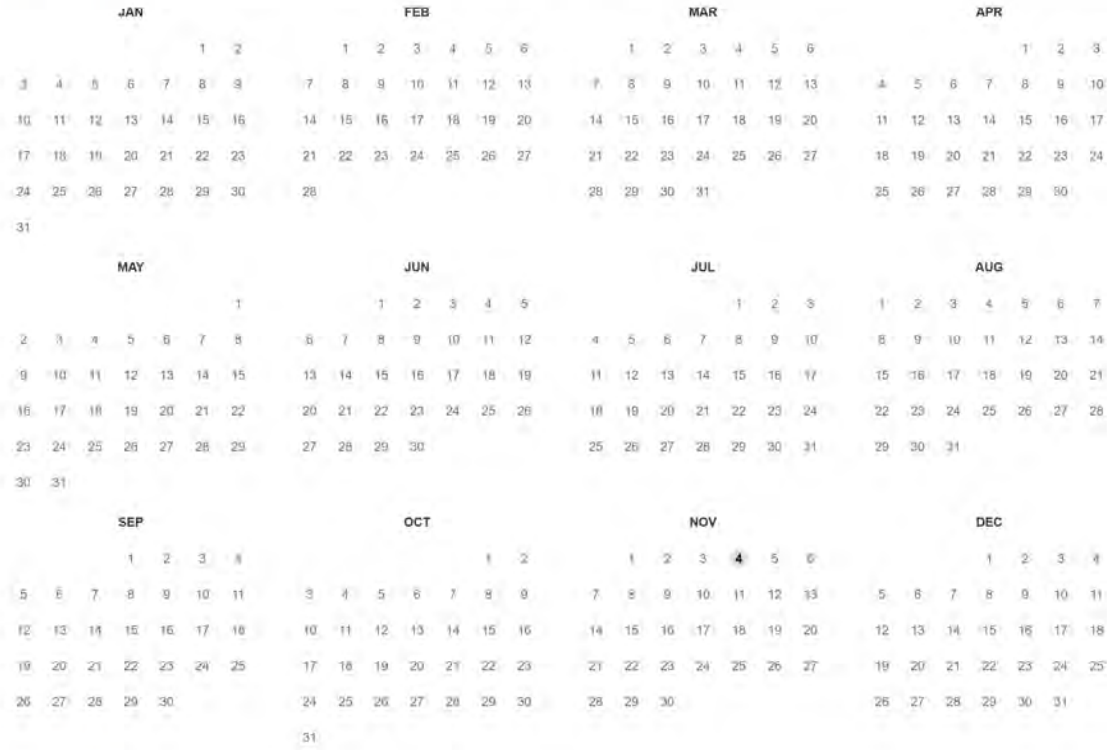

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Table of Contents

ITU-T Rec. H.263 (02/98) VIDEO CODING FOR LOW BIT RATE COMMUNICATION
Summary
Source
CONTENTS
VIDEO CODING FOR LOW BIT RATE COMMUNICATION
1 Scope
2 References
3 Brief specification
3.1 Video input and output
3.2 Digital output and input
3.3 Sampling frequency
3.4 Source coding algorithm
3.5 Bit rate
3.6 Buffering
3.7 Symmetry of transmission
3.8 Error handling
3.9 Multipoint operation
4 Source coder
4.1 Source format
4.2 Video source coding algorithm
4.3 Coding control
4.4 Forced updating
4.5 Byte alignment of start codes
5 Syntax and semantics
5.1 Picture layer
5.2 Group of Blocks Layer
5.3 Macroblock layer
5.4 Block layer
6 Decoding process
6.1 Motion compensation
6.2 Coefficients decoding
6.3 Reconstruction of blocks
ANNEX A - Inverse transform accuracy specification
ANNEX B - Hypothetical Reference Decoder
ANNEX C - Considerations for multipoint
C.1 Freeze picture request
C.2 Fast update request
C.3 Freeze picture release
C.4 Continuous Presence Multipoint and Video Multiplexing (CPM)
ANNEX D - Unrestricted Motion Vector mode
D.1 Motion vectors over picture boundaries
D.2 Extension of the motion vector range
ANNEX E - Syntax-based Arithmetic Coding mode
E.1 Introduction
E.2 Specification of SAC encoder

E.3 Specification of SAC decoder
E.4 Syntax
E.5 PSC_FIFO
E.6 Header layer symbols
E.7 Macroblock and Block layer symbols
E.8 SAC models
ANNEX F - Advanced Prediction mode
F.1 Introduction
F.2 Four motion vectors per macroblock
F.3 Overlapped motion compensation for luminance
ANNEX G - PB-frames mode
G.1 Introduction
G.2 PB-frames and INTRA blocks
G.3 Block layer
G.4 Calculation of vectors for the B-picture in a PB-frame
G.5 Prediction of a B-block in a PB-frame
ANNEX H - Forward error correction for coded video signal
H.1 Introduction
H.2 Error correction framing
H.3 Error correcting code
H.4 Relock time for error corrector framing
ANNEX I - Advanced INTRA Coding mode
I.1 Introduction
I.2 Syntax
I.3 Decoding process
ANNEX J - Deblocking Filter mode
J.1 Introduction
J.2 Relation to UMV and AP modes (Annexes D and F)
J.3 Definition of the deblocking edge filter
ANNEX K - Slice Structured mode
K.1 Introduction
K.2 Structure of slice layer
ANNEX L - Supplemental Enhancement Information Specification
L.1 Introduction
L.2 PSUPP format
L.3 Do Nothing
L.4 Full-Picture Freeze Request
L.5 Partial-Picture Freeze Request
L.6 Resizing Partial-Picture Freeze Request
L.7 Partial-Picture Freeze-Release Request
L.8 Full-Picture Snapshot Tag
L.9 Partial-Picture Snapshot Tag
L.10 Video Time Segment Start Tag
L.11 Video Time Segment End Tag
L.12 Progressive Refinement Segment Start Tag
L.13 Progressive Refinement Segment End Tag
L.14 Chroma Keying Information
L.15 Extended Function Type
ANNEX M - Improved PB-frames mode
M.1 Introduction
M.2 B-macroblock prediction modes
M.3 Calculation of vectors for bidirectional prediction of a the B-macro□lock
M.4 MODB table
ANNEX N - Reference Picture Selection mode
N.1 Introduction
N.2 Video source coding algorithm
N.3 Channel for back-channel messages
N.4 Syntax
N.5 Decoder process
ANNEX O - Temporal, SNR, and Spatial Scalability mode
O.1 Overview
O.2 Transmission order of pictures
O.3 Picture layer syntax
O.4 Macroblock layer syntax
O.5 Motion vector decoding
O.6 Interpolation filters
ANNEX P - Reference picture resampling
P.1 Introduction
P.2 Syntax
P.3 Resampling algorithm
P.4 Example of implementation
P.5 Factor-of-4 resampling
ANNEX Q - Reduced-Resolution Update mode
Q.1 Introduction
Q.2 Decoding procedure
Q.3 Extension of referenced picture
Q.4 Reconstruction of motion vectors
Q.5 Enlarged overlapped motion compensation for luminance
Q.6 Upsampling of the reduced-resolution reconstructed prediction error
Q.7 Block boundary filter
ANNEX R - Independent Segment Decoding mode
R.1 Introduction
R.2 Mode operation
R.3 Constraints on usage
ANNEX S - Alternative INTER VLC mode
S.1 Introduction
S.2 Alternative INTER VLC for coefficients
S.3 Alternative INTER VLC for CBPY
ANNEX T - Modified Quantization mode
T.1 Introduction
T.2 Modified DQUANT Update

T.3 Altered quantization step size for chrominance coefficients
T.4 Modified coefficient range
T.5 Usage restrictions
APPENDIX I - Error tracking
I.1 Introduction
I.2 Error tracking
APPENDIX II - Recommended Optional Enhancement
II.1 Introduction
II.2 Levels of preferred mode support
II.3 Picture formats and picture clock frequencies

APPENDIX ISO01

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Contents

Pt. 1. Systems -- pt. 2. Video -- pt. 3. Audio -- pt. 4. Compliance testing

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Part 2:
Video

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Contents

Page

Foreword iii

Introduction iv

Section 1: General 1

1.1 Scope 1

1.2 Normative references 1

Section 2: Technical elements 3

2.1 Definitions 3

2.2 Symbols and abbreviations 11

2.3 Method of describing bitstream syntax 13

2.4 Requirements 15

Annexes

A 8 by 8 Inverse discrete cosine transform 39

B Variable length code tables 40

C Video buffering verifier 49

D Guide to encoding video 51

E Bibliography 108

F List of patent holders 109

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1) Replace subclause 2.4.3.2 (page 25, line 38) by:

"

The value for intra_quantizer_matrix[0] shall always be 8.

".

ICS 681.3.04(084.14) **Ref. No. ISO/IEC 11172-2:1993/Cor.2:1999(E)**

2) Replace subclause 2.4.3.6 (page 30, line 2) by:

"

If macroblock_pattern is zero, cbp=0.

".

3) Replace subclause 2.4.3.7 (page 30, line 25) by:

"

The number of bits in the following dct_dc_differential code, dct_dc_size_luminance, is derived according to the VLC table B.5a.

".

4) Replace subclause 2.4.3.7 (page 30, line 29) by:

"

The number of bits in the following dct_dc_differential code, dct_dc_size_chrominance, is derived according to the VLC table B.5b.

".

5) Replace subclause 2.4.3.7 (page 30, line 32) by:

"

If dct_dc_size_luminance or dct_dc_size_chrominance (as appropriate) is zero, then dct_dc_differential is not present in the bitstream.

".

6) Replace subclause 2.4.3.7 (page 30, line 35) by:

"

If dct_dc_size_luminance or dct_dc_size_chrominance (as appropriate) is greater than zero, then dct_zz[0] is computed as follows from dct_dc_differential:

".

7) Replace subclause 2.4.3.7 (page 30, line 37-43) by:

"

For luminance blocks:

```
if ( dct_dc_differential & ( 1 << (dct_dc_size_luminance-1)) ) dct_zz[0] = dct_dc_differential ;
else dct_zz[0] = ( (-1) << (dct_dc_size_luminance) ) | (dct_dc_differential+1) ;
```

For chrominance blocks:

```
if ( dct_dc_differential & ( 1 << (dct_dc_size_chrominance-1)) ) dct_zz[0] = dct_dc_differential ;
else dct_zz[0] = ( (-1) << (dct_dc_size_chrominance) ) | (dct_dc_differential+1) ;
```

".

8) Replace subclause 2.4.3.7 (page 30, table) by:

"

example for dct_dc_size_luminance = 3

".

9) Replace subclause 2.4.4.4 (page 38, lines 4-5) by:

"

In B-pictures, the skipped macroblock is defined to have the same direction of prediction (forward, backward, or bidirectional) as the prior macroblock, differential motion vectors equal to zero, and no DCT coefficients.

".

10) Replace subclause D.6.5.2 (page 99, line 39) by:

"

Whereas in P-pictures skipped macroblocks have a motion vector equal to zero, in B-pictures skipped macroblocks have the same motion vector and the same direction of prediction (forward, backward, or bidirectional) as the previous macroblock, which cannot be intra coded.

".

11) Replace subclause D.6.7, Table D.22 by:

"

Table D.22 -- Example of the coded data elements needed to generate repeated pictures

Value (bits)	Mnemonic	Length (bits)
0000 0000 0000 0000	picture_start_code	32 bits
0000 0001 0000 0000		
xxxx xxxx xx	temporal_reference	10 bits
010	picture_coding_type	3 bits
xxxx xxxx xxxx xxxx	vbv_delay	16 bits
0	full_pel_forward_vector	1 bit
001	forward_f_code	3 bits
0	Extra_bit_picture	1 bit
0000 00	stuffing	6 bits
0000 0000 0000 0000	slice_start_code	32 bits
0000 0001 0000 0001		
0000 1	quantizer_scale	5 bits
1	macroblock_address_increment	1 bit
001	macroblock_type	3 bits
0	motion_horizontal_forward_code	1 bit
0	motion_vertical_forward_code	1 bit
0000 0001 000 (x 11)	macroblock_escape (x11)	121 bits
0000 0011 001	macroblock_address_increment	11 bits
001	macroblock_type	3 bits
0	motion_horizontal_forward_code	1 bit
0	motion_vertical_forward_code	1 bit
0	Extra_bit_slice	1 bit
000	stuffing	3 bits
	Total	256 bits

".

12) Replace subclause 2.3 (page 14, line 37) by:

"

2.3.1 Definition of bytealigned function

".

13) Replace subclause 2.3 (page 14, line 42) by:

"

2.3.2 Definition of nextbits function

".

14) Replace subclause 2.3 (page 14, line 46) by:

"

2.3.3 Definition of next_start_code function

".

15) Replace subclause 2.4.1 (page 15, line 5) by:

"

2.4.1.1 Video sequence

".

16) Replace subclause 2.4.1 (page 15, line 22) by:

"

2.4.1.2 Sequence header

".

17) Replace subclause 2.4.1 (page 15, line 27) by:
"
2.4.1.3 Group of pictures
".

18) Replace subclause 2.4.1 (page 16, line 15) by:
"
2.4.1.4 Picture
".

19) Replace subclause 2.4.1 (page 17, line 1) by:
"
2.4.1.5 Slice
".

20) Replace subclause 2.4.1 (page 17, line 10) by:
"
2.4.1.6 Macroblock
".

21) Replace subclause 2.4.1 (page 17, line 23) by:
"
2.4.1.7 Block
".

22) Replace subclause 2.4.1 (page 17, line 30) by:
"
2.4.1.8 Reserved, Forbidden and Marker bit
".

23) Replace subclause D.5.2 (page 68, line 20) by:
"
D.5.2.1 Group of pictures start code
".

24) Replace subclause D.5.2 (page 68, line 32) by:
"
D.5.2.2 Time code
".

25) Replace subclause D.5.2 (page 69, line 1) by:
"
D.5.2.3 Closed GOP
".

26) Replace subclause D.5.2 (page 69, line 24) by:
"
D.5.2.4 Broken link
".

27) Replace subclause D.5.2 (page 69, line 37) by:
"
D.5.2.5 Extension data
".

28) Replace subclause D.5.2 (page 69, line 49) by:
"
D.5.2.6 User data
".

29) Adjust right margin of the paragraph in subclause 2.4.1 (page 17, lines 12-16) to other paragraphs.

INTERNATIONAL STANDARD ISO/IEC 11172-2:1993
TECHNICAL CORRIGENDUM 1

Published 1996-04-15

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION
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Information technology — Coding of moving pictures and associated audio for digital storage media at up to about 1,5 Mbit/s —

Part 2:
Video

TECHNICAL CORRIGENDUM 1

Technologies de l'information — Codage de l'image animée et du son associé pour les supports de stockage numérique jusqu'à environ 1,5 Mbit/s —

Partie 2: Vidéo

RECTIFICATIF TECHNIQUE 1

Technical corrigendum 1 to International Standard ISO/IEC 11172-2:1993 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology.*

UDC 681.3.04(084.14) **Ref. No. ISO/IEC 11172-2:1993/Cor.1:1996(E)**

Descriptors: data processing, moving pictures, video data, video recording, data storage, digital storage, coded representation, coding (data conversion), digital encoders.

Page 112
At the end of Annex F add:

The following table gives the part or parts of ISO/IEC 11172 to which the patent statements received apply.

An "X" in the row corresponding to a company in the column corresponding to a part means that the statement from that company applies to that part. Three "N"s in the row corresponding to a company mean that the statement from that company did not mention any part.

Table F.1

COMPANY	Part 1	Part 2	Part 3
AT & T	N	N	N
Aware	N	N	N
Bellcore	N	N	N
The British Broadcasting Corporation	N	N	N
British Telecommunications plc	N	N	N
CCETT	N	N	N
CNET	N	N	N
Compression Labs, Incorporated	N	N	N
CSELT		X	
CompuSonics Corporation	N	N	N
Daimler Benz AG	N	N	N
Dornier Gmbh	N	N	N
Fraunhofer Gesselschaft zur Foerderung der Angerwandten Forschung			X
Hitachi Ltd.	N	N	N
Institut für Rundfunktechnik Gmbh	N	N	N
International Business Machines Corporation	N	N	N
KDD Corporation	N	N	N
Licentia Patent-Verwaltungs-Gmbh	N	N	N
Massachusetts Institute of Technology	N	N	N
Matsushita Electric Industrial Co. Ltd	X	X	X
Mitsubishi Electric Corporation	N	N	N
NEC Corporation		X	X
Nippon Hoso Kyokai	N	N	N
Philips Electronics NV	N	N	N
Pioneer Electronic Corporation	N	N	N
Ricoh Co, Ltd	N	N	N
Schawartz Engineering & Design	N	N	N
Sony Corporation	X	X	X
Symbionics	N	N	N
Telefunken Fernseh und Rundfunk GmbH	N	N	N
Thomson Consumer Electronics	N	N	N
Toppan Printing Co, Ltd	N	N	N
Toshiba Corporation	N	N	N
Victor Company of Japan Ltd	N	N	N

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

International Standard ISO/IEC 11172-2 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Sub-Committee SC 29, *Coded representation of audio, picture, multimedia and hypermedia information.*

ISO/IEC 11172 consists of the following parts, under the general title *Information technology — Coding of moving pictures and associated audio for digital storage media at up to about 1,5 Mbit/s*:

— *Part 1: Systems*

— *Part 2: Video*

— *Part 3: Audio*

— *Part 4: Compliance testing*

Annexes A, B and C form an integral part of this part of ISO/IEC 11172. Annexes D, E and F are for information only.

Introduction

Note -- Readers interested in an overview of the MPEG Video layer should read this Introduction and then proceed to annex D, before returning to clauses 1 and 2.

0.1 Purpose

This part of ISO/IEC 11172 was developed in response to the growing need for a common format for representing compressed video on various digital storage media such as CDs, DATs, Winchester disks and optical drives. This part of ISO/IEC 11172 specifies a coded representation that can be used for compressing video sequences to bitrates around 1,5 Mbit/s. The use of this part of ISO/IEC 11172 means that motion video can be manipulated as a form of computer data and can be transmitted and received over existing and future networks. The coded representation can be used with both 625-line and 525-line television and provides flexibility for use with workstation and personal computer displays.

This part of ISO/IEC 11172 was developed to operate principally from storage media offering a continuous transfer rate of about 1,5 Mbit/s. Nevertheless it can be used more widely than this because the approach taken is generic.

0.1.1 Coding parameters

The intention in developing this part of ISO/IEC 11172 has been to define a source coding algorithm with a large degree of flexibility that can be used in many different applications. To achieve this goal, a number of the parameters defining the characteristics of coded bitstreams and decoders are contained in the bitstream itself. This allows for example, the algorithm to be used for pictures with a variety of sizes and aspect ratios and on channels or devices operating at a wide range of bitrates.

Because of the large range of the characteristics of bitstreams that can be represented by this part of ISO/IEC 11172, a sub-set of these coding parameters known as the "Constrained Parameters" has been defined. The aim in defining the constrained parameters is to offer guidance about a widely useful range of parameters. Conforming to this set of constraints is not a requirement of this part of ISO/IEC 11172. A flag in the bitstream indicates whether or not it is a Constrained Parameters bitstream.

Summary of the Constrained Parameters:

Horizontal picture size	Less than or equal to 768 pels
Vertical picture size	Less than or equal to 576 lines
Picture area	Less than or equal to 396 macroblocks
Pel rate	Less than or equal to 396x25 macroblocks/s
Picture rate	Less than or equal to 30 Hz
Motion vector range	Less than -64 to +63,5 pels (using half-pel vectors) [backward_f_code and forward_f_code <= 4 (see table D.7)]
Input buffer size (in VBV model)	Less than or equal to 327 680 bits
Bitrate	Less than or equal to 1 856 000 bits/s (constant bitrate)

0.2 Overview of the algorithm

The coded representation defined in this part of ISO/IEC 11172 achieves a high compression ratio while preserving good picture quality. The algorithm is not lossless as the exact pel values are not preserved during coding. The choice of the techniques is based on the need to balance a high picture quality and compression ratio with the requirement to make random access to the coded bitstream. Obtaining good picture quality at the bitrates of interest demands a very high compression ratio, which is not achievable with intraframe coding alone. The need for random access, however, is best satisfied with pure intraframe coding. This requires a careful balance between intra- and interframe coding and between recursive and non-recursive temporal redundancy reduction.

A number of techniques are used to achieve a high compression ratio. The first, which is almost independent from this part of ISO/IEC 11172, is to select an appropriate spatial resolution for the signal. The algorithm then uses block-based motion compensation to reduce the temporal redundancy. Motion compensation is used for causal prediction of the current picture from a previous picture, for non-causal prediction of the current picture from a future picture, or for interpolative prediction from past and future pictures. Motion vectors are defined for each 16-pel by 16-line region of the picture. The difference signal, the prediction error, is further compressed using the discrete cosine transform (DCT) to remove spatial correlation before it is quantized in an irreversible process that discards the less important information. Finally, the motion vectors are combined with the DCT information, and coded using variable length codes.

0.2.1 Temporal processing

Because of the conflicting requirements of random access and highly efficient compression, three main picture types are defined. Intra-coded pictures (I-Pictures) are coded without reference to other pictures. They provide access points to the coded sequence where decoding can begin, but are coded with only a moderate compression ratio. Predictive coded pictures (P-Pictures) are coded more efficiently using motion compensated prediction from a past intra or predictive coded picture and are generally used as a reference for further prediction. Bidirectionally-predictive coded pictures (B-Pictures) provide the highest degree of compression but require both past and future reference pictures for motion compensation. Bidirectionally-predictive coded pictures are never used as references for prediction. The organisation of the three picture types in a sequence is very flexible. The choice is left to the encoder and will depend on the requirements of the application. Figure 1 illustrates the relationship between the three different picture types.

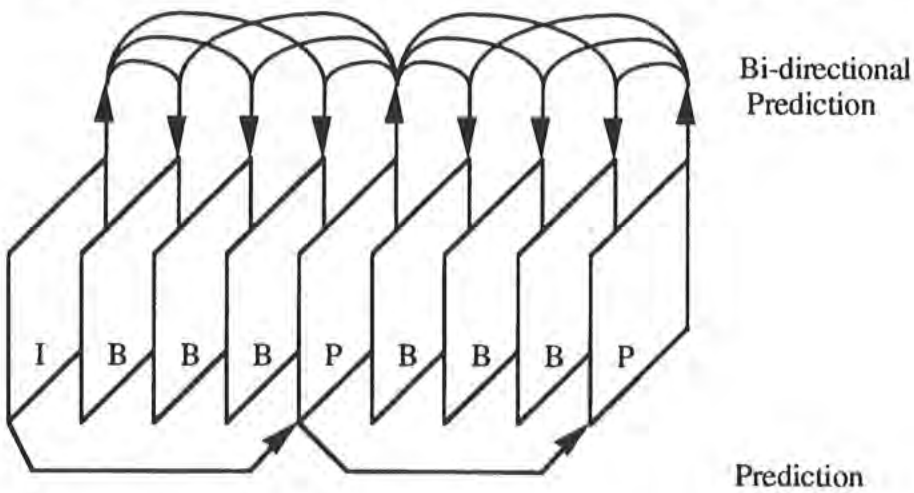


Figure 1 -- Example of temporal picture structure

The fourth picture type defined in this part of ISO/IEC 11172, the D-picture, is provided to allow a simple, but limited quality, fast-forward playback mode.

0.2.2 Motion representation - macroblocks

The choice of 16 by 16 macroblocks for the motion-compensation unit is a result of the trade-off between increasing the coding efficiency provided by using motion information and the overhead needed to store it. Each macroblock can be one of a number of different types. For example, intra-coded, forward-predictive-coded, backward-predictive coded, and bidirectionally-predictive-coded macroblocks are permitted in bidirectionally-predictive coded pictures. Depending on the type of the macroblock, motion vector information and other side information are stored with the compressed prediction error signal in each macroblock. The motion vectors are encoded differentially with respect to the last coded motion vector, using variable-length codes. The maximum length of the vectors that may be represented can be programmed, on a picture-by-picture basis, so that the most demanding applications can be met without compromising the performance of the system in more normal situations.

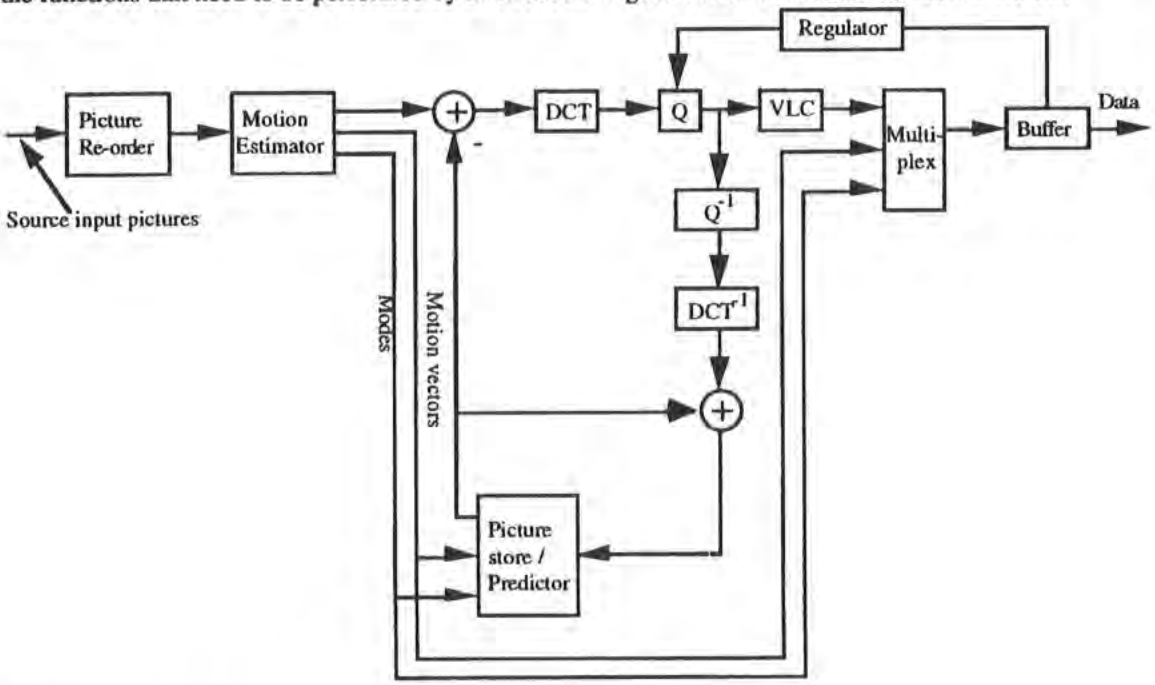
It is the responsibility of the encoder to calculate appropriate motion vectors. This part of ISO/IEC 11172 does not specify how this should be done.

0.2.3 Spatial redundancy reduction

Both original pictures and prediction error signals have high spatial redundancy. This part of ISO/IEC 11172 uses a block-based DCT method with visually weighted quantization and run-length coding. Each 8 by 8 block of the original picture for intra-coded macroblocks or of the prediction error for predictive-coded macroblocks is transformed into the DCT domain where it is scaled before being quantized. After quantization many of the coefficients are zero in value and so two-dimensional run-length and variable length coding is used to encode the remaining coefficients efficiently.

0.3 Encoding

This part of ISO/IEC 11172 does not specify an encoding process. It specifies the syntax and semantics of the bitstream and the signal processing in the decoder. As a result, many options are left open to encoders to trade-off cost and speed against picture quality and coding efficiency. This clause is a brief description of the functions that need to be performed by an encoder. Figure 2 shows the main functional blocks.



where

DCT is discrete cosine transform
DCT^{-1} is inverse discrete cosine transform
Q is quantization
Q^{-1} is dequantization
VLC is variable length coding

Figure 2 -- Simplified video encoder block diagram

The input video signal must be digitized and represented as a luminance and two colour difference signals (Y, C_b, C_r). This may be followed by preprocessing and format conversion to select an appropriate window, resolution and input format. This part of ISO/IEC 11172 requires that the colour difference signals (C_b and C_r) are subsampled with respect to the luminance by 2:1 in both vertical and horizontal directions and are reformatted, if necessary, as a non-interlaced signal.

The encoder must choose which picture type to use for each picture. Having defined the picture types, the encoder estimates motion vectors for each 16 by 16 macroblock in the picture. In P-Pictures one vector is needed for each non-intra macroblock and in B-Pictures one or two vectors are needed.

If B-Pictures are used, some reordering of the picture sequence is necessary before encoding. Because B-Pictures are coded using bidirectional motion compensated prediction, they can only be decoded after the subsequent reference picture (an I or P-Picture) has been decoded. Therefore the pictures are reordered by the

encoder so that the pictures arrive at the decoder in the order for decoding. The correct display order is recovered by the decoder.

The basic unit of coding within a picture is the macroblock. Within each picture, macroblocks are encoded in sequence, left to right, top to bottom. Each macroblock consists of six 8 by 8 blocks: four blocks of luminance, one block of Cb chrominance, and one block of Cr chrominance. See figure 3. Note that the picture area covered by the four blocks of luminance is the same as the area covered by each of the chrominance blocks. This is due to subsampling of the chrominance information to match the sensitivity of the human visual system.

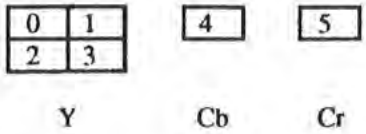


Figure 3 -- Macroblock structure

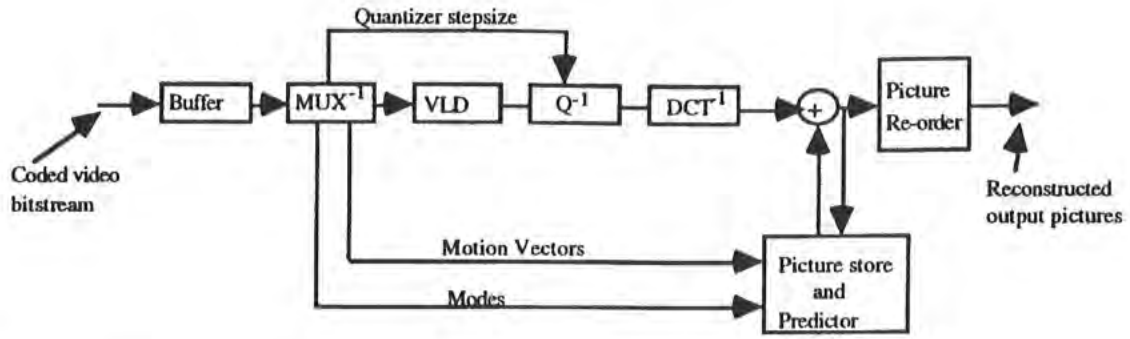
Firstly, for a given macroblock, the coding mode is chosen. It depends on the picture type, the effectiveness of motion compensated prediction in that local region, and the nature of the signal within the block. Secondly, depending on the coding mode, a motion compensated prediction of the contents of the block based on past and/or future reference pictures is formed. This prediction is subtracted from the actual data in the current macroblock to form an error signal. Thirdly, this error signal is separated into 8 by 8 blocks (4 luminance and 2 chrominance blocks in each macroblock) and a discrete cosine transform is performed on each block. Each resulting 8 by 8 block of DCT coefficients is quantized and the two-dimensional block is scanned in a zig-zag order to convert it into a one-dimensional string of quantized DCT coefficients. Fourthly, the side-information for the macroblock (mode, motion vectors etc) and the quantized coefficient data are encoded. For maximum efficiency, a number of variable length code tables are defined for the different data elements. Run-length coding is used for the quantized coefficient data.

A consequence of using different picture types and variable length coding is that the overall data rate is variable. In applications that involve a fixed-rate channel, a FIFO buffer may be used to match the encoder output to the channel. The status of this buffer may be monitored to control the number of bits generated by the encoder. Controlling the quantization process is the most direct way of controlling the bitrate. This part of ISO/IEC 11172 specifies an abstract model of the buffering system (the Video Buffering Verifier) in order to constrain the maximum variability in the number of bits that are used for a given picture. This ensures that a bitstream can be decoded with a buffer of known size.

At this stage, the coded representation of the picture has been generated. The final step in the encoder is to regenerate I-Pictures and P-Pictures by decoding the data so that they can be used as reference pictures for subsequent encoding. The quantized coefficients are dequantized and an inverse 8 by 8 DCT is performed on each block. The prediction error signal produced is then added back to the prediction signal and limited to the required range to give a decoded reference picture.

0.4 Decoding

Decoding is the inverse of the encoding operation. It is considerably simpler than encoding as there is no need to perform motion estimation and there are many fewer options. The decoding process is defined by this part of ISO/IEC 11172. The description that follows is a very brief overview of one possible way of decoding a bitstream. Other decoders with different architectures are possible. Figure 4 shows the main functional blocks.



Where

DCT^{-1}	is inverse discrete cosine transform
Q^{-1}	is dequantization
MUX^{-1}	is demultiplexing
VLD	is variable length decoding

Figure 4 -- Basic video decoder block diagram

For fixed-rate applications, the channel fills a FIFO buffer at a constant rate with the coded bitstream. The decoder reads this buffer and decodes the data elements in the bitstream according to the defined syntax.

As the decoder reads the bitstream, it identifies the start of a coded picture and then the type of the picture. It decodes each macroblock in the picture in turn. The macroblock type and the motion vectors, if present, are used to construct a prediction of the current macroblock based on past and future reference pictures that have been stored in the decoder. The coefficient data are decoded and dequantized. Each 8 by 8 block of coefficient data is transformed by an inverse DCT (specified in annex A), and the result is added to the prediction signal and limited to the defined range.

After all the macroblocks in the picture have been processed, the picture has been reconstructed. If it is an I-picture or a P-picture it is a reference picture for subsequent pictures and is stored, replacing the oldest stored reference picture. Before the pictures are displayed they may need to be re-ordered from the coded order to their natural display order. After reordering, the pictures are available, in digital form, for post-processing and display in any manner that the application chooses.

0.5 Structure of the coded video bitstream

This part of ISO/IEC 11172 specifies a syntax for a coded video bitstream. This syntax contains six layers, each of which either supports a signal processing or a system function:

Layers of the syntax	Function
Sequence layer	Random access unit: context
Group of pictures layer	Random access unit: video
Picture layer	Primary coding unit
Slice layer	Resynchronization unit
Macroblock layer	Motion compensation unit
Block layer	DCT unit

0.6 Features supported by the algorithm

Applications using compressed video on digital storage media need to be able to perform a number of operations in addition to normal forward playback of the sequence. The coded bitstream has been designed to support a number of these operations.

0.6.1 Random access

Random access is an essential feature for video on a storage medium. Random access requires that any picture can be decoded in a limited amount of time. It implies the existence of access points in the bitstream - that is segments of information that are identifiable and can be decoded without reference to other segments of data. A spacing of two random access points (Intra-Pictures) per second can be achieved without significant loss of picture quality.

0.6.2 Fast search

Depending on the storage medium, it is possible to scan the access points in a coded bitstream (with the help of an application-specific directory or other knowledge beyond the scope of this part of ISO/IEC 11172) to obtain a fast-forward and fast-reverse playback effect.

0.6.3 Reverse playback

Some applications may require the video signal to be played in reverse order. This can be achieved in a decoder by using memory to store entire groups of pictures after they have been decoded before being displayed in reverse order. An encoder can make this feature easier by reducing the length of groups of pictures.

0.6.4 Error robustness

Most digital storage media and communication channels are not error-free. Appropriate channel coding schemes should be used and are beyond the scope of this part of ISO/IEC 11172. Nevertheless the compression scheme defined in this part of ISO/IEC 11172 is robust to residual errors. The slice structure allows a decoder to recover after a data error and to resynchronize its decoding. Therefore, bit errors in the compressed data will cause errors in the decoded pictures to be limited in area. Decoders may be able to use concealment strategies to disguise these errors.

0.6.5 Editing

There is a conflict between the requirement for high coding efficiency and easy editing. The coding structure and syntax have not been designed with the primary aim of simplifying editing at any picture. Nevertheless a number of features have been included that enable editing of coded data.

Information technology — Coding of moving pictures and associated audio for digital storage media at up to about 1,5 Mbit/s —

Part 2:
Video

Section 1: General

1.1 Scope

This part of ISO/IEC 11172 specifies the coded representation of video for digital storage media and specifies the decoding process. The representation supports normal speed forward playback, as well as special functions such as random access, fast forward playback, fast reverse playback, normal speed reverse playback, pause and still pictures. This part of ISO/IEC 11172 is compatible with standard 525- and 625-line television formats, and it provides flexibility for use with personal computer and workstation displays.

ISO/IEC 11172 is primarily applicable to digital storage media supporting a continuous transfer rate up to about 1,5 Mbit/s, such as Compact Disc, Digital Audio Tape, and magnetic hard disks. Nevertheless it can be used more widely than this because of the generic approach taken. The storage media may be directly connected to the decoder, or via communications means such as busses, LANs, or telecommunications links. This part of ISO/IEC 11172 is intended for non-interlaced video formats having approximately 288 lines of 352 pels and picture rates around 24 Hz to 30 Hz.

1.2 Normative references

The following International Standards contain provisions which, through reference in this text, constitute provisions of this part of ISO/IEC 11172. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO/IEC 11172 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO/IEC 11172-1:1993 *Information technology - Coding of moving pictures and associated audio for digital storage media at up to about 1,5 Mbit/s - Part 1: Systems.*

ISO/IEC 11172-3:1993 *Information technology - Coding of moving pictures and associated audio for digital storage media at up to about 1,5 Mbit/s - Part 3 Audio.*

CCIR Recommendation 601-2 *Encoding parameters of digital television for studios.*

CCIR Report 624-4 *Characteristics of systems for monochrome and colour television.*

CCIR Recommendation 648 *Recording of audio signals.*

CCIR Report 955-2 *Sound broadcasting by satellite for portable and mobile receivers, including Annex IV Summary description of Advanced Digital System II.*

CCITT Recommendation J.17 *Pre-emphasis used on Sound-Programme Circuits.*

IEEE Draft Standard P1180/D2 1990 *Specification for the implementation of 8x 8 inverse discrete cosine transform".*

IEC publication 908:1987 *CD Digital Audio System.*

Section 2: Technical elements

2.1 Definitions

For the purposes of ISO/IEC 11172, the following definitions apply. If specific to a part, this is noted in square brackets.

2.1.1 ac coefficient [video]: Any DCT coefficient for which the frequency in one or both dimensions is non-zero.

2.1.2 access unit [system]: In the case of compressed audio an access unit is an audio access unit. In the case of compressed video an access unit is the coded representation of a picture.

2.1.3 adaptive segmentation [audio]: A subdivision of the digital representation of an audio signal in variable segments of time.

2.1.4 adaptive bit allocation [audio]: The assignment of bits to subbands in a time and frequency varying fashion according to a psychoacoustic model.

2.1.5 adaptive noise allocation [audio]: The assignment of coding noise to frequency bands in a time and frequency varying fashion according to a psychoacoustic model.

2.1.6 alias [audio]: Mirrored signal component resulting from sub-Nyquist sampling.

2.1.7 analysis filterbank [audio]: Filterbank in the encoder that transforms a broadband PCM audio signal into a set of subsampled subband samples.

2.1.8 audio access unit [audio]: For Layers I and II an audio access unit is defined as the smallest part of the encoded bitstream which can be decoded by itself, where decoded means "fully reconstructed sound". For Layer III an audio access unit is part of the bitstream that is decodable with the use of previously acquired main information.

2.1.9 audio buffer [audio]: A buffer in the system target decoder for storage of compressed audio data.

2.1.10 audio sequence [audio]: A non-interrupted series of audio frames in which the following parameters are not changed:

- ID
- Layer
- Sampling Frequency
- For Layer I and II: Bitrate index

2.1.11 backward motion vector [video]: A motion vector that is used for motion compensation from a reference picture at a later time in display order.

2.1.12 Bark [audio]: Unit of critical band rate. The Bark scale is a non-linear mapping of the frequency scale over the audio range closely corresponding with the frequency selectivity of the human ear across the band.

2.1.13 bidirectionally predictive-coded picture; B-picture [video]: A picture that is coded using motion compensated prediction from a past and/or future reference picture.

2.1.14 bitrate: The rate at which the compressed bitstream is delivered from the storage medium to the input of a decoder.

2.1.15 block companding [audio]: Normalizing of the digital representation of an audio signal within a certain time period.

2.1.16 block [video]: An 8-row by 8-column orthogonal block of pels.

2.1.17 bound [audio]: The lowest subband in which intensity stereo coding is used.

2.1.18 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.

2.1.19 byte: Sequence of 8-bits.

2.1.20 channel: A digital medium that stores or transports an ISO/IEC 11172 stream.

2.1.21 channel [audio]: The left and right channels of a stereo signal

2.1.22 chrominance (component) [video]: A matrix, block or single pel representing one of the two colour difference signals related to the primary colours in the manner defined in CCIR Rec 601. The symbols used for the colour difference signals are Cr and Cb.

2.1.23 coded audio bitstream [audio]: A coded representation of an audio signal as specified in ISO/IEC 11172-3.

2.1.24 coded video bitstream [video]: A coded representation of a series of one or more pictures as specified in this part of ISO/IEC 11172.

2.1.25 coded order [video]: The order in which the pictures are stored and decoded. This order is not necessarily the same as the display order.

2.1.26 coded representation: A data element as represented in its encoded form.

2.1.27 coding parameters [video]: The set of user-definable parameters that characterize a coded video bitstream. Bitstreams are characterised by coding parameters. Decoders are characterised by the bitstreams that they are capable of decoding.

2.1.28 component [video]: A matrix, block or single pel from one of the three matrices (luminance and two chrominance) that make up a picture.

2.1.29 compression: Reduction in the number of bits used to represent an item of data.

2.1.30 constant bitrate coded video [video]: A compressed video bitstream with a constant average bitrate.

2.1.31 constant bitrate: Operation where the bitrate is constant from start to finish of the compressed bitstream.

2.1.32 constrained parameters [video]: The values of the set of coding parameters defined in 2.4.3.2.

2.1.33 constrained system parameter stream (CSPS) [system]: An ISO/IEC 11172 multiplexed stream for which the constraints defined in 2.4.6 of ISO/IEC 11172-1 apply.

2.1.34 CRC: Cyclic redundancy code.

2.1.35 critical band rate [audio]: Psychoacoustic function of frequency. At a given audible frequency it is proportional to the number of critical bands below that frequency. The units of the critical band rate scale are Barks.

2.1.36 critical band [audio]: Psychoacoustic measure in the spectral domain which corresponds to the frequency selectivity of the human ear. This selectivity is expressed in Bark.

2.1.37 data element: An item of data as represented before encoding and after decoding.

2.1.38 dc-coefficient [video]: The DCT coefficient for which the frequency is zero in both dimensions.

2.1.39 dc-coded picture; D-picture [video]: A picture that is coded using only information from itself. Of the DCT coefficients in the coded representation, only the dc-coefficients are present.

2.1.40 DCT coefficient: The amplitude of a specific cosine basis function.

2.1.41 decoded stream: The decoded reconstruction of a compressed bitstream.

2.1.42 decoder input buffer [video]: The first-in first-out (FIFO) buffer specified in the video buffering verifier.

2.1.43 decoder input rate [video]: The data rate specified in the video buffering verifier and encoded in the coded video bitstream.

2.1.44 decoder: An embodiment of a decoding process.

2.1.45 decoding (process): The process defined in ISO/IEC 11172 that reads an input coded bitstream and produces decoded pictures or audio samples.

2.1.46 decoding time-stamp; DTS [system]: A field that may be present in a packet header that indicates the time that an access unit is decoded in the system target decoder.

2.1.47 de-emphasis [audio]: Filtering applied to an audio signal after storage or transmission to undo a linear distortion due to emphasis.

2.1.48 dequantization [video]: The process of rescaling the quantized DCT coefficients after their representation in the bitstream has been decoded and before they are presented to the inverse DCT.

2.1.49 digital storage media; DSM: A digital storage or transmission device or system.

2.1.50 discrete cosine transform; DCT [video]: Either the forward discrete cosine transform or the inverse discrete cosine transform. The DCT is an invertible, discrete orthogonal transformation. The inverse DCT is defined in annex A.

2.1.51 display order [video]: The order in which the decoded pictures should be displayed. Normally this is the same order in which they were presented at the input of the encoder.

2.1.52 dual channel mode [audio]: A mode, where two audio channels with independent programme contents (e.g. bilingual) are encoded within one bitstream. The coding process is the same as for the stereo mode.

2.1.53 editing: The process by which one or more compressed bitstreams are manipulated to produce a new compressed bitstream. Conforming edited bitstreams must meet the requirements defined in this part of ISO/IEC 11172.

2.1.54 elementary stream [system]: A generic term for one of the coded video, coded audio or other coded bitstreams.

2.1.55 emphasis [audio]: Filtering applied to an audio signal before storage or transmission to improve the signal-to-noise ratio at high frequencies.

2.1.56 encoder: An embodiment of an encoding process.

2.1.57 encoding (process): A process, not specified in ISO/IEC 11172, that reads a stream of input pictures or audio samples and produces a valid coded bitstream as defined in ISO/IEC 11172.

2.1.58 entropy coding: Variable length lossless coding of the digital representation of a signal to reduce redundancy.

2.1.59 fast forward playback [video]: The process of displaying a sequence, or parts of a sequence, of pictures in display-order faster than real-time.

2.1.60 FFT: Fast Fourier Transformation. A fast algorithm for performing a discrete Fourier transform (an orthogonal transform).

2.1.61 filterbank [audio]: A set of band-pass filters covering the entire audio frequency range.

2.1.62 fixed segmentation [audio]: A subdivision of the digital representation of an audio signal into fixed segments of time.

2.1.63 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.

2.1.64 forced updating [video]: The process by which macroblocks are intra-coded from time-to-time to ensure that mismatch errors between the inverse DCT processes in encoders and decoders cannot build up excessively.

2.1.65 forward motion vector [video]: A motion vector that is used for motion compensation from a reference picture at an earlier time in display order.

2.1.66 frame [audio]: A part of the audio signal that corresponds to audio PCM samples from an Audio Access Unit.

2.1.67 free format [audio]: Any bitrate other than the defined bitrates that is less than the maximum valid bitrate for each layer.

2.1.68 future reference picture [video]: The future reference picture is the reference picture that occurs at a later time than the current picture in display order.

2.1.69 granules [Layer II] [audio]: The set of 3 consecutive subband samples from all 32 subbands that are considered together before quantization. They correspond to 96 PCM samples.

2.1.70 granules [Layer III] [audio]: 576 frequency lines that carry their own side information.

2.1.71 group of pictures [video]: A series of one or more coded pictures intended to assist random access. The group of pictures is one of the layers in the coding syntax defined in this part of ISO/IEC 11172.

2.1.72 Hann window [audio]: A time function applied sample-by-sample to a block of audio samples before Fourier transformation.

2.1.73 Huffman coding: A specific method for entropy coding.

2.1.74 hybrid filterbank [audio]: A serial combination of subband filterbank and MDCT.

2.1.75 IMDCT [audio]: Inverse Modified Discrete Cosine Transform.

2.1.76 intensity stereo [audio]: A method of exploiting stereo irrelevance or redundancy in stereophonic audio programmes based on retaining at high frequencies only the energy envelope of the right and left channels.

2.1.77 interlace [video]: The property of conventional television pictures where alternating lines of the picture represent different instances in time.

2.1.78 intra coding [video]: Coding of a macroblock or picture that uses information only from that macroblock or picture.

2.1.79 intra-coded picture; I-picture [video]: A picture coded using information only from itself.

2.1.80 ISO/IEC 11172 (multiplexed) stream [system]: A bitstream composed of zero or more elementary streams combined in the manner defined in ISO/IEC 11172-1.

2.1.81 joint stereo coding [audio]: Any method that exploits stereophonic irrelevance or stereophonic redundancy.

2.1.82 joint stereo mode [audio]: A mode of the audio coding algorithm using joint stereo coding.

2.1.83 layer [audio]: One of the levels in the coding hierarchy of the audio system defined in ISO/IEC 11172-3.

2.1.84 layer [video and systems]: One of the levels in the data hierarchy of the video and system specifications defined in ISO/IEC 11172-1 and this part of ISO/IEC 11172.

2.1.85 luminance (component) [video]: A matrix, block or single pel representing a monochrome representation of the signal and related to the primary colours in the manner defined in CCIR Rec 601. The symbol used for luminance is Y.

2.1.86 macroblock [video]: The four 8 by 8 blocks of luminance data and the two 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 pel data and sometimes to the coded representation of the pel values and other data elements defined in the macroblock layer of the syntax defined in this part of ISO/IEC 11172. The usage is clear from the context.

2.1.87 mapping [audio]: Conversion of an audio signal from time to frequency domain by subband filtering and/or by MDCT.

2.1.88 masking [audio]: A property of the human auditory system by which an audio signal cannot be perceived in the presence of another audio signal .

2.1.89 masking threshold [audio]: A function in frequency and time below which an audio signal cannot be perceived by the human auditory system.

2.1.90 MDCT [audio]: Modified Discrete Cosine Transform.

2.1.91 motion compensation [video]: The use of motion vectors to improve the efficiency of the prediction of pel values. The prediction uses motion vectors to provide offsets into the past and/or future reference pictures containing previously decoded pel values that are used to form the prediction error signal.

2.1.92 motion estimation [video]: The process of estimating motion vectors during the encoding process.

2.1.93 motion vector [video]: A two-dimensional vector used for motion compensation that provides an offset from the coordinate position in the current picture to the coordinates in a reference picture.

2.1.94 MS stereo [audio]: A method of exploiting stereo irrelevance or redundancy in stereophonic audio programmes based on coding the sum and difference signal instead of the left and right channels.

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

2.1.96 non-tonal component [audio]: A noise-like component of an audio signal.

2.1.97 Nyquist sampling: Sampling at or above twice the maximum bandwidth of a signal.

2.1.98 pack [system]: A pack consists of a pack header followed by one or more packets. It is a layer in the system coding syntax described in ISO/IEC 11172-1.

2.1.99 packet data [system]: Contiguous bytes of data from an elementary stream present in a packet.

2.1.100 packet header [system]: The data structure used to convey information about the elementary stream data contained in the packet data.

2.1.101 packet [system]: A packet consists of a header followed by a number of contiguous bytes from an elementary data stream. It is a layer in the system coding syntax described in ISO/IEC 11172-1.

2.1.102 padding [audio]: A method to adjust the average length in time of an audio frame to the duration of the corresponding PCM samples, by conditionally adding a slot to the audio frame.

2.1.103 past reference picture [video]: The past reference picture is the reference picture that occurs at an earlier time than the current picture in display order.

2.1.104 pel aspect ratio [video]: The ratio of the nominal vertical height of pel on the display to its nominal horizontal width.

2.1.105 pel [video]: Picture element.

2.1.106 picture period [video]: The reciprocal of the picture rate.

2.1.107 picture rate [video]: The nominal rate at which pictures should be output from the decoding process.

2.1.108 picture [video]: 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. The Picture layer is one of the layers in the coding syntax defined in this part of ISO/IEC 11172. Note that the term "picture" is always used in ISO/IEC 11172 in preference to the terms field or frame.

2.1.109 polyphase filterbank [audio]: A set of equal bandwidth filters with special phase interrelationships, allowing for an efficient implementation of the filterbank.

2.1.110 prediction [video]: The use of a predictor to provide an estimate of the pel value or data element currently being decoded.

2.1.111 predictive-coded picture; P-picture [video]: A picture that is coded using motion compensated prediction from the past reference picture.

2.1.112 prediction error [video]: The difference between the actual value of a pel or data element and its predictor.

2.1.113 predictor [video]: A linear combination of previously decoded pel values or data elements.

2.1.114 presentation time-stamp; PTS [system]: A field that may be present in a packet header that indicates the time that a presentation unit is presented in the system target decoder.

2.1.115 presentation unit; PU [system]: A decoded audio access unit or a decoded picture.

2.1.116 psychoacoustic model [audio]: A mathematical model of the masking behaviour of the human auditory system.

2.1.117 quantization matrix [video]: A set of sixty-four 8-bit values used by the dequantizer.

2.1.118 quantized DCT coefficients [video]: DCT coefficients before dequantization. A variable length coded representation of quantized DCT coefficients is stored as part of the compressed video bitstream.

2.1.119 quantizer scalefactor [video]: A data element represented in the bitstream and used by the decoding process to scale the dequantization.

2.1.120 random access: The process of beginning to read and decode the coded bitstream at an arbitrary point.

2.1.121 reference picture [video]: Reference pictures are the nearest adjacent I- or P-pictures to the current picture in display order.

2.1.122 reorder buffer [video]: A buffer in the system target decoder for storage of a reconstructed I-picture or a reconstructed P-picture.

2.1.123 requantization [audio]: Decoding of coded subband samples in order to recover the original quantized values.

2.1.124 reserved: The term "reserved" when used in the clauses defining the coded bitstream indicates that the value may be used in the future for ISO/IEC defined extensions.

2.1.125 reverse playback [video]: The process of displaying the picture sequence in the reverse of display order.

2.1.126 scalefactor band [audio]: A set of frequency lines in Layer III which are scaled by one scalefactor.

2.1.127 scalefactor index [audio]: A numerical code for a scalefactor.

2.1.128 scalefactor [audio]: Factor by which a set of values is scaled before quantization.

2.1.129 sequence header [video]: A block of data in the coded bitstream containing the coded representation of a number of data elements.

2.1.130 side information: Information in the bitstream necessary for controlling the decoder.

2.1.131 skipped macroblock [video]: A macroblock for which no data are stored.

2.1.132 slice [video]: A series of macroblocks. It is one of the layers of the coding syntax defined in this part of ISO/IEC 11172.

2.1.133 slot [audio]: A slot is an elementary part in the bitstream. In Layer I a slot equals four bytes, in Layers II and III one byte.

2.1.134 source stream: A single non-multiplexed stream of samples before compression coding.

2.1.135 spreading function [audio]: A function that describes the frequency spread of masking.

2.1.136 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 layers in the coding syntax.

2.1.137 STD input buffer [system]: A first-in first-out buffer at the input of the system target decoder for storage of compressed data from elementary streams before decoding.

2.1.138 stereo mode [audio]: Mode, where two audio channels which form a stereo pair (left and right) are encoded within one bitstream. The coding process is the same as for the dual channel mode.

2.1.139 stuffing (bits); stuffing (bytes) : Code-words that may be inserted into the compressed bitstream that are discarded in the decoding process. Their purpose is to increase the bitrate of the stream.

2.1.140 subband [audio]: Subdivision of the audio frequency band.

2.1.141 subband filterbank [audio]: A set of band filters covering the entire audio frequency range. In ISO/IEC 11172-3 the subband filterbank is a polyphase filterbank.

2.1.142 subband samples [audio]: The subband filterbank within the audio encoder creates a filtered and subsampled representation of the input audio stream. The filtered samples are called subband samples. From 384 time-consecutive input audio samples, 12 time-consecutive subband samples are generated within each of the 32 subbands.

2.1.143 syncword [audio]: A 12-bit code embedded in the audio bitstream that identifies the start of a frame.

2.1.144 synthesis filterbank [audio]: Filterbank in the decoder that reconstructs a PCM audio signal from subband samples.

2.1.145 system header [system]: The system header is a data structure defined in ISO/IEC 11172-1 that carries information summarising the system characteristics of the ISO/IEC 11172 multiplexed stream.

2.1.146 system target decoder; STD [system]: A hypothetical reference model of a decoding process used to describe the semantics of an ISO/IEC 11172 multiplexed bitstream.

2.1.147 time-stamp [system]: A term that indicates the time of an event.

2.1.148 triplet [audio]: A set of 3 consecutive subband samples from one subband. A triplet from each of the 32 subbands forms a granule.

2.1.149 tonal component [audio]: A sinusoid-like component of an audio signal.

2.1.150 variable bitrate: Operation where the bitrate varies with time during the decoding of a compressed bitstream.

2.1.151 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.

2.1.152 video buffering verifier; VBV [video]: 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.

2.1.153 video sequence [video]: A series of one or more groups of pictures. It is one of the layers of the coding syntax defined in this part of ISO/IEC 11172.

2.1.154 zig-zag scanning order [video]: A specific sequential ordering of the DCT coefficients from (approximately) the lowest spatial frequency to the highest.

2.2 Symbols and abbreviations

The mathematical operators used to describe this International Standard are similar to those used in the C programming language. However, integer division with truncation and rounding are specifically defined. The bitwise operators are defined assuming twos-complement representation of integers. Numbering and counting loops generally begin from zero.

2.2.1 Arithmetic operators

+	Addition.
-	Subtraction (as a binary operator) or negation (as a unary operator).
++	Increment.
- -	Decrement.
*	Multiplication.
^	Power.
/	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.
//	Integer division with rounding to the nearest integer. Half-integer values are rounded away from zero unless otherwise specified. For example 3//2 is rounded to 2, and -3//2 is rounded to -2.
DIV	Integer division with truncation of the result towards $-\infty$.
| |	Absolute value. $\lvert x \rvert = x$ when $x > 0$ $\lvert x \rvert = 0$ when $x == 0$ $\lvert x \rvert = -x$ when $x < 0$
%	Modulus operator. Defined only for positive numbers.
Sign( )	Sign(x) = 1 $x > 0$ 0 $x == 0$ -1 $x < 0$
NINT ( )	Nearest integer operator. Returns the nearest integer value to the real-valued argument. Half-integer values are rounded away from zero.
sin	Sine.
cos	Cosine.
exp	Exponential.
√	Square root.
$\log_{10}$	Logarithm to base ten.
$\log_e$	Logarithm to base e.
$\log_2$	Logarithm to base 2.

2.2.2 Logical operators

||	Logical OR.
&&	Logical AND.

! Logical NOT.

2.2.3 Relational operators

> Greater than.

>= Greater than or equal to.

< Less than.

<= Less than or equal to.

== Equal to.

!= Not equal to.

max [,...,] the maximum value in the argument list.

min [,...,] the minimum value in the argument list.

2.2.4 Bitwise operators

A twos complement number representation is assumed where the bitwise operators are used.

& AND.

| OR.

>> Shift right with sign extension.

<< Shift left with zero fill.

2.2.5 Assignment

= Assignment operator.

2.2.6 Mnemonics

The following mnemonics are defined to describe the different data types used in the coded bit-stream.

bslbf Bit string, left bit first, where "left" is the order in which bit strings are written in ISO/IEC 11172. Bit strings are written as a string of 1s and 0s within single quote marks, e.g. '1000 0001'. Blanks within a bit string are for ease of reading and have no significance.

ch Channel. If ch has the value 0, the left channel of a stereo signal or the first of two independent signals is indicated. (Audio)

nch Number of channels; equal to 1 for single_channel mode, 2 in other modes. (Audio)

gr Granule of 3 * 32 subband samples in audio Layer II, 18 * 32 sub-band samples in audio Layer III. (Audio)

main_data The main_data portion of the bitstream contains the scalefactors, Huffman encoded data, and ancillary information. (Audio)

main_data_beg The location in the bitstream of the beginning of the main_data for the frame. The location is equal to the ending location of the previous frame's main_data plus one bit. It is calculated from the main_data_end value of the previous frame. (Audio)

part2_length The number of main_data bits used for scalefactors. (Audio)

rpchof	Remainder polynomial coefficients, highest order first. (Audio)
sb	Subband. (Audio)
sblimit	The number of the lowest sub-band for which no bits are allocated. (Audio)
scfsi	Scalefactor selection information. (Audio)
switch_point_l	Number of scalefactor band (long block scalefactor band) from which point on window switching is used. (Audio)
switch_point_s	Number of scalefactor band (short block scalefactor band) from which point on window switching is used. (Audio)
uimsbf	Unsigned integer, most significant bit first.
vlclbf	Variable length code, left bit first, where "left" refers to the order in which the VLC codes are written.
window	Number of the actual time slot in case of block_type==2, $0 \leq$ window ≤ 2. (Audio)

The byte order of multi-byte words is most significant byte first.

2.2.7 Constants

π	3,14159265358...
e	2,71828182845...

2.3 Method of describing bitstream syntax

The bitstream retrieved by the decoder is described in 2.4.2. Each data item in the bitstream is in bold type. It is described by its name, its length in bits, and a mnemonic for its type and order of transmission.

The action caused by a decoded data element in a bitstream depends on the value of that data element and on data elements previously decoded. The decoding of the data elements and definition of the state variables used in their decoding are described in 2.4.3. The following constructs are used to express the conditions when data elements are present, and are in normal type:

Note this syntax uses the 'C'-code convention that a variable or expression evaluating to a non-zero value is equivalent to a condition that is true.

while (condition) {
  data_element
  . . .
}
	If the condition is true, then the group of data elements occurs next in the data stream. This repeats until the condition is not true.

do {
  data_element
  . . .
} while (condition)
	The data element always occurs at least once.
	
	The data element is repeated until the condition is not true.

if (condition) {
  data_element
  . . .
}
	If the condition is true, then the first group of data elements occurs next in the data stream.

else {
  data_element
  . . .
}
	If the condition is not true, then the second group of data elements occurs next in the data stream.

for (expr1; expr2; expr3) {	expr1 is an expression specifying the initialization of the loop. Normally it specifies the initial state of the counter. expr2 is a condition specifying a test made before each iteration of the loop. The loop terminates when the condition is not true. expr3 is an expression that is performed at the end of each iteration of the loop, normally it increments a counter.
data_element	
. . .	
}	

Note that the most common usage of this construct is as follows:

for (i = 0; i < n; i++) {	The group of data elements occurs n times. Conditional constructs within the group of data elements may depend on the value of the loop control variable i, which is set to zero for the first occurrence, incremented to one for the second occurrence, and so forth.
data_element	
. . .	
}	

As noted, the group of data elements may contain nested conditional constructs. For compactness, the { } may be omitted when only one data element follows.

data_element [ ]	data_element [] is an array of data. The number of data elements is indicated by the context.
data_element [n]	data_element [n] is the n+1th element of an array of data.
data_element [m][n]	data_element [m][n] is the m+1,n+1 th element of a two-dimensional array of data.
data_element [l][m][n]	data_element [l][m][n] is the l+1,m+1,n+1 th element of a three-dimensional array of data.
data_element [m..n]	is the inclusive range of bits between bit m and bit n in the data_element.

While the syntax is expressed in procedural terms, it should not be assumed that 2.4.3 implements a satisfactory decoding procedure. In particular, it defines a correct and error-free input bitstream. Actual decoders must include a means to look for start codes in order to begin decoding correctly, and to identify errors, erasures or insertions while decoding. The methods to identify these situations, and the actions to be taken, are not standardized.

Definition of bytealigned function

The function bytealigned () returns 1 if the current position is on a byte boundary, that is the next bit in the bitstream is the first bit in a byte. Otherwise it returns 0.

Definition of nextbits function

The function nextbits () permits comparison of a bit string with the next bits to be decoded in the bitstream.

Definition of next_start_code function

The next_start_code function removes any zero bit and zero byte stuffing and locates the next start code.

Syntax	No. of bits	Mnemonic
next_start_code() {		
while (!bytealigned())		
zero_bit	1	"0"
while (nextbits() != '0000 0000 0000 0000 0000 0001')		
zero_byte	8	"00000000"
}		

This function checks whether the current position is bytealigned. If it is not, zero stuffing bits are present. After that any number of zero bytes may be present before the start-code. Therefore start-codes are always bytealigned and may be preceded by any number of zero stuffing bits.

2.4 Requirements

2.4.1 Coding structure and parameters

Video sequence

A coded video sequence commences with a sequence header and is followed by one or more groups of pictures and is ended by a sequence_end_code. Immediately before each of the groups of pictures there may be a sequence header. Within each sequence, pictures shall be decodable continuously.

In each of these repeated sequence headers all of the data elements with the permitted exception of those defining the quantization matrices (load_intra_quantizer_matrix, load_non_intra_quantizer_matrix and optionally intra_quantizer_matrix and non_intra_quantizer_matrix) shall have the same values as in the first sequence header. The quantization matrices may be redefined each time that a sequence header occurs in the bitstream. Thus the data elements load_intra_quantizer_matrix, load_non_intra_quantizer_matrix and optionally intra_quantizer_matrix and non_intra_quantizer_matrix may have any (non-forbidden) values.

Repeating the sequence header allows the data elements of the initial sequence header to be repeated in order that random access into the video sequence is possible. In addition the quantization matrices may be changed inside the video sequence as required.

Sequence header

A video sequence header commences with a sequence_header_code and is followed by a series of data elements.

Group of pictures

A **group of pictures** is a series of one or more coded pictures intended to assist random access into the sequence. In the stored bitstream, the first coded picture in a group of pictures is an I-Picture. The order of the pictures in the coded stream is the order in which the decoder processes them in normal playback. In particular, adjacent B-Pictures in the coded stream are in display order. The last coded picture, in display order, of a group of pictures is either an I-Picture or a P-Picture.

The following is an example of groups of pictures taken from the beginning of a video sequence. In this example the first group of pictures contains seven pictures and subsequent groups of pictures contain nine pictures. There are two B-pictures between successive P-pictures and also two B-pictures between successive I- and P-pictures. Picture '1I' is used to form a prediction for picture '4P'. Pictures '4P' and '1I' are both used to form predictions for pictures '2B' and '3B'. Therefore the order of pictures in the coded sequence shall be '1I', '4P', '2B', '3B'. However, the decoder should display them in the order '1I', '2B', '3B', '4P'.

At the encoder input,

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
I	B	B	P	B	B	P	B	B	I	B	B	P	B	B	P	B	B	I	B	B	P	B	B	P

At the encoder output, in the stored bitstream, and at the decoder input,

1	4	2	3	7	5	6	10	8	9	13	11	12	16	14	15	19	17	18	22	20	21	25	23	24
I	P	B	B	P	B	B	I	B	B	P	B	B	P	B	B	I	B	B	P	B	B	P	B	B

where the double vertical bars mark the group of pictures boundaries. Note that in this example, the first group of pictures is two pictures shorter than subsequent groups of pictures, since at the beginning of video coding there are no B-pictures preceding the first I-Picture. However, in general, in display order, there may be B-Pictures preceding the first I-Picture in the group of pictures, even for the first group of pictures to be decoded.

At the decoder output,

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

A group of pictures may be of any length. A group of pictures shall contain one or more I-Pictures. Applications requiring random access, fast-forward playback, or fast and normal reverse playback may use relatively short groups of pictures. Groups of pictures may also be started at scene cuts or other cases where motion compensation is ineffective.

The number of consecutive B-Pictures is variable. Neither B- nor P-Pictures need be present.

A video sequence of groups of pictures that is read by the decoder may be different from the one at the encoder output due to editing.

Picture

A source or reconstructed picture consists of three rectangular matrices of eight-bit numbers; a luminance matrix (Y), and two chrominance matrices (Cb and Cr). The Y-matrix shall have an even number of rows and columns, and the Cb and Cr matrices shall be one half the size of the Y-matrix in both horizontal and vertical dimensions.

The Y, Cb and Cr components are related to the primary (analogue) Red, Green and Blue Signals (E'_R, E'_G and E'_B) as described in CCIR Recommendation 601. These primary signals are gamma pre-corrected. The assumed value of gamma is not defined in this part of ISO/IEC 11172 but may typically be in the region approximately 2,2 to approximately 2,8. Applications which require accurate colour reproduction may choose to specify the value of gamma more accurately, but this is outside the scope of this part of ISO/IEC 11172.

The luminance and chrominance samples are positioned as shown in figure 5, where "x" marks the position of the luminance (Y) samples and "0" marks the position of the chrominance (Cb and Cr) samples:

```
x       x   |   x       x   |   x       x
    0       |       0       |       0
x       x   |   x       x   |   x       x
___   ___   ___   ___   ___   ___   ___   ___   ___   ___
x       x   |   x       x   |   x       x
    0       |       0       |       0
x       x   |   x       x   |   x       x
___   ___   ___   ___   ___   ___   ___   ___   ___   ___
x       x   |   x       x   |   x       x
    0       |       0       |       0
x       x   |   x       x   |   x       x
```

Figure 5 -- The position of luminance and chrominance samples.

There are four types of coded picture that use different coding methods.

An **Intra-coded picture (I-picture)** is coded using information only from itself.

A **Predictive-coded picture (P-picture)** is a picture which is coded using motion compensated prediction from a past I-Picture or P-Picture.

A **Bidirectionally predictive-coded picture (B-picture)** is a picture which is coded using motion compensated prediction from a past and/or future I-Picture or P-Picture.

A **dc coded (D) picture** is coded using information only from itself. Of the DCT coefficients only the dc ones are present. The D-Pictures shall not be in a sequence containing any other picture types.

Slice

A **slice** is a series of an arbitrary number of macroblocks with the order of macroblocks starting from the upper-left of the picture and proceeding by raster-scan order from left to right and top to bottom. The first and last macroblocks of a slice shall not be skipped macroblocks (see 2.4.4.4). Every slice shall contain at least one macroblock. Slices shall not overlap and there shall be no gaps between slices. The position of slices may change from picture to picture. The first slice shall start with the first macroblock in the picture and the last slice shall end with the last macroblock in the picture.

Macroblock

A **macroblock** contains a 16-pel by 16-line section of luminance component and the spatially corresponding 8-pel by 8-line section of each chrominance component. A macroblock has 4 luminance blocks and 2 chrominance blocks. The term "macroblock" can refer to source or reconstructed data or to scaled, quantized coefficients. The order of blocks in a macroblock is top-left, top-right, bottom-left, bottom-right blocks for Y, followed by Cb and Cr. Figure 6 shows the arrangement of these blocks. A skipped macroblock is one for which no information is stored (see 2.4.4.4).

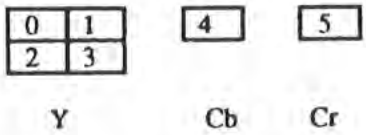


Figure 6 -- The arrangement of blocks in a macroblock.

Block

A **block** is an orthogonal 8-pel by 8-line section of a luminance or chrominance component.

The term "block" can refer either to source and reconstructed data or to the corresponding coded data elements.

Reserved, Forbidden and Marker bit

The terms "reserved" and "forbidden" are used in the description of some values of several fields in the coded bitstream.

The term "reserved" indicates that the value may be used in the future for ISO/IEC-defined extensions.

The term "forbidden" indicates a value that shall never be used (usually in order to avoid emulation of start codes).

The term "marker_bit" indicates a one bit field in which the value zero is forbidden. These marker bits are introduced at several points in the syntax to avoid start-code emulation.

2.4.2 Specification of the coded video bitstream syntax

2.4.2.1 Start codes

Start codes are reserved bit patterns that do not otherwise occur in the video stream. All start codes are bytealigned.

Name	Hexadecimal value
picture_start_code	00000100
slice_start_codes (including slice_vertical_positions)	00000101 through 000001AF
reserved	000001B0
reserved	000001B1
user_data_start_code	000001B2
sequence_header_code	000001B3
sequence_error_code	000001B4
extension_start_code	000001B5
reserved	000001B6
sequence_end_code	000001B7
group_start_code	000001B8
system start codes (see note)	000001B9 through 000001FF
NOTE - System start codes are defined in ISO/IEC 11172-1.	

The use of the start codes is defined in the following syntax description with the exception of the sequence_error_code. The sequence_error_code has been allocated for use by the digital storage media interface to indicate where uncorrectable errors have been detected.

2.4.2.2 Video sequence layer

Syntax	No. of bits	Mnemonic
video_sequence() {		
next_start_code()		
do {		
sequence_header()		
do {		
group_of_pictures()		
} while (nextbits() == group_start_code)		
} while (nextbits() == sequence_header_code)		
sequence_end_code	**32**	**bslbf**
}		

2.4.2.3 Sequence header

Syntax	No.of bits	Mnemonic
sequence_header() {		
sequence_header_code	32	bslbf
horizontal_size	12	uimsbf
vertical_size	12	uimsbf
pel_aspect_ratio	4	uimsbf
picture_rate	4	uimsbf
bit_rate	18	uimsbf
marker_bit	1	"1"
vbv_buffer_size	10	uimsbf
constrained_parameters_flag	1	
load_intra_quantizer_matrix	1	
if (load_intra_quantizer_matrix)		
intra_quantizer_matrix []	8*64	uimsbf
load_non_intra_quantizer_matrix	1	
if (load_non_intra_quantizer_matrix)		
non_intra_quantizer_matrix []	8*64	uimsbf
next_start_code()		
if (nextbits() == extension_start_code) {		
extension_start_code	32	bslbf
while (nextbits () != '0000 0000 0000 0000 0000 0001') {		
sequence_extension_data	8	
}		
next_start_code()		
}		
if (nextbits() == user_data_start_code) {		
user_data_start_code	32	bslbf
while (nextbits() != '0000 0000 0000 0000 0000 0001') {		
user_data	8	
}		
next_start_code()		
}		
}		

2.4.2.4 Group of pictures layer

Syntax	No. of bits	Mnemonic
group_of_pictures() {		
group_start_code	32	bslbf
time_code	25	
closed_gop	1	
broken_link	1	
next_start_code()		
if (nextbits() == extension_start_code) {		
extension_start_code	32	bslbf
while (nextbits() != '0000 0000 0000 0000 0000 0001') {		
group_extension_data	8	
}		
next_start_code()		
}		
if (nextbits() == user_data_start_code) {		
user_data_start_code	32	bslbf
while (nextbits() != '0000 0000 0000 0000 0000 0001') {		
user_data	8	
}		
next_start_code()		
}		
do {		
picture()		
} while (nextbits() == picture_start_code)		
}		

2.4.2.5 Picture layer

Syntax	No. of bits	Mnemonic
picture() {		
picture_start_code	32	bslbf
temporal_reference	10	uimsbf
picture_coding_type	3	uimsbf
vbv_delay	16	uimsbf
if ((picture_coding_type == 2) || (picture_coding_type == 3)) {		
full_pel_forward_vector	1	
forward_f_code	3	uimsbf
}		
if (picture_coding_type == 3) {		
full_pel_backward_vector	1	
backward_f_code	3	uimsbf
}		
while (nextbits() == '1') {		
extra_bit_picture	1	"1"
extra_information_picture	8	
}		
extra_bit_picture	1	"0"
next_start_code()		
if (nextbits() == extension_start_code) {		
extension_start_code	32	bslbf
while (nextbits() != '0000 0000 0000 0000 0000 0001') {		
picture_extension_data	8	
}		
next_start_code()		
}		
if (nextbits() == user_data_start_code) {		
user_data_start_code	32	bslbf
while (nextbits() != '0000 0000 0000 0000 0000 0001') {		
user_data	8	
}		
next_start_code()		
}		
do {		
slice()		
} while (nextbits() == slice_start_code)		
}		

2.4.2.6 Slice layer

Syntax	No. of bits	Mnemonic
slice() {		
slice_start_code	32	bslbf
quantizer_scale	5	uimsbf
while (nextbits() == '1') {		
extra_bit_slice	1	"1"
extra_information_slice	8	
}		
extra_bit_slice	1	"0"
do {		
macroblock()		
} while (nextbits() != '000 0000 0000 0000 0000 0000')		
next_start_code()		
}		

2.4.2.7 Macroblock layer

Syntax	No. of bits	Mnemonic
macroblock () {		
while (nextbits() == '0000 0001 111')		
macroblock_stuffing	11	vlclbf
while (nextbits() == '0000 0001 000')		
macroblock_escape	11	vlclbf
macroblock_address_increment	1-11	vlclbf
macroblock_type	1-6	vlclbf
if (macroblock_quant)		
quantizer_scale	5	uimsbf
if (macroblock_motion_forward) {		
motion_horizontal_forward_code	1-11	vlclbf
if ((forward_f != 1) &&		
(motion_horizontal_forward_code != 0))		
motion_horizontal_forward_r	1-6	uimsbf
motion_vertical_forward_code	1-11	vlclbf
if ((forward_f != 1) &&		
(motion_vertical_forward_code != 0))		
motion_vertical_forward_r	1-6	uimsbf
}		
if (macroblock_motion_backward) {		
motion_horizontal_backward_code	1-11	vlclbf
if ((backward_f != 1) &&		
(motion_horizontal_backward_code != 0))		
motion_horizontal_backward_r	1-6	uimsbf
motion_vertical_backward_code	1-11	vlclbf
if ((backward_f != 1) &&		
(motion_vertical_backward_code != 0))		
motion_vertical_backward_r	1-6	uimsbf
}		
if (macroblock_pattern)		
coded_block_pattern	3-9	vlclbf
for (i=0; i<6; i++)		
block(i)		
if (picture_coding_type == 4)		
end_of_macroblock	1	"1"
}		

2.4.2.8 Block layer

Syntax	No. of bits	Mnemonic
block(i) {		
if (pattern_code[i]) {		
if (macroblock_intra) {		
if (i<4) {		
dct_dc_size_luminance	2-7	vlclbf
if(dc_size_luminance != 0)		
dct_dc_differential	1-8	uimsbf
}		
else {		
dct_dc_size_chrominance	2-8	vlclbf
if(dc_size_chrominance !=0)		
dct_dc_differential	1-8	uimsbf
}		
}		
else {		
dct_coeff_first	2-28	vlclbf
}		
if (picture_coding_type != 4) {		
while (nextbits() != '10')		
dct_coeff_next	3-28	vlclbf
end_of_block	2	vlclbf
}		
}		
}		

2.4.3 Semantics for the video bitstream syntax

2.4.3.1 Video sequence layer

sequence_end_code -- The sequence_end_code is the bit string 000001B7 in hexadecimal. It terminates a video sequence.

2.4.3.2 Sequence header

sequence_header_code -- The sequence_header_code is the bit string 000001B3 in hexadecimal. It identifies the beginning of a sequence header.

horizontal_size -- The horizontal_size is the width of the displayable part of the luminance component in pels. The width of the encoded luminance component in macroblocks, mb_width, is (horizontal_size+15)/16. The displayable part of the picture is left-aligned in the encoded picture.

vertical_size -- The vertical_size is the height of the displayable part of the luminance component in pels. The height of the encoded luminance component in macroblocks, mb_height, is (vertical_size+15)/16. The displayable part of the picture is top-aligned in the encoded picture.

pel_aspect_ratio -- This is a four-bit integer defined in the following table.

pel_aspect_ratio	height/width	example
0000	forbidden	
0001	1,0000	VGA etc.
0010	0,6735	
0011	0,7031	16:9, 625line
0100	0,7615	
0101	0,8055	
0110	0,8437	16:9, 525line
0111	0,8935	
1000	0,9157	CCIR601, 625line
1001	0,9815	
1010	1,0255	
1011	1,0695	
1100	1,0950	CCIR601, 525line
1101	1,1575	
1110	1,2015	
1111	reserved	

picture_rate -- This is a four-bit integer defined in the following table.

picture_rate	pictures per second
0000	forbidden
0001	23,976
0010	24
0011	25
0100	29,97
0101	30
0110	50
0111	59,94
1000	60
. . .	reserved
1111	reserved

Applications and encoders should take into account the fact that 23,976, 29,97 and 59,94 are not exact representations of the nominal picture rate. The exact values are found from 24 000/1 001, 30 000/1 001, and 60 000/1 001 and can be derived from CCIR Report 624-4.

bit_rate -- This is an integer specifying the bitrate of the bitstream measured in units of 400 bits/s, rounded upwards. The value zero is forbidden. The value 3FFFF (11 1111 1111 1111 1111) identifies variable bit rate operation.

marker_bit -- This is one bit that shall be set to "1".

vbv_buffer_size -- This is a 10-bit integer defining the size of the VBV (Video Buffering Verifier, see annex C) buffer needed to decode the sequence. It is defined as:

B = 16 * 1 024 * vbv_buffer_size

where B is the minimum VBV buffer size in bits required to decode the sequence (see annex C).

constrained_parameters_flag -- This is a one-bit flag which may be set to "1" if the following data elements meet the following constraints:

horizontal_size <= 768 pels,
vertical_size <= 576 pels,
((horizontal_size+15)/16) *((vertical_size+15)/16) <= 396,
((horizontal_size+15)/16) *((vertical_size+15)/16))*picture_rate <= 396*25,
picture_rate <= 30 pictures/s.
forward_f_code <= 4 (see 2.4.3.4)
backward_f_code <= 4 (see 2.4.3.4)

If the constrained_parameters_flag is set, then the vbv_buffer_size field shall indicate a VBV buffer size less than or equal to 327 680 bits (20*1024*16; i.e. 40 kbytes).

If the constrained_parameters_flag is set, then the bit_rate field shall indicate a coded data rate less than or equal to 1 856 000 bits/s.

load_intra_quantizer_matrix -- This is a one-bit flag which is set to "1" if an intra_quantizer_matrix follows. If it is set to "0" then the default values defined below in raster-scan order, are used until the next occurence of the sequence header.

8	16	19	22	26	27	29	34
16	16	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	83

intra_quantizer_matrix -- This is a list of sixty-four 8-bit unsigned integers. The new values, stored in the zigzag scanning order shown in 2.4.4.1, replace the default values shown above. The value zero is forbidden. The value for intra_quant[0][0] shall always be 8. The new values shall be in effect until the next occurence of a sequence header.

load_non_intra_quantizer_matrix -- This is a one-bit flag which is set to "1" if a non_intra_quantizer_matrix follows. If it is set to "0" then the default values defined below are used until the next occurence of the sequence header.

16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16
16	16	16	16	16	16	16	16

non_intra_quantizer_matrix -- This is a list of sixty-four 8-bit unsigned integers. The new values, stored in the zigzag scanning order shown in 2.4.4.1, replace the default values shown above. The value zero is forbidden. The new values shall be in effect until the next occurence of a sequence header.

extension_start_code -- The extension_start_code is the bit string 000001B5 in hexadecimal. It identifies the beginning of extension data. The extension data continue until receipt of another start code. It is a requirement to parse extension data correctly.

sequence_extension_data -- Reserved.

user_data_start_code -- The user_data_start_code is the bit string 000001B2 in hexadecimal. It identifies the beginning of user data. The user data continues until receipt of another start code.

user_data -- The user_data is defined by the users for their specific applications. The user data shall not contain a string of 23 or more zero bits.

2.4.3.3 Group of pictures layer

group_start_code -- The group_start_code is the bit string 000001B8 in hexadecimal. It identifies the beginning of a group of pictures.

time_code -- This is a 25-bit field containing the following: drop_frame_flag, time_code_hours, time_code_minutes, marker_bit, time_code_seconds and time_code_pictures. The fields correspond to the fields defined in the IEC standard (Publication 461) for "time and control codes for video tape recorders" (see annex E). The code refers to the first picture in the group of pictures that has a temporal_reference of zero. The drop_frame_flag can be set to either "0" or "1". It may be set to "1" only if the picture rate is 29,97Hz. If it is "0" then pictures are counted assuming rounding to the nearest integral number of pictures per second, for example 29,97 Hz would be rounded to and counted as 30 Hz. If it is "1" then picture numbers 0 and 1 at the start of each minute, except minutes 0, 10, 20, 30, 40, 50 are omitted from the count.

time_code	range of value	bits	
drop_frame_flag		1	
time_code_hours	0 - 23	5	**uimsbf**
time_code_minutes	0 - 59	6	**uimsbf**
marker_bit	1	1	**"1"**
time_code_seconds	0 - 59	6	**uimsbf**
time_code_pictures	0 - 59	6	**uimsbf**

closed_gop -- This is a one-bit flag which may be set to "1" if the group of pictures has been encoded without motion vectors pointing to the previous group of pictures.

This bit is provided for use during any editing which occurs after encoding. If the previous group of pictures is removed by editing, **broken_link** may be set to "1" so that a decoder may avoid displaying the B-Pictures immediately following the first I-Picture of the group of pictures. However if the **closed_gop** bit indicates that there are no prediction references to the previous group of pictures then the editor may choose not to set the **broken_link** bit as these B-Pictures can be correctly decoded in this case.

broken_link -- This is a one-bit flag which shall be set to "0" during encoding. It is set to "1" to indicate that the B-Pictures immediately following the first I-Picture of a group of pictures cannot be correctly decoded because the other I-Picture or P-Picture which is used for prediction is not available (because of the action of editing).

A decoder may use this flag to avoid displaying pictures that cannot be correctly decoded.

extension_start_code -- See 2.4.3.2.

group_extension_data -- Reserved.

user_data_start_code -- See 2.4.3.2.

user_data -- See 2.4.3.2.

2.4.3.4 Picture layer

picture_start_code -- The picture_start_code is a string of 32-bits having the value 00000100 in hexadecimal.

temporal_reference -- The temporal_reference is a 10-bit unsigned integer associated with each input picture. It is incremented by one, modulo 1024, for each input picture. For the earliest picture (in display order) in each group of pictures, the temporal_reference is reset to zero.

The temporal_reference is assigned (in sequence) to the pictures in display order, no temporal_reference shall be omitted from the sequence.

picture_coding_type -- The picture_coding_type identifies whether a picture is an intra-coded picture(I), predictive-coded picture(P), bidirectionally predictive-coded picture(B), or intra-coded with only dc coefficients picture(D) according to the following table. D-pictures shall never be included in the same video sequence as the other picture coding types.

picture_coding_type	coding method
000	forbidden
001	intra-coded (I)
010	predictive-coded (P)
011	bidirectionally-predictive-coded (B)
100	dc intra-coded (D)
101	reserved
...	...
111	reserved

vbv_delay -- The vbv_delay is a 16-bit unsigned integer. For constant bitrate operation, the vbv_delay is used to set the initial occupancy of the decoder's buffer at the start of decoding the picture so that the decoder's buffer does not overflow or underflow. The vbv_delay measures the time needed to fill the VBV buffer from an initially empty state at the target bit rate, R, to the correct level immediately before the current picture is removed from the buffer.

The value of vbv_delay is the number of periods of the 90kHz system clock that the VBV should wait after receiving the final byte of the picture start code. It may be calculated from the state of the VBV as follows:

$$\text{vbv\_delay}_n = 90\,000 * B_n^* / R$$

where:

$n > 0$

B_n^* = VBV occupancy, measured in bits, immediately before removing picture n from the buffer but after removing any group of picture layer data, sequence header data and the **picture_start_code** that immediately precedes the data elements of picture n.

R = bitrate measured in bits/s. The full precision of the bitrate rather than the rounded value encoded by the **bit_rate** field in the sequence header shall be used by the encoder in the VBV model.

For non-constant bitrate operation vbv_delay shall have the value FFFF in hexadecimal.

full_pel_forward_vector -- If set to "1", then the motion vector values decoded represent integer pel offsets (rather than half-pel units) as reflected in the equations of 2.4.4.2.

forward_f_code -- An unsigned integer taking values 1 through 7. The value zero is forbidden. The variables forward_r_size and forward_f used in the process of decoding the forward motion vectors are derived from **forward_f_code** as described in 2.4.4.2

full_pel_backward_vector -- If set to "1", then the motion vector values decoded represent integer pel offsets (rather than half pel units) as reflected in the equations of 2.4.4.3.

backward_f_code -- An unsigned integer taking values 1 through 7. The value zero is forbidden. The variables backward_r_size and backward_f used in the process of decoding the backward motion vectors are derived from **backward_f_code** as described in 2.4.4.3.

extra_bit_picture -- A bit indicates the presence of the following extra information. If extra_bit_picture is set to "1", extra_information_picture will follow it. If it is set to "0", there are no data following it.

extra_information_picture -- Reserved.

extension_start_code -- See 2.4.3.2.

picture_extension_data -- Reserved.

user_data_start_code -- See 2.4.3.2.

user_data -- See 2.4.3.2.

2.4.3.5 Slice layer

slice_start_code -- The slice_start_code is a string of 32-bits. The first 24-bits have the value 000001 in hexadecimal and the last 8-bits are the slice_vertical_position having a value in the range 01 through AF hexadecimal inclusive.

slice_vertical_position -- This is given by the last eight bits of the slice_start_code. It is an unsigned integer giving the vertical position in macroblock units of the first macroblock in the slice. The slice_vertical_position of the first row of macroblocks is one. Some slices may have the same slice_vertical_position, since slices may start and finish anywhere. Note that the slice_vertical_position is constrained by 2.4.1 to define non-overlapping slices with no gaps between them. The maximum value of slice_vertical_position is 175.

quantizer_scale -- An unsigned integer in the range 1 to 31 used to scale the reconstruction level of the retrieved DCT coefficient levels. The decoder shall use this value until another quantizer_scale is encountered either at the slice layer or the macroblock layer. The value zero is forbidden.

extra_bit_slice -- A bit indicates the presence of the following extra information. If extra_bit_slice is set to "1", extra_information_slice will follow it. If it is set to "0", there are no data following it.

extra_information_slice -- Reserved.

2.4.3.6 Macroblock layer

macroblock_stuffing -- This is a fixed bit string "0000 0001 111" which can be inserted by the encoder to increase the bit rate to that required of the storage or transmission medium. It is discarded by the decoder.

macroblock_escape -- The macroblock_escape is a fixed bit-string "0000 0001 000" which is used when the difference between macroblock_address and previous_macroblock_address is greater than 33. It causes the value of macroblock_address_increment to be 33 greater than the value that will be decoded by subsequent macroblock_escapes and the macroblock_address_increment codewords.

For example, if there are two macroblock_escape codewords preceding the macroblock_address_increment, then 66 is added to the value indicated by macroblock_address_increment.

macroblock_address_increment -- This is a variable length coded integer coded as per table B.1 which indicates the difference between macroblock_address and previous_macroblock_address. The maximum value of macroblock_address_increment is 33. Values greater than this can be encoded using the macroblock_escape codeword.

The macroblock_address is a variable defining the absolute position of the current macroblock. The macroblock_address of the top-left macroblock is zero.

The previous_macroblock_address is a variable defining the absolute position of the last non-skipped macroblock (see 2.4.4.4 for the definition of skipped macroblocks) except at the start of a slice. At the start of a slice, previous_macroblock_address is reset as follows:

previous_macroblock_address=(slice_vertical_position-1)*mb_width-1;

The spatial position in macroblock units of a macroblock in the picture (mb_row, mb_column) can be computed from the macroblock_address as follows:

mb_row = macroblock_address / mb_width
mb_column = macroblock_address % mb_width

where mb_width is the number of macroblocks in one row of the picture.

NOTE - The slice_vertical_position differs from mb_row by one.

macroblock_type -- Variable length coded indicator which indicates the method of coding and content of the macroblock according to the tables B.2a through B.2d.

macroblock_quant -- Derived from macroblock_type.

macroblock_motion_forward -- Derived from macroblock_type.

macroblock_motion_backward -- Derived from macroblock_type.

macroblock_pattern -- Derived from macroblock_type.

macroblock_intra -- Derived from macroblock_type.

quantizer_scale -- An unsigned integer in the range 1 to 31 used to scale the reconstruction level of the retrieved DCT coefficient levels. The value zero is forbidden. The decoder shall use this value until another quantizer_scale is encountered either at the slice layer or the macroblock layer. The presence of quantizer_scale is determined from macroblock_type.

motion_horizontal_forward_code -- motion_horizontal_forward_code is decoded according to table B.4. The decoded value is required (along with forward_f - see 2.4.4.2) to decide whether or not motion_horizontal_forward_r appears in the bitstream.

motion_horizontal_forward_r -- An unsigned integer (of forward_r_size bits - see 2.4.4.2) used in the process of decoding forward motion vectors as described in 2.4.4.2.

motion_vertical_forward_code -- motion_vertical_forward_code is decoded according to table B.4. The decoded value is required (along with forward_f - see 2.4.4.2) to decide whether or not motion_vertical_forward_r appears in the bitstream.

motion_vertical_forward_r -- An unsigned integer (of forward_r_size bits - see 2.4.4.2) used in the process of decoding forward motion vectors as described in 2.4.4.2.

motion_horizontal_backward_code -- motion_horizontal_backward_code is decoded according to table B.4. The decoded value is required (along with backward_f - see 2.4.4.2) to decide whether or not motion_horizontal_backward_r appears in the bitstream.

motion_horizontal_backward_r -- An unsigned integer (of backward_r_size bits - see 2.4.4.2) used in the process of decoding backward motion vectors as described in 2.4.4.2.

motion_vertical_backward_code -- motion_vertical_backward_code is decoded according to table B.4. The decoded value is required (along with backward_f) to decide whether or not motion_vertical_backward_r appears in the bitstream.

motion_vertical_backward_r -- An unsigned integer (of backward_r_size bits) used in the process of decoding backward motion vectors as described in 2.4.4.3.

coded_block_pattern -- coded_block_pattern is a variable length code that is used to derive the variable cbp according to table B.3. If macroblock_intra is zero, cbp=0. Then the pattern_code[i] for i=0 to 5 is derived from cbp using the following:

```
pattern_code[i] = 0;
if ( cbp & (1<<(5-i)) ) pattern_code[i] = 1;
if ( macroblock_intra ) pattern_code[i] = 1 ;
```

pattern_code[0] -- If 1, then the upper left luminance block is to be received in this macroblock.

pattern_code[1] -- If 1, then the upper right luminance block is to be received in this macroblock.

pattern_code[2] -- If 1, then the lower left luminance block is to be received in this macroblock.

pattern_code[3] -- If 1, then the lower right luminance block is to be received in this macroblock..

pattern_code[4] -- If 1, then the chrominance block Cb is to be received in this macroblock.

pattern_code[5] -- If 1, then the chrominance block Cr is to be received in this macroblock.

end_of_macroblock -- This is a bit which is set to "1" and exists only in D-Pictures.

2.4.3.7 Block layer

dct_dc_size_luminance -- The number of bits in the following dct_dc_differential code, dc_size_luminance, is derived according to the VLC table B.5a. Note that this data element is used in intra coded blocks.

dct_dc_size_chrominance -- The number of bits in the following dct_dc_differential code, dc_size_chrominance, is derived according to the VLC table B.5b. Note that this data element is used in intra coded blocks.

dct_dc_differential -- A variable length unsigned integer. If dc_size_luminance or dc_size_chrominance (as appropriate) is zero, then dct_dc_differential is not present in the bitstream. dct_zz [] is the array of quantized DCT coefficients in zig-zag scanning order. dct_zz[i] for i=0..63 shall be set to zero initially. If dc_size_luminance or dc_size_chrominance (as appropriate) is greater than zero, then dct_zz[0] is computed as follows from dct_dc_differential:

For luminance blocks:

```
if ( dct_dc_differential & ( 1 << (dc_size_luminance-1)) ) dct_zz[0] = dct_dc_differential ;
else dct_zz[0] = ( (-1) << (dc_size_luminance) ) | (dct_dc_differential+1) ;
```

For chrominance blocks:

```
if ( dct_dc_differential & ( 1 << (dc_size_chrominance-1)) ) dct_zz[0] = dct_dc_differential ;
else dct_zz[0] = ( (-1) << (dc_size_chrominance) ) | (dct_dc_differential+1) ;
```

Note that this data element is used in intra coded blocks.

example for dc_size_luminance = 3	
dct_dc_differential	dct_zz[0]
000	-7
001	-6
010	-5
011	-4
100	4
101	5
110	6
111	7

dct_coeff_first -- A variable length code according to tables B.5c through B.5f for the first coefficient. The variables run and level are derived according to these tables. The zigzag-scanned quantized DCT coefficient list is updated as follows.

```
i = run ;
if ( s == 0 ) dct_zz[i] = level ;
if ( s == 1 ) dct_zz[i] = - level ;
```

The terms dct_coeff_first and dct_coeff_next are run-length encoded and dct_zz[i], i>=0 shall be set to zero initially. A variable length code according to tables B.5c through B.5f is used to represent the run-length and level of the DCT coefficients. Note that this data element is used in non-intra coded blocks.

dct_coeff_next -- A variable length code according to tables B.5c through B.5f for coefficients following the first retrieved. The variables run and level are derived according to these tables. The zigzag-scanned quantized DCT coefficient list is updated as follows.

```
i = i + run +1 ;
if ( s == 0 ) dct_zz[i] = level ;
if ( s == 1 ) dct_zz[i] = - level ;
```

If macroblock_intra == 1 then the term i shall be set to zero before the first dct_coeff_next of the block. The decoding of dct_coeff_next shall not cause i to exceed 63.

end_of_block -- This symbol is always used to indicate that no additional non-zero coefficients are present. It is used even if dct_zz[63] is non-zero. Its value is the bit-string "10" as defined in table B.5c.

2.4.4 The video decoding process

Compliance requirements for decoders are contained in ISO/IEC 11172-4.

2.4.4.1 Intra-coded macroblocks

In I-pictures all macroblocks are intra-coded and stored. In P-pictures and B-pictures, some macroblocks may be intra-coded as identified by macroblock_type. Thus, macroblock_intra identifies the intra-coded macroblocks.

The variables mb_row and mb_column locate the macroblock in the picture. They are defined in 2.4.3.6. The definitions of dct_dc_differential, and dct_coeff_next also have defined the zigzag-scanned quantized DCT coefficient list, dct_zz[]. Each dct_zz[] is located in the macroblock as defined by pattern_code[].

Define dct_recon[m][n] to be the matrix of reconstructed DCT coefficients of the block, where the first index identifies the row and the second the column of the matrix. Define dct_dc_y_past, dct_dc_cb_past and dct_dc_cr_past to be the dct_recon[0][0] of the most recently decoded intra-coded Y, Cb and Cr blocks respectively. The predictors dct_dc_y_past, dct_dc_cb_past and dct_dc_cr_past shall all be reset at the start of a slice and at non-intra-coded macroblocks (including skipped macroblocks) to the value 1 024 (128*8).

Define intra_quant[m][n] to be the intra quantizer matrix that is specified in the sequence header.

Note that intra_quant[0][0] is used in the dequantizer calculations for simplicity of description, but the result is overwritten by the subsequent calculation for the dc coefficient.

Define scan[m][n] to be the matrix defining the zigzag scanning sequence as follows:

0	1	5	6	14	15	27	28
2	4	7	13	16	26	29	42
3	8	12	17	25	30	41	43
9	11	18	24	31	40	44	53
10	19	23	32	39	45	52	54
20	22	33	38	46	51	55	60
21	34	37	47	50	56	59	61
35	36	48	49	57	58	62	63

Where n is the horizontal index and m is the vertical index.

Define past_intra_address as the macroblock_address of the most recently retrieved intra-coded macroblock within the slice. It shall be reset to -2 at the beginning of each slice.

Then dct_recon[m][n] shall be computed by any means equivalent to the following procedure for the first luminance block:

```
for (m=0; m<8; m++) {
        for (n=0; n<8; n++) {
                i = scan[m][n] ;
                dct_recon[m][n] = ( 2 * dct_zz[i] * quantizer_scale * intra_quant[m][n] ) /16 ;
                if ( ( dct_recon[m][n] & 1 ) == 0 )
                        dct_recon[m][n] = dct_recon[m][n] - Sign(dct_recon[m][n]) ;
                if (dct_recon[m][n] > 2 047)  dct_recon[m][n] = 2 047 ;
                if (dct_recon[m][n] < -2 048)  dct_recon[m][n] = -2 048 ;
        }
}
dct_recon[0][0] = dct_zz[0] * 8 ;
if ( ( macroblock_address - past_intra_address > 1) )
        dct_recon[0][0] = (128 * 8) + dct_recon[0][0] ;
else
        dct_recon[0][0] = dct_dc_y_past + dct_recon[0][0] ;
dct_dc_y_past = dct_recon[0][0] ;
```

Note that this process disallows even valued numbers. This has been found to prevent accumulation of mismatch errors.

For the subsequent luminance blocks in the macroblock, in the order of the list defined by the array pattern_code[]:

```
for (m=0; m<8; m++) {
        for (n=0; n<8; n++) {
                i = scan[m][n] ;
                dct_recon[m][n] = ( 2 * dct_zz[i] * quantizer_scale * intra_quant[m][n] ) /16 ;
                if ( ( dct_recon[m][n] & 1 ) == 0 )
                        dct_recon[m][n] = dct_recon[m][n] - Sign(dct_recon[m][n]) ;
                if (dct_recon[m][n] > 2 047)  dct_recon[m][n] = 2 047 ;
                if (dct_recon[m][n] < -2 048)  dct_recon[m][n] = -2 048 ;
        }
}
dct_recon[0][0] = dct_dc_y_past + (dct_zz[0] * 8) ;
dct_dc_y_past = dct_recon[0][0] ;
```

For the chrominance Cb block,:

```
for (m=0; m<8; m++) {
        for (n=0; n<8; n++) {
                i = scan[m][n] ;
                dct_recon[m][n] = ( 2 * dct_zz[i] * quantizer_scale * intra_quant[m][n] ) /16 ;
                if ( ( dct_recon[m][n] & 1 ) == 0 )
                        dct_recon[m][n] = dct_recon[m][n] - Sign(dct_recon[m][n]) ;
                if (dct_recon[m][n] > 2 047)  dct_recon[m][n] = 2 047 ;
                if (dct_recon[m][n] < -2 048)  dct_recon[m][n] = -2 048 ;
        }
}
dct_recon[0][0] = dct_zz[0] * 8 ;
if (  ( macroblock_address - past_intra_address ) > 1 )
        dct_recon[0][0] = (128 * 8) + dct_recon[0][0] ;
else
        dct_recon[0][0] = dct_dc_cb_past + dct_recon[0][0] ;
dct_dc_cb_past = dct_recon[0][0] ;
```

For the chrominance Cr block, :

```
for (m=0; m<8; m++) {
        for (n=0; n<8; n++) {
                i = scan[m][n] ;
                dct_recon[m][n] = ( 2 * dct_zz[i] * quantizer_scale * intra_quant[m][n] ) /16 ;
                if ( ( dct_recon[m][n] & 1 ) == 0 )
                        dct_recon[m][n] = dct_recon[m][n] - Sign(dct_recon[m][n]) ;
                if (dct_recon[m][n] > 2 047)  dct_recon[m][n] = 2 047 ;
                if (dct_recon[m][n] < -2 048)  dct_recon[m][n] = -2 048 ;
        }
}
dct_recon[0][0] = dct_zz[0] * 8 ;
if (  ( macroblock_address - past_intra_address ) > 1 )
        dct_recon[0][0] = (128 * 8) + dct_recon[0][0] ;
else
        dct_recon[0][0] = dct_dc_cr_past + dct_recon[0][0] ;
dct_dc_cr_past = dct_recon[0][0] ;
```

After all the blocks in the macroblock are processed:

```
past_intra_address = macroblock_address ;
```

Values in the coded data elements leading to dct_recon[0][0] < 0 or dct_recon[0][0] > 2 047 are not permitted.

Once the DCT coefficients are reconstructed, the inverse DCT transform defined in annex A shall be applied to obtain the inverse transformed pel values in the range [-256, 255]. These pel values shall be limited to

the range [0, 255] and placed in the luminance and chrominance matrices in the positions defined by mb_row , mb_column, and the list defined by the array pattern_code[].

2.4.4.2 Predictive-coded macroblocks in P-pictures

Predictive-coded macroblocks in P-Pictures are decoded in two steps.

First, the value of the forward motion vector for the macroblock is reconstructed and a prediction macroblock is formed, as detailed below.

Second, the DCT coefficient information stored for some or all of the blocks is decoded, dequantized, inverse DCT transformed, and added to the prediction macroblock.

Let **recon_right_for** and **recon_down_for** be the reconstructed horizontal and vertical components of the motion vector for the current macroblock, and recon_right_for_prev and recon_down_for_prev be the reconstructed motion vector for the previous predictive-coded macroblock. If the current macroblock is the first macroblock in the slice, or if the last macroblock that was decoded contained no motion vector information (either because it was skipped or macroblock_motion_forward was zero), then recon_right_for_prev and recon_down_for_prev shall be set to zero.

If no forward motion vector data exists for the current macroblock (either because it was skipped or macroblock_motion_forward == 0), the motion vectors shall be set to zero.

If forward motion vector data exists for the current macroblock, then any means equivalent to the following procedure shall be used to reconstruct the motion vector horizontal and vertical components.

forward_r_size and forward_f are derived from forward_f_code as follows:

```
        forward_r_size = forward_f_code - 1
        forward_f = 1 << forward_r_size

if ( (forward_f == 1) || (motion_horizontal_forward_code == 0) ) {
        complement_horizontal_forward_r = 0;
} else {
        complement_horizontal_forward_r = forward_f - 1 - motion_horizontal_forward_r;
}
if ( (forward_f == 1) || (motion_vertical_forward_code == 0) ) {
        complement_vertical_forward_r = 0;
} else {
        complement_vertical_forward_r = forward_f - 1 - motion_vertical_forward_r;
}

right_little = motion_horizontal_forward_code * forward_f;
if (right_little == 0) {
        right_big = 0;
} else {
        if (right_little > 0) {
                right_little = right_little - complement_horizontal_forward_r ;
                right_big = right_little - (32 * forward_f);
        } else {
                right_little = right_little + complement_horizontal_forward_r ;
                right_big = right_little + (32 * forward_f);
        }
}
```

```
down_little = motion_vertical_forward_code * forward_f;
if (down_little == 0) {
        down_big = 0;
} else {
        if (down_little > 0) {
                down_little = down_little - complement_vertical_forward_r ;
                down_big = down_little - (32 * forward_f);
        } else {
                down_little = down_little + complement_vertical_forward_r ;
                down_big = down_little + (32 * forward_f);
        }
}
```

Values of forward_f, motion_horizontal_forward_code and if present, motion_horizontal_forward_r shall be such that right_little is not equal to forward_f * 16.

Values of forward_f, motion_vertical_forward_code and if present, motion_vertical_forward_r shall be such that down_little is not equal to forward_f * 16.

```
max = ( 16 * forward_f ) - 1 ;
min = ( -16 * forward_f ) ;

new_vector = recon_right_for_prev + right_little ;
if ( (new_vector <= max) && (new_vector >= min) )
        recon_right_for = recon_right_for_prev + right_little ;
else
        recon_right_for = recon_right_for_prev + right_big ;
recon_right_for_prev = recon_right_for ;

if ( full_pel_forward_vector ) recon_right_for = recon_right_for << 1 ;
new_vector = recon_down_for_prev + down_little ;
if ( (new_vector <= max) && (new_vector >= min) )
        recon_down_for = recon_down_for_prev + down_little ;
else
        recon_down_for = recon_down_for_prev + down_big ;
recon_down_for_prev = recon_down_for ;
if ( full_pel_forward_vector ) recon_down_for = recon_down_for << 1 ;
```

The motion vectors in whole pel units for the macroblock, right_for and down_for, and the half pel unit flags, right_half_for and down_half_for, are computed as follows:

for luminance	for chrominance
right_for = recon_right_for >> 1 ; down_for = recon_down_for >> 1 ; right _half_for = recon_right_for - (2*right_for) ; down_half_for = recon_down_for - (2*down_for) ;	right_for = (recon_right_for / 2) >> 1 ; down_for = (recon_down_for / 2) >> 1 ; right_half_for = recon_right_for/2 - (2*right_for) ; down_half_for = recon_down_for/2 - (2*down_for);

Motion vectors leading to references outside a reference picture's boundaries are not allowed.

A positive value of the reconstructed horizontal motion vector (right_for) indicates that the referenced area of the past reference picture is to the right of the macroblock in the coded picture.

A positive value of the reconstructed vertical motion vector (down_for) indicates that the referenced area of the past reference picture is below the macroblock in the coded picture.

Defining pel_past[][] as the pel values of the past picture referenced by the forward motion vector, and pel[][] as the predictors for the pel values of the block being decoded, then:

```
if ( (! right_half_for )&& (! down_half_for) )
        pel[i][j] = pel_past[i+down_for][j+right_for] ;
```

```
if ( (! right_half_for) &&  down_half_for )
        pel[i][j] = ( pel_past[i+down_for][j+right_for] +
                                        pel_past[i+down_for+1][j+right_for] ) // 2 ;

if (  right_half_for && (! down_half_for) )
        pel[i][j] = ( pel_past[i+down_for][j+right_for] +
                                        pel_past[i+down_for][j+right_for+1] ) // 2 ;

if (  right_half_for &&  down_half_for )
        pel[i][j] = ( pel_past[i+down_for][j+right_for] + pel_past[i+down_for+1][j+right_for] +
        pel_past[i+down_for][j+right_for+1] + pel_past[i+down_for+1][j+right_for+1] ) // 4 ;
```

Define non_intra_quant[m][n] to be the non-intra quantizer matrix that is specified in the sequence header.

The DCT coefficients for each block present in the macroblock shall be reconstructed by any means equivalent to the following procedure:

```
for ( m=0; m<8; m++ ) {
        for ( n=0; n<8; n++ ) {
                i = scan[m][n] ;
                dct_recon[m][n] = ( ( (2 * dct_zz[i]) + Sign(dct_zz[i]) ) *
                                quantizer_scale * non_intra_quant[m][n] ) / 16 ;
                if ( ( dct_recon[m][n] & 1 ) == 0 )
                        dct_recon[m][n] = dct_recon[m][n] - Sign(dct_recon[m][n]) ;
                if (dct_recon[m][n] > 2047)  dct_recon[m][n] = 2047 ;
                if (dct_recon[m][n] < -2048)  dct_recon[m][n] = -2048 ;
                if ( dct_zz[i] == 0 )
                        dct_recon[m][n] = 0 ;
        }
}
```

dct_recon[m][n] = 0 for all m, n in skipped macroblocks and when pattern[i] == 0.

Once the DCT coefficients are reconstructed, the inverse DCT transform defined in annex A shall be applied to obtain the inverse transformed pel values in the interval [-256, 255]. The inverse DCT pel values shall be added to the pel[i][j] which were computed above using the motion vectors. The result of the addition shall be limited to the interval [0,255]. The location of the pels is determined from mb_row, mb_column and the pattern_code list.

2.4.4.3 Predictive-coded macroblocks in B-pictures

Predictive-coded macroblocks in B-Pictures are decoded in four steps.

First, the value of the forward motion vector for the macroblock is reconstructed from the retrieved forward motion vector information, and the forward motion vector reconstructed for the previous macroblock, using the same procedure as for calculating the forward motion vector in P-pictures. However, for B-pictures the previous reconstructed motion vectors shall be reset only for the first macroblock in a slice, or when the last macroblock that was decoded was an intra-coded macroblock. If no forward motion vector data exists for the current macroblock, the motion vectors shall be obtained by:

recon_right_for = recon_right_for_prev,
recon_down_for = recon_down_for_prev.

Second, the value of the backward motion vector for the macroblock shall be reconstructed from the retrieved backward motion vector information, and the backward motion vector reconstructed for the previous macroblock using the same procedure as for calculating the forward motion vector in B-pictures. In this procedure, the variables needed to find the backward motion vector are substituted for the variables needed to find the forward motion vector. The variables and coded data elements used to calculate the backward motion vector are:

recon_right_back_prev, recon_down_back_prev, backward_f_code, full_pel_backward_vector
motion_horizontal_backward_code, motion_horizontal_backward_r,
motion_vertical_backward_code, motion_vertical_backward_r,

backward_r_size and backward_f are derived from backward_f_code as follows:

```
backward_r_size = backward_f_code - 1
backward_f = 1 << backward_r_size
```

The following variables result from applying the algorithm in 2.4.4.2, modified as described in the previous paragraphs in this clause:

right_for	right_half_for	down_for	down_half_for
right_back	right_half_back	down_back	down_half_back

They define the integral and half pel value of the rightward and downward components of the forward motion vector (which references the past picture in display order) and the backward motion vector (which references the future picture in display order).

Third, the predictors of the pel values of the block being decoded, pel [][], are calculated. If only forward motion vector information was retrieved for the macroblock, then pel[][] of the decoded picture shall be calculated according to the formulas in 2.4.4.2. If only backward motion vector information was retrieved for the macroblock, then pel[][] of the decoded picture shall be calculated according to the formulas in the predictive-coded macroblock clause, with "back" replacing "for", and pel_future[][] replacing pel_past[][]. If both forward and backward motion vectors information are retrieved, then let pel_for[][] be the value calculated from the past picture by use of the reconstructed forward motion vector, and let pel_back[][] be the value calculated from the future picture by use of the reconstructed backward motion vector. Then the value of pel[][] shall be calculated by:

```
pel[][] = ( pel_for[][] + pel_back[][] ) // 2 ;
```

Define non_intra_quant[m][n] to be the non-intra quantizer matrix that is specified in the sequence header.

Fourth, the DCT coefficients for each block present in the macroblock shall be reconstructed by any means equivalent to the following procedure:

```
for ( m=0; m<8; m++ ) {
        for ( n=0; n<8; n++ ) {
                i = scan[m][n] ;
                dct_recon[m][n] = ( ( (2 * dct_zz[i]) + Sign(dct_zz[i]) ) *
                                quantizer_scale * non_intra_quant[m][n] ) / 16 ;
                if ( ( dct_recon[m][n] & 1 ) == 0 )
                        dct_recon[m][n] = dct_recon[m][n] - Sign(dct_recon[m][n]) ;
                if (dct_recon[m][n] > 2 047)  dct_recon[m][n] = 2 047 ;
                if (dct_recon[m][n] < -2 048)  dct_recon[m][n] = -2 048 ;
                if ( dct_zz[i] == 0 )
                        dct_recon[m][n] = 0 ;
        }
}
```

dct_recon[m][n] = 0 for all m, n in skipped macroblocks and when pattern[i] == 0.

Once the DCT coefficients are reconstructed, the inverse DCT transform defined in annex A shall be applied to obtain the inverse transformed pel values in the range [-256, 255]. The inverse DCT pel values shall be added to pel[][], which were computed above from the motion vectors. The result of the addition shall be limited to the interval [0,255]. The location of the pels is determined from mb_row, mb_column and the pattern_code list.

2.4.4.4 Skipped macroblocks

For some macroblocks there are no coded data, that is neither motion vector information nor DCT information is available to the decoder. These macroblocks are called skipped macroblocks and are indicated when the macroblock_address_increment is greater than 1.

In I-pictures, all macroblocks shall be coded and there shall be no skipped macroblocks.

In P-pictures, the skipped macroblock is defined to be a macroblock with a reconstructed motion vector equal to zero and no DCT coefficients.

In B-pictures, the skipped macroblock is defined to have the same macroblock_type (forward, backward, or both motion vectors) as the prior macroblock, differential motion vectors equal to zero, and no DCT coefficients. In a B-picture, a skipped macroblock shall not follow an intra-coded macroblock.

2.4.4.5 Forced updating

This function is achieved by forcing the use of an intra-coded macroblock. The update pattern is not defined. For control of accumulation of IDCT mismatch error, each macroblock shall be intra-coded at least once per every 132 times it is coded in a P-picture without an intervening I-picture.

Annex A

(normative)

8 by 8 Inverse discrete cosine transform

The 8 by 8 inverse discrete cosine transform for I-pictures and P-pictures shall conform to IEEE Draft Standard, P1180/D2, July 18, 1990. For B-pictures this specification may also be applied but may be unnecessarily stringent. Note that clause 2.3 of P1180/D2 "Considerations of Specifying IDCT Mismatch Errors" requires the specification of periodic intra-coding in order to control the accumulation of mismatch errors. The maximum refresh period requirement for this part of ISO/IEC 11172 shall be 132 intra-coded pictures or predictive-coded pictures as stated in 2.4.4.5, which is the same as indicated in P1180/D2 for visual telephony according to CCITT Recommendation H.261 [5].

Annex B

(normative)

Variable length code tables

Introduction

This annex contains the variable length code tables for macroblock addressing, macroblock type, macroblock pattern, motion vectors, and DCT coefficients.

B.1 Macroblock addressing

Table B.1. -- Variable length codes for macroblock_address_increment.

macroblock_address_ increment VLC code	increment value
1	1
011	2
010	3
0011	4
0010	5
0001 1	6
0001 0	7
0000 111	8
0000 110	9
0000 1011	10
0000 1010	11
0000 1001	12
0000 1000	13
0000 0111	14
0000 0110	15
0000 0101 11	16

macroblock_address_ increment VLC code	increment value
0000 0101 10	17
0000 0101 01	18
0000 0101 00	19
0000 0100 11	20
0000 0100 10	21
0000 0100 011	22
0000 0100 010	23
0000 0100 001	24
0000 0100 000	25
0000 0011 111	26
0000 0011 110	27
0000 0011 101	28
0000 0011 100	29
0000 0011 011	30
0000 0011 010	31
0000 0011 001	32
0000 0011 000	33
0000 0001 111	macroblock_stuffing
0000 0001 000	macroblock_escape

B.2 Macroblock type

The properties of the macroblock are determined by the macroblock type VLC according to these tables.

Table B.2a. -- Variable length codes for macroblock_type in intra-coded pictures (I-pictures).

macroblock_ typeVLC code	macroblock_ quant	macroblock_ motion_ forward	macroblock_ motion_ backward	macroblock_ pattern	macroblock_ intra
1	0	0	0	0	1
01	1	0	0	0	1

Table B.2b. -- Variable length codes for macroblock_type in predictive-coded pictures (P-pictures).

macroblock_ typeVLC code	macroblock_ quant	macroblock_ motion_ forward	macroblock_ motion_ backward	macroblock_ pattern	macroblock_ intra
1	0	1	0	1	0
01	0	0	0	1	0
001	0	1	0	0	0
00011	0	0	0	0	1
00010	1	1	0	1	0
00001	1	0	0	1	0
000001	1	0	0	0	1

Table B.2c. -- Variable length codes for macroblock_type in bidirectionally predictive-coded pictures (B-pictures).

macroblock_ typeVLC code	macroblock_ quant	macroblock_ motion_ forward	macroblock_ motion_ backward	macroblock_ pattern	macroblock_ intra
10	0	1	1	0	0
11	0	1	1	1	0
010	0	0	1	0	0
011	0	0	1	1	0
0010	0	1	0	0	0
0011	0	1	0	1	0
00011	0	0	0	0	1
00010	1	1	1	1	0
000011	1	1	0	1	0
000010	1	0	1	1	0
000001	1	0	0	0	1

Table B.2d. -- Variable length codes for macroblock_type in dc intra-coded pictures (D-pictures).

macroblock_ typeVLC code	macroblock_ quant	macroblock_ motion_ forward	macroblock_ motion_ backward	macroblock_ pattern	macroblock_ intra
1	0	0	0	0	1

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B.3 Macroblock pattern

Table B.3. -- Variable length codes for coded_block_pattern.

coded_block_pattern VLC code	cbp
111	60
1101	4
1100	8
1011	16
1010	32
1001 1	12
1001 0	48
1000 1	20
1000 0	40
0111 1	28
0111 0	44
0110 1	52
0110 0	56
0101 1	1
0101 0	61
0100 1	2
0100 0	62
0011 11	24
0011 10	36
0011 01	3
0011 00	63
0010 111	5
0010 110	9
0010 101	17
0010 100	33
0010 011	6
0010 010	10
0010 001	18
0010 000	34
0001 1111	7
0001 1110	11
0001 1101	19

coded_block_pattern VLC code	cbp
0001 1100	35
0001 1011	13
0001 1010	49
0001 1001	21
0001 1000	41
0001 0111	14
0001 0110	50
0001 0101	22
0001 0100	42
0001 0011	15
0001 0010	51
0001 0001	23
0001 0000	43
0000 1111	25
0000 1110	37
0000 1101	26
0000 1100	38
0000 1011	29
0000 1010	45
0000 1001	53
0000 1000	57
0000 0111	30
0000 0110	46
0000 0101	54
0000 0100	58
0000 0011 1	31
0000 0011 0	47
0000 0010 1	55
0000 0010 0	59
0000 0001 1	27
0000 0001 0	39

B.4 Motion vectors

Table B.4. -- Variable length codes for motion_horizontal_forward_code, motion_vertical_forward_code, motion_horizontal_backward_code, and motion_vertical_backward_code.

motion VLC code	code
0000 0011 001	-16
0000 0011 011	-15
0000 0011 101	-14
0000 0011 111	-13
0000 0100 001	-12
0000 0100 011	-11
0000 0100 11	-10
0000 0101 01	-9
0000 0101 11	-8
0000 0111	-7
0000 1001	-6
0000 1011	-5
0000 111	-4
0001 1	-3
0011	-2
011	-1
1	0
010	1
0010	2
0001 0	3
0000 110	4
0000 1010	5
0000 1000	6
0000 0110	7
0000 0101 10	8
0000 0101 00	9
0000 0100 10	10
0000 0100 010	11
0000 0100 000	12
0000 0011 110	13
0000 0011 100	14
0000 0011 010	15
0000 0011 000	16

B.5 DCT coefficients

Table B.5a -- Variable length codes for dct_dc_size_luminance.

VLC code	dct_dc_size_luminance
100	0
00	1
01	2
101	3
110	4
1110	5
11110	6
111110	7
1111110	8

Table B.5b. -- Variable length codes for dct_dc_size_chrominance.

VLC code	dct_dc_size_chrominance
00	0
01	1
10	2
110	3
1110	4
11110	5
111110	6
1111110	7
11111110	8

Table B.5c. -- Variable length codes for dct_coeff_first and dct_coeff_next.

dct_coeff_first and dct_coeff_next variable length code (NOTE1)	run	level
10	end_of_block	
1 s (NOTE2)	0	1
11 s (NOTE3)	0	1
011 s	1	1
0100 s	0	2
0101 s	2	1
0010 1 s	0	3
0011 1 s	3	1
0011 0 s	4	1
0001 10 s	1	2
0001 11 s	5	1
0001 01 s	6	1
0001 00 s	7	1
0000 110 s	0	4
0000 100 s	2	2
0000 111 s	8	1
0000 101 s	9	1
0000 01	escape	
0010 0110 s	0	5
0010 0001 s	0	6
0010 0101 s	1	3
0010 0100 s	3	2
0010 0111 s	10	1
0010 0011 s	11	1
0010 0010 s	12	1
0010 0000 s	13	1
0000 0010 10 s	0	7
0000 0011 00 s	1	4
0000 0010 11 s	2	3
0000 0011 11 s	4	2
0000 0010 01 s	5	2
0000 0011 10 s	14	1
0000 0011 01 s	15	1
0000 0010 00 s	16	1

NOTES
1 - The last bit 's' denotes the sign of the level, '0' for positive '1' for negative.
2 - This code shall be used for dct_coeff_first.
3 - This code shall be used for dct_coeff_next.

Table B.5d. -- Variable length codes for dct_coeff_first and dct_coeff_next.

dct_coeff_first and dct_coeff_next variable length code (NOTE)	run	level
0000 0001 1101 s	0	8
0000 0001 1000 s	0	9
0000 0001 0011 s	0	10
0000 0001 0000 s	0	11
0000 0001 1011 s	1	5
0000 0001 0100 s	2	4
0000 0001 1100 s	3	3
0000 0001 0010 s	4	3
0000 0001 1110 s	6	2
0000 0001 0101 s	7	2
0000 0001 0001 s	8	2
0000 0001 1111 s	17	1
0000 0001 1010 s	18	1
0000 0001 1001 s	19	1
0000 0001 0111 s	20	1
0000 0001 0110 s	21	1
0000 0000 1101 0 s	0	12
0000 0000 1100 1 s	0	13
0000 0000 1100 0 s	0	14
0000 0000 1011 1 s	0	15
0000 0000 1011 0 s	1	6
0000 0000 1010 1 s	1	7
0000 0000 1010 0 s	2	5
0000 0000 1001 1 s	3	4
0000 0000 1001 0 s	5	3
0000 0000 1000 1 s	9	2
0000 0000 1000 0 s	10	2
0000 0000 1111 1 s	22	1
0000 0000 1111 0 s	23	1
0000 0000 1110 1 s	24	1
0000 0000 1110 0 s	25	1
0000 0000 1101 1 s	26	1

NOTE - The last bit 's' denotes the sign of the level, '0' for positive, '1' for negative.

Table B.5e. -- Variable length codes for dct_coeff_first and dct_coeff_next (concluded).

dct_coeff_first and dct_coeff_next variable length code (NOTE)	run	level
0000 0000 0111 11 s	0	16
0000 0000 0111 10 s	0	17
0000 0000 0111 01 s	0	18
0000 0000 0111 00 s	0	19
0000 0000 0110 11 s	0	20
0000 0000 0110 10 s	0	21
0000 0000 0110 01 s	0	22
0000 0000 0110 00 s	0	23
0000 0000 0101 11 s	0	24
0000 0000 0101 10 s	0	25
0000 0000 0101 01 s	0	26
0000 0000 0101 00 s	0	27
0000 0000 0100 11 s	0	28
0000 0000 0100 10 s	0	29
0000 0000 0100 01 s	0	30
0000 0000 0100 00 s	0	31
0000 0000 0011 000 s	0	32
0000 0000 0010 111 s	0	33
0000 0000 0010 110 s	0	34
0000 0000 0010 101 s	0	35
0000 0000 0010 100 s	0	36
0000 0000 0010 011 s	0	37
0000 0000 0010 010 s	0	38
0000 0000 0010 001 s	0	39
0000 0000 0010 000 s	0	40
0000 0000 0011 111 s	1	8
0000 0000 0011 110 s	1	9
0000 0000 0011 101 s	1	10
0000 0000 0011 100 s	1	11
0000 0000 0011 011 s	1	12
0000 0000 0011 010 s	1	13
0000 0000 0011 001 s	1	14
0000 0000 0001 0011 s	1	15
0000 0000 0001 0010 s	1	16
0000 0000 0001 0001 s	1	17
0000 0000 0001 0000 s	1	18
0000 0000 0001 0100 s	6	3
0000 0000 0001 1010 s	11	2
0000 0000 0001 1001 s	12	2
0000 0000 0001 1000 s	13	2
0000 0000 0001 0111 s	14	2
0000 0000 0001 0110 s	15	2
0000 0000 0001 0101 s	16	2
0000 0000 0001 1111 s	27	1
0000 0000 0001 1110 s	28	1
0000 0000 0001 1101 s	29	1
0000 0000 0001 1100 s	30	1
0000 0000 0001 1011 s	31	1

NOTE - The last bit 's' denotes the sign of the level, '0' for positive, '1' for negative.

Table B.5f. -- Encoding of run and level following an escape code either as a 14-bit fixed length code (-127 <= level <= 127) or as a 22-bit fixed length code (-255 <= level <= -128, 128 <= level <= 255).
(Note - This yields total escape code lengths of 20-bits and 28-bits respectively).

fixed length code	run
0000 00	0
0000 01	1
0000 10	2
...	...
...	...
...	...
...	...
...	...
...	...
1111 11	63

fixed length code	level
forbidden	-256
1000 0000 0000 0001	-255
1000 0000 0000 0010	-254
...	
1000 0000 0111 1111	-129
1000 0000 1000 0000	-128
1000 0001	-127
1000 0010	-126
...	...
1111 1110	-2
1111 1111	-1
forbidden	0
0000 0001	1
...	...
0111 1111	127
0000 0000 1000 0000	128
0000 0000 1000 0001	129
...	
0000 0000 1111 1111	255

Annex C

(normative)

Video buffering verifier

Constant rate coded video bitstreams shall meet constraints imposed through a Video Buffering Verifier (VBV) defined in clause C.1.

The VBV is a hypothetical decoder which is conceptually connected to the output of an encoder. Coded data are placed in the input buffer of the model decoder at the constant bitrate that is being used. Coded data is removed from the buffer as defined in C.1.4, below. It is a requirement of the encoder (or editor) that the bitstream it produces will not cause the VBV input buffer to either overflow or underflow.

C.1 Video buffering verifier

C.1.1 The VBV and the video encoder have the same clock frequency as well as the same picture rate, and are operated synchronously.

C.1.2 The VBV has an input buffer of size B, where B is given in the vbv_buffer_size field in the sequence header.

C.1.3 The VBV input buffer is initially empty. After filling the input buffer with all the data that precedes the first picture start code and the picture start code itself, the input buffer is filled from the bitstream for the time specified by the vbv_delay field in the video bitstream.

C.1.4 All of the picture data for the picture that has been in the buffer longest is instantaneously removed. Then after each subsequent picture interval all of the picture data for the picture which at that time has been in the buffer longest is instantaneously removed.

> For the purposes of this annex picture data includes any sequence header and group of picture layer data that immediately precede the picture start code as well as all the picture data elements and any trailing stuffing bits or bytes. For the first coded picture in the video sequence, any zero bit or byte stuffing immediately preceding the sequence header is also included in the picture data.

The VBV buffer is examined immediately before removing any picture data and immediately after this picture data is removed. Each time the VBV is examined its occupancy shall lie between zero bits and B bits where, B is the size of the VBV buffer indicated by vbv_buffer_size in the sequence header.

This is a requirement for the entire video bitstream.

To meet these requirements the number of bits for the (n+1)'th coded picture d_{n+1} shall satisfy

$$d_{n+1} > B_n + (2R/P) - B$$

$$d_{n+1} <= B_n + (R/P)$$

Real-valued arithmetic is used in these inequalities.

where

$n >= 0$

B = VBV receiving buffer size given by **vbv_buffer_size** * 16 384 bits.

B_n = the buffer occupancy (measured in bits) just after time t_n

R = bitrate measured in bits/s. The full precision of the bitrate rather than the rounded value encoded by the **bit_rate** field in the sequence header shall be used by the encoder in the VBV model.

P = nominal number of pictures per second

t_n = the time when the n'th coded picture is removed from the VBV buffer

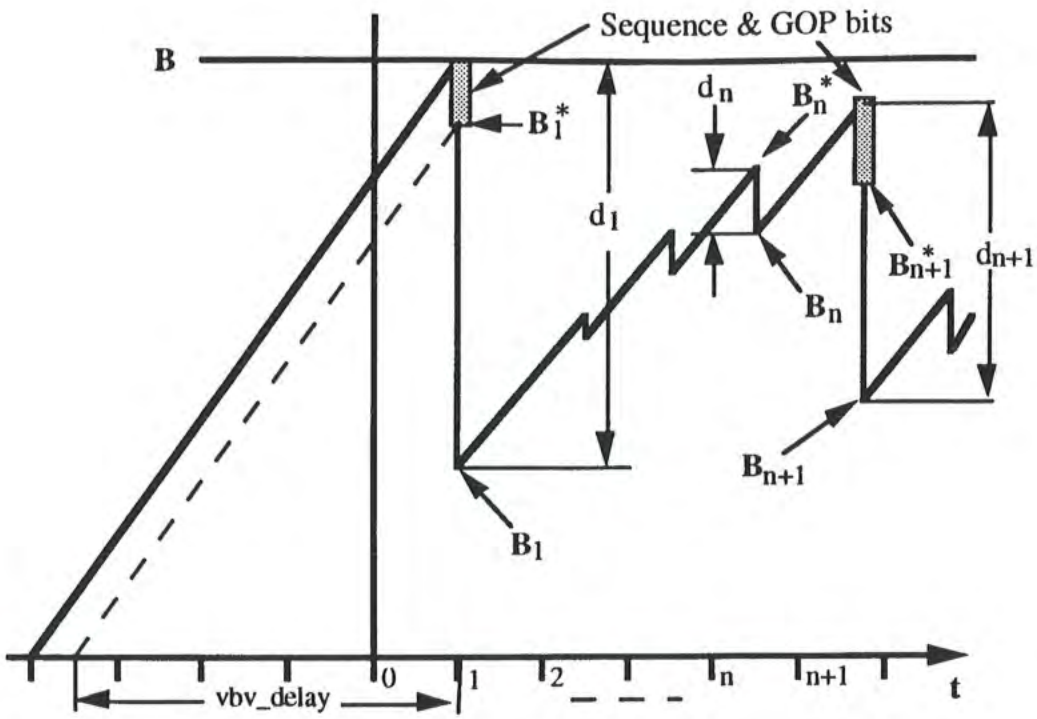


Figure C.1 -- VBV buffer occupancy

Annex D

(informative)

Guide to encoding video

D.1 Introduction

This annex provides background material to help readers understand and implement this part of ISO/IEC 11172. The normative clauses of this part of ISO/IEC 11172 do not specify the design of a decoder. They provide even less information about encoders; they do not specify what algorithms encoders should employ in order to produce a valid bitstream. The normative material is written in a concise form and contains few examples; consequently is not easy to understand. This annex attempts to address this problem by explaining coding methods, giving examples, and discussing encoding and decoding algorithms which are not directly covered by this part of ISO/IEC 11172.

The normative clauses specify the bitstream in such a way that it is fairly straightforward to design a compliant decoder. Decoders may differ considerably in architecture and implementation details, but have very few choices during the decoding process: the methods and the results of the decoding process are closely specified. Decoders do have some freedom in methods of post processing and display, but the results of such post processing cannot be used in subsequent decoding steps.

The situation is quite different for encoders. This part of ISO/IEC 11172 does not specify how to design or implement an encoder which produces good quality video. This annex devotes a major part to discussing encoder algorithms.

This part of ISO/IEC 11172 was developed by ISO/IEC JTC1/SC29/WG11 which is widely known as MPEG (Moving Pictures Expert Group). This part of ISO/IEC 11172 was developed in response to industry needs for an efficient way of storing and retrieving audio and video information on digital storage media (DSM). CD-ROM is an inexpensive medium which can deliver data at approximately 1,2 Mbits/s, and this part of ISO/IEC 11172 was aimed at approximately this data rate. The "constrained parameters bitstream", a subset of all permissible bitstreams that is expected to be widely used, is limited to data rates up to 1 856 000 bits/s. However, it should be noted that this part of ISO/IEC 11172 is not limited to this value and may be used at higher data rates.

Two other relevant International Standards were being developed during the work of the MPEG video committee: H.261 by CCITT aimed at telecommunications applications [5], and ISO/IEC 10918 by the ISO/IEC JTC1/SC29 (JPEG) committee aimed at the coding of still pictures [6]. Elements of both of these standards were incorporated into this part of ISO/IEC 11172, but subsequent development work by the committee resulted in coding elements that are new to this part of ISO/IEC 11172. Le Gall [2] gives an account of the method by which ISO/IEC JTC1/SC29/WG11 (MPEG) developed this part of ISO/IEC 11172, and a summary of this part of ISO/IEC 11172 itself.

D.2 Overview

D.2.1 Video concepts

This part of ISO/IEC 11172 defines a format for compressed digital video. This annex describes some ways in which practical encoders and decoders might be implemented.

Although this part of ISO/IEC 11172 is quite flexible, the basic algorithms have been tuned to work well at data rates of about 1 to 1,5 M bits/s, at spatial resolutions of about 350 pels horizontally by about 250 pels vertically, and picture rates of about 24 to 30 pictures/s. The use of the word "picture" as opposed to "frame" is deliberate. This part of ISO/IEC 11172 codes progressively-scanned images and does not recognize the concept of interlace. Interlaced source video must be converted to a non-interlaced format before coding. After decoding, the decoder may optionally produce an interlaced format for display.

This part of ISO/IEC 11172 is designed to permit several methods of viewing coded video which are normally associated with VCRs such as forward playback, freeze picture, fast forward, fast reverse, and slow

forward. In addition, random access may be possible. The ability of the decoder to implement these modes depends to some extent on the nature of the digital storage medium on which the coded video is stored.

The overall process of encoding and decoding is illustrated below:

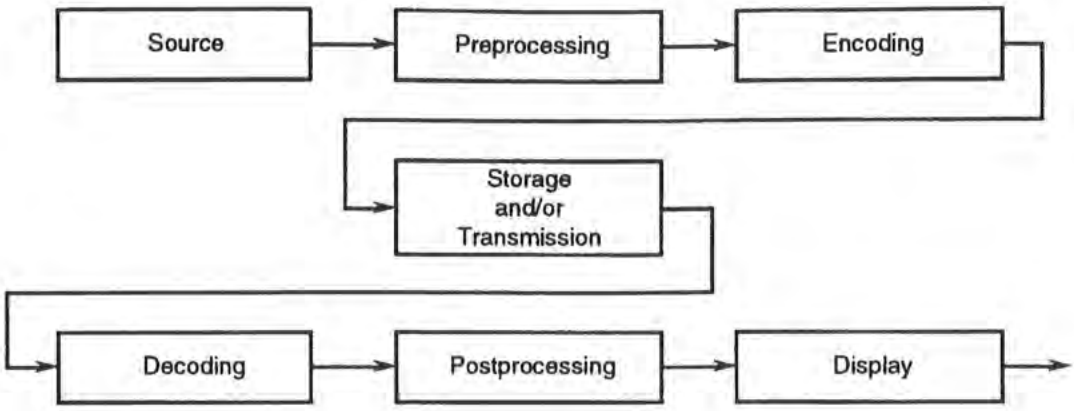


Figure D.1 -- Coding and decoding process

Figure D.1 shows a typical sequence of operations that must be performed before moving pictures can be seen by a viewer. The unencoded source may exist in many forms, such as the CCIR 601 format. Clause D.3 describes how such a source may be converted into the appropriate resolution for subsequent encoding. In the encoding step, the encoder must be aware of the decoder buffer capacity, and the need of the decoder to match the rate of the media to the rate of filling the picture buffer with each successive picture. To this end, a model of the decoder buffer and its overflow and underflow problem is introduced in D.4, and rate control is described in D.6.1 The structure of an ISO/IEC 11172-2 bitstream is covered in D.5, as are the coding operations that compress the video. Following the encoding process, the bitstream may be copied to a storage medium. To view the moving pictures, the decoder accesses the ISO/IEC 11172-2 bitstream, and decodes it as described in D.7. Postprocessing for display is described in D.8.

D.2.2 MPEG video compression techniques

Video is represented as a succession of individual pictures, and each picture is treated as a two-dimensional array of picture elements (pels). The colour representation for each pel consists of three components: Y (luminance), and two chrominance components, Cb and Cr.

Compression of digitized video comes from the use of several techniques: subsampling of the chrominance information to match the sensitivity of the human visual system (HVS), quantization, motion compensation (MC) to exploit temporal redundancy, frequency transformation by discrete cosine transform (DCT) to exploit spatial redundancy, variable length coding (VLC), and picture interpolation.

D.2.2.1 Subsampling of chrominance information

The HVS is most sensitive to the resolution of an image's luminance component, so the Y pel values are encoded at full resolution. The HVS is less sensitive to the chrominance information. Subsampling reduces the number of pel values by systematically combining them with a type of averaging process. This reduces the amount of information to be compressed by other techniques.The International Standard retains one set of chrominance pels for each 2x2 neighbourhood of luminance pels.

D.2.2.2 Quantization

Quantization represents a range of values by a single value in the range. For example, converting a real number to the nearest integer is a form of quantization. The quantized range can be concisely represented as an integer code, which can be used to recover the quantized value during decoding. The difference between the actual value and the quantized value is called the quantization noise. Under some circumstances, the HVS is less sensitive to quantization noise so such noise can be allowed to be large, thus increasing coding efficiency.

D.2.2.3 Predictive coding

Predictive coding is a technique to improve the compression through statistical redundancy. Based on values of pels previously decoded, both the encoder and decoder can estimate or predict the value of a pel yet to be encoded or decoded. The difference between the predicted and actual values is encoded. This difference value is the prediction error which the decoder can use to correct the prediction. Most error values will be small and cluster around the value 0 since pel values typically do not have large changes within a small spatial neighbourhood. The probability distribution of the prediction error is skewed and compresses better than the distribution of the pel values themselves. Additional information can be discarded by quantizing the prediction error. In this International Standard predictive coding is also used for the dc-values of successive luminance or chrominance blocks and in the encoding of motion vectors.

D.2.2.4 Motion compensation and interframe coding

Motion compensation (MC) predicts the values of a block pels in a picture by relocating a block of neighbouring pel values from a known picture. The motion is described as a two-dimensional motion vector that specifies where to retrieve a block of pel values from a previously decoded picture that is used to predict pel values of the current block. The simplest example is a scene where the camera is not moving, and no objects in the scene are moving. The pel values at each image location remain the same, and the motion vector for each block is 0. In general however, the encoder may transmit a motion vector for each macroblock. The translated block from the known picture becomes a prediction for the block in the picture to be encoded. The technique relies on the fact that within a short sequence of pictures of the same general scene, many objects remain in the same location while others move only a short distance.

D.2.2.5 Frequency transformation

The discrete cosine transform (DCT) converts an 8 by 8 block of pel values to an 8 by 8 matrix of horizontal and vertical spatial frequency coefficients. An 8 by 8 block of pel values can be reconstructed by performing the inverse discrete cosine transform (IDCT) on the spatial frequency coefficients. In general, most of the energy is concentrated in the low frequency coefficients, which are conventionally written in the upper left corner of the transformed matrix. Compression is achieved by a quantization step, where the quantization intervals are identified by an index. Since the encoder identifies the interval and not the exact value within the interval, the pel values of the block reconstructed by the IDCT have reduced accuracy.

The DCT coefficient in location (0,0) (upper left) of the block represents the zero horizontal and zero vertical frequency and is called the dc coefficient. The dc coefficient is proportional to the average pel value of the 8 by 8 block, and additional compression is provided through predictive coding since the difference in the average value of neighbouring 8 by 8 blocks tends to be relatively small. The other coefficients represent one or more nonzero horizontal or nonzero vertical spatial frequencies, and are called ac coefficients. The quantization level of the coefficients corresponding to the higher spatial frequencies favors the creation of an ac coefficient of 0 by choosing a quantization step size such that the HVS is unlikely to perceive the loss of the particular spatial frequency unless the coefficient value lies above the particular quantization level. The statistical encoding of the expected runs of consecutive zero-valued coefficients of higher-order coefficients accounts for considerable compression gain. To cluster nonzero coefficients early in the series and encode as many zero coefficients as possible following the last nonzero coefficient in the ordering, the coefficient sequence is specified to be a zig-zag ordering; see figure D.30. The ordering concentrates the highest spatial frequencies at the end of the series.

D.2.2.6 Variable-length coding

Variable-length coding (VLC) is a statistical coding technique that assigns codewords to values to be encoded. Values of high frequency of occurrence are assigned short codewords, and those of infrequent occurrence are assigned long codewords. On average, the more frequent shorter codewords dominate, such that the code string is shorter than the original data.

D.2.2.7 Picture interpolation

If the decoder reconstructs a picture from the past and a picture from the future, then the intermediate pictures can be reconstructed by the technique of interpolation, or bidirectional prediction. Blocks in the intermediate pictures can be forward and backward predicted and translated by means of motion vectors. The decoder may reconstruct pel values belonging to a given block as an average of values from the past and future pictures.

D.2.3 Bitstream hierarchy

The ISO/IEC 11172-2 coding scheme is arranged in layers corresponding to a hierarchical structure. A **sequence** is the top layer of the coding hierarchy and consists of a header and some number of **groups-of-pictures (GOPs)**. The sequence header initializes the state of the decoder. This allows decoders to decode any sequence without being affected by past decoding history.

A **GOP** is a random access point, i.e. it is the smallest coding unit that can be independently decoded within a sequence, and consists of a header and some number of **pictures**. The GOP header contains time and editing information.

A **picture** corresponds to a single frame of motion video, or to a movie frame. There are four picture types: **I-pictures**, or *intra coded pictures*, which are coded without reference to any other pictures; **P-pictures**, or *predictive coded pictures*, which are coded using motion compensation from a previous I or P-picture; **B-pictures**, or *bidirectionally* predictive coded pictures, which are coded using motion compensation from a previous and a future I or P-picture, and **D** pictures, or *D* pictures, which are intended only for a fast forward search mode. A typical coding scheme contains a mix of I, P, and B-pictures. Typically, an I-picture may occur every half a second, to give reasonably fast random access, with two B-pictures inserted between each pair of I or P-pictures.

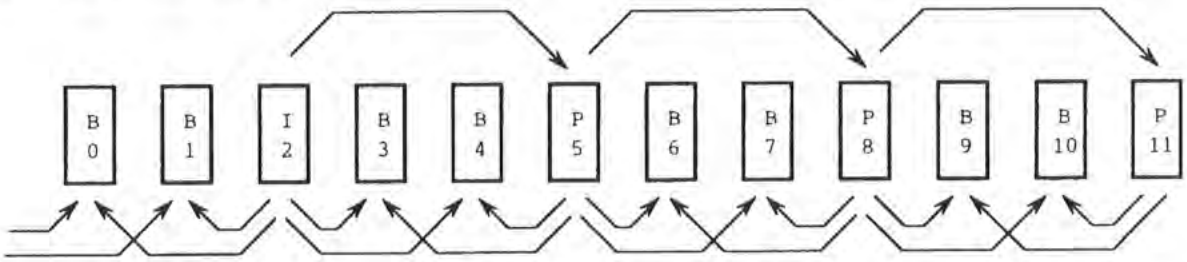


Figure D.2 -- Dependency relationship between I, B, and P-pictures

Figure D.2 illustrates a number of pictures in display order. The arrows show the dependency relationship of the predictive and bidirectionally predictive coded pictures.

Note that because of the picture dependencies, the bitstream order, i.e. the order in which pictures are transmitted, stored, or retrieved, is not the display order, but rather the order which the decoder requires them to decode the bitstream. An example of a sequence of pictures, in display order, might be:

I	B	B	P	B	B	P	B	B	P	B	B	I	B	B	P	B	B	P
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Figure D.3 -- Typical sequence of pictures in display order

whereas the bitstream order would be as shown below:

I	P	B	B	P	B	B	P	B	B	I	B	B	P	B	B	P	B	B
0	3	1	2	6	4	5	9	7	8	12	10	11	15	13	14	18	16	17

Figure D.4 -- Typical sequence of pictures in bitstream order

Because the B-pictures depend on the following (in display order) I or P-picture, the I or P-picture must be transmitted and decoded before the dependent B-pictures.

Pictures consist of a header and one or more **slices**. The picture header contains time, picture type, and coding information.

A **slice** provides some immunity to data corruption. Should the bitstream become unreadable within a picture, the decoder should be able to recover by waiting for the next slice, without having to drop an entire picture.

Slices consist of a header and one or more **macroblocks.** At the start of each slice all of the predictors, for dc values and motion vectors, are reset. The slice header contains position and quantizer scale information. This is sufficient for recovery from local corruption.

A **macroblock** is the basic unit for motion compensation and quantizer scale changes.

Each **macroblock** consists of a header and six component 8 by 8 **blocks**: four blocks of luminance, one block of Cb chrominance, and one block of Cr chrominance. See figure D.5. The macroblock header contains quantizer scale and motion compensation information.

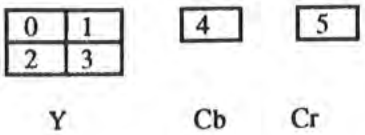


Figure D.5 -- Macroblock structure

A **macroblock** contains a 16-pel by 16-line section of luminance component and the spatially corresponding 8-pel by 8-line section of each chrominance component. A skipped macroblock is one for which no information is stored (see 2.4.4.4).

Note that the picture area covered by the four blocks of luminance is the same as the area covered by each of the chrominance blocks. This is due to subsampling of the chrominance information.

Blocks are the basic coding unit, and the DCT is applied at this block level. Each block contains 64 component **pels** arranged in an 8 by 8 array as shown in figure D.6.

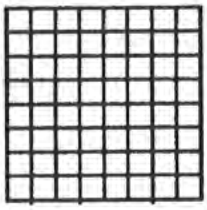


Figure D.6 -- Block structure

D.2.4 Decoder overview

A simplified block diagram of a possible decoder implementation is shown below:

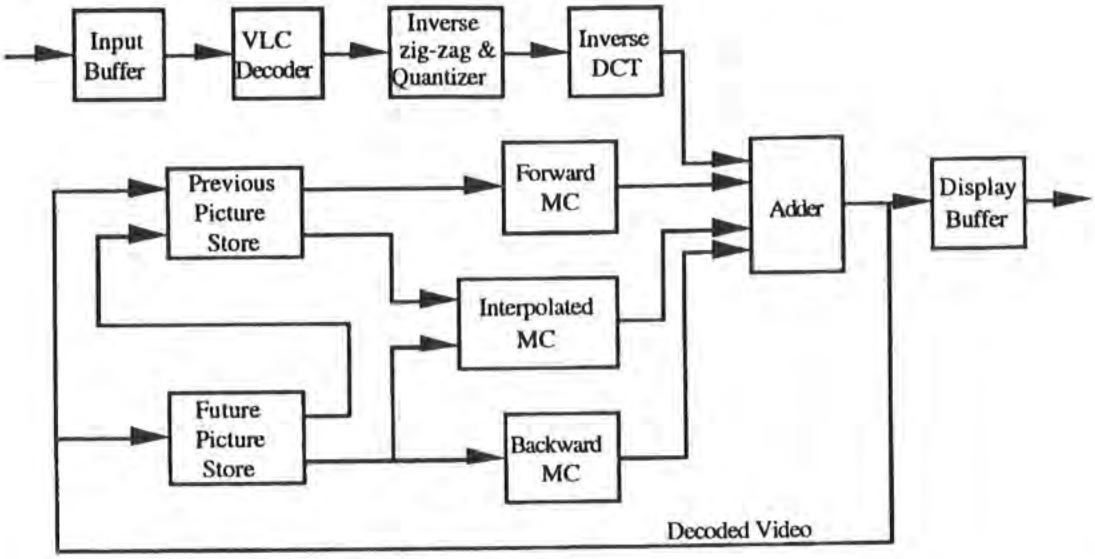


Figure D.7 -- Simplified decoder block diagram

It is instructive to follow the method which the decoder uses to decode a bitstream containing the sequence of pictures given in Fig D.4, and display them in the order given in Fig D.3. The following description is simplified for clarity.

The input bitstream is accumulated in the Input Buffer until needed. The Variable Length Code (VLC) Decoder decodes the header of the first picture, picture 0, and determines that it is an I-picture. The VLC Decoder produces quantized coefficients corresponding to the quantized DCT coefficients. These are assembled for each 8 by 8 block of pels in the image by inverse zig-zag scanning. The Inverse Quantizer produces the actual DCT coefficients using the quantization step size. The coefficients are then transformed into pel values by the Inverse DCT transformer and stored in the Previous Picture Store and the Display Buffer. The picture may be displayed at the appropriate time.

The VLC Decoder decodes the header of the next picture, picture 3, and determines that it is a P-picture. For each block, the VLC Decoder decodes motion vectors giving the displacement from the stored previous picture, and quantized coefficients corresponding to the quantized DCT coefficients of the difference block. These quantized coefficients are inverse quantized to produce the actual DCT coefficients. The coefficients are then transformed into pel difference values and added to the predicted block produced by applying the motion vectors to blocks in the stored previous picture. The resultant block is stored in the Future Picture Store and the Display Buffer. This picture cannot be displayed until B-pictures 1 and 2 have been received, decoded, and displayed.

The VLC Decoder decodes the header of the next picture, picture 1, and determines that it is a B-picture. For each block, the VLC decoder decodes motion vectors giving the displacement from the stored previous or future pictures or both, and quantized coefficients corresponding to the quantized DCT coefficients of the difference block. These quantized coefficients are inverse quantized to produce the actual DCT coefficients. The coefficients are then inverse transformed into difference pel values and added to the predicted block produced by applying the motion vectors to the stored pictures. The resultant block is then stored in the Display Buffer. It may be displayed at the appropriate time.

The VLC Decoder decodes the header of the next picture, picture 2, and determines that it is a B-picture. It is decoded using the same method as for picture 1. After decoding picture 2, picture 0, which is in the Previous Picture Store, is no longer needed and may be discarded.

The VLC Decoder decodes the header of the next picture, picture 6, and determines that it is a P-picture. The picture in the Future Picture Store is copied into the Previous Picture Store, then decoding proceeds as for picture 3. Picture 6 should not be displayed until pictures 4 and 5 have been received and displayed.

The VLC Decoder decodes the header of the next picture, picture 4, and determines that it is a B-picture. It is decoded using the same method as for picture 1.

The VLC Decoder decodes the header of the next picture, picture 5, and determines that it is a B-picture. It is decoded using the same method as for picture 1.

The VLC Decoder decodes the header of the next picture, picture 9, and determines that it is a P-picture. It then proceeds as for picture 6.

The VLC Decoder decodes the header of the next picture, picture 7, and determines that it is a B-picture. It is decoded using the same method as for picture 1.

The VLC Decoder decodes the header of the next picture, picture 8, and determines that it is a B-picture. It is decoded using the same method as for picture 1.

The VLC Decoder decodes the header of the next picture, picture 12, and determines that it is an I-picture. It is decoded using the same method as for picture 0. This process is repeated for the subsequent pictures.

D.3 Preprocessing

The source material may exist in many forms, e.g. computer files or CCIR 601 format, but in general, it must be processed before being encoded. This clause discusses some aspects of preprocessing.

For a given data rate and source material, there is an optimum picture rate and spatial resolution at which to code if the best perceived quality is desired. If the resolution is too high, then too many bits will be expended on the overhead associated with each block leaving too few to code the values of each pel accurately. If the resolution is too low, the pel values will be rendered accurately, but high frequency detail will be lost. The optimum resolution represents a tradeoff between the various coding artifacts (e.g. noise and blockiness) and the perceived resolution and sharpness of the image. This tradeoff is further complicated by the unknowns of the final viewing conditions, e.g. screen brightness and the distance of the viewer from the screen.

At data rates of 1 to 1,5 Mbits/s, reasonable choices are: picture rates of 24, 25 and 30 pictures/s, a horizontal resolution of between 250 and 400 pels, and a vertical resolution of between 200 and 300 lines. Note that these values are not normative and other picture rates and resolutions are valid.

D.3.1 Conversion from CCIR 601 video to MPEG SIF

The two widely used scanning standards for colour television are 525 and 625 lines at 29,97 and 25 frames/s respectively. The number of lines containing picture information in the transmitted signal is 484 for the 525-line system and 576 for the 625-line system. Both use interlaced scanning with two fields per picture.

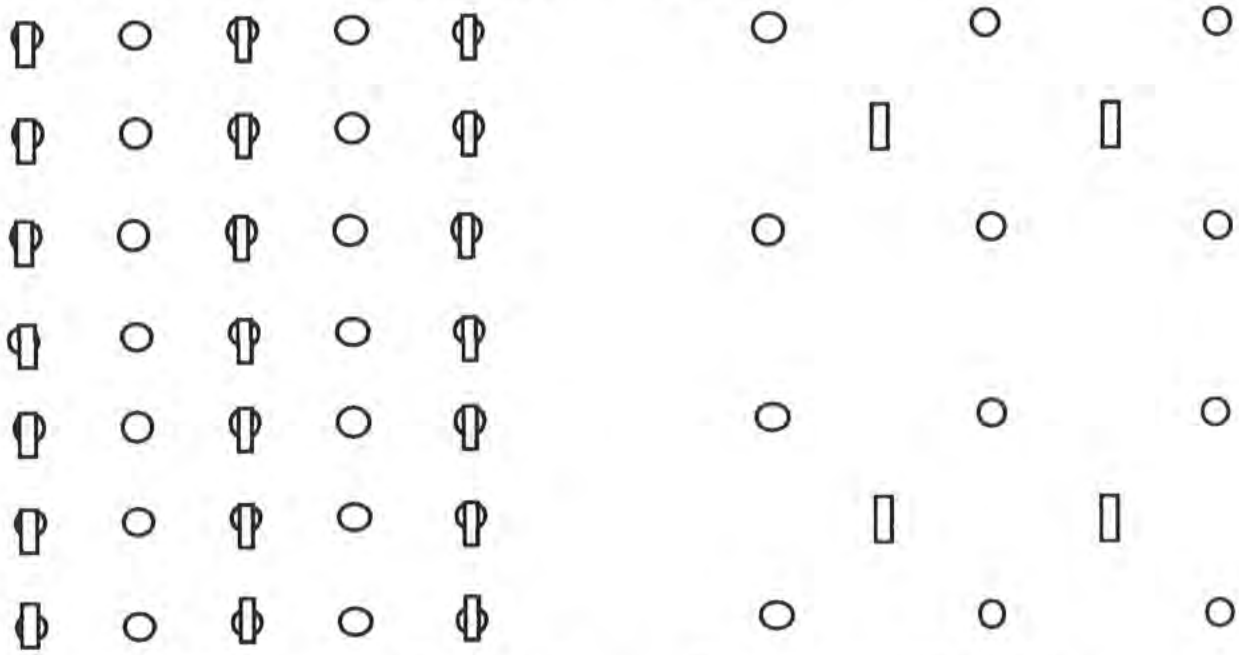
CCIR Recommendation 601 defines standards for the digital coding of colour television signals in component form. Of these the 4:2:2 standard has become widely adopted; the sampling frequency used for the luminance signal, Y, is 13,5 MHz and the two colour difference signals, Cb or B-Y and Cr or R-Y, are both sampled at 6,75 MHz. The number of luminance samples in the digital active line is 720 but only about 702 will be used in practice by the analogue active line.

The number of picture elements in the height and width of the picture, in the standards defined above, are too large for effective coding at data rates between 1 and 1,5 Mbit/s. More appropriate values are obtained by decreasing the resolution in both directions to a half. This reduces the pel rate by a factor of four. Interlace should be avoided as it increases the difficulties in achieving low data rates.

One way to reduce the vertical resolution is to use only the odd or the even fields. If the other field is simply discarded, spatial aliasing will be introduced, and this may produce visible and objectionable artifacts. More sophisticated methods of rate conversion require more computational power, but can perceptibly reduce the aliasing artifacts.

The horizontal and vertical resolutions may be halved by filtering and subsampling. Consider a picture in the 4:2:2 format. See the CCIR 601 sampling pattern of figure D.8(a). Such a sampling pattern may be converted to the SIF sampling pattern of figure D.8(b) as follows. The odd field only may be extracted, reducing the number of lines by two, and then the horizontal decimation filter used on the remaining lines to

reduce the horizontal resolution by a factor of two. In addition the chrominance values may be vertically decimated. The filters for luminance and chrominance have to be chosen carefully since particular attention has to be given to the location of the samples in the respective International Standards. The temporal relationship between luminance and chrominance must also be correct.



(a) Sampling pattern for 4:2:2 (CCIR 601) (b) Sampling pattern for MPEG (SIF)
Circles represent luminance; Boxes represent Chrominance

Figure D.8 -- Conversion of CCIR 601 to SIF

The following 7-tap FIR filter has been found to give good results in decimating the luminance:

-29	0	88	138	88	0	-29	// 256

Figure D.9 -- Luminance subsampling filter tap weights

Use of a power of two for the divisor allows a simple hardware implementation.

The chrominance samples have to appear in the between the luminance samples both horizontally and vertically. The following linear filter with a phase shift of half a pel may be found useful.

1	3	3	1	// 8

Figure D.10 -- Chrominance subsampling filter tap weights

To recover the samples consistent with the CCIR 601 grid of figure D.8(a), the process of interpolation is used. The interpolation filter applied to a zero-padded signal can be chosen to be equal to the decimation filter employed for the luminance and the two chrominance values in the encoder.

Note that these filters are not part of the International Standard, and other filters may be used.

At the end of the lines some special technique such as renormalizing the filter or replicating the last pel, must be adopted. The following example shows a horizontal line of 16 luminance pels and the same line after filtering and subsampling. In this example the data in the line is reflected at each end.

10 12 20 30 35 15 19 11 11 19 26 45 80 90 92 90
12 32 23 9 12 49 95 92

Figure D.11 -- Example of filtering and subsampling of a line of pels

The result of this filtering and subsampling is a source input format (SIF) which has a luminance resolution of 360 x 240 or 360 x 288, and a chrominance resolution which is half that of the luminance in each dimension.

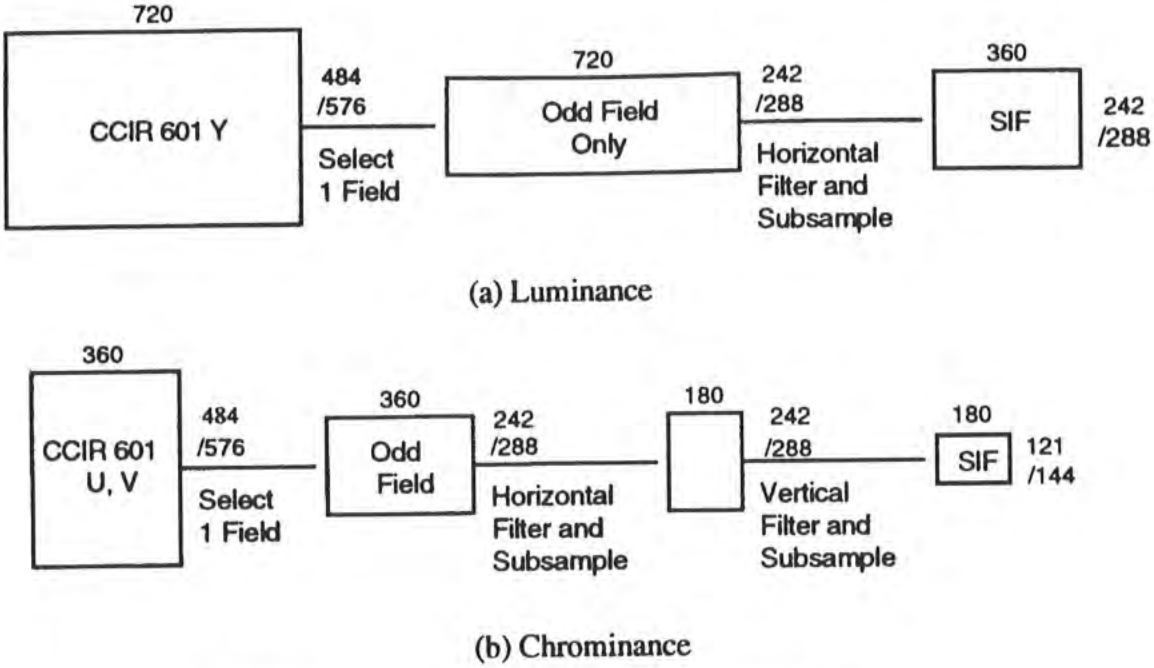


Figure D.12 -- Conversion from CCIR 601 into SIF

The SIF is not quite optimum for processing by MPEG video coders. MPEG video divides the luminance component into macroblocks of 16x16 pels. The horizontal resolution, 360, is not divisible by 16. The same is true of the vertical resolution, 242, in the case of 525-line systems. A better match is obtained in the horizontal direction by discarding the 4 pels at the end of every line of the subsampled picture. Care must be taken that this results in the correct configuration of luminance and chrominance samples in the macroblock. The remaining picture is called the significant pel area, and corresponds to the dark area in figure D.13:

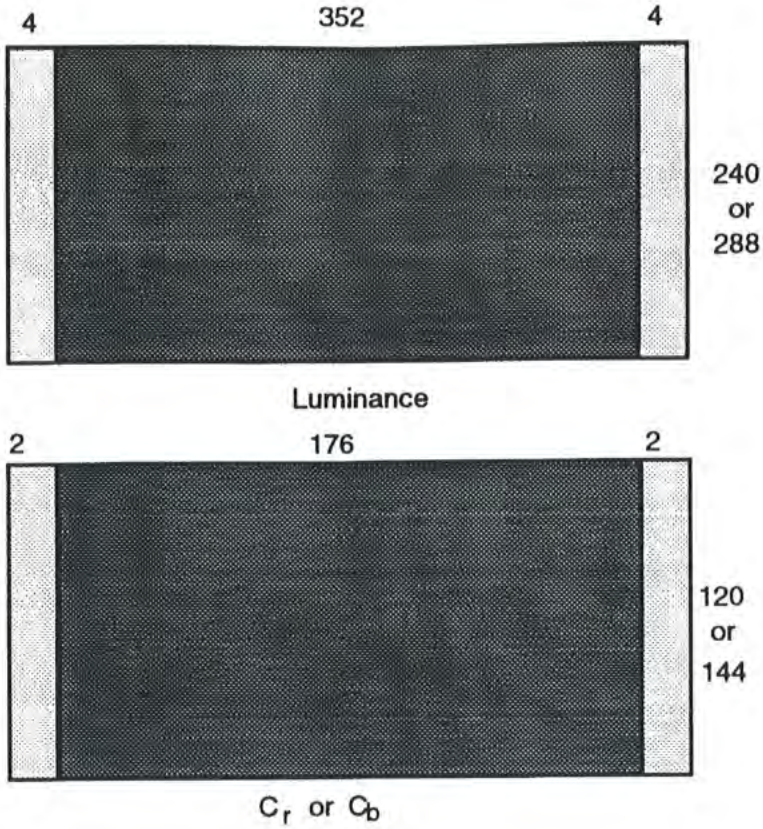


Figure D.13 -- Source input with significant pel area shaded dark

The conversion process is summarized in table D.1.

Table D.1 -- Conversion of source formats

Picture Rate (Hz)	29,97	25
Picture Aspect Ratio (width:height)	4:3	4:3
Luminance (Y)		
CCIR Sample Resolution	720 x 484	720 x 576
SIF	360 x 242	360 x 288
Significant Pel Area	352 x 240	352 x 288
Chrominance (Cb Cr)		
CCIR Sample Resolution	360 x 484	360 x 576
SIF	180 x 121	180 x 144
Significant Pel Area	176 x 120	176 x 144

The preprocessing into the SIF format is not normative, other processing steps and other resolutions may be used. The picture size need not even be a multiple of 16. In this case an MPEG video coder adds padding pels to the right or bottom edges of a picture in order to bring the transmitted resolution up to a multiple of 16, and the decoder discards these after decoding the picture. For example, a horizontal resolution of 360 pels could be coded by adding 8 padding pels to the right edge of each horizontal row bringing the total up to 368 pels. 23 macroblocks would be coded in each row. The decoder would discard the extra padding pels after decoding, giving a final decoded horizontal resolution of 360 pels.

D.3.2 Conversion from film

If film material can be digitized at 24 pictures/s, then it forms an excellent source for an ISO/IEC 11172-2 bitstream. It may be digitized at the desired spatial resolution. The picture_rate field in the video sequence header, see 2.4.2.3, allows the picture rate of 24 pictures/s to be specified exactly.

Sometimes the source material available for compression consists of film material which has been converted to video at some other rate. The encoder may detect this and recode at the original film rate. For example, 24 pictures/s film material may have been digitized and converted to a 30 frame/s system by the technique of 3:2 pulldown. In this mode digitized pictures are shown alternately for 3 and for 2 television field times. This alternation may not be exact since the actual frame rate might be 29,97 frames/s and not the 30 frames/s that the 3:2 pulldown technique gives. In addition the pulldown timing might have been changed by editing and splicing after the conversion. A sophisticated encoder might detect the duplicated fields, average them to reduce digitization noise, and code the result at the original 24 pictures/s rate. This should give a significant improvement in quality over coding at 30 pictures per second, since direct coding at 30 pictures/s destroys the 3:2 pulldown timing and gives a jerky appearance to the final decoded video.

D.4 Model decoder

D.4.1 Need for a decoder model

A coded bitstream contains different types of pictures, and each type ideally requires a different number of bits to encode. In addition, the video may vary in complexity with time, and an encoder may wish to devote more coding bits to one part of a sequence than to another. For constant bitrate coding, varying the number of bits allocated to each picture requires that the decoder have buffering to store the bits not needed to decode the immediate picture. The extent to which an encoder can vary the number of bits allocated to each picture depends on the amount of this buffering. If the amount of the buffering is large an encoder can use greater variations, increasing the picture quality, but at the cost of increasing the decoding delay. Encoders need to know the size of the amount of the decoder's buffering in order to determine to what extent they can vary the distribution of coding bits among the pictures in the sequence.

The model decoder is defined to solve two problems. It constrains the variability in the number of bits that may be allocated to different pictures and it allows a decoder to initialize its buffering when the system is started. It should be noted that Part 1 of this International Standard addresses the initialisation of buffers and the maintenance of synchronisation during playback in the case when two or more elementary streams (for example one audio and one video stream) are multiplexed together. The tools defined in ISO/IEC 11172-1 for the maintenance of synchronisation should be used by decoders when multiplexed streams are being played.

D.4.2 Decoder model

Annex C contains the definition of a parameterized model decoder for this purpose. It is known as a Video Buffer Verifier (VBV). The parameters used by a particular encoder are defined in the bitstream. This really defines a model decoder that is needed if encoders are to be assured that the coded bitstreams they produce will be decodable. The model decoder looks like this:

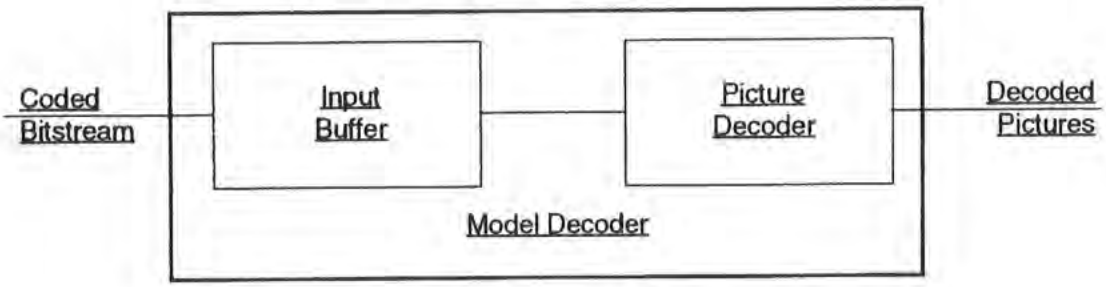


Figure D.14 -- Model decoder

A fixed-rate channel is assumed to put bits at a constant rate into the Input Buffer. At regular intervals, set by the picture rate, the Picture Decoder instantaneously removes all the bits for the next picture from the Input Buffer. If there are too few bits in the Input Buffer, i.e. all the bits for the next picture have not been received, then the Input Buffer underflows and there is an underflow error. If, during the time between picture starts, the capacity of the Input Buffer is exceeded, then there is an overflow error.

Practical decoders differ from this model in several important ways. They may implement their buffering at a different point in the decoder, or distribute it throughout the decoder. They may not remove all the bits required to decode a picture from the Input Buffer instantaneously, they may not be able to control the start

of decoding very precisely as required by the buffer fullness parameter in the picture header, and they take a finite time to decode. They may also be able to delay decoding for a short time to reduce the chances of underflow occuring. But these differences depend in degree and kind on the exact method of implementation. To satisfy requirements of different implementations, the MPEG video committee (ISO/IEC JTC1 SC29/WG11) chose a very simple model for the decoder. Practical implementations of decoders must ensure that they can decode the bitstream constrained by this model. In many cases this will be achieved by using an Input Buffer that is larger than the minimum required, and by using a decoding delay that is larger than the value derived from the vbv_delay parameter. The designer must compensate for differences between the actual design and the model in order to guarantee that the decoder can handle any bitstream that satisfies the model.

Encoders monitor the status of the model to control the encoder so that overflow problems do not occur. The calculated buffer fullness is transmitted at the start of each picture so that the decoder can maintain synchronization.

D.4.3 Buffer size and delay

For constant bit rate operation each picture header contains a vbv_delay parameter to enable decoders to start their decoding correctly. This parameter defines the time needed to fill the Input Buffer of figure D.14 from an empty state to the correct level immediately before the Picture Decoder removes all the bits for the picture. This time is thus a delay and is measured in units of 1/90 000 s. This number was chosen because it is almost an exact multiple of the picture durations: 1/24, 1/25, 1/29,97 and 1/30, and because it is comparable in duration to an audio sample.

The delay is given by

$$\mathbf{D = vbv\_delay} \ / \ 90\ 000 \text{ s}$$

For example, if vbv_delay were 9 000, then the delay would be 0,1 sec. This means that at the start of a picture the Input Buffer of the model decoder should contain exactly 0,1 s worth of data from the input bitstream.

The bit rate, R, is defined in the sequence header. The number of bits in the Input Buffer at the beginning of the picture is thus given by:

$$\mathbf{B = D * R = vbv\_delay * R} \ / \ 90\ 000 \text{ bits}$$

For example, if vbv_delay were 9 000 and R were 1,2 Mbits/s, then the number of bits in the Input Buffer would be 120 000.

The constrained parameter bitstream requires that the Input Buffer have a capacity of 327 680 bits, and B should never exceed this value.

D.5 MPEG video bitstream syntax

This clause describes the video bitstream in a top-down fashion. A sequence is the top level of video coding. It begins with a sequence header which defines important parameters needed by the decoder. The sequence header is followed by one or more groups of pictures. Groups of pictures, as the name suggests, consist of one or more individual pictures. The sequence may contain additional sequence headers. A sequence is terminated by a sequence_end_code. ISO/IEC 11172-1 allows considerable flexibility in specifying application parameters such as bit rate, picture rate, picture resolution, and picture aspect ratio. These parameters are specified in the sequence header.

If these parameters, and some others, fall within certain limits, then the bitstream is called a constrained parameter bitstream.

D.5.1 Sequence

A video sequence commences with a sequence header and is followed by one or more groups of pictures and is ended by a sequence_end_code. Additional sequence headers may appear within the sequence. In each such repeated sequence header, all of the data elements with the permitted exception of those defining quantization matrices (load_intra_quantizer_matrix, load_non_intra_quantizer_matrix and optionally

intra_quantizer_matrix and non_intra_quantizer_matrix) shall have the same values as the first sequence header. Repeating the sequence header with its data elements makes random access into the video sequence possible. The quantization matrices may be redefined as required with each repeated sequence header.

The encoder may set such parameters as the picture size and aspect ratio in the sequence header, to define the resources that a decoder requires. In addition, user data may be included.

D.5.1.1 Sequence header code

A coded sequence begins with a sequence header and the header starts with the sequence start code. Its value is:

hex: 00 00 01 B3
binary: 0000 0000 0000 0000 0000 0001 1011 0011

This is a unique string of 32 bits that cannot be emulated anywhere else in the bitstream, and is byte-aligned, as are all start codes. To achieve byte alignment the encoder may precede the sequence start code with any number of zero bits. These can have a secondary function of preventing decoder input buffer underflow. This procedure is called *bit stuffing*, and may be performed before any start code. The stuffing bits must all be zero. The decoder discards all such stuffing bits.

The sequence start code, like all video start codes, begins with a string of 23 zeros. The coding scheme ensures that such a string of consecutive zeros cannot be produced by any other combination of codes, i.e. it cannot be emulated by other codes in the video bitstream. This string of zeros can only be produced by a start code, or by stuffing bits preceding a start code.

D.5.1.2 Horizontal size

This is a 12-bit number representing the width of the picture in pels, i.e. the horizontal resolution. It is an unsigned integer with the most significant bit first. A value of zero is not allowed (to avoid start code emulation) so the legal range is from 1 to 4 095. In practice values are usually a multiple of 16. At 1,5 Mbits/s, a popular horizontal resolution is 352 pels. The value 352 is derived from half the CCIR 601 horizontal resolution of 720, rounded down to the nearest multiple of 16 pels. Otherwise the encoder must fill out the picture on the right to the next higher multiple of 16 so that the last few pels can be coded in a macroblock. The decoder should discard these extra pels before display.

For efficient coding of the extra pels, the encoder should add pel values that reduce the number of bits generated in the transformed block . Replicating the last column of pels is usually superior to filling in the remaining pels with a gray level.

D.5.1.3 Vertical size

This is a 12-bit number representing the height of the picture in pels, i.e. the vertical resolution. It is an unsigned integer with the most significant bit first. A value of zero is not allowed (to avoid start code emulation) so the legal range is from 1 to 4 095. In practice values are usually a multiple of 16. Note that the maximum value of slice_vertical_position is 175 (decimal), which corresponds to a picture height of 2 800 lines. At 1,5 Mbits/s, a popular vertical resolution is 240 to 288 pels. Values of 240 pels are convenient for interfacing to 525-line NTSC systems, and values of 288 pels are more appropriate for 625-line PAL and SECAM systems.

If the vertical resolution is not a multiple of 16 lines, the encoder must fill out the picture at the bottom to the next higher multiple of 16 so that the last few lines can be coded in a macroblock. The decoder should discard these extra lines before display.

For efficient coding, replicating the last line of pels is usually better than filling in the remaining pels with a grey level.

D.5.1.4 Pel aspect ratio

This is a four-bit number which defines the shape of the pel on the viewing screen. This is needed since the horizontal and vertical picture sizes by themselves do not specify the shape of the displayed picture.

The pel aspect ratio does not give the shape directly but is an index to the following look up table:

Table D.2 -- Pel aspect ratio

CODE	HEIGHT/WIDTH	COMMENT
0000	undefined	Forbidden
0001	1,0	square pels
0010	0,6735	
0011	0,7031	16:9 625-line
0100	0,7615	
0101	0,8055	
0110	0,8437	16:9 525-line
0111	0,8935	
1000	0,9157	702x575 at 4:3 = 0,9157
1001	0,9815	
1010	1,0255	
1011	1,0695	
1100	1,0950	711x487 at 4:3 = 1,0950
1101	1,1575	
1110	1,2015	
1111	undefined	reserved

The code 0000 is forbidden to avoid start code emulation. The code 0001 has square pels. This is appropriate for many computer graphics systems. The code 1000 is suitable for displaying pictures on the 625-line 50Hz TV system (see CCIR Recommendation 601).

height / width = 0,75 * 702 / 575 = 0,9157

The code 1100 is suitable for displaying pictures on the 525-line 60Hz TV system (see CCIR Recommendation 601).

height / width = 0,75 * 711 / 487 = 1,0950

The code 1111 is reserved for possible future extensions to this part of ISO/IEC 11172.

The remaining points in the table were filled in by interpolating between these two points 1000 and 1100 using the formula:

aspect ratio = 0,5855 + 0,044N

where N is the value of the code in table D.2. These additional pel aspect ratios might be useful for HDTV where ratios of 16:9 and 5:3 have been proposed.

It is evident that the specification does not allow all possible pel aspect ratios to be specified. We therefore presume that a certain degree of tolerance is allowable. Encoders will convert the actual pel aspect ratio to the nearest value in the table, and decoders will display the decoded values to the nearest pel aspect ratio of which they are capable.

D.5.1.5 Picture rate

This is a four-bit integer which is an index to the following table:

Table D.3 -- Picture rate

CODE	PICTURES PER SECOND
0000	Forbidden
0001	23,976
0010	24
0011	25
0100	29,97
0101	30
0110	50
0111	59,94
1000	60
1001	Reserved
.	.
.	.
1111	Reserved

The allowed picture rates are commonly available sources of analog or digital sequences. One advantage in not allowing greater flexibility in picture rates is that standard techniques may be used to convert to the display rate of the decoder if it does not match the coded rate.

D.5.1.6 Bit rate

The bit rate is an 18-bit integer giving the bit rate of the data channel in units of 400 bits/s. The bit rate is assumed to be constant for the entire sequence. The actual bit rate is rounded up to the nearest multiple of 400 bits/s. For example, a bit rate of 830 100 bits/s would be rounded up to 830 400 bits/s giving a coded bit rate of 2 076 units.

If all 18 bits are 1 then the bitstream is intended for variable bit rate operation. The value zero is forbidden.

For constant bit rate operation, the bit rate is used by the decoder in conjunction with the vbv_delay parameter in the picture header to maintain synchronization of the decoder with a constant rate data channel. If the stream is multiplexed using ISO/IEC 11172-1, the time-stamps and system clock reference information defined in ISO/IEC 11172-1 provide a more appropriate tool for performing this function.

D.5.1.7 Marker bit

The bit rate is followed by a single reserved bit which is always set to 1. This bit prevents emulation of start codes.

D.5.1.8 VBV buffer size

The buffer size is a 10-bit integer giving the minimum required size of the input buffer in the model decoder in units of 16 384 bits (2 048 bytes). For example, a buffer size of 20 would require an input buffer of 20 x 16 384 = 327 680 bits (= 40 960 bytes). Decoders may provide more memory than this, but if they provide less they will probably run into buffer overflow problems while the sequence is being decoded.

D.5.1.9 Constrained Parameter flag

If certain parameters specified in the bitstream fall within predefined limits, then the bitstream is called a constrained parameter bitstream. Thus the constrained parameter bitstream is a standard of performance giving guidelines to encoders and decoders to facilitate the exchange of bitstreams.

The bitrate parameter allows values up to about 100 Mbits/s, but a constrained parameter bitstream must have a bit rate of 1,856 Mbits/s or less. Thus the bit rate parameter must be 3 712 or less.

The picture rate parameter allows picture rates up to 60 pictures/s, but a constrained parameter bitstream must have a picture rate of 30 pictures/s or less.

The resolution of the coded picture is also specified in the sequence header. Horizontal resolutions up to 4 095 pels are allowed by the syntax, but in a constrained parameter bitstream the resolution is limited to 768 pels or less. Vertical resolutions up to 4 095 pels are allowed, but that in a constrained parameter

bitstream is limited to 576 pels or less. In a constrained parameter bitstream, the total number of macroblocks per picture is limited to 396. This sets a limit on the maximum area of the picture which is only about one quarter of the area of a 720x576 pel picture. In a constrained parameter bitstream, the pel rate is limited to 2 534 400 pels/s. For a given picture rate, this sets another limit on the maximum area of the picture. If the picture has the maximum area of 396 macroblocks, then the picture rate is restricted to 25 pictures/s or less. If the picture rate has the maximum constrained value of 30 pictures/s the maximum area is limited to 330 macroblocks.

A constrained parameter bitstream can be decoded by a model decoder with a buffer size of 327 680 bits without overflowing or underflowing during the decoding process. The maximum buffer size that can be specified for a constrained parameter bitstream is 20 units.

A constrained parameter bitstream uses a forward_f_code or backward_f_code less than or equal to 4. This constrains the maximum range of motion vectors that can be represented in the bitstream (see table D.7).

If all these conditions are met, then the bitstream is constrained and the constrained_parameters_flag in the sequence header should be set to 1. If any parameter is exceeded, the flag shall be set to 0 to inform decoders that more than a minimum capability is required to decode the sequence.

D.5.1.10 Load intra quantizer matrix

This is a one-bit flag. If it is set to 1, sixty-four 8-bit integers follow. These define an 8 by 8 set of weights which are used to quantize the DCT coefficients. They are transmitted in the zigzag scan order shown in figure D.30. None of these weights can be zero. The first weight must be eight which matches the fixed quantization level of the dc coefficient.

If the flag is set to zero, the intra quantization matrix must be reset to the following default value:

8	16	19	22	26	27	29	34
16	16	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	83

Figure D.15 -- Default intra quantization matrix

The default quantization matrix is based on work performed by ISO/IEC JTC1 SC29/WG10 (JPEG) [6]. Experience has shown that it gives good results over a wide range of video material. For resolutions close to 350x250 there should normally be no need to redefine the intra quantization matrix. If the picture resolution departs significantly from this nominal resolution, then some other matrix may give perceptibly better results.

The weights increase to the right and down. This reflects the human visual system which is less sensitive to quantization noise at higher frequencies.

D.5.1.11 Load non-intra quantizer matrix

This is a one-bit flag. If it is set to 1, sixty-four 8-bit integers follow in zigzag scan order. None of these integers can be zero.

If the flag is set to zero, the non-intra quantization matrix must be reset to the following default value which consists of all 16s.

$$\begin{vmatrix} 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \\ 16 & 16 & 16 & 16 & 16 & 16 & 16 & 16 \end{vmatrix}$$

Figure D.16 -- Default non-intra quantization matrix

This flat default quantization matrix was adopted from H.261 which uses a flat matrix for the equivalent of P-pictures [5]. Little work has been performed to determine the optimum non-intra matrix for MPEG video coding, but evidence suggests that it is more dependent on video material than is the intra matrix. The optimum non-intra matrix may be somewhere between the flat default non-intra matrix and the strongly frequency-dependent values of the default intra matrix.

D.5.1.12 Extension data

This start code is byte-aligned and is 32 bits long. Its value is

hex: 00 00 01 B5
binary: 0000 0000 0000 0000 0000 0001 1011 0101

It may be preceded by any number of zeros. If it is present then it will be followed by an undetermined number of data bytes terminated by the next start code. These data bytes are reserved for future extensions to this part of ISO/IEC 11172, and should not be generated by encoders. MPEG video decoders should have the capability to discard any extension data found.

D.5.1.13 User data

A user data start code may follow the optional extension data. This start code is byte-aligned and is 32 bits long. Its value is

hex: 00 00 01 B2
binary: 0000 0000 0000 0000 0000 0001 1011 0010

It may be preceded by any number of zeros. If it is present then it will be followed by an undetermined number of data bytes terminated by the next start code. These data bytes can be used by the encoder for any purpose. The only restriction on the data is that they cannot emulate a start code, even if not byte-aligned. This means that a string of 23 consecutive zeros must not occur. One way to prevent emulation is to force the most significant bit of alternate bytes to be a 1.

In closed encoder-decoder systems the decoder may be able to use the data. In the more general case, decoders should be capable of discarding the user data.

D.5.2 Group of pictures

Two distinct picture orderings exist, the display order and the bitstream order (as they appear in the video bitstream). A group of pictures (gop) is a set of pictures which are contiguous in display order. A group of pictures must contain at least one I-picture. This required picture may be followed by any number of I and P-pictures. Any number of B-pictures may be interspersed between each pair of I or P-pictures, and may also precede the first I-picture.

Property 1. A group of pictures, in bitstream order, must start with an I-picture and may be followed by any number of I, P or B-pictures in any order.

Property 2. Another property of a group of pictures is that it must begin, in display order, with an I or a B-picture, and must end with an I or a P-picture. The smallest group of pictures consists of a single I-picture, whereas the largest size is unlimited.

The original concept of a group of pictures was a set of pictures that could be coded and displayed independently of any other group. In the final version of this part of ISO/IEC 11172 this is not always true, and any B-pictures preceding (in display order) the first I-picture in a group may require the last picture in the previous group in order to be decoded. Nevertheless encoders can still construct groups of pictures which are independent of one another. One way to do this is to omit any B-pictures preceding the first I-picture. Another way is to allow such B-pictures, but to code them using only backward motion compensation.

Property 3. From a coding point of view, a concisely stated property is that a group of pictures begins with a group of pictures header, and either ends at the next group of pictures header or at the next sequence header or at the end of sequence, whichever comes first.

Some examples of groups of pictures are given below:

```
I
I  P  P
I  B  P  B  P
B  B  I  B  P  B  P
B  B  I  B  B  P  B  B  P  B  B  P
B  I  B  B  B  B  P  B  I  B  B  I  I
```

Figure D.17 -- Examples of groups of pictures in display order

These examples illustrate what is possible, and do not constitute a suggestion for structures of groups of pictures.

Group of pictures start code

The group of pictures header starts with the Group of Pictures start code. This code is byte-aligned and is 32 bits long. Its value is

hex: 00 00 01 B8
binary: 0000 0000 0000 0000 0000 0001 1011 1000

It may be preceded by any number of zeros. The encoder may have inserted some zeros to get byte alignment, and may have inserted additional zeros to prevent buffer underflow. An editor may have inserted zeros in order to match the vbv_delay parameter of the first picture in the group.

Time code

A time code of 25 bits immediately follows the group of pictures start code. This encodes the same information as the SMPTE time code [4].

The time code can be broken down into six fields as shown in table D.4.

Table D.4 -- Time code fields

FIELD	BITS	VALUES
Drop frame flag	1	
Hours	5	0 to 23
Minutes	6	0 to 59
Fixed	1	1
Seconds	6	0 to 59
Picture number	6	0 to 60

The time code refers to the first picture in the group in display order, i.e. the first picture with a temporal reference of zero. The SMPTE time code is included to provide a video time identification to applications. It may be discontinuous. The presentation time-stamp in the System layer (Part 1) has a much higher precision and identifies the time of presentation of the picture.

Closed GOP

A one bit flag follows the time code. It denotes whether the group of pictures is open or closed. Closed groups can be decoded without using decoded pictures of the previous group for motion compensation, whereas open groups require such pictures to be available.

A typical example of a closed group is shown in figure D.18a.

I	B	B	**P**	B	B	**P**	B	B	**P**	B	B	**P**
0	1	2	3	4	5	6	7	8	9	10	11	12

(a) closed group

B	B	**I**	B	B	**P**	B	B	**P**	B	B	**P**	B	B	**P**
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

(b) open or closed group

Figure D.18 -- Example groups of pictures in display order

A less typical example of a closed group is shown in figure D.18b. In this example, the B-pictures which precede the first I-picture must use backward motion compensation only, i.e. any motion compensation must be based only on picture number 2 in the group.

If the closed_gop flag is set to 0 then the group is open. The first B-pictures that precede the first I-picture in the group may have been encoded using the last picture in the previous group for motion compensation.

Broken link

A one bit flag follows the closed_gop flag. It denotes whether the B-pictures which precede the first I-picture in the GOP can be correctly decoded. If it is set to 1, these pictures cannot be correctly decoded because the I-picture or P-picture from the previous group pictures that is required to form the predictions is not available (presumably because the preceding group of pictures has been removed by editing). The decoder will probably choose not to display these B-pictures.

If the sequence is edited so that the original group of pictures no longer precedes the current group of pictures then this flag normally will be set to 1 by the editor. However, if the closed_gop flag for the current group of pictures is set, then the editor should not set the broken_link flag. Because the group of pictures is closed, the first B-pictures (if any) can still be decoded correctly.

Extension data

This start code is byte-aligned and is 32 bits long. Its value is

hex: 00 00 01 B5
binary: 0000 0000 0000 0000 0000 0001 1011 0101

It may be preceded by any number of zeros. If it is present then it will be followed by an undetermined number of data bytes terminated by the next start code. These data bytes are reserved for future extensions to this part of ISO/IEC 11172, and should not be generated by encoders. MPEG video decoders should have the capability to discard any extension data found.

User data

A user data start code may follow the optional extension data. This start code is byte-aligned and is 32 bits long. Its value is

hex: 00 00 01 B2
binary: 0000 0000 0000 0000 0000 0001 1011 0010

It may be preceded by any number of zeros. If it is present then it will be followed by an undetermined number of data bytes terminated by the next start code. These data bytes can be used by the encoder for any purpose. The only restriction on the data is that they cannot emulate a start code, even if not byte-aligned.

This means that a string of 23 consecutive zeros must not occur. One way to prevent emulation is to force the most significant bit of alternate bytes to be a 1.

In closed encoder-decoder systems the decoder may be able to use the data. In the more general case, decoders should be capable of discarding the user data.

D.5.3 Picture

The picture layer contains all the coded information for one picture. The header identifies the temporal reference of the picture, the picture coding type, the delay in the video buffer verifier (VBV) and, if appropriate, the range of motion vectors used.

D.5.3.1 Picture header and start code

A *picture* begins with a picture header. The header starts with a picture start code. This code is byte-aligned and is 32 bits long. Its value is:

hex: 00 00 01 00
binary: 0000 0000 0000 0000 0000 0001 0000 0000

It may be preceded by any number of zeros.

D.5.3.2 Temporal reference

The Temporal Reference is a ten-bit number which can be used to define the order in which the pictures must be displayed. It may be useful since pictures are not transmitted in display order, but rather in the order which the decoder needs to decode them. The first picture, in display order, in each group must have Temporal Reference equal to zero. This is incremented by one for each picture in the group.

Some example groups of pictures with their Temporal Reference numbers are given below:

Example (a) in	**I**	B	**P**	B	**P**							
display order	0	1	2	3	4							
Example (a) in	**I**	**P**	B	**P**	B							
decoding order	0	2	1	4	3							
Example (b) in	B	B	**I**	B	B	**P**	B	B	**P**	B	B	**P**
display order	0	1	2	3	4	5	6	7	8	9	10	11
Example (b) in	**I**	B	B	**P**	B	B	**P**	B	B	**P**	B	B
coded order	2	0	1	5	3	4	8	6	7	11	9	10
Example (c) in	B	**I**	B	B	B	B	**P**	B	**I**	B	B	**I**	**I**
display order	0	1	2	3	4	5	6	7	8	9	10	11	12
Example (c) in	**I**	B	**P**	B	B	B	B	**I**	B	**I**	B	B	**I**
coded order	1	0	6	2	3	4	5	8	7	11	9	10	12

Figure D.19 -- Examples of groups of pictures and temporal references

If there are more than 1024 pictures in a group, then the Temporal Reference is reset to zero and then increments anew. This is illustrated below:

B	B	I	B	B	P	...	P	B	B	P	...	P	B	B	P	display order
0	1	2	3	4	5	...	1 022	1 023	0	1	...	472	473	474	475	

Figure D.20 -- Example group of pictures containing 1 500 pictures

D.5.3.3 Picture coding type

A three bit number follows the temporal reference. This is an index into the following table defining the type of picture.

Table D.5 -- Picture types

CODE	PICTURE TYPE
000	Forbidden
001	I-picture
010	P-picture
011	B-picture
100	D Picture
101	Reserved
110	Reserved
111	Reserved

The various types of pictures are described in D.2.3. Codes 101 through 111 are reserved for future extensions to this part of ISO/IEC 11172. Decoders should be capable of discarding all pictures of this type, and scan for the next picture start code, group start code or sequence start code. Code 000 will never be used to avoid start code emulation.

D.5.3.4 VBV delay

For constant bit rate operation, vbv_delay can be used at the start of decoding and after a random access to ensure that the correct number of bits have been read by the decoder before the first picture is displayed.

The buffer fullness is not specified in bits but rather in units of time. The vbv_delay is a 16-bit number defining the time needed in units of 1/90 000 s to fill the input buffer of the model decoder from an empty state to the correct state at the bit rate specified in the sequence header.

For example, suppose the vbv_delay had a decimal value of 30000, then the time delay would be:

$$D = 30\,000 / 90\,000 = 1 / 3 \text{ s}$$

If the channel bit rate were 1,2 Mbits/s then the contents of the buffer before the picture is decoded would be:

$$B = 1\,200\,000 / 3 = 400\,000 \text{ bits}$$

If the decoder determined that its actual buffer fullness differed significantly from this value, then it would have to adopt some strategy for regaining synchronization.

The meaning of vbv_delay is undefined for variable bit rate operation.

D.5.3.5 Full pel forward vector

This is a one bit flag giving the precision of the forward motion vectors. If it is 1 then the precision of the vectors is in integer pels, if it is zero then the precision is half a pel. Thus if the flag is set to one the vectors have twice the range than they do if the flag set to zero.

This flag is present only in the headers of P-pictures and B-pictures. It is absent in I-pictures and D pictures.

D.5.3.6 Forward f-code

This is a three-bit number and, like the full pel forward vector flag, is present only in the headers of P-pictures and B-pictures. It provides information used for decoding the coded forward vectors and controls the maximum size of the forward vectors that can be coded. It can take only values of 1 through 7; a value of zero is forbidden.

Two parameters used in decoding the forward motion vectors are derived from forward_f_code, forward_r_size and forward_f.

The forward_r_size is one less than the forward_f_code and so can take values 0 through 6.

The forward_f parameter is given by table D.6:

Table D.6 -- f_codes

forward/backward_f_code	forward/backward_f
1	1
2	2
3	4
4	8
5	16
6	32
7	64

D.5.3.7 Full pel backward vector

This is a one bit flag giving the precision of the backward motion vectors. If it is 1 then the precision of the vectors is in integer pels, if it is zero then the precision is half a pel. Thus if the flag is set to one the vectors have twice the range than they do if the flag set to zero.

This flag is only present in the headers of B-pictures. It is absent in I-pictures, P-pictures and D pictures.

D.5.3.8 Backward f-code

This is a three-bit number and, like the full pel backward vector flag, is present only in the headers of B-pictures. It provides information used for decoding the coded backward vectors. It can take only values of 1 through 7; a value of zero is forbidden.

The backward_f parameter is derived from the backward_f_code and is given by table D.6

D.5.3.9 Extra picture information

Extra picture information is the next field in the picture header. Any number of information bytes may be present. An information byte is preceded by a flag bit which is set to 1. Information bytes are therefore generally not byte-aligned. The last information byte is followed by a zero bit. The smallest size of this field is therefore one bit, a 0, that has no information bytes. The largest size is unlimited. The following example has 16 bits of extra information denoted by E:

1 E E E E E E E E 1 E E E E E E E E 0

Where E is an extra information bit.

The extra information bytes are reserved for future extensions to this part of ISO/IEC 11172. The meaning of these bytes is currently undefined, so encoders must not generate such bytes and decoders must be capable of discarding them.

D.5.3.10 Extension data

This start code is byte-aligned and is 32 bits long. Its value is:

hex: 00 00 01 B5
binary: 0000 0000 0000 0000 0000 0001 1011 0101

It may be preceded by any number of zeros. If it is present then it will be followed by an undetermined number of data bytes terminated by the next start code. These data bytes are reserved for future extensions to this part of ISO/IEC 11172, and should not be generated by encoders. MPEG video decoders must be capable of discarding them.

D.5.3.11 User data

This start code is byte-aligned and is 32 bits long. Its value is

hex: 00 00 01 B2
binary: 0000 0000 0000 0000 0000 0001 1011 0010

It may be preceded by any number of zeros. If it is present then it will be followed by an undetermined number of data bytes terminated by the next start code. These data bytes can be used by the encoder for any purpose. The only restriction on the data is that they cannot emulate a start code, even if not byte-aligned. One way to prevent emulation is to force the most significant bit of alternate bytes to be a 1.

In closed encoder-decoder systems the decoder may be able to use the data. In the more general case, decoders should be capable of discarding the user data.

D.5.4 Slice

Pictures are divided into slices. Each slice consists of an integral number of macroblocks in raster scan order. Slices can be of different sizes within a picture, and the division in one picture need not be the same as the division in any other picture. Slices can begin and end at any macroblock in a picture subject to the following restrictions. The first slice must begin at the top left of the picture, and the end of the last slice must be the bottom right macroblock of the picture. There can be no gaps between slices, nor can slices overlap. The minimum number of slices in a picture is one, the maximum number is equal to the number of macroblocks.

Each slice starts with a slice start code, the exact value of which defines the vertical position of the slice. This is followed by a code that sets the quantization step-size. At the start of each slice the predictors for the dc coefficient values and the predictors for the vector decoding are all reset. The horizontal position of the start of the slice is given by the macroblock address of the first macroblock in the slice. The result of all this is that, within a picture, a slice can be decoded without information from the previous slices. Therefore, if a data error occurs, decoding can begin again at the subsequent slice.

If the data are to be used in an error free environment, then one slice per picture may be appropriate. If the environment is noisy, then one slice per row of macroblocks may be more desirable, as shown in figure D.21.

1 begin	end 1
2 begin	end 2
3 begin	end 3
4 begin	end 4
5 begin	end 5
6 begin	end 6
7 begin	end 7
8 begin	end 8
9 begin	end 9
10 begin	end 10
11 begin	end 11
12 begin	end 12
13 begin	end 13

Figure D.21 -- Possible arrangement of slices in a 256x192 picture

In this figure and in the next, each strip is one macroblock high, i.e. 16 pels high.

Since each slice header requires 40 bits, there is some penalty for including more than the minimum number of slices. For example, a sequence with a vertical resolution of 240 lines coded at 30 pictures/s requires approximately 40x30 = 1 200 bits/s for the slice headers using one slice per picture, and 40x15x30 = 18 000 bits/s with one slice per row, an additional overhead of 16 800 bits/s. The calculation is approximate and underestimates the impact, since the inclusion of a slice imposes additional requirements that the macroblock immediately before the slice header be coded, as well as the first macroblock in the slice.

The coding structure permits great flexibility in dividing a picture up into slices. One possible arrangement is shown in figure D.22.

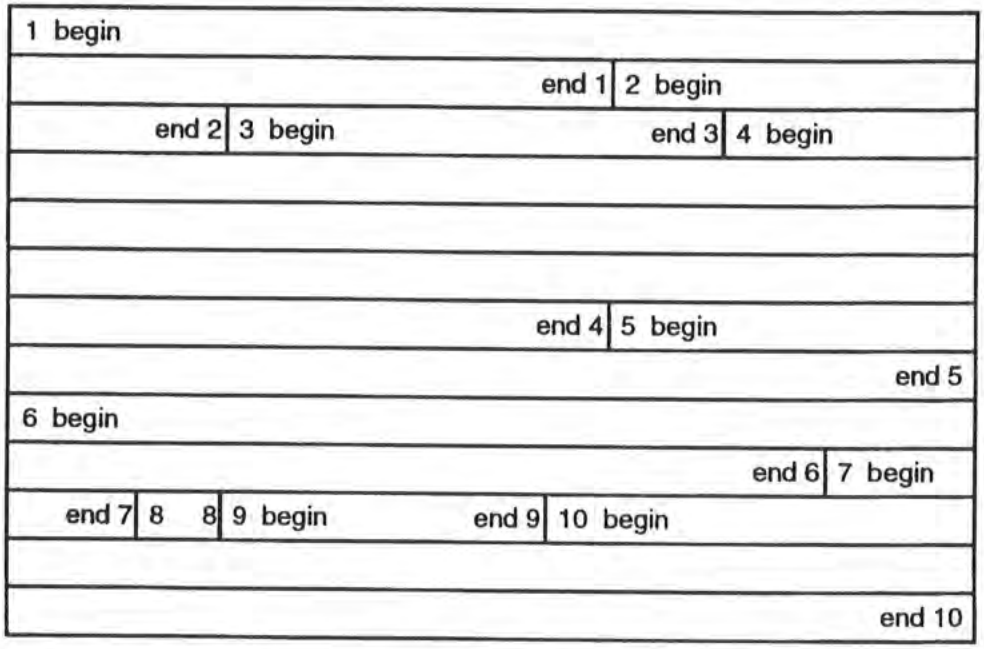


Figure D.22 -- Possible arrangement of slices in a 256x192 picture

This division into slices is given for illustrative purposes only. It is not intended as a suggestion on how to divide a picture into slices.

D.5.4.1 Slice header and start code

Slices start with a slice header. Each slice header starts with a slice start code. This code is byte-aligned and is 32 bits long. The last eight bits can take on a range of values which define the vertical position of the slice in the picture. The permitted slice start codes are:

hex:	from	00 00 01 01
	to	00 00 01 AF
binary:	from	0000 0000 0000 0000 0000 0001 0000 0001
	to	0000 0000 0000 0000 0000 0001 1010 1111

Each slice start code may be preceded by any number of zeros.

The last 8 bits of the slice start code give the slice vertical position, i.e the vertical position of the first macroblock in the slice in units of macroblocks starting with position 1 at the top of the picture. A useful variable is macroblock row. This is similar to slice vertical position except that row 0 is at the top of the picture. Thus

slice vertical position = macroblock row + 1

For example, a slice start code of 00000101 hex means that the first macroblock in the slice is at vertical position 1 or macroblock row 0, i.e. at the top of the picture. A slice start code of 00000120 hex means

that the first macroblock is at vertical position 32 or macroblock row 31, i.e. at the 496th row of pels. It is possible for two or more slices to have the same vertical position.

The maximum vertical position is 175 units. A slice with this position would require a vertical size of 175x16 = 2 800 pels.

The horizontal position of the first macroblock in the slice can be calculated from its macroblock address increment. Thus its position in the picture can be determined without referring to any previous slice or macroblock. Thus a decoder may decode any slice in a picture without having decoded any other slice in the same picture. This feature allows decoders to recover from bit errors by searching for the next slice start code and then resuming decoding.

D.5.4.2 Quantizer scale

The quantizer scale is a five-bit integer which is used by the decoder to calculate the DCT coefficients from the transmitted quantized coefficients. A value of 0 is forbidden, so the quantizer scale can have any value between 1 and 31 inclusive.

Note in addition that the quantizer scale may be set at any macroblock.

D.5.4.3 Extra slice information

Extra slice information forms the last field in the slice header. Any number of information bytes may be present. An information byte is preceded by a flag bit which is set to 1. Information bytes are therefore generally not byte-aligned. The last information byte is followed by a zero bit. The smallest size of this field is therefore one bit, a 0, that has no information bytes. The largest size is unlimited. The following example has 24 bits of extra information denoted by E:

1 E E E E E E E E 1 E E E E E E E E 1 E E E E E E E E 0

The extra information bytes are reserved for future extensions to this part of ISO/IEC 11172. The meaning of these bytes is currently undefined, so encoders must not generate such bytes and decoders must discard them.

The slice header is followed by code defining the macroblocks in the slice.

D.5.5 Macroblock

Slices are divided into macroblocks of 16 x 16 pels. Macroblocks are coded with a header that contains information on the macroblock address, macroblock type, and the optional quantizer scale. The header is followed by data defining each of the six blocks in the macroblock It is convenient to discuss the macroblock header fields in the order in which they are coded.

D.5.5.1 Macroblock stuffing

The first field in the macroblock header is "macroblock stuffing". This is an optional field, and may be inserted or omitted at the discretion of the encoder. If present it consists of any number of 11-bit strings with the pattern "0000 0001 111". This stuffing code is used by the encoder to prevent underflow, and is discarded by the decoder. If the encoder determines that underflow is about to occur, then it can insert as many stuffing codes into the first field of the macroblock header it likes.

Note that an encoder has other strategies to prevent buffer underflow. It can insert stuffing bits immediately before a start code. It can reduce the quantizer scale to increase the number of coded coefficients. It can even start a new slice.

D.5.5.2 Macroblock address increment and macroblock escape

Macroblocks have an address which is the number of the macroblock in raster scan order. The top left macroblock in a picture has address 0, the next one to the right has address 1 and so on. If there are M macroblocks in a picture, then the bottom right macroblock has an address M-1.

The address of a macroblock is indicated by transmitting the difference between the addresses of the current macroblock and the previously coded macroblock. This difference is called the macroblock address increment. In I-pictures, all macroblocks are coded and so the macroblock address increment is nearly always one. There is one exception. At the beginning of each slice the macroblock address is set to that of the right hand macroblock of the previous row. At the beginning of the picture it is set to -1. If a slice does not start at the left edge of the picture, then the macroblock address increment for the first macroblock in the slice will be larger than one. For example, the picture of figure D.22 has 16 macroblocks per row. At the start of slice 2 the macroblock address is set to 15 which is the address of the macroblock at the right hand edge of the top row of macroblocks. If the first slice contained 26 macroblocks, 10 of them would be in the second row, so the address of the first macroblock in slice 2 would be 26 and the macroblock address increment would be 11.

Macroblock address increments are coded using the VLC codes in the table in B.1.

It can be seen that there is no code to indicate a macroblock address increment of zero. This is why the macroblock address is set to -1 rather than zero at the top of a picture. The first macroblock will have an increment of one making its address equal to zero.

The macroblock address increments allow the position of the macroblock within the picture to be determined. For example, assume that a slice header has the start code equal to 00 00 01 0A hex, that the picture width is 256 pels, and that a macroblock address increment code 0000111 is in the macroblock header of the first macroblock in the slice. A picture width of 256 pels implies that there are 16 macroblocks per row in this picture. The slice start code tells us that the slice vertical position is 10, and so the macroblock row is 9. The slice header sets the previous macroblock address to the last macroblock on row 8, which has address 143. The macroblock address increment VLC leads to a macroblock address increment of 8, and so the macroblock address of the first macroblock in the slice is 143 + 8 = 151.

The macroblock row may be calculated from the address:

$$\begin{aligned} \text{macroblock row} &= \text{macroblock address} / \text{macroblock width} \\ &= 151 \ / \ 16 \\ &= 9 \end{aligned}$$

The division symbol signifies integer truncation, not rounding.

The macroblock column may also be calculated from the address:

$$\begin{aligned} \text{macroblock column} &= \text{macroblock address} \ \% \ \text{macroblock width} \\ &= 151 \ \% \ 16 \\ &= 7 \end{aligned}$$

Columns are numbered from the left of the picture starting at 0.

There are two special codewords: escape and stuffing.

The escape code means "add 33 to the following macroblock address increment". This allows increments greater than 33 to be coded. For example, an increment of 40 would be coded as escape plus an increment of 7:

0000 0001 0000 0010

An increment of 70 would be coded as two escape codes followed by the code for an increment of 4:

0000 0001 0000 0000 0010 0000 11

The stuffing code is included since the decoder must be able to distinguish it from increment codes. It is used by the encoder to prevent underflow, and is discarded by the decoder.

D.5.5.3 Macroblock types

Each of the picture types I, P, and B, have their own macroblock types. See, respectively, D.6.3, D.6.4, and D.6.5 for the codes and their descriptions.

D.5.5.4 Motion horizontal/vertical forward/backward codes

The interpretation of these codes is explained in D.6.2.3.

D.5.5.5 Motion horizontal/vertical forward/backward R

The interpretation of these codes is explained in D.6.2.3.

D.5.5.6 Coded block pattern

This code describes which blocks within the macroblock are coded and transmitted. The interpretation of this code is explained in D.6.4.2.

D.5.5.7 End of macroblock

This code is used only in D-pictures and is described in D.6.6.

D.5.6 Block

A block is an array of 8 by 8 component pel values, treated as a unit and input to the Discrete Cosine Transform (DCT). Blocks of 8 by 8 pels are transformed into arrays of 8 by 8 DCT coefficients using the two dimensional discrete cosine transform.

D.6 Coding MPEG video

D.6.1 Rate control and adaptive quantization

The encoder must control the bit rate so that the model decoder input buffer neither overflows nor underflows. Since the model decoder removes all the bits associated with a picture from the input buffer instantaneously, it is necessary to control only the total number of bits per picture. The encoder should allocate the total numbers of bits among the various types of pictures so that the perceived quality is suitably balanced. The distribution will vary with the scene content and with the particular distribution of the three picture types (I, P and B-pictures).

Within a picture the encoder should allocate the total number of bits available among the macroblocks to maximize the visual quality of the picture.

One method by which an encoder controls the bit rate is to vary the quantizer scale. This is set in each slice header, and may be set at the beginning of any macroblock, giving the encoder excellent control over the bit rate within a picture.

D.6.1.1 Rate control within a sequence

For a typical coding scheme represented by the following group of pictures in display order:

B B I B B P B B P B B P B B P

it has been found that good results can be obtained by matching the visual quality of the I and P-pictures, and by reducing the code size of the B-pictures to save bits giving a generally lower quality for the B-pictures.

The best allocation of bits among the picture types depends on the scene content. Work of the MPEG video committee suggests that allotting P-pictures about 2-5 times as many bits as B-pictures, and allotting I-pictures up to 3 times as many bits as P-pictures gives good results for typical natural scenes. If there is little motion or change in the video, then a greater proportion of the bits should be allotted to the I-pictures.

If there is a lot of motion or change, then the proportion allotted to I-pictures should be reduced and most of the savings given to the P-pictures.

A reasonable encoder algorithm is to start with the foregoing estimates, then reallocate bits dynamically depending on the nature of the video.

D.6.1.2 Rate control within a picture

If the buffer is heading toward overflow, the quantizer scale should be increased. If this action is not sufficient to prevent an impending overflow then, as a last resort, the encoder could discard high frequency DCT coefficients and transmit only low frequency ones. Although this would probably produce visible artifacts in the decoded video, it would in no way compromise the validity of the coded bitstream.

If the buffer is heading toward underflow, the quantizer scale should be reduced. If this is not sufficient, the encoder can insert macroblock stuffing into the bitstream, or add leading zeros to start codes.

Under normal circumstances, the encoder calculates and monitors the state of the model decoder buffer and changes the quantizer scale to avert both overflow and underflow problems.

One simple algorithm that helps accomplish this is to monitor the buffer fullness. Assume that the bits have been allocated among the various picture types, and that an average quantizer scale for each picture type has been established. The actual buffer fullness at any macroblock in a picture can be calculated and compared with the nominal fullness, i.e. the value that would be obtained if the bits were uniformly distributed among all the macroblocks in the picture. If the buffer fullness is larger than the nominal value, then the quantizer scale should be set higher than the average, whereas if the buffer fullness is smaller than the nominal, the quantizer scale should be set lower than the average.

If the quantizer scale is kept constant over a picture, then, for a given number of coding bits, the total mean square error of the coded picture will tend to be close to the minimum. However, the visual appearance of most pictures can be improved by varying the quantizer scale over the picture, making it smaller in smooth areas of the picture and larger in busy areas. This technique reduces the visibility of blockiness in smooth areas at the expense of increased quantization noise in the busy areas where, however, it is masked by the image detail.

Thus a good algorithm for controlling the bitrate within a picture adjusts the quantizer scale depending on both the calculated buffer fullness and on the local image content. Examples of techniques for rate control and quantization may be found in [7][8].

D.6.1.3 Buffer fullness

To give the best visual quality, the encoder should almost fill the input buffer before instructing the decoder to start decoding.

D.6.2 Motion estimation and compensation

D.6.2.1 Motion compensation

P-pictures use motion compensation to exploit temporal redundancy in the video. Decoders construct a predicted block of pels from pels in a previously transmitted picture. Motion within the pictures (e.g. a pan) usually implies that the pels in the previous picture will be in a different position from the pels in the current block, and the displacement is given by motion vectors encoded in the bitstream. The predicted block is usually a good estimate of the current block, and it is usually more efficient to transmit the motion vector plus the difference between the predicted block and the current block, than to transmit a description of the current block by itself.

Consider the following typical group of pictures.

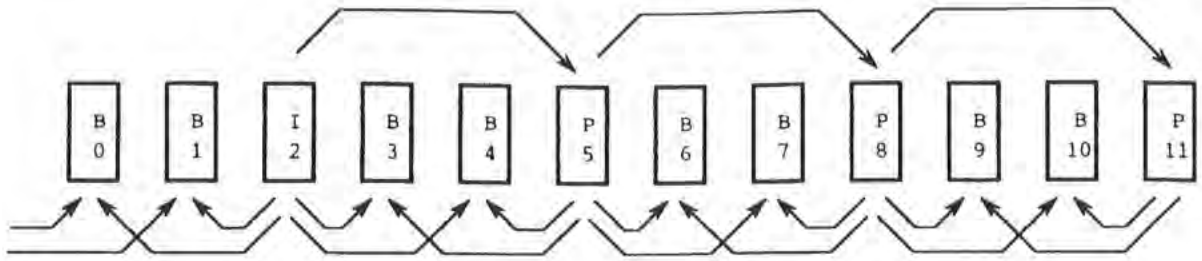


Figure D.23 -- Group of pictures in display order

The I-picture, picture 2, is decoded without requiring any motion vectors. The first P-picture, number 5, is decoded using motion vectors from picture 2. This motion compensation is called forward motion compensation since it is forward in time. Motion vectors define the motion of a macroblock, i.e. the motion of a 16x16 block of luminance pels and the associated chrominance components. Typically, most macroblocks in a P-picture use motion compensation. Non-zero motion vectors are transmitted differentially with reference to the last transmitted motion vector.

The transmitted vectors usually have a precision of half a pel. The maximum range of the vector is set by the forward_f parameter in the picture header. Sometimes, if the motion is unusually large, the range may be doubled and the accuracy reduced to integer pels, by the full_pel_forward_vector bit in the picture header.

A positive value of the horizontal or vertical component of the motion vector signifies that the prediction is formed from pels in the referenced picture which are spatially to the right or below the pels being predicted.

Not all macroblocks in a P-picture necessarily use motion compensation. Some macroblocks, as defined by the transmitted macroblock type (see table B.2b), may be intra-coded, and these are reconstructed without motion compensation. Full details defining the method of decoding the vectors and constructing the motion-compensated macroblock are given in 2.4.4.2.

P-picture 8 in figure D.23 uses forward motion compensation from picture 5. P-pictures always use forward motion compensation from the last transmitted I or P-picture.

B-pictures may use motion compensation from the previous I or P-picture, from the next (in display order) I or P-picture, or both; i.e., from the last two transmitted I or P-pictures.

Prediction is called forward if reference is made to a picture in the past and called backward if reference is made to a picture in the future. For example, B-picture 3 in figure D.23 uses forward motion compensation from I-picture 2, and backward motion compensation from P-picture 5. B-pictures may use both forward and backward motion compensation and average the result. This operation is called interpolative motion compensation.

All three types of motion compensation are useful, and typically are used in coding B-pictures. Interpolative motion compensation has the advantage of averaging any noise present. Forward or backward motion compensation may be more useful near the edges of pictures, or where a foreground object is passing in front of a fixed or slow moving background.

Note that this technique of coding with P and B-pictures increases the coding efficiency. B-pictures can have greater errors of reconstruction than I or P-pictures to conserve coding bits, but since they are not used as the basis of motion compensation for future pictures, these errors may be tolerated.

D.6.2.2 Motion estimation

Motion compensation in a decoder is straightforward, but motion estimation which includes determining the best motion vectors and which must be performed by the encoder, presents a formidable computational challenge.

Various methods are available to the encoder. The more computationally intensive methods tend to give better results, so there is tradeoff to be made in the encoder: computational power, and hence cost, versus coded video quality.

Using a search strategy the encoder attempts to match the pels in a macroblock with those in a previous or future picture. The vector corresponding to the best match is reported after the search is completed.

D.6.2.2.1 Block matching criteria

In seeking a match, the encoder must decide whether to use the decoded past and future pictures as the reference, or use the original past and future pictures. For motion estimation, use of the decoded pictures by the encoder gives the smallest error in the error picture, whereas use of the original pictures gives the most accurate motion vectors. The choice depends on whether the artifacts of increased noise, or greater spurious motion are judged to be the more objectionable. There is usually little or no difference in quality between the two methods. Note that the decoder does not perform motion estimation. It performs motion compensated prediction and interpolation using vectors calculated in the encoder and stored in the bitstream. In motion compensated prediction and interpolation, both the encoder and decoder must use the decoded pictures as the references.

Several matching criteria are available. The mean square error of the difference between the motion-compensated block and the current block is an obvious choice. Another possible criterion is the mean absolute difference between the motion-compensated block and the current block.

For half pel shifts, the pel values could be interpolated by several methods. Since the decoder uses a simple linear interpolation, there is little reason to use a more complex method in the encoder. The linear interpolation method given in this part of ISO/IEC 11172 is equivalent to the following. Consider four pels having values A, B, D and E as shown in figure D.24:

A	h	B
v	c	
D		E

Figure D.24 -- Interpolation of half pel shifts

The value of the horizontally interpolated pel is

$$h = (A + B) // 2$$

where the double division symbol means division with rounding to the nearest integer. Half integer values are to be rounded to the next higher value. Thus if A = 4 and B = 9 then h = 6.5 which is rounded up to 7.

The value of the vertically interpolated pel is

$$v = (A + D) // 2$$

The value of the central interpolated pel is

$$c = (A + B + D + E) // 4$$

D.6.2.2.2 Search range

Once a block matching criterion has been selected, some kind of search strategy must be adopted. This must recognize the limitations of the VLC tables used to code the vectors. The maximum range of the vector depends upon forward_f_code or backward_f_code. The motion vector ranges are given in table D.7.

Table D.7 -- Range of motion vectors

forward_f_code or backward_f_code	Motion vector range	
	full_pel=0	full_pel=1
1	-8 to 7,5	-16 to 15
2	-16 to 15,5	-32 to 31
3	-32 to 31,5	-64 to 63
4	-64 to 63,5	-128 to 127
5	-128 to 127,5	-256 to 255
6	-256 to 255,5	-512 to 511
7	-512 to 511,5	-1 024 to 1 023

The range depends on the value of full_pel_forward_vector or full_pel_backward_vector in the picture header. Thus if all the motion vectors were found to be 15 pels or less, the encoder would usually select half pel accuracy and a forward_f_code or backward_f_code value of 2.

The search must be constrained to take place within the boundaries of the decoded reference picture. Motion vectors which refer to pels outside the picture are not allowed. Any bitstream which refers to such pels does not conform to this part of ISO/IEC 11172.

D.6.2.2.3 2-D search strategy

There are many possible methods of searching another picture for the best match to a current block, and a few simple ones will be described.

The simplest search is a full search. Within the chosen search range all possible displacements are evaluated using the block matching criterion.

The full search is computationally expensive, and practical encoders may not be able to afford the time required for a full search.

A simple modification of the full search is to search using only integer pel displacements. Once the best integer match has been found, the eight neighbouring half-integer pel displacements are evaluated, and the best one selected as illustrated below:

```
*       *       *       *       *       y

*       *       *       *       *       y+1
                +   +   +               y+1,5
*       *       +   *   +       *       *       y+2
                +   +   +               y+2,5
*       *       *       *       *       *       y+3

*       *       *       *       *       *       y+4
x       x+1     x+2     x+3     x+4
```

Figure D.25 -- Integer pel and half pel displacements

Assume that the position x+2,y+2 gives the best integer displacement matching using the selected block matching criterion, then the encoder would evaluate the eight positions with half pel displacements marked by + signs in figure D.25. If one of them were a better match then it would become the motion vector, otherwise the motion vector would remain that of the integer displacement x+2,y+2.

If during the integer pel search, two or more positions have the same block matching value, the encoder can adopt a consistent tie-breaking rule.

The modified full search algorithm is approximately an order of magnitude simpler than the full search. Using only integer displacements for the first stage of the search reduces the number of evaluations by a factor of four. In addition, the evaluations are simpler since the pel differences can be calculated directly and do not have to be interpolated.

For some applications even the modified full search may be too time consuming, and a faster search method may be required. One such method is the logarithmic search.

D.6.2.2.4 Logarithmic search

In this search method, grids of 9 displacements are examined, and the search continued based on a smaller grid centered on the position of the best match. If the grids are reduced in size by a factor of 3 at each step then the search is maximally efficient in the sense that any integer shift has a unique selection path to it. This method will find the best match only for a rather limited set of image types. A more robust method is to reduce the size of the grids by a smaller factor at each step, e.g. by a factor of 2. The scaling factors can also be adjusted to match the search ranges of table D.7.

The method will be illustrated with an example. Consider the set of integer shifts in figure D.26:

*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	1	*	*	*	1	*	*	*	1	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	2	*	2	*	2	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	2	*	1	*	2	*	1	*	*	*	1	*	*	*
*	*	*	*	3	3	3	*	*	*	*	*	*	*	*
*	2	*	2	3	2	3	*	*	*	*	*	*	*	*
*	*	*	*	3	3	3	*	*	*	*	*	*	*	*
*	*	*	1	*	*	*	1	*	*	*	1	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Figure D.26 -- Logarithmic search method for integer pel shifts

The first grid has a spacing of 4 pels. The first step examines pels at shifts of 0, 4, or -4 pels in each direction, marked 1 in figure D.26. The best position is used as the center point of the second grid. Assume it is the pel marked 1 directly to the left of the center pel. The second grid has a spacing of 2 pels. The second step examines pels at shifts of 0, 2, or -2 pels in each direction from the center of the new grid, marked 2 in the figure. The best position is used as the center point of the third grid, assume it is the lower right pel of the second grid. The third grid has a spacing of 1 pel. The third step examines pels at shifts of 0, 1, or -1 pels in each direction from the center of the grid. The best position is used as the center point of the fourth grid. The fourth grid has a spacing of 1/2 pel. The fourth step examines pels at shifts of 0, 1/2, or -1/2 pels in each direction from the center of the grid using the same method as in the modified full search. The best position determines the motion vector.

Some possible grid spacings for various search ranges are given in table D.8.

Table D.8 -- Grid spacings for logarithmic searches

forward_f_code	RANGE	STEPS	GRID SPACINGS
1	±7,5	4	4 2 1 1/2
2	±15,5	5	8 4 2 1 1/2
3	±31,5	6	16 8 4 2 1 1/2

For P-pictures only forward searches are performed, but B-pictures require both forward and backward searches. Not all the vectors calculated during the search are necessarily used. In B-pictures either forward or backward motion compensation might be used instead of interpolated motion compensation, and in both P and B-pictures the encoder might decide that a block is better coded as intra, in which case no vectors are transmitted.

D.6.2.2.5 Telescopic search

Even with the faster methods of the modified full search, or the logarithmic search, the search might be quite expensive. For example, if the encoder decides to use a maximum search range of 7 pels per picture

interval, and if there are 4 B-pictures preceding a P-picture, then the full search range for the P-picture would be 35 pels. This large search range may exceed the capabilities of the encoder.

One way of reducing the search range is to use a telescopic search technique. This is best explained by illustrating with an example. Consider the group of pictures in figure D.27.

I	B	B	B	P	B	B	B	P	B	B	B	P
0	1	2	3	4	5	6	7	8	9	10	11	12

Figure D.27 -- Example group of pictures in display order

The encoder might proceed using its selected block matching criterion and D search strategy. For each P-picture and the preceding B-pictures, it first calculates all the forward vectors, then calculates all the backward vectors. The first set of pictures consists of pictures 0 through 4.

To calculate the complete set of forward vectors, the encoder first calculates all the forward vectors from picture 0 to picture 1 using a 2-D search strategy centered on zero displacement. It next calculates all the forward vectors from picture 0 to picture 2 using a 2-D search strategy centered on the displacements calculated for the corresponding block of picture 1. It next calculates all the forward vectors from picture 0 to picture 3 using a 2-D search strategy centered on the displacements calculated for the corresponding block of picture 2. Finally, it calculates all the forward vectors from picture 0 to picture 4 using a 2-D search strategy centered on the displacements calculated for the corresponding block of picture 3.

To calculate the complete set of backward vectors, the encoder first calculates all the backward vectors from picture 4 to picture 3 using a 2-D search strategy centered on zero displacement. It next calculates all the backward vectors from picture 4 to picture 2 using a 2-D search strategy centered on the displacements calculated for the corresponding block of picture 3. Finally, it calculates all the backward vectors from picture 4 to picture 1 using a 2-D search strategy centered on the displacements calculated for the corresponding block of picture 2.

Further methods of motion estimation are given by Netravali and Haskell [1].

D.6.2.3 Coding of motion vectors

The motion vector of a macroblock tends to be well correlated with the vector of the previous macroblock. For example, in a pan all vectors would be roughly the same. Motion vectors are coded using a DPCM technique to make use of this correlation.

In P-pictures the motion vector used for DPCM, the prediction vector, is set to zero at the start of each slice and at each intra-coded macroblock. Note that macroblocks which are coded as predictive but which have no motion vector, also set the prediction vector to zero.

In B-pictures there are two motion vectors, forward and backward. Each vector is coded relative to the predicted vector of the same type. Both motion vectors are set to zero at the start of each slice and at each intra-coded macroblock. Note that predictive macroblocks which have only a forward vector do not affect the value of the predicted backward vector. Similarly, predictive macroblocks which have only a backward vector do not affect the value of the predicted forward vector.

The range of the vectors is set by two parameters. The full_pel_forward_vector and full_pel_backward_vector flags in the picture header determine whether the vectors are defined in half-pel or integer-pel units.

A second parameter, forward_f_code or backward_f_code, is related to the number of bits appended to the VLC codes in table D.9.

Table D.9 -- Differential motion code.

VLC code	Value
0000 0011 001	-16
0000 0011 011	-15
0000 0011 101	-14
0000 0011 111	-13
0000 0100 001	-12
0000 0100 011	-11
0000 0100 11	-10
0000 0101 01	-9
0000 0101 11	-8
0000 0111	-7
0000 1001	-6
0000 1011	-5
0000 11	-4
0001 1	-3
0011	-2
011	-1
1	0
010	1
0010	2
0001 0	3
0000 110	4
0000 1010	5
0000 1000	6
0000 0110	7
0000 0101 10	8
0000 0101 00	9
0000 0100 10	10
0000 0100 010	11
0000 0100 000	12
0000 0011 110	13
0000 0011 100	14
0000 0011 010	15
0000 0011 000	16

Advantage is taken of the fact that the range of displacement vector values is constrained. Each VLC represents a pair of difference values. Only one of the pair will yield a motion vector falling within the permitted range.

The range of the vector is limited to the values shown in table D.7. The values obtained by decoding the differential values must be kept within this range by adding or subtracting a modulus which depends on the f value as shown in table D.10.

Table D.10 -- Modulus for motion vectors

forward_f_code or backward_f_code	MODULUS
1	32
2	64
3	128
4	256
5	512
6	1 024
7	2 048

The use of the modulus, which refers only to the numbers in tables D.8 through D.10, will be illustrated by an example. Assume that a slice has the following vectors, expressed in the units set by the full pel flag.

3 10 30 30 -14 -16 27 24

The range is such that an f value of 2 can be used. The initial prediction is zero, so the differential values are

3 7 20 0 -44 -2 43 -3

The differential values are reduced to the range -32 to +31 by adding or subtracting the modulus 64 corresponding to the forward_f_code of 2.

3 7 20 0 20 -2 -21 -3

To create the codeword, (mvd + (sign(mvd)*(forward_f-1))) is divided by forward_f. The signed quotient of this division is used to find a variable length codeword from table D.9. Then the absolute value of the remainder is used to generate a fixed length code that is concatenated with the variable length code. The codes generated by this example are shown below:

Value	VLC Code
3	0010 0
7	0000 1100
20	0000 0100 101
0	1
20	0000 0100 101
-2	0111
-21	0000 0100 0110
-3	0011 0

D.6.3 Coding I-pictures

In coding I-pictures, the encoder has two main decisions to make that are not mandated by this part of ISO/IEC 11172. These are: how to divide the picture up into slices, and how to set the quantizer scale.

D.6.3.1 Slices in I-pictures

Division of the picture into slices is described in D.5.4.

D.6.3.2 Macroblocks in I-pictures

D.6.3.2.1 Macroblock types in I-pictures

There are two types of macroblock in I-pictures. Both use intra coding. One uses the current quantizer scale, whereas the other defines a new value for the quantizer scale. They are identified in the coded bitstream by the VLC codes given in table D.11.

Table D.11 -- Macroblock type VLC for I-pictures (table B.2a.)

TYPE	QUANT	VLC
intra-d		1
intra-q	1	01

The types are referred to names in this annex. Intra-d is the default type where the quantizer scale is not changed. Intra-q sets the quantizer scale.

In order to allow for possible future extension to MPEG video, the VLC for intra-q is 01 rather than 0. Additional types could be added to this table without interfering with the existing entries. The VLC table is thus open for future additions, and not closed. A policy of making the coding tables open in this way was adopted by in developing this part of ISO/IEC 11172. The advantage of future extension was judged to be worth the slight coding inefficiency.

D.6.3.2.2 Quantizer scale

If the macroblock type is intra-q, then the macroblock header contains a five-bit integer which defines the quantizer scale. This is used by the decoder to calculate the DCT coefficients from the transmitted quantized coefficients. A value of 0 is forbidden, so the quantizer scale can have any value between 1 and 31 inclusive.

Note that also the quantizer scale is set in a slice header.

If the block type is intra-d, then no quantizer scale is transmitted and the decoder uses the previously set value. For a discussion on strategies encoders might use to set the quantizer scale, see D.6.1.

Note that the cost of transmitting a new quantizer scale is six bits: one for the extra length of the macroblock type code, and five to define the value. Although this is normally a small fraction of the bits allocated to coding each macroblock, the encoder should exercise some restraint and avoid making a large number of very small changes.

D.6.3.3 DCT transform

The DCT is illustrated in figure D.28.

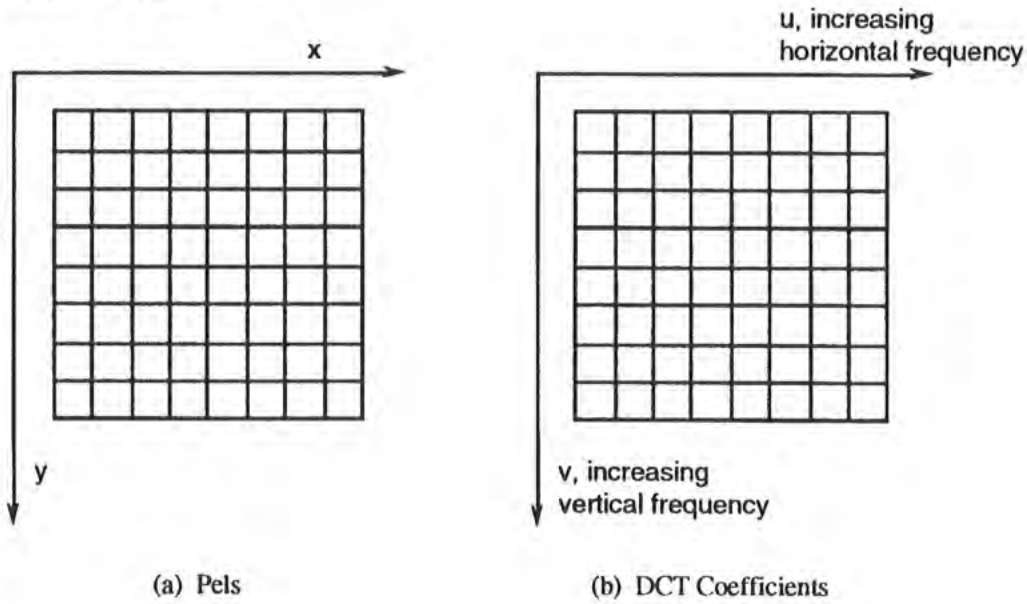


Figure D.28 -- Transformation of pels to coefficients

The pels are shown in raster scan order, whereas the coefficients are arranged in frequency order. The top left coefficient is the dc term and is proportional to the average value of the component pel values. The other coefficients are called ac coefficients. The ac coefficients to the right of the dc coefficient represent increasing horizontal frequencies, whereas ac coefficients below the dc coefficient represent increasing vertical frequencies. The remaining ac coefficients contain both horizontal and vertical frequency components. Note that an image containing only vertical lines contains only horizontal frequencies.

The coefficient array contains all the information of the pel array and the pel array can be exactly reconstructed from the coefficient array, except for information lost by the use of finite arithmetic precision.

The two-dimensional DCT is defined as

$$\mathbf{F(u,v)} = \frac{1}{4} \sum_{x=0}^{7} \sum_{y=0}^{7} \mathbf{f}\,(\mathbf{x,y}) \cos\,(\pi(2\mathbf{x}+1)\mathbf{u}/16) \cos\,(\pi(2\mathbf{y}+1)\mathbf{v}/16)$$

with: $u, v, x, y = 0, 1, 2, \ldots 7$
where x, y = spatial coordinates in the pel domain
u, v = coordinates in the transform domain
$C(u) = 1/\sqrt{2}$ for $u = 0$
$C(v) = 1/\sqrt{2}$ for $v = 0$
$= 1$ otherwise

This transform is separable, i.e. a one-dimensional DCT transform may be applied first in the horizontal direction and then in the vertical direction. The formula for the one dimensional transform is:

$$F(u) = \frac{1}{2} C(u) \sum_{x=0}^{7} f(x)\cos(\pi(2x+1)u/16)$$

$$C(u) = 1/\sqrt{2} \text{ for } u = 0$$
$$= 1 \text{ otherwise}$$

Fast DCT transforms exist, analogous to fast Fourier transforms. See reference [3].

The input pel values have a range from 0 to 255, giving a dynamic range for the dc coefficient from 0 to 2 040. The maximum dynamic range for any ac coefficient is about -1 000 to 1 000. Note that for P and B-pictures the component pels represent difference values and range from -255 to 255. This gives a maximum dynamic range for any coefficient of about -2 000 to 2 000. The encoder may thus represent the coefficients using 12 bits whose values range from -2 048 to 2 047.

D.6.3.4 Quantization

Each array of 8 by 8 coefficients produced by the DCT transform operation is quantized to produce an 8 by 8 array of quantized coefficients. Normally the number of non-zero quantized coefficients is quite small, and this is one of the main reasons why the compression scheme works as well as it does.

The coefficients are quantized with a uniform quantizer. The characteristic of this quantizer, only for I-blocks, is shown below:

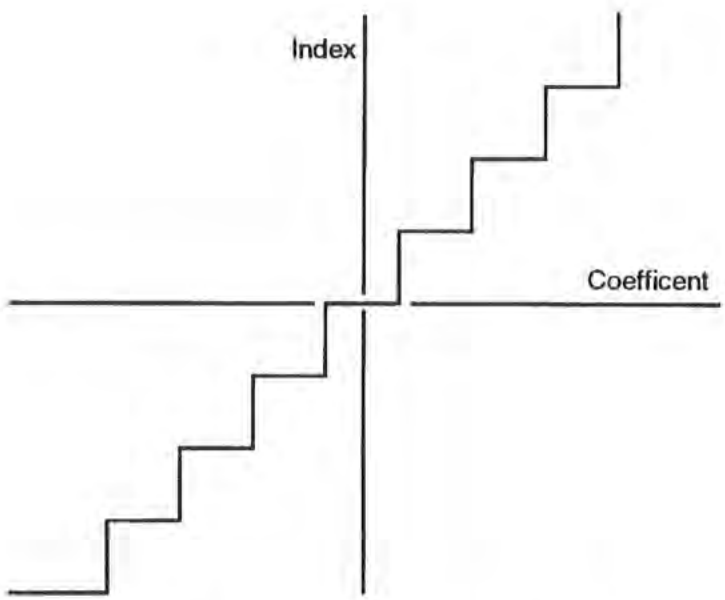


Figure D.29. -- Uniform quantizer characteristics

The value of the coefficient is divided by the quantizer step size and rounded to the nearest whole number to produce the quantized coefficient. Half integer values may be rounded up or down without directly affecting image quality. However, rounding towards zero tends to give the smallest code size and so is preferred. For example, with a step size of 16 all coefficients with values between 25 and 40 inclusive would give a quantized coefficient of 2.

The quantizer step size is derived from the quantization matrix and the quantizer scale. It can thus be different for different coefficients, and may change between macroblocks. The only exception is the dc coefficient which is treated differently.

The eye is quite sensitive to large area luminance errors, and so the accuracy of coding the dc value is fixed. The quantizer step size for the dc coefficients of the luminance and chrominance components is fixed at eight. The dc quantized coefficient is obtained by dividing the dc coefficient by eight and rounding to the nearest whole number. This effectively quantizes the average dc value to one part in 256 for the reconstructed pels.

For example, a dc coefficient of 21 is quantized to a value of 3, independent of the value of the quantizer scale.

The ac coefficients are quantized using the intra quantization matrix. The quantized coefficient i[u,v] is produced by quantizing the coefficient c[u,v] for I-blocks. One equation is given by the formula:

$$i[u,v] = 8 * c[u,v] \;//\; (q * m[u,v])$$

where m[u,v] is the corresponding element of the intra quantization matrix, and q is the quantizer scale. The quantized coefficient is limited to the range -255 to +255.

The intra quantization matrix might be the default matrix, or it might have been downloaded in the sequence header.

D.6.3.5 Coding of quantized coefficients

The top left coefficient in figure D.28b is called the dc coefficient, the remainder are called ac coefficients. The dc coefficient is correlated with the dc coefficient of the preceding block, and advantage is taken of this in coding. The ac coefficients are not well correlated, and are coded independently.

After the dc coefficient of a block has been quantized it is coded losslessly by a DPCM technique. Coding of the luminance blocks within a macroblock follows the raster scan order of figure D.5, 0 to 3. Thus the dc value of block 3 becomes the dc predictor for block 0 of the following macroblock. The dc value of each chrominance block is coded using the dc value of the corresponding block of the previous macroblock as a predictor. At the beginning of each slice, all three dc predictors for Y, Cb and Cr, are set to 1 024 (128*8).

The differential dc values thus generated are categorized according to their absolute value as shown in table D.12.

Table D.12. -- Differential dc size and VLC

DIFFERENTIAL DC (absolute value)	SIZE	VLC CODE (luminance)	VLC CODE (chrominance)
0	0	100	00
1	1	00	01
2 to 3	2	01	10
4 to 7	3	101	110
8 to 15	4	110	1110
16 to 31	5	1110	1111 0
32 to 63	6	1111 0	1111 10
64 to 127	7	1111 10	1111 110
128 to 255	8	1111 110	1111 1110

The size is transmitted using a VLC. This VLC is different for luminance and chrominance since the statistics are different.

The size defines the number of additional bits required to define the level uniquely. Thus a size of 6 is followed by 6 additional bits. These bits define the level in order, from low to high. Thus the first of these extra bits gives the sign: 0 for negative and 1 for positive. A size of zero requires no additional bits.

The additional codes are given in table D.13.

Table D.13. -- Differential dc additional code

DIFFERENTIAL DC	SIZE	ADDITIONAL CODE
-255 to -128	8	00000000 to 01111111
-127 to -64	7	0000000 to 0111111
-63 to -32	6	000000 to 011111
-31 to -16	5	00000 to 01111
-15 to -8	4	0000 to 0111
-7 to -4	3	000 to 011
3 to -2	2	00 to 01
-1	1	0
0	0	
1	1	1
2 to 3	2	10 to 11
4 to 7	3	100 to 111
8 to 15	4	1000 to 1111
16 to 31	5	10000 to 11111
32 to 63	6	100000 to 111111
64 to 127	7	1000000 to 1111111
128 to 255	8	10000000 to 11111111

For example, a luminance dc change of 10 would be coded as 1101010. table D.12 shows that the first three bits 110 indicate that the size is 4. This means that four additional bits are required to define the exact value. The next bit is a 1, and table D.13 shows that the differential dc value must be somewhere between 8 and 15 inclusive. The last three bits, 010, show that the exact value is 10.

The decoder reconstructs dc quantized coefficients by following the inverse procedure.

The ac quantized coefficients are coded using a run length and level technique. The quantized coefficients are first scanned in the zigzag order shown in figure D.30.

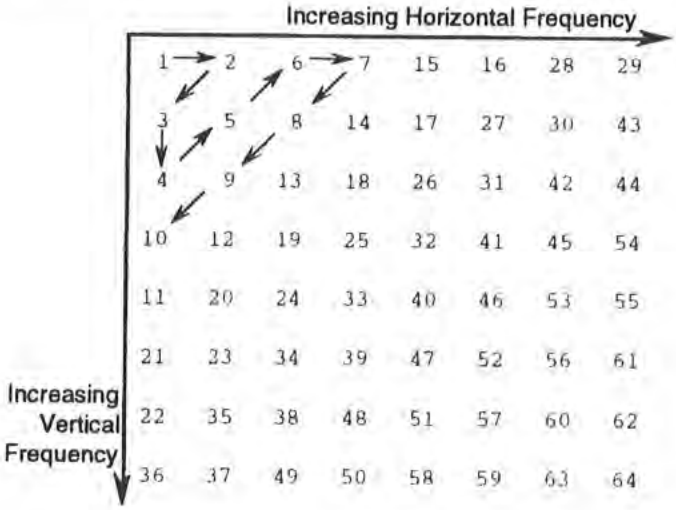


Figure D.30. -- Quantized coefficient block in zigzag scan order

The scanning order starts at 1, passes through 2, 3 etc in order, eventually reaching 64 in the bottom right corner. The length of a run is the number of zero quantized coefficients skipped over. For example, the quantized coefficients in figure D.31 produce the list of run lengths and levels in table D.14.

1	0	0	0	0	0	0	0	0
2	-3	0	0	0	0	0	0	0
4	-5	0	0	0	0	0	0	0
1	0	0	130	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Figure D.31. -- Example quantized coefficients

Table D.14. -- Example run lengths and levels

RUN-LENGTH	LEVEL
1	2
0	4
0	-3
3	-5
0	1
14	130
end	

The scan starts at position 2 since the top left quantized coefficient is coded separately as the dc quantized coefficient.

Using a zig zag scan rather than a raster scan is more efficient as it gives fewer runs and can be coded with shorter VLC codes.

The list of run lengths and levels is coded using table D.15 Not all possible combinations of run length and level are in these tables, only the more common ones. For combinations not in the tables, an escape sequence is used. In table D.15, the last bit 's' denotes the sign of the level; 0 means a positive level and 1 means a negative level. The escape code is used followed by the run length derived from table D.16 and then the level from table D.17.

Table D.15. -- Combination codes for DCT quantized coefficients. s = 0 for positive level, s = 1 for negative level

RUN	LEVEL	VLC CODE
EOB		10
0	1	1s IF 1st COEFF
0	1	11s NOT 1st COEFF
0	2	0100 s
0	3	0010 1s
0	4	0000 110s
0	5	0010 0110 s
0	6	0010 0001 s
0	7	0000 0010 10s
0	8	0000 0001 1101 s
0	9	0000 0001 1000 s
0	10	0000 0001 0011 s
0	11	0000 0001 0000 s
0	12	0000 0000 1101 0s
0	13	0000 0000 1100 1s
0	14	0000 0000 1100 0s
0	15	0000 0000 1011 1s
0	16	0000 0000 0111 11s
0	17	0000 0000 0111 10s
0	18	0000 0000 0111 01s
0	19	0000 0000 0111 00s
0	20	0000 0000 0110 11s
0	21	0000 0000 0110 10s
0	22	0000 0000 0110 01s
0	23	0000 0000 0110 00s
0	24	0000 0000 0101 11s
0	25	0000 0000 0101 10s
0	26	0000 0000 0101 01s
0	27	0000 0000 0101 00s
0	28	0000 0000 0100 11s
0	29	0000 0000 0100 10s
0	30	0000 0000 0100 01s
0	31	0000 0000 0100 00s
0	32	0000 0000 0011 000s
0	33	0000 0000 0010 111s
0	34	0000 0000 0010 110s
0	35	0000 0000 0010 101s
0	36	0000 0000 0010 100s
0	37	0000 0000 0010 011s
0	38	0000 0000 0010 010s
0	39	0000 0000 0010 001s
0	40	0000 0000 0010 000s
1	1	011s
1	2	0001 10s
1	3	0010 0101 s
1	4	0000 0011 00s
1	5	0000 0001 1011 s
1	6	0000 0000 1011 0s
1	7	0000 0000 1010 1s
1	8	0000 0000 0011 111s
1	9	0000 0000 0011 110s
1	10	0000 0000 0011 101s
1	11	0000 0000 0011 100s
1	12	0000 0000 0011 011s
1	13	0000 0000 0011 010s
1	14	0000 0000 0011 001s
1	15	0000 0000 0001 0011s
1	16	0000 0000 0001 0010s
1	17	0000 0000 0001 0001s
1	18	0000 0000 0001 0000s
2	1	0101 s
2	2	0000 100s
2	3	0000 0010 11s
2	4	0000 0001 0100 s
2	5	0000 0000 1010 0s
3	1	0011 1s
3	2	0010 0100 s
3	3	0000 0001 1100 s
3	4	0000 0000 1001 1s
4	1	0011 0s
4	2	0000 0011 11s
4	3	0000 0001 0010 s
5	1	0001 11s
5	2	0000 0010 01s
5	3	0000 0000 1001 0s
6	1	0001 01s
6	2	0000 0001 1110 s
6	3	0000 0000 0001 0100s
7	1	0001 00s
7	2	0000 0001 0101 s
8	1	0000 111s
8	2	0000 0001 0001 s
9	1	0000 101s
9	2	0000 0000 1000 1s
10	1	0010 0111 s
10	2	0000 0000 1000 0s
11	1	0010 0011 s
11	2	0000 0000 0001 1010s
12	1	0010 0010 s
12	2	0000 0000 0001 1001s
13	1	0010 0000 s
13	2	0000 0000 0001 1000s
14	1	0000 0011 10s
14	2	0000 0000 0001 0111s
15	1	0000 0011 01s
15	2	0000 0000 0001 0110s
16	1	0000 0010 00s
16	2	000 0000 0001 0101s
17	1	0000 0001 1111 s
18	1	0000 0001 1010 s
19	1	0000 0001 1001 s
20	1	0000 0001 0111 s
21	1	0000 0001 0110 s
22	1	0000 0000 1111 1s
23	1	0000 0000 1111 0s
24	1	0000 0000 1110 1s
25	1	0000 0000 1110 0s
26	1	0000 0000 1101 1s
27	1	0000 0000 0001 1111s
28	1	0000 0000 0001 1110s
29	1	0000 0000 0001 1101s
30	1	0000 0000 0001 1100s
31	1	0000 0000 0001 1011s
ESCAPE		0000 01

Table D.16. -- Zero run length codes

RUN-LENGTH	CODE
0	0000 00
1	0000 01
2	0000 10
.	.
62	1111 10
63	1111 11

Table D.17. -- Level codes for DCT quantized coefficients

LEVEL	CODE
-256	FORBIDDEN
-255	1000 0000 0000 0001
-254	1000 0000 0000 0010
.	.
-129	1000 0000 0111 1111
-128	1000 0000 1000 0000
-127	1000 0001
-126	1000 0010
.	.
-2	1111 1110
-1	1111 1111
0	FORBIDDEN
1	0000 0001
2	0000 0010
.	.
126	0111 1110
127	0111 1111
128	0000 0000 1000 0000
129	0000 0000 1000 0001
.	.
254	0000 0000 1111 1110
255	0000 0000 1111 1111

Using tables D.15 through D.17 we can derive the VLC codes for the example of table D.14:

Table D.18. -- Example run lengths, values, and VLC codes

RUN	VALUE	VLC CODE	COMMENT
1	2	0001 100	
0	4	0000 1100	
0	-3	0010 11	
3	-5	0000 0100 0011 1111 1011	esc seq
0	1	110	
14	130	0000 0100 1110 0000 0000 1000 0010	esc seq
EOB		10	

The first three codes in table D.18 are derived directly from table D.15. The next code is derived indirectly since table D.15 does not contain an entry corresponding to a run length of 3 and a level of 5. Instead the escape code 000001 is used. This is followed by the six-bit code 000011 from table D.16 indicating a run length of 3. Lastly the eight-bit code from table D.17 (11111011 - indicating a level of -5) is appended.

After the last coefficient has been coded, an EOB code is used to inform the decoder that there are no more quantized coefficients in the current 8 by 8 block. This EOB code is used even if the last quantized coefficient is at the bottom right of the block.

There are two codes for the 0,1 run length, level combination, as indicated in table D.15. Intra block coding always has the first quantized coefficient, the dc quantized coefficient, coded using the dc size method. Consequently intra blocks always use the code 11s to denote a run length, level combination of 0,1. It will

be seen later that predictively coded blocks code the dc quantized coefficient differently, and may use the shorter code.

D.6.4 Coding P-pictures

As in I-pictures, each P-picture is divided up into one or more slices, which are, in turn, divided into macroblocks. Coding is more complex than for I-pictures, since motion-compensated macroblocks may be constructed. The difference between the motion compensated macroblock and the current macroblock is transformed with a two-dimensional DCT giving an array of 8 by 8 transform coefficients. The coefficients are quantized to produce a set of quantized coefficients. The quantized coefficients are then encoded using a run-length value technique.

As in I-pictures, the encoder needs to store the decoded P-picture since this may be used as the starting point for motion compensation. Therefore, the encoder will reconstruct the image from the quantized coefficients.

In coding P-pictures, the encoder has more decisions to make than in the case of I-pictures. These decisions are: how to divide the picture up into slices, determine the best motion vectors to use, decide whether to code each macroblock as intra or predicted, and how to set the quantizer scale.

D.6.4.1 Slices in P-pictures

P-pictures are divided into slices in the same way as I-pictures. The same considerations as to the best method of dividing a picture into slices apply, see D.5.4.

D.6.4.2 Macroblocks in P-pictures

Slices are divided into macroblocks in the same way as for I-pictures. The major difference is the complexity introduced by motion compensation.

The macroblock header may contain stuffing. The position of the macroblock is determined by the macroblock address. Whereas the macroblock address increment within a slice for I-pictures is restricted to one, it may be larger for P-pictures. Any macroblocks thus skipped over are called "skipped macroblocks". The decoder copies them from the previous picture into the current picture. Skipped macroblocks are as predicted macroblocks with a zero motion vector for which no additional correction is available. They require very few bits to transmit.

The next field in the macroblock header defines the macroblock type.

D.6.4.2.1 Macroblock types in P-pictures

There are eight types of macroblock in P-pictures:

Table D.19 -- Macroblock type VLC for P-pictures (table B.2b)

TYPE	VLC	INTRA	MOTION FORWARD	CODED PATTERN	QUANT
pred-mc	1	0	1	1	0
pred-c	01	0	0	1	0
pred-m	001	0	1	0	0
intra-d	0001 1	1	0	0	0
pred-mcq	0001 0	0	1	1	1
pred-cq	0000 1	0	0	1	1
intra-q	0000 01	1	0	0	1
skipped	N/A				

Not all possible combinations of motion compensation, coding, quantization, and intra coding occur. For example, with intracoded macroblocks, intra-d and intra-q, motion vectors are not transmitted.

Skipped macroblocks have no VLC code. Instead they are coded by having the macroblock address increment code skip over them.

D.6.4.2.2 Quantizer scale

If the macroblock type is pred-mcq, pred-cq or intra-q, i.e. if the QUANT column in table D.19 has a 1, then a quantizer scale is transmitted . If the macroblock types are pred-mc, pred-c or intra-d, then the DCT correction is coded using the previously established value for the quantizer scale.

D.6.4.2.3 Motion vectors

If the macroblock type is pred-m, pred-mc or pred-mq, i.e. if the MOTION FORWARD column in table D.19 has a 1, then horizontal and vertical forward motion vectors are transmitted in succession..

D.6.4.2.4 Coded block pattern

If the macroblock type is pred-c, pred-mc, pred-cq or pred-mcq, i.e. if the CODED PATTERN column in table D.19 has a 1, then a coded block pattern is transmitted. This informs the decoder which of the six blocks in the macroblock are coded, i.e. have transmitted DCT quantized coefficients, and which are not coded, i.e. have no additional correction after motion compensation.

The coded block pattern is a number from 0 to 63 that indicates which of the blocks are coded, i.e. have at least one transmitted coefficient, and which are not coded. To understand the structure of the coded block pattern, we refer to figure D.5 and introduce the variables PN to indicate the status of each of the six blocks. If block N is coded then PN has the value one, if it is not coded then PN is zero. The coded block pattern is defined by the equation:

$$CBP = 32*P0 + 16*P1 + 8*P2 + 4*P3 + 2*P4 + P5$$

This is equivalent to the definition given in 2.4.3.6.

For example, if the top two luminance blocks and the Cb block are coded, and the other three are not, then P0 = 1, P1 = 1, P2 = 0, P3 = 0, P4 = 1, and P5 = 0. The coded block pattern is:

$$CBP = 32*1 + 16*1 + 8*0 + 4*0 + 2*1 + 0 = 50$$

Certain patterns are more common than others. Advantage is taken of this fact to increase the coding efficiency and transmit a VLC representing the coded block pattern, rather than the coded block pattern itself. The VLC codes are given in table D.20.

Table D.20 -- VLC table for coded block pattern

CBP	VLC CODE	CBP	VLC CODE	CBP	VLC CODE
60	111	5	0010 111	51	0001 0010
4	1101	9	0010 110	23	0001 0001
8	1100	17	0010 101	43	0001 0000
16	1011	33	0010 100	25	0000 1111
32	1010	6	0010 011	37	0000 1110
12	1001 1	10	0010 010	26	0000 1101
48	1001 0	18	0010 001	38	0000 1100
20	1000 1	34	0010 000	29	0000 1011
40	1000 0	7	0001 1111	45	0000 1010
28	0111 1	11	0001 1110	53	0000 1001
44	0111 0	19	0001 1101	57	0000 1000
52	0110 1	35	0001 1100	30	0000 0111
56	0110 0	13	0001 1011	46	0000 0110
1	0101 1	49	0001 1010	54	0000 0101
61	0101 0	21	0001 1001	58	0000 0100
2	0100 1	41	0001 1000	31	0000 0011 1
62	0100 0	14	0001 0111	47	0000 0011 0
24	0011 11	50	0001 0110	55	0000 0010 1
36	0011 10	22	0001 0101	59	0000 0010 0
3	0011 01	42	0001 0100	27	0000 0001 1
63	0011 00	15	0001 0011	39	0000 0001 0

Thus the coded block pattern of the previous example, 50, would be represented by the code "00010110".

Note that there is no code representing the state in which none of the blocks are coded, a coded block pattern equal to zero. Instead, this state is indicated by the macroblock type.

For macroblocks in I-pictures, and for intra coded macroblocks in P and B-pictures, the coded block pattern is not transmitted, but is assumed to have a value of 63, i.e. all the blocks in the macroblock are coded.

The use of coded block patterns instead of transmitting end of block codes for all blocks follows the practice in CCITT Recommendation H.261.

D.6.4.3 Selection of macroblock type

An encoder has the difficult task of choosing between the different types of macroblocks.

An exhaustive method is to try coding a macroblock to the same degree of accuracy using each type, then choose the type that requires the least number of coding bits.

A simpler method, and one that is computationally less expensive, is to make a series of decisions. One way to order these decisions is:

1: motion compensation or no motion compensation, i.e. is a motion vector transmitted or is it assumed to be zero.
2: intra or non intra coding, i.e. is the macroblock type intra or is it predicted using the motion vector found in step 1.
3: if the macroblock type is non-intra, is it coded or not coded, i.e. is the residual error large enough to be coded using the DCT transform.
4: decide if the quantizer scale is satisfactory or should be changed.

These decisions are summarized in figure D.32.

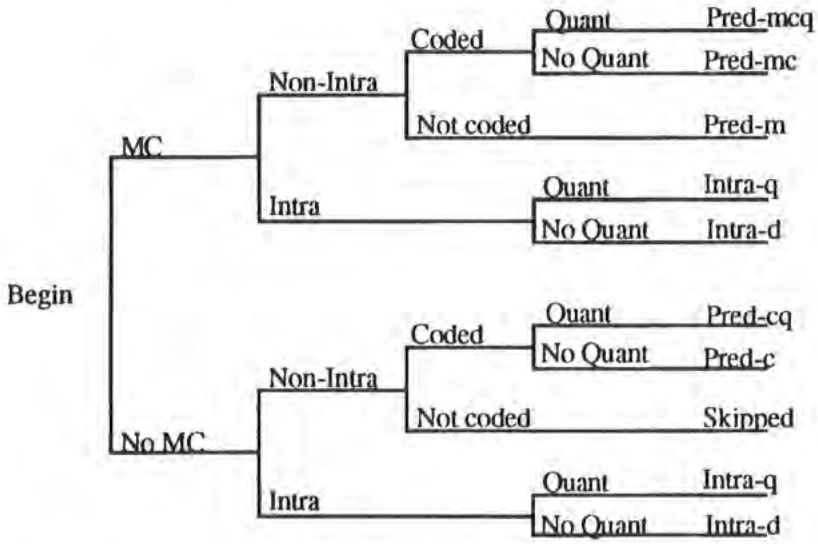


Figure D.32 -- Selection of macroblock types in P-pictures

The four decision steps are discussed in the next four clauses.

D.6.4.3.1 Motion compensation decision

The encoder has an option whether to transmit motion vectors or not for predictive-coded macroblocks. If the motion vector is zero then some code may be saved by not transmitting the motion vectors. Thus one algorithm is to search for the best match and compare the error of the predicted block with that formed with a zero vector. If the motion-compensated block is only slightly better than the uncompensated block, using the selected block matching criterion, then the zero vector might be used to save coding bits.

An algorithm used in the development of both CCITT Recommendation H.261 and this part of ISO/IEC 11172 was as follows.

The block-matching criterion is the sum of absolute differences of all the luminance pels in a macroblock, when compared with the motion-compensated macroblock. If the sum is M for the motion-compensated block, and Z for the zero vector, then the decision of whether to make use of the motion vector is defined by figure D.33.

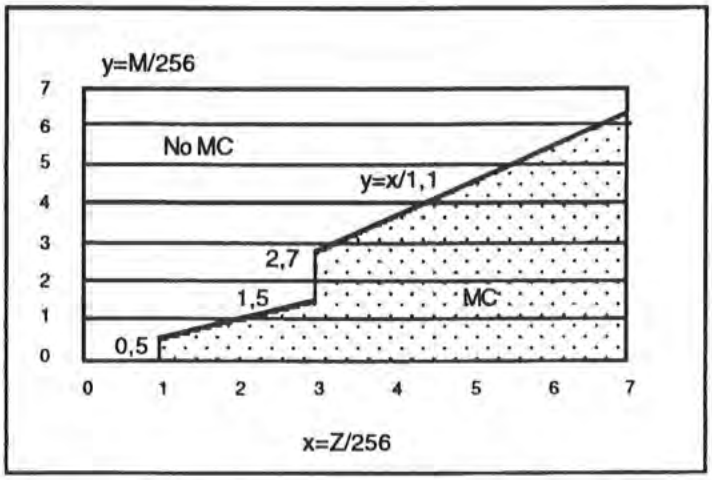


Figure D.33 -- Characteristic MC/No MC

Points on the line dividing the No MC (no motion compensation, i.e. zero vector), from the MC (motion compensation) regions, are regarded as belonging to the no motion compensation region.

It can be seen that if the error is sufficiently low, then no motion compensation should be used. Thus a way to speed up the decision is to examine the zero vector first and decide if it is good enough.

The foregoing algorithm was designed for telecommunications sequences in which the camera was fixed, and in which any movement of the background caused by the "drag along effect" of nearby moving objects was very objectionable. Great care was taken to reduce this spurious motion, and this accounts for the curious shape of the boundary between the two regions in figure D.33.

D.6.4.3.2 Intra/non-intra coding decision

After the encoder has determined the best motion vector, it is in a position to decide whether to use it, or disregard it entirely and code the macroblock as intra. The obvious way to do this is to code the block as intra, and compare the total number of bits required when coded as motion compensated plus correction with the same quantizer scale. The method using the fewest bits may be used.

This may be too computationally expensive for the encoder to do, and a faster algorithm may be required. One such algorithm, used in the simulation model during the development of this part of ISO/IEC 11172, was based on the variance of the luminance component of the macroblock. The variance of the current macroblock and of the difference macroblock (current - motion-compensated previous) is compared. It is calculated using the method represented by the following C program fragment. Note that in calculating the variance of the difference macroblock, the average value is assumed to be zero.

```
int pelp[16][16];        /* Pel values in the Previous macroblock after motion compensation */
int pelc[16][16];        /* Pel values in the Current macroblock */
long dif;                /* Difference between two pel values */
long sum;                /* Sum of the current pel values */
long vard;               /*  Variance of the Difference macroblock */
long varc;               /*Variance of the Current macroblock */
int x,y;                 /* coordinates */

sum = 0;
vard = 0;
varc = 0;
for (y=0;y<16;y++) {
        for (x=0;x<16;x++) {
                sum = sum + pelc[y][x];
                varc = varc + (pelc[y][x]*pelc[y][x]);

                dif = pelc[y][x] - pelp[y][x];
                vard = vard + (dif*dif);
        }
}
vard = vard/256;    /* assumes mean is close to zero */
varc = ( varc/256 ) - ( (sum/256)*(sum/256) );
```

The decision as to whether to code as intra or non intra is then based on figure D.34.

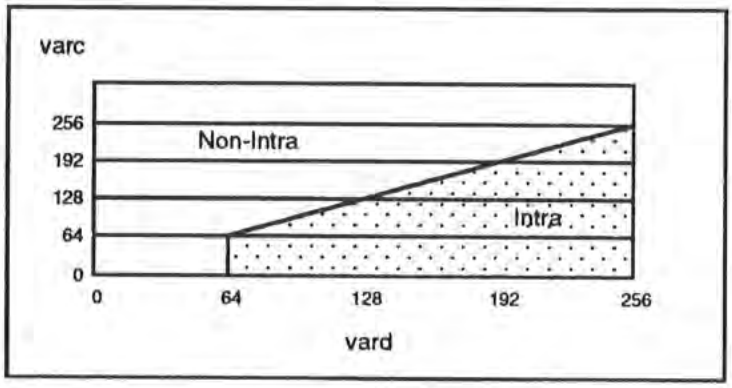


Figure D.34 -- Characteristic intra/non-intra

Points on the line dividing the non-intra from the intra regions, are regarded as belonging to the non-intra region.

D.6.4.3.3 Coded/not coded decision

The choice of coded or not coded is a result of quantization; when all coefficients are zero then a block is not coded. A macroblock is not coded if no block in it is coded, else it is coded.

D.6.4.3.4 Quantizer/no quantizer decision

Generally the quantizer scale is changed based on local scene content to improve the picture quality, and on the buffer fullness of the model decoder to prevent overflow and underflow.

D.6.4.4 DCT transform

Coefficients of intra blocks are transformed into quantized coefficients in the same way that they were for intra blocks in I-pictures. Prediction of the dc coefficient differs, however. The dc predicted values are all set to 1 024 (128*8) for intra blocks in P and B-pictures, unless the previous block was intra coded.

Coefficients of non-intra blocks are coded in a similar way. The main difference is that the coefficients to be transformed represent differences between pel values rather than the pel values themselves. The differences are obtained by subtracting the motion-compensated pel values from the previous picture from

the pel values in the current macroblock. Since the coding is of differences, there is no spatial prediction of the dc term.

D.6.4.5 Quantization of P-pictures

Intra macroblocks in P and B-pictures are quantized using the same method as described for I-pictures.

Non-intra macroblocks in P and B-pictures are quantized using the quantizer scale and the non-intra quantization matrix. Both dc and the ac coefficients are quantized the same way.

The following quantization formula was derived by inverting the reconstruction formula given in 2.4.4.2. Note that the divisor indicates truncation towards zero.

```
int coefforig;      /* original coefficient */
int coeffqant;      /* quantized coefficient */
int coeffrec;       * reconstructed coefficient */
int niqmatrix;      /* non-intra quantization matrix */
int quantscale;     /* quantizer scale */

coeffqant = (8 * coefforig) / (quantscale * niqmatrix);
```

The process is illustrated below:

niqmatrix	16	16	16	16	16
quantscale	10	10	10	10	10
coefforig	-39--20	-19~19	20~39	40~59	60~79
coeffqant	-1	0	1	2	3
coeffrec	-29	0	29	49	69

The last line shows the reconstructed coefficient values. The following diagram shows the characteristics of this quantizer. The flat spot around zero gives this type of quantizer its name: a dead-zone quantizer.

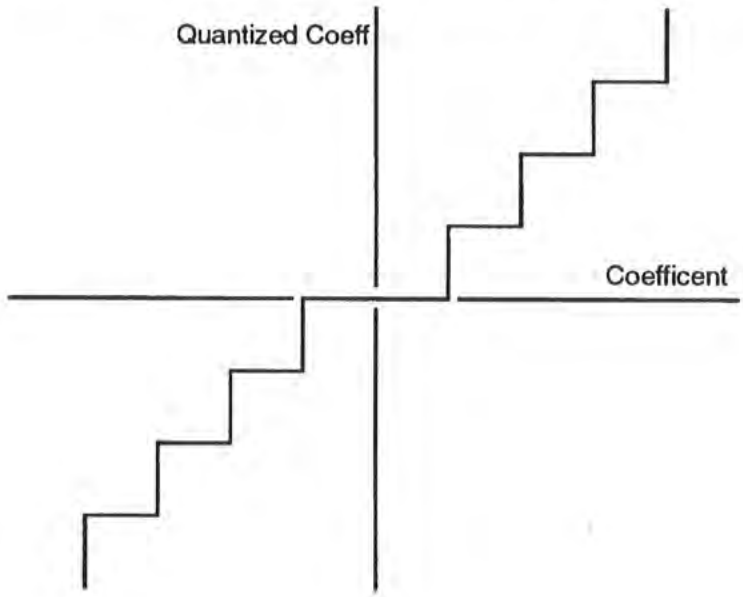


Figure D.35 -- Dead zone quantizer characteristic

D.6.4.6 Coding of quantized coefficients

D.6.4.6.1 Coding of intra blocks

Intra blocks in P-pictures are coded the same way as intra blocks in I-pictures. The only difference lies in the prediction of the dc coefficient. The dc predicted value is 128, unless the previous block was intra coded.

D.6.4.6.2 Coding of non–intra blocks

The coded block pattern is transmitted indicating which blocks have coefficient data. These are coded in a similar way to the coding of intra blocks except that the dc coefficient is coded in the same way as the ac coefficients.

D.6.5 Coding B-pictures

As in I and P-pictures, each B-picture is divided up into one or more slices, which are, in turn, divided into macroblocks. Coding is more complex than for P-pictures, since several types of motion compensated macroblock may be constructed: forward, backward, and interpolated. The difference between the motion-compensated macroblock and the current macroblock is transformed with a two-dimensional DCT giving an array of 8 by 8 transform coefficients. The coefficients are quantized to produce a set of quantized coefficients. The quantized coefficients are then encoded using a run-length value technique.

The encoder does not need to store the decoded B-pictures since they will not be used for motion compensation.

In coding B-pictures, the encoder has more decisions to make than in the case of P-pictures. These decisions are: how to divide the picture up into slices, determine the best motion vectors to use, decide whether to use forward or backward or interpolated motion compensation or to code as intra, and how to set the quantizer scale.

D.6.5.1 Slices in B-pictures

B-pictures are divided into slices in the same way as I and P-pictures. Since B-pictures are not used as a reference for motion compensation, errors in B-pictures are slightly less important than in I or P-pictures. Consequently, it might be appropriate to use fewer slices for B-pictures.

D.6.5.2 Macroblocks in B-pictures

Slices are divided into macroblocks in the same way as for I-pictures.

The macroblock header may contain stuffing. The position of the macroblock is determined by the macroblock address. Whereas the macroblock address increment within a slice for I-pictures is restricted to one, it may be larger for B-pictures. Any macroblocks thus skipped over are called "skipped macroblocks". Skipped macroblocks in B-pictures differ from skipped macroblocks in P-pictures. Whereas in P-pictures skipped macroblocks have a motion vector equal to zero, in B-pictures skipped macroblocks have the same motion vector and the same macroblock type as the previous macroblock, which cannot be intra coded. As there is no additional DCT correction, they require very few bits to transmit.

The next field in the macroblock header defines the macroblock type.

D.6.5.2.1 Macroblock types in B-pictures

There are 12 types of macroblock in B-pictures:

Table D.21 -- Macroblock type VLC for B-pictures (table B.2d)

TYPE	VLC	INTRA	MOTION FORWARD	MOTION BACKWARD	CODED PATTERN	QUANT
pred-i	10	0	1	1	0	0
pred-ic	11	0	1	1	1	0
pred-b	010	0	0	1	0	0
pred-bc	011	0	0	1	1	0
pred-f	0010	0	1	0	0	0
pred-fc	0011	0	1	0	1	0
intra-d	0001 1	1	0	0	0	0
pred-icq	0001 0	0	1	1	1	1
pred-fcq	0000 11	0	1	0	1	1
pred-bcq	0000 10	0	0	1	1	1
intra-q	0000 01	1	0	0	0	1
skipped	N/A					

Compared with P-pictures, there are extra types due to the introduction of the backward motion vector. If only a forward motion vector is present, then the motion compensated-macroblock is constructed from a previous picture, as in P-pictures. If only a backward motion vector is present, then the motion-compensated macroblock is constructed from a future picture. If both forward and backward motion vectors are present, then motion-compensated macroblocks are constructed from both previous and future pictures, and the result is averaged to form the "interpolated" motion-compensated macroblock.

D.6.5.2.2 Quantizer scale

If the macroblock type is pred-icq, pred-fcq, pred-bcq, or intra-q, i.e. if the QUANT column in table D.21 has a 1, then a quantizer scale is transmitted. For the remaining macroblock types, the DCT correction is coded using the previously established value for the quantizer scale.

D.6.5.2.3 Motion vectors

If the MOTION FORWARD column in table D.21 has a 1, then horizontal and vertical forward motion vectors are transmitted in succession. If the MOTION BACKWARD column in table D.21 has a 1, then horizontal and vertical backward motion vectors are transmitted in succession. If both types are present then four component vectors are transmitted in the following order:

horizontal forward
vertical forward
horizontal backward
vertical backward

D.6.5.2.4 Coded block pattern

If the CODED PATTERN column in table D.21 has a 1, then a coded block pattern is transmitted. This informs the decoder which of the six blocks in the macroblock are coded, i.e. have transmitted DCT quantized coefficients, and which are not coded, i.e. have no additional correction after motion compensation.

D.6.5.3 Selection of macroblock type

The encoder has more types of macroblock to choose from in B-pictures, than in P-pictures, and consequently its job is a little harder.

For the simulation model used during development of this part of ISO/IEC 11172, the following sequential decision algorithm was used:

1: motion compensation mode, i.e. is forward or backward or interpolative motion compensation best? What of the vector values?
2: intra or non intra coding, i.e. is the macroblock type intra or is it motion compensated using mode and the vectors found in step 1?
3: if the macroblock type is non-intra, is it coded or not coded, i.e. is the residual error large enough to be coded using the DCT transform.
4: decide if the quantizer scale is satisfactory or should be changed.

These decisions are summarized in the following diagram:

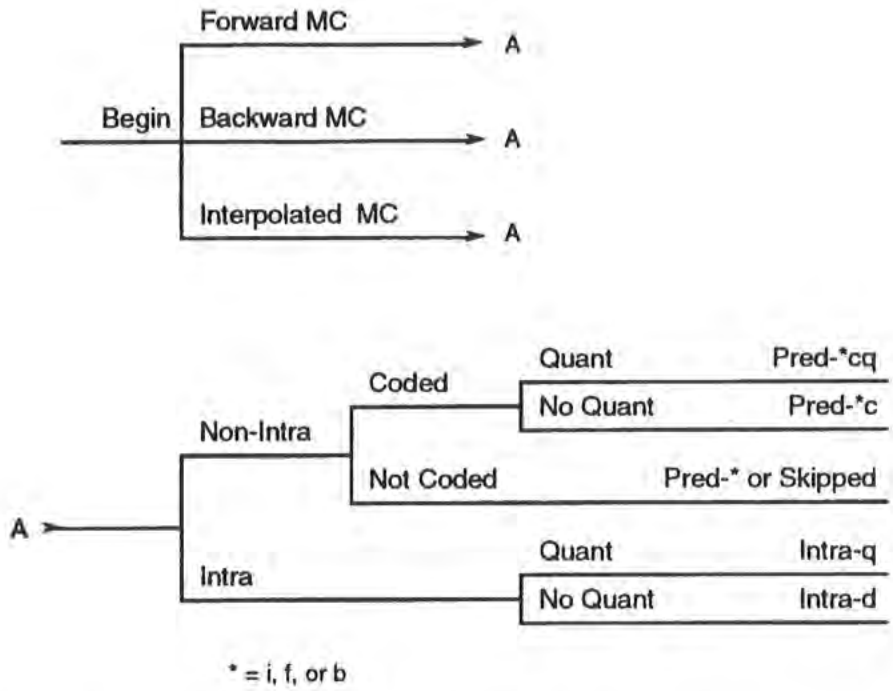


Figure D.36 -- Selection of macroblock type in B-pictures

The four decision steps are discussed in the next four clauses.

D.6.5.3.1 Selecting motion-compensation mode

An encoder should attempt to code B-pictures using skipped macroblocks if possible. This suggests that the encoder should first examine the case where the motion compensation is the same as for the previous macroblock. If the previous macroblock was non-intra, and if the motion-compensated block is good enough, there will be no additional DCT correction required and the block can be coded as skipped.

If the macroblock cannot be coded as skipped, then the following procedure may be followed.

For the simulation model, the selection of a motion compensation mode for a macroblock was based on the minimization of a cost function. The cost function was the MSE of the luminance difference between the motion-compensated macroblock and the current macroblock. The encoder calculated the best motion-compensated macroblock for forward motion compensation. It then calculated the best motion-compensated macroblock for backward motion compensation by a similar method. Finally it averaged the two motion-compensated macroblocks to produce the interpolated macroblock. It then selected the one that had the smallest mean square difference between it and the current macroblock. In the event of a tie, interpolative mode was chosen.

D.6.5.3.2 Intra/non–intra coding decision

Based on the smallest MSE, a decision is made between the best of the three possible prediction modes and the Intra mode. The calculation is similar to that of P-pictures. The variances of the difference macroblock, vard, and of the current macroblock, varc, are calculated.

In the simulation model the final decision was based on simply the macroblock type with the smallest variance. If the two variances were equal, non-intra coding was chosen.

D.6.5.3.3 Coded/not–coded decision

The choice of coded or not coded is a result of quantization, when all coefficients are zero then a block is not coded. A macroblock is not coded if no block in it is coded, else it is coded.

D.6.5.4 DCT transform

Coefficients of blocks are transformed into quantized coefficients in the same way that they are for blocks in P-pictures.

D.6.5.5 Quantization of B-pictures

Blocks in B-pictures are quantized in the same way as for P-pictures.

D.6.5.6 Coding quantized coefficients

Blocks in B-pictures are coded the same way as blocks in P-pictures.

D.6.6 Coding D-pictures

D pictures contain only low frequency information. They are intended to be used for fast visible search modes. It is intended that the low frequency information they contain is sufficient for the user to locate the desired video.

D pictures are coded as the dc coefficients of blocks. There is a bit transmitted for the macroblock type, although only one macroblock type exists. In addition there is a bit denoting end of macroblock.

D.6.7 Coding at lower picture rates

This part of ISO/IEC 11172 does not allow pictures to be dropped at the encoder. This differs from the case of CCITT Recommendation H.261 [5] where temporal sub-sampling may be done by omitting coded pictures from the sequence. This part of ISO/IEC 11172 requires that all source pictures must be encoded and that coded pictures must be inserted into the bitstream nominally at the rate defined by the **picture_rate** field in the sequence header.

Despite this requirement it is possible for encoders to operate at a lower effective picture rate than the one defined in the sequence header by using P-pictures or B-pictures that consist entirely of macroblocks that are copied from a neighbouring reference picture with no DCT information. This creates a flexible method of temporal sub-sampling and picture repetition that may be implemented in the encoder by inserting a defined block of data. For example, to encode at an effective rate of 12,5 Hz in a 25 Hz bitstream, alternate pictures can be copied from the preceding picture by inserting the block of data in table D.22.

Table D.22 -- Example of the coded data elements needed to generate repeated pictures

Value (bits)	Mnemonic	Length (bits)
0000 0000 0000 0000	picture_start_code	32 bits
0000 0001 0000 0000		
xxxx xxxx xx	temporal_reference	10 bits
010	picture_coding_type	3 bits
xxxx xxxx xxxx xxxx	vbv_delay	16 bits
0	full_pel_forward_code	1 bit
001	forward_f_code	3 bits
0000 000	stuffing	7 bits
0000 0000 0000 0000	slice_start_code	32 bits
0000 0001 0000 0001		
0000 1	quantizer_scale	5 bits
1	macroblock_address_increment	1 bit
001	macroblock_type	3 bits
0	motion_horizontal_forward_code	1 bit
0	motion_vertical_forward_code	1 bit
0000 0001 000 (x 11)	macroblock_escape (x11)	121 bits
0000 0011 001	macroblock_address_increment	11 bits
001	macroblock_type	3 bits
0	motion_horizontal_forward_code	1 bit
0	motion_vertical_forward_code	1 bit
0000	stuffing	4 bits
	Total	256 bits

D.7 Decoding MPEG video

D.7.1 Decoding a sequence

D.7.1.1 Decoding for forward playback

At the beginning of a sequence, the decoder will decode the sequence header including the sequence parameters. If a parameter exceeds the capability of the decoder, then the decoder should report this. If the decoder determines that it can decode the bitstream, then it will set up its parameters to match those defined in the sequence header. This will include the horizontal and vertical resolutions and aspect ratio, the bit rate, and the quantization matrices.

Next the decoder will decode the group of pictures header, including the closed_gop and broken_link information, and take any appropriate action. It will decode the first picture header in the group of pictures and read the vbv_delay field. If the decoder uses the vbv_delay information to start-up decoding rather than the information in the system stream (ISO/IEC 11172-1) then it must delay displaying pictures until after a time determined by the vbv_delay information and a knowledge of the decoder's architecture.

If the closed-gop flag is 0, indicating that the group is open, and the broken_link flag is 1, then any B-pictures preceding (in display order) the first I-picture in the group cannot be decoded. The decoder may adopt one of several strategies. It may display the first I-picture during the time that the undecodable B-pictures would be displayed. This strategy maintains audio synchronization and buffer fullness. However it is likely that the broken link has occured because of post coding editing, in which case audio may be discontinuous. An alternative strategy might be to discard the B-pictures entirely, and delay decoding the I-picture until the buffer fullness is within limits.

If playback begins from a random point in the bitstream, the decoder should discard all the bits until it finds a sequence start code, a group of pictures start code, or a picture start code which introduces an I-picture. The slices and macroblocks in the picture are decoded and written into a display buffer, and perhaps into another buffer. The decoded pictures may be post processed and displayed in the order defined by the temporal reference at the picture rate defined in the sequence header.

Subsequent pictures are processed at the appropriate times to avoid buffer overflow and underflow.

D.7.1.2 Decoding for fast playback

Fast forward can be supported by D pictures. It can also be supported by an appropriate spacing of I-pictures in a sequence. For example, if I-pictures were spaced regularly every 10 pictures, then a decoder might be able to playback the sequence at 10 times the normal speed by decoding and displaying only the I-pictures. This simple concept places considerable burdens on the media and the decoder. The media must be capable of speeding up and delivering 10 times the data rate, the decoder must be capable of accepting this higher data rate and decoding the I-pictures. Since I-pictures typically require significantly more bits to code than P or B-pictures, the decoder will have to decode significantly more than 10% of the data, even if it can search for picture start codes and discard the data for P and B-pictures.

For example, a sequence might be coded as follows:

I B P B P B P B P B I B P B P B P B P B I ...

Assume that the average code size per picture is C, that each B-picture requires 0,3C, that each P-picture requires 1,5C, and that each I-picture requires 2,5C, then the I-pictures require 25% of the code for their 10% of the display time.

Another way to achieve fast forward in a constant bit rate application, is for the media itself to sort out the I-pictures and transmit them. This would allow the data rate to remain constant. Since this selection process can be made to produce a valid ISO/IEC 11172-2 bitstream, the decoder should be able to decode it. If every I-picture of the preceding example were selected, then one I-picture would be transmitted every 2.5 picture periods, and the speed up rate would be 10/2,5 = 4 times. The decoder might be able to display the I-pictures at exactly 2,5 periods, or it might alternate displays at 2 and 3 periods.

If alternate I-pictures of the preceding example were selected, then one I-picture would again be transmitted every 2,5 picture periods, but the speed up rate would be 20/2,5 = 8 times.

If one in N I-pictures of the preceding example were selected, then the speed up rate would be 10N/2,5 = 4N times.

D.7.1.3 Decoding for pause and step modes

Decoding for pause requires the decoder to be able to control the incoming bitstream, and display a decoded picture without decoding any additional pictures. If the decoder has full control over the bitstream, then it can be stopped for pause and resumed when playback resumes. If the decoder has less control, as in the case of a CD ROM, then there may be a delay before playback can be resumed.

D.7.1.4 Decoding for reverse playback

To decode a bitstream and playback in reverse, the decoder must decode each group of pictures in the forward direction, store the decoded pictures, then display them in reverse order. This places severe storage requirements on the decoder in addition to any problems in gaining access to the coded bitstream in the correct order.

To reduce decoder memory requirements, groups of pictures should be small. There is no mechanism in the syntax for the encoder to state what the decoder requirements are in order to playback in reverse.

The amount of display buffer storage may be reduced by reordering the pictures, either by having the storage unit read and transmit them in another order, or by reordering the coded pictures in a decoder buffer. To illustrate the savings, consider the following typical group of pictures:

B	B	**I**	B	B	**P**	B	B	**P**	B	B	**P**	pictures in display order
0	1	2	3	4	5	6	7	8	9	10	11	temporal reference
I	B	B	**P**	B	B	**P**	B	B	**P**	B	B	pictures in coded order
2	0	1	5	3	4	8	6	7	11	9	10	temporal reference
I	**P**	**P**	**P**	B	B	B	B	B	B	B	B	pictures in new order
2	5	8	11	10	9	7	6	4	3	1	0	temporal reference

Figure D.37 -- Example group of pictures

The decoder would decode the pictures in the new order, and display them in the reverse of the normal display order. Since the B-pictures are not decoded until they are ready to be displayed, the display buffer storage is minimized. The first two B-pictures, 0 and 1, would remain stored in the input buffer until the last P-picture in the previous group of pictures is decoded.

D.8 Post processing

D.8.1 Editing

Editing of a video sequence is best performed before compression, but situations arise where only the coded bitstream is available. One possible method would be to decode the bitstream, perform the required editing, and recode the bitstream. This usually leads to a loss in video quality, and it is better, if possible, to edit the coded bitstream itself.

Although editing may take several forms, the following discussion pertains only to editing at the picture level: deletion of coded video material from a bitstream, insertion of coded video material into a bitstream, or rearrangement of coded video material within a bitstream.

If editing is anticipated, e.g. clip video is provided analogous to clip art for still pictures, then the video can be encoded with well defined cutting points. These cutting points are places at which the bitstream may be broken apart or joined. Each cutting point should be followed by a closed group of pictures. This allows smooth playback after editing.

An editor must take care to ensure that the bitstream it produces is a legal bitstream. In particular it must ensure that the new bitstream complies with the requirements of the video buffering verifier. This is a difficult task and in general it will not be possible to edit together arbitrary sections of bitstreams that comply with this part of ISO/IEC 11172 to produce another bitstream that also complies with this part of ISO/IEC 11172 (see for example figure D.38).

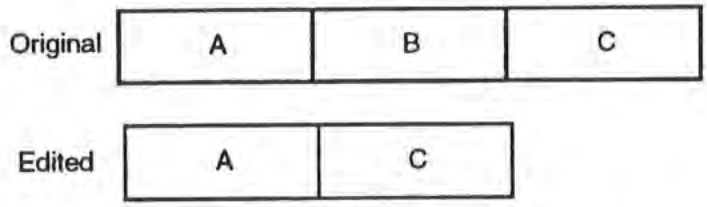


Figure D.38 -- Sequences

It may however be possible to deliberately encode bitstreams in a manner that allows some editing to occur. For instance, if all Groups of Pictures had the same number of pictures and were encoded with the same number of bits, then many of the problems of complying with the video buffering verifier would be solved.

The easiest editing task is to cut at the beginning of groups of pictures. If the group of pictures following the cut is open, which can be detected by examining the closed_gop flag in the group of pictures header, then the editor must set the broken_link bit to 1 to indicate to the decoder that the previous group of pictures cannot be used for decoding any B-pictures.

D.8.2 Resampling

The decoded bitstream may not match the picture rate or the spatial resolution of the display device. In this quite frequent situation, the decoded video must be resampled or scaled.

One example, considered under preprocessing, is the case where the decoded video has SIF resolution and must be converted to CCIR 601 resolution.

D.8.2.1 Conversion of MPEG SIF to CCIR 601 format

A SIF is converted to its corresponding CCIR 601 format by spatial upsampling. A linear phase FIR filter is applied after the insertion of zeroes between samples. A filter that can be used for upsampling the luminance is shown in figure D.39:

-12	0	140	256	140	0	-12	// 256

Figure D.39 -- Upsampling filter for luminance

At the end of the lines some special technique, such as replicating the last pel, must be adopted.

According to CCIR Rec. 601 the chrominance samples need to be co-sited with the luminance samples 1, 3, 5,... In order to achieve the proper location, the upsampling filter should have an even number of taps,as shown in figure D.40.

1	3	3	1	// 4

Figure D.40 -- Upsampling filter for chrominance

The SIF may be reconstructed by adding four black pels to each end of the horizontal luminance lines in the decoded bitmap, and two gray pels to each end of the horizontal chrominance lines. The luminance SIF may then be upsampled horizontally and vertically. The chrominance SIF should be upsampled once horizontally and twice vertically. This process is illustrated by the following diagram:

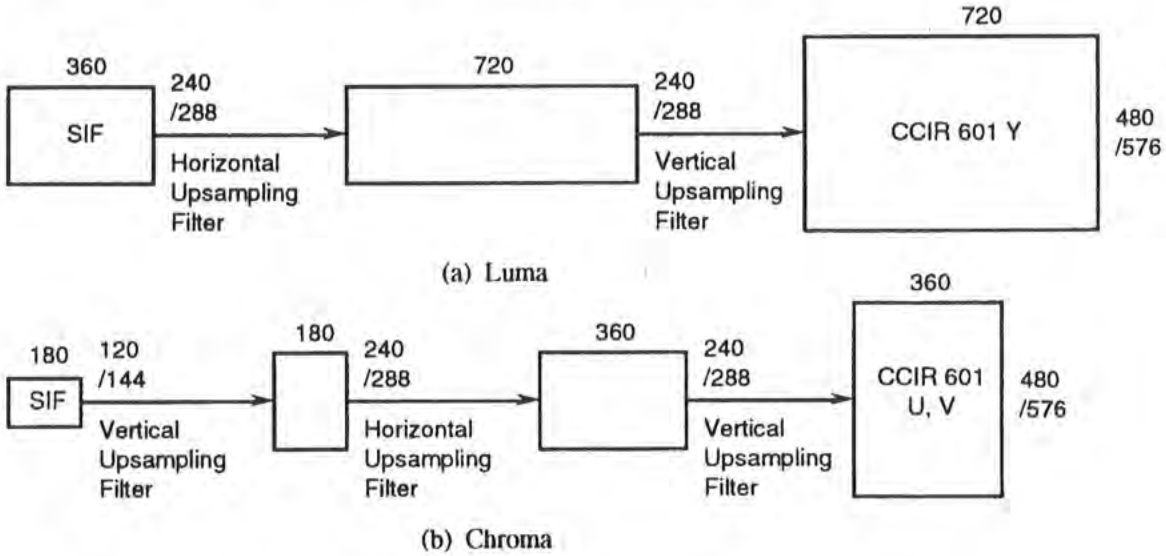


Figure D.41 -- Simplified decoder block diagram

D.8.2.2 Temporal resampling

Since the picture rates are limited to those commonly used in the television industry, the same techniques may be applied. For example, conversion from 24 pictures/s to 60 fields/s may be achieved by the technique of 3:2 pulldown.

Video coded at 25 pictures/s can be converted to 50 fields/s by displaying the original decoded lines in the odd CCIR 601 fields, and the interpolated lines in the even fields. Video coded at 29,97 or 30 pictures/s may be converted to a field rate twice as large using the same method.

Video coded at 23,976 or 24 pictures/s may be converted to 50 fields/s by speeding it up by about 4% and decoding it as if it had been encoded at 25 pictures/s. The decoded pictures could be displayed in the odd fields, and interpolated pictures in the even fields. The audio must be maintained in synchronization, either by increasing the pitch, or by speeding it up without a pitch change.

Video coded at 23,976 or 24 pictures/s may be converted to 59,94 or 60 fields/s using the technique of 3:2 pull down.

Annex E

(informative)

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Annex F

(informative)

List of patent holders

The user's attention is called to the possibility that - for some of the processes specified in this part of ISO/IEC 11172 - compliance with this International Standard may require use of an invention covered by patent rights.

By publication of this part of ISO/IEC 11172, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. However, each company listed in this annex has filed with the Information Technology Task Force (ITTF) a statement of willingness to grant a license under such rights that they hold on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license.

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APPENDIX ITU01

H.263 : Video coding for low bit rate communication

Recommendation H.263 (02/98)

Table of Contents

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INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

H.263

(02/98)

SERIES H: AUDIOVISUAL AND MULTIMEDIA SYSTEMS

Infrastructure of audiovisual services – Coding of moving video

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Video coding for low bit rate communication

ITU-T Recommendation H.263

(Previously CCITT Recommendation)

ITU-T H-SERIES RECOMMENDATIONS

AUDIOVISUAL AND MULTIMEDIA SYSTEMS

Characteristics of transmission channels used for other than telephone purposes	H.10–H.19
Use of telephone-type circuits for voice-frequency telegraphy	H.20–H.29
Telephone circuits or cables used for various types of telegraph transmission or simultaneous transmission	H.30–H.39
Telephone-type circuits used for facsimile telegraphy	H.40–H.49
Characteristics of data signals	H.50–H.99
CHARACTERISTICS OF VISUAL TELEPHONE SYSTEMS	H.100–H.199
INFRASTRUCTURE OF AUDIOVISUAL SERVICES	
General	H.200–H.219
Transmission multiplexing and synchronization	H.220–H.229
Systems aspects	H.230–H.239
Communication procedures	H.240–H.259
Coding of moving video	**H.260–H.279**
Related systems aspects	H.280–H.299
Systems and terminal equipment for audiovisual services	H.300–H.399

For further details, please refer to ITU-T List of Recommendations.

ITU-T RECOMMENDATION H.263

VIDEO CODING FOR LOW BIT RATE COMMUNICATION

Summary

This Recommendation specifies a coded representation that can be used for compressing the moving picture component of audio-visual services at low bit rates. The basic configuration of the video source coding algorithm is based on Recommendation H.261 and is a hybrid of inter-picture prediction to utilize temporal redundancy and transform coding of the remaining signal to reduce spatial redundancy. The source coder can operate on five standardized video source formats: sub-QCIF, QCIF, CIF, 4CIF and 16CIF, and can also operate using a broad range of custom video formats.

The decoder has motion compensation capability, allowing optional incorporation of this technique in the coder. Half pixel precision is used for the motion compensation, as opposed to Recommendation H.261 where full pixel precision and a loopfilter are used. Variable length coding is used for the symbols to be transmitted.

In addition to the basic video source coding algorithm, sixteen negotiable coding options are included for improved compression performance and the support of additional capabilities. Additional supplemental information may also be included in the bitstream for enhanced display capability and for external usage.

Source

ITU-T Recommendation H.263 was revised by ITU-T Study Group 16 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 6th of February 1998.

FOREWORD

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

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1.

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

NOTE

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

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CONTENTS

		Page
1	Scope	1
2	References	1
3	Brief specification	2
3.1	Video input and output	2
3.2	Digital output and input	2
3.3	Sampling frequency	2
3.4	Source coding algorithm	2
	3.4.1 Continuous Presence Multipoint and Video Multiplex mode	3
	3.4.2 Unrestricted Motion Vector mode	3
	3.4.3 Syntax-based Arithmetic Coding mode	3
	3.4.4 Advanced Prediction mode	3
	3.4.5 PB-frames mode	3
	3.4.6 Forward Error Correction	3
	3.4.7 Advanced INTRA Coding mode	4
	3.4.8 Deblocking Filter mode	4
	3.4.9 Slice Structured mode	4
	3.4.10 Supplemental enhancement information	4
	3.4.11 Improved PB-frames mode	4
	3.4.12 Reference Picture Selection mode	4
	3.4.13 Temporal, SNR and Spatial Scalability mode	5
	3.4.14 Reference Picture Resampling mode	5
	3.4.15 Reduced-Resolution Update mode	5
	3.4.16 Independent Segment Decoding mode	5
	3.4.17 Alternative INTER VLC mode	5
	3.4.18 Modified Quantization mode	5
3.5	Bit rate	6
3.6	Buffering	6
3.7	Symmetry of transmission	6
3.8	Error handling	6
3.9	Multipoint operation	7
4	Source coder	7
4.1	Source format	7
4.2	Video source coding algorithm	9
	4.2.1 GOBs, slices, macroblocks and blocks	9
	4.2.2 Prediction	11

Page

4.2.3 Motion compensation 12
4.2.4 Quantization 12
4.3 Coding control 13
4.4 Forced updating 13
4.5 Byte alignment of start codes 13
5 Syntax and semantics 13
5.1 Picture layer 22
5.1.1 Picture Start Code (PSC) (22 bits) 22
5.1.2 Temporal Reference (TR) (8 bits) 23
5.1.3 Type Information (PTYPE) (Variable Length) 23
5.1.4 Plus PTYPE (PLUSPTYPE) (Variable Length) 24
5.1.5 Custom Picture Format (CPFMT) (23 bits) 27
5.1.6 Extended Pixel Aspect Ratio (EPAR) (16 bits) 28
5.1.7 Custom Picture Clock Frequency Code (CPCFC) (8 bits) 28
5.1.8 Extended Temporal Reference (ETR) (2 bits) 28
5.1.9 Unlimited Unrestricted Motion Vectors Indicator (UUI) (Variable length) 29
5.1.10 Slice Structured Submode bits (SSS) (2 bits) 29
5.1.11 Enhancement Layer Number (ELNUM) (4 bits) 29
5.1.12 Reference Layer Number (RLNUM) (4 bits) 29
5.1.13 Reference Picture Selection Mode Flags (RPSMF) (3 bits) 29
5.1.14 Temporal Reference for Prediction Indication (TRPI) (1 bit) 30
5.1.15 Temporal Reference for Prediction (TRP) (10 bits) 30
5.1.16 Back-Channel message Indication (BCI) (Variable length) 30
5.1.17 Back-Channel Message (BCM) (Variable length) 30
5.1.18 Reference Picture Resampling Parameters (RPRP) (Variable length) 30
5.1.19 Quantizer Information (PQUANT) (5 bits) 30
5.1.20 Continuous Presence Multipoint and Video Multiplex (CPM) (1 bit) 31
5.1.21 Picture Sub-Bitstream Indicator (PSBI) (2 bits) 31
5.1.22 Temporal Reference for B-pictures in PB-frames (TR_B) (3/5 bits) 31
5.1.23 Quantization information for B-pictures in PB-frames (DBQUANT) (2 bits) 31
5.1.24 Extra Insertion Information (PEI) (1 bit) 31
5.1.25 Supplemental Enhancement Information (PSUPP) (0/8/16 ... bits) 31
5.1.26 Stuffing (ESTUF) (Variable length) 32
5.1.27 End Of Sequence (EOS) (22 bits) 32
5.1.28 Stuffing (PSTUF) (Variable length) 32
5.2 Group of Blocks Layer 32
5.2.1 Stuffing (GSTUF) (Variable length) 32

Page

5.2.2 Group of Block Start Code (GBSC) (17 bits) 33
5.2.3 Group Number (GN) (5 bits)..... 33
5.2.4 GOB Sub-Bitstream Indicator (GSBI) (2 bits)..... 33
5.2.5 GOB Frame ID (GFID) (2 bits)..... 33
5.2.6 Quantizer Information (GQUANT) (5 bits)..... 33
5.3 Macroblock layer..... 33
5.3.1 Coded macroblock indication (COD) (1 bit) 34
5.3.2 Macroblock type & Coded Block Pattern for Chrominance (MCBPC) (Variable length) 34
5.3.3 Macroblock mode for B-blocks (MODB) (Variable length)..... 37
5.3.4 Coded Block Pattern for B-blocks (CBPB) (6 bits)..... 37
5.3.5 Coded Block Pattern for luminance (CBPY) (Variable length)..... 37
5.3.6 Quantizer Information (DQUANT) (2 bits/Variable Length)..... 37
5.3.7 Motion Vector Data (MVD) (Variable length) 38
5.3.8 Motion Vector Data (MVD_{2-4}) (Variable length)..... 40
5.3.9 Motion Vector Data for B-macroblock (MVDB) (Variable length)..... 40
5.4 Block layer..... 40
5.4.1 DC coefficient for INTRA blocks (INTRADC) (8 bits)..... 41
5.4.2 Transform Coefficient (TCOEF) (Variable length) 41
6 Decoding process 44
6.1 Motion compensation..... 44
6.1.1 Differential motion vectors 44
6.1.2 Interpolation for subpixel prediction..... 46
6.2 Coefficients decoding..... 46
6.2.1 Inverse quantization 46
6.2.2 Clipping of reconstruction levels 46
6.2.3 Zigzag positioning..... 47
6.2.4 Inverse transform..... 47
6.3 Reconstruction of blocks..... 47
6.3.1 Summation 47
6.3.2 Clipping..... 48
Annex A – Inverse transform accuracy specification..... 48
Annex B – Hypothetical Reference Decoder..... 49

Page

Annex C – Considerations for multipoint 51

C.1 Freeze picture request 51

C.2 Fast update request 51

C.3 Freeze picture release 51

C.4 Continuous Presence Multipoint and Video Multiplexing (CPM) 51

C.4.1 End Of Sub-Bitstream code (EOSBS) (23 bits) 52

C.4.2 Ending Sub-Bitstream Indicator (ESBI) (2 bits) 53

Annex D – Unrestricted Motion Vector mode 53

D.1 Motion vectors over picture boundaries 53

D.1.1 Restrictions for motion vector values 54

D.2 Extension of the motion vector range 54

Annex E – Syntax-based Arithmetic Coding mode 56

E.1 Introduction 56

E.2 Specification of SAC encoder 57

E.3 Specification of SAC decoder 58

E.4 Syntax 58

E.5 PSC_FIFO 59

E.6 Header layer symbols 59

E.7 Macroblock and Block layer symbols 60

E.8 SAC models 61

Annex F – Advanced Prediction mode 64

F.1 Introduction 64

F.2 Four motion vectors per macroblock 64

F.3 Overlapped motion compensation for luminance 65

Annex G – PB-frames mode 68

G.1 Introduction 68

G.2 PB-frames and INTRA blocks 69

G.3 Block layer 69

G.4 Calculation of vectors for the B-picture in a PB-frame 69

G.5 Prediction of a B-block in a PB-frame 70

Annex H – Forward error correction for coded video signal 72

H.1 Introduction 72

H.2 Error correction framing 72

H.3 Error correcting code 72

Page

H.4 Relock time for error corrector framing 72

Annex I – Advanced INTRA Coding mode 73

I.1 Introduction 73

I.2 Syntax 74

I.3 Decoding process 74

Annex J – Deblocking Filter mode 80

J.1 Introduction 80

J.2 Relation to UMV and AP modes (Annexes D and F) 81

J.3 Definition of the deblocking edge filter 81

Annex K – Slice Structured mode 85

K.1 Introduction 85

K.2 Structure of slice layer 86

K.2.1 Stuffing (SSTUF) (Variable length) 86

K.2.2 Slice Start Code (SSC) (17 bits) 86

K.2.3 Slice Emulation Prevention Bit 1 (SEPB1) (1 bit) 86

K.2.4 Slice Sub-Bitstream Indicator (SSBI) (4 bits) 86

K.2.5 Macroblock Address (MBA) (5/6/7/9/11/12/13/14 bits) 87

K.2.6 Slice Emulation Prevention Bit 2 (SEPB2) (1 bit) 87

K.2.7 Quantizer Information (SQUANT) (5 bits) 87

K.2.8 Slice Width Indication in Macroblocks (SWI) (3/4/5/6/7 bits) 87

K.2.9 Slice Emulation Prevention Bit 3 (SEPB3) (1 bit) 88

Annex L – Supplemental Enhancement Information Specification 88

L.1 Introduction 88

L.2 PSUPP format 88

L.3 Do Nothing 89

L.4 Full-Picture Freeze Request 89

L.5 Partial-Picture Freeze Request 89

L.6 Resizing Partial-Picture Freeze Request 90

L.7 Partial-Picture Freeze-Release Request 90

L.8 Full-Picture Snapshot Tag 90

L.9 Partial-Picture Snapshot Tag 91

L.10 Video Time Segment Start Tag 91

L.11 Video Time Segment End Tag 91

L.12 Progressive Refinement Segment Start Tag 91

L.13 Progressive Refinement Segment End Tag 91

Page

L.14 Chroma Keying Information 92

L.15 Extended Function Type 94

Annex M – Improved PB-frames mode 94

M.1 Introduction 94

M.2 B_{PB}-macroblock prediction modes 95

M.2.1 Bidirectional prediction 95

M.2.2 Forward prediction 95

M.2.3 Backward prediction 95

M.3 Calculation of vectors for bidirectional prediction of a the B-macroblock 95

M.4 MODB table 95

Annex N – Reference Picture Selection mode 96

N.1 Introduction 96

N.2 Video source coding algorithm 97

N.3 Channel for back-channel messages 97

N.3.1 Separate logical channel mode 98

N.3.2 Videomux mode 98

N.4 Syntax 98

N.4.1 Forward channel 98

N.4.2 Back-Channel Message (BCM) syntax 100

N.5 Decoder process 101

Annex O – Temporal, SNR, and Spatial Scalability mode 102

O.1 Overview 102

O.1.1 Temporal scalability 102

O.1.2 SNR scalability 103

O.1.3 Spatial scalability 104

O.1.4 Multilayer scalability 105

O.2 Transmission order of pictures 106

O.3 Picture layer syntax 108

O.4 Macroblock layer syntax 108

O.4.1 Coded macroblock indication (COD) (1 bit) 110

O.4.2 MBTYPE/MCBPC (VLC) 110

O.4.3 Coded Block Pattern for Chrominance (CBPC) (Variable length) 112

O.4.4 Coded Block Pattern for Luminance (CBPY) (Variable length) 112

O.4.5 Quantizer Information (DQUANT) (2 bits/Variable length) 113

O.4.6 Motion vector data (MVDFW, MVDBW) (Variable length) 113

Page

O.5 Motion vector decoding 113

O.5.1 Differential motion vectors 113

O.5.2 Motion vectors in direct mode 113

O.6 Interpolation filters 113

Annex P – Reference picture resampling 116

P.1 Introduction 116

P.2 Syntax 119

P.2.1 Warping Displacement Accuracy (WDA) (2 bits) 119

P.2.2 Warping parameters (Variable length) 119

P.2.3 Fill Mode (FILL_MODE) (2 bits) 120

P.2.4 Fill Color Specification (Y_FILL, C_B_EPB, C_B_FILL, C_R_EPB, C_R_FILL) (26 bits) 120

P.3 Resampling algorithm 121

P.4 Example of implementation 124

P.4.1 Displacements of virtual points 124

P.4.2 Resampling algorithm 124

P.5 Factor-of-4 resampling 126

P.5.1 Factor-of-4 upsampling 126

P.5.2 Factor-of-4 downsampling 128

Annex Q – Reduced-Resolution Update mode 129

Q.1 Introduction 129

Q.2 Decoding procedure 130

Q.2.1 Reference preparation 131

Q.2.2 Macroblock layer decoding 131

Q.2.3 Picture store 132

Q.2.4 Display 132

Q.3 Extension of referenced picture 133

Q.4 Reconstruction of motion vectors 134

Q.5 Enlarged overlapped motion compensation for luminance 136

Q.6 Upsampling of the reduced-resolution reconstructed prediction error 138

Q.6.1 Upsampling procedure for the pixels inside a 16 × 16 reconstructed prediction error block 140

Q.6.2 Upsampling procdedure for the pixels at the boundary of 16 × 16 reconstructed prediction error block 141

Q.7 Block boundary filter 141

Q.7.1 Definition of the default block boundary filter 142

Page

Q.7.2 Definition of the block boundary filter when Deblocking Filter mode is used 142

Annex R – Independent Segment Decoding mode 143

R.1 Introduction 143

R.2 Mode operation 143

R.3 Constraints on usage 144

R.3.1 Constraint on segment shapes 144

R.3.2 Constraint on changes of segment shapes 144

Annex S – Alternative INTER VLC mode 145

S.1 Introduction 145

S.2 Alternative INTER VLC for coefficients 145

S.2.1 Encoder action 145

S.2.2 Decoder action 145

S.3 Alternative INTER VLC for CBPY 146

Annex T – Modified Quantization mode 146

T.1 Introduction 146

T.2 Modified DQUANT Update 146

T.2.1 Small-step QUANT alteration 146

T.2.2 Arbitrary QUANT selection 147

T.3 Altered quantization step size for chrominance coefficients 147

T.4 Modified coefficient range 148

T.5 Usage restrictions 148

Appendix I – Error tracking 149

I.1 Introduction 149

I.2 Error tracking 149

Appendix II – Recommended Optional Enhancement 150

II.1 Introduction 150

II.2 Levels of preferred mode support 151

II.2.1 Level 1 preferred modes 151

II.2.2 Level 2 preferred modes 152

II.2.3 Level 3 preferred modes 152

II.3 Picture formats and picture clock frequencies 153

Recommendation H.263

VIDEO CODING FOR LOW BIT RATE COMMUNICATION

(revised in 1998)

1 Scope

This Recommendation specifies a coded representation that can be used for compressing the moving picture component of audio-visual services at low bit rates. The basic configuration of the video source coding algorithm is based on Recommendation H.261. Sixteen negotiable coding options are included for improved performance and increased functionality. This Recommendation contains Version 2 of Recommendation H.263, which is fully compatible with the original Recommendation, adding only optional features to the original Version 1 content of the Recommendation.

2 References

The following Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below.

[1] ITU-R Recommendation BT.601-5 (1995), *Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios.*

Reference [1] is referenced herein to define the (Y, C_B, C_R) colour space and its 8-bit integer representation for pictures used by video codecs designed according to this Recommendation. (Reference [1] is not used to define any other aspects of this Recommendation.)

The following additional ITU-T Recommendations are mentioned for illustration purposes in this text; however, they do not constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

[2] ITU-T Recommendation H.223 (1996), *Multiplexing protocol for low bit rate multimedia communication.*

[3] ITU-T Recommendation H.242 (1997), *System for establishing communication between audiovisual terminals using digital channels up to 2 Mbit/s.*

[4] ITU-T Recommendation H.245 (1998), *Control protocol for multimedia communication.*

[5] ITU-T Recommendation H.261 (1993), *Video codec for audiovisual services at p × 64 kbit/s.*

[6] ITU-T Recommendation H.262 (1995) | ISO/IEC 13818-2:1996, *Information technology – Generic coding of moving pictures and associated audio information: Video.*

[7] ITU-T Recommendation H.324 (1998), *Terminal for low bit rate multimedia communication.*

3 Brief specification

An outline block diagram of the codec is given in Figure 1.

3.1 Video input and output

To permit a single Recommendation to cover use in and between regions using 625- and 525-line television standards, the standardized source formats on which the source coder operates are based on a Common Intermediate Format (CIF). It is also possible using external negotiation (for example, Recommendation H.245), to enable the use of a wide range of optional custom source formats. The standards of the input and output television signals, which may, for example, be composite or component, analogue or digital and the methods of performing any necessary conversion to and from the source coding format are not subject to recommendation.

3.2 Digital output and input

The video coder provides a self-contained digital bitstream which may be combined with other multi-facility signals (for example as defined in Recommendation H.223). The video decoder performs the reverse process.

3.3 Sampling frequency

Pictures are sampled at an integer multiple of the video line rate. This sampling clock and the digital network clock are asynchronous.

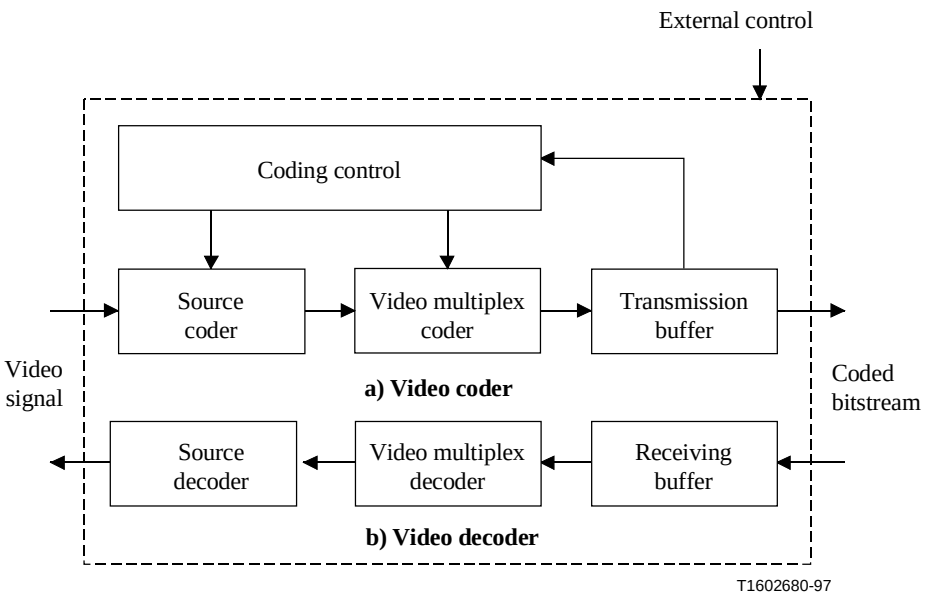


Figure 1/H.263 – Outline block diagram of the video codec

3.4 Source coding algorithm

A hybrid of inter-picture prediction to utilize temporal redundancy and transform coding of the remaining signal to reduce spatial redundancy is adopted. The decoder has motion compensation capability, allowing optional incorporation of this technique in the coder. Half pixel precision is used for the motion compensation, as opposed to Recommendation H.261 where full pixel precision and a loopfilter are used. Variable length coding is used for the symbols to be transmitted.

In addition to the core H.263 coding algorithm, sixteen negotiable coding options can be used, either together or separately (subject to certain restrictions). Additional supplemental information may also be included in the bitstream for enhanced display capability and for external usage. A forward error correction method for application to the resulting video bitstream is provided for use when necessary. The negotiable coding options, forward error correction, and supplemental information usage are described in the subsequent subclauses.

3.4.1 Continuous Presence Multipoint and Video Multiplex mode

In this optional mode, up to four separate video "Sub-Bitstreams" can be sent within the same video channel. This feature is designed for use in continuous presence multipoint application or other situations in which separate logical channels are not available, but the use of multiple video bitstreams is desired (see also Annex C).

3.4.2 Unrestricted Motion Vector mode

In this optional mode, motion vectors are allowed to point outside the picture. The edge pixels are used as prediction for the "non-existing" pixels. With this mode a significant gain is achieved if there is movement across the edges of the picture, especially for the smaller picture formats (see also Annex D). Additionally, this mode includes an extension of the motion vector range so that larger motion vectors can be used. This is especially useful in case of camera movement and large picture formats.

3.4.3 Syntax-based Arithmetic Coding mode

In this optional mode, arithmetic coding is used instead of variable length coding. The SNR and reconstructed pictures will be the same, but significantly fewer bits will be produced (see also Annex E).

3.4.4 Advanced Prediction mode

In this optional mode, Overlapped Block Motion Compensation (OBMC) is used for the luminance part of P-pictures (see also Annex F). Four 8×8 vectors instead of one 16×16 vector are used for some of the macroblocks in the picture. The encoder has to decide which type of vectors to use. Four vectors use more bits, but give better prediction. The use of this mode generally gives a considerable improvement. A subjective gain is achieved because OBMC results in less blocking artifacts.

3.4.5 PB-frames mode

A PB-frame consists of two pictures being coded as one unit. The name PB comes from the name of picture types in Recommendation H.262 where there are P-pictures and B-pictures. Thus a PB-frame consists of one P-picture which is predicted from the previous decoded P-picture and one B-picture which is predicted from both the previous decoded P-picture and the P-picture currently being decoded. The name B-picture was chosen because parts of B-pictures may be bidirectionally predicted from the past and future pictures. With this coding option, the picture rate can be increased considerably without substantially increasing the bit rate (see also Annex G). However, an Improved PB-frames mode is also provided (see also Annex M). The original PB-frames mode is retained herein only for purposes of compatibility with systems made prior to the adoption of the Improved PB-frames mode.

3.4.6 Forward Error Correction

A forward error correction method is specified for use when necessary for the protection of the video bitstream for use when appropriate. The method provided for forward error correction is the same BCH code method specified also in Recommendation H.261 (see also Annex H).

3.4.7 Advanced INTRA Coding mode

In this optional mode, INTRA blocks are first predicted from neighbouring INTRA blocks prior to coding (see also Annex I). Separate Variable Length Code (VLC) tables are defined for the INTRA blocks. The technique is applied to INTRA-macroblocks within INTRA pictures and to INTRA-macroblocks within INTER pictures. This mode significantly improves the compression performance over the INTRA coding of the core H.263 syntax.

3.4.8 Deblocking Filter mode

In this optional mode, a filter is applied across the 8×8 block edge boundaries of decoded I- and P-pictures to reduce blocking artifacts (see also Annex J). The purpose of the filter is to mitigate the occurrence of block edge artifacts in the decoded picture. The filter affects the picture that is used for the prediction of subsequent pictures and thus lies within the motion prediction loop.

3.4.9 Slice Structured mode

In this optional mode, a "slice" layer is substituted for the GOB layer of the bitstream syntax (see also Annex K). The purposes of this mode are to provide enhanced error resilience capability, to make the bitstream more amenable to use with an underlying packet transport delivery, and to minimize video delay. A slice is similar to a GOB, in that it is a layer of the syntax that lies between the picture layer and the macroblock layer. However, the use of a slice layer allows a flexible partitioning of the picture, in contrast with the fixed partitioning and fixed transmission order required by the GOB structure.

3.4.10 Supplemental enhancement information

Additional supplemental information may be included in the bitstream to signal enhanced display capability or to provide information for external usage (see also Annex L). This supplemental information can be used to signal a full-picture or partial-picture freeze or freeze-release request with or without resizing, can also be used to tag particular pictures or sequences of pictures within the video stream for external usage, and can be used to convey chroma key information for video compositing. The supplemental information may be present in the bitstream even though the decoder may not be capable of providing the enhanced capability to use it, or even to properly interpret it – simply discarding the supplemental information is allowable by decoders unless a requirement to provide the requested capability has been negotiated by external means.

3.4.11 Improved PB-frames mode

This optional mode represents an improvement compared to the PB-frames mode option (see also Annexes G and M). The main difference between the two modes is that in the Improved PB-frames mode, each B-block may be forward predicted using a separate motion vector or backward predicted with a zero vector. This significantly improves coding efficiency in situations in which downscaled P-vectors are not good candidates for B-prediction. The backward prediction is particularly useful when there is a scene cut between the previous P-frame and the PB-frame.

3.4.12 Reference Picture Selection mode

An optional mode is provided which improves the performance of real-time video communication over error-prone channel by allowing temporal prediction from pictures other than the most recently-sent reference picture (see also Annex N). This mode can be used with back-channel status messages which are sent back to the encoder to inform it about whether its bitstream is being properly received. In error-prone channel environments, this mode allows the encoder to optimize its video encoding for the conditions of the channel.

3.4.13 Temporal, SNR and Spatial Scalability mode

In this optional mode, there is support for temporal, SNR, and spatial scalability (see also Annex O). Scalability implies that a bitstream is composed of a base layer and one or more associated enhancement layers. The base layer is a separately decodable bitstream. The enhancement layers can be decoded in conjunction with the base layer to increase perceived quality by either increasing the picture rate, increasing the picture quality, or increasing the picture size. SNR scalability refers to enhancement information to increase the picture quality without increasing picture resolution. Spatial scalability refers to enhancement information to increase the picture quality by increasing picture resolution either horizontally, vertically, or both. There is also support for temporal scalability by the use of B-pictures. A B-picture is a scalability enhancement containing pictures that can be bidirectionally predicted from two pictures in a reference layer, one temporally previous to the current picture and one temporally subsequent. B-pictures allows enhancement layer information to be used to increase perceived quality by increasing the picture rate of the displayed enhanced video sequence. This mode can be useful for heterogenous networks with varying bandwidth capacity and also in conjunction with error correction schemes.

3.4.14 Reference Picture Resampling mode

A syntax is provided for supporting an optional mode for which the reference picture used for video image prediction is processed by a resampling operation prior to its use in forming a predictor for the current input picture (see also Annex P). This allows efficient dynamic selection of an appropriate image resolution for video encoding, and can also support picture warping for use as a global motion compensator or special-effect generator.

3.4.15 Reduced-Resolution Update mode

An optional mode is provided which allows reduced-resolution updates to a reference picture having a higher resolution (see also Annex Q). This mode is expected to be used when encoding a highly active scene, and allows an encoder to increase the picture rate at which moving parts of a scene can be represented, while maintaining a higher resolution representation in more static areas of the scene.

3.4.16 Independent Segment Decoding mode

An optional mode is provided which allows a picture to be constructed without any data dependencies which cross GOB or multi-GOB video picture segments or slice boundaries (see also Annex R). This mode provides error robustness by preventing the propagation of erroneous data across the boundaries of the video picture segment areas.

3.4.17 Alternative INTER VLC mode

An optional mode is provided which improves the efficiency of INTER picture coding when significant changes are evident in the picture (see also Annex S). This efficiency improvement is obtained by allowing a VLC code originally designed for INTRA pictures to be used for some INTER picture coefficients as well.

3.4.18 Modified Quantization mode

An optional mode is provided which improves the bit-rate control ability for encoding, reduces chrominance quantization error, expands the range of representable DCT coefficients, and places certain restrictions on coefficient values (see also Annex T). This mode modifies the semantics of the differential quantization step size parameter of the bitstream by broadening the range of step size changes that can be specified. It also reduces the quantization step size used for chrominance data. The range of DCT coefficient levels is broadened to ensure that any possible coefficient value can be

encoded to within the accuracy allowed by the step size. Certain restrictions are also placed on coefficients in this mode to increase error detection performance and minimize decoder complexity.

3.5 Bit rate

The transmission clock is provided externally. The video bit rate may be variable. In this Recommendation no constraints on the video bit rate are given; constraints will be given by the terminal or the network.

3.6 Buffering

The encoder shall control its output bitstream to comply with the requirements of the hypothetical reference decoder defined in Annex B. Video data shall be provided on every valid clock cycle. This can be ensured by MCBPC stuffing (see Tables 7 and 8) or, when forward error correction is used, also by forward error correction stuffing frames (see Annex H).

The number of bits created by coding any single picture shall not exceed a maximum value specified by the parameter BPPmaxKb which is measured in units of 1024 bits. The minimum allowable value of the BPPmaxKb parameter depends on the largest picture size that has been negotiated for use in the bitstream (see Table 1). The picture size is measured as the picture width times height for the luminance (Y) component, measured in pixels. An encoder may use a larger value for BPPmaxKb than as specified in Table 1, provided the larger value is first negotiated by external means, for example Recommendation H.245.

When the Temporal, SNR, and Spatial Scalability mode (Annex O) is employed, the number of bits sent for each picture in each enhancement layer shall not exceed the maximum value specified by BPPmaxKb.

Table 1/H.263 – Minimum BPPmaxKb for different source picture formats

Y picture size in pixels	Minimum BPPmaxKb
up to 25 344 (or QCIF)	64
25 360 to 101 376 (or CIF)	256
101 392 to 405 504 (or 4CIF)	512
405 520 and above	1024

3.7 Symmetry of transmission

The codec may be used for bidirectional or unidirectional visual communication.

3.8 Error handling

Error handling should be provided by external means (for example, Recommendation H.223). If it is not provided by external means (for example, in Recommendation H.221) the optional error correction code and framing as described in Annex H can be used.

A decoder can send a command to encode one or more GOBs (or slices if Annex K is employed) of its next picture in INTRA mode with coding parameters such as to avoid buffer overflow. A decoder can also send a command to transmit only non-empty GOB headers if the Slice Structured mode (see Annex K) is not in use. The transmission method for these signals is by external means (for example, Recommendation H.245).

3.9 Multipoint operation

Features necessary to support switched multipoint operation are included in Annex C.

4 Source coder

4.1 Source format

The source coder operates on non-interlaced pictures having a source format which is defined in terms of:

1) the picture format, as determined by the number of pixels per line, the number of lines per picture, and the pixel aspect ratio; and

2) the timing between pictures, as determined by the Picture Clock Frequency (PCF). For example, the Common Intermediate Format (CIF) has 352 pixels per line, 288 lines, a pixel aspect ratio of 12:11, and a picture clock frequency of 30 000/1001 pictures per second.

The source coder operates on non-interlaced pictures occurring at a Picture Clock Frequency (PCF) of 30 000/1001 (approximately 29.97) times per second, termed the CIF PCF. It is also possible to negotiate the use of an optional custom PCF by external means. A custom PCF is given by 1 800 000/(clock divisor * clock conversion factor) where clock divisor can have values of 1 through 127 and clock conversion factor can either be 1000 or 1001. The tolerance on the picture clock frequency is ± 50 ppm.

Pictures are coded as luminance and two colour difference components (Y, C_B and C_R). These components and the codes representing their sampled values are as defined in ITU-R Recommendation BT.601-5.

- Black = 16;
- White = 235;
- Zero colour difference = 128;
- Peak colour difference = 16 and 240.

These values are nominal ones and the coding algorithm functions with input values of 1 through to 254.

There are five standardized picture formats: sub-QCIF, QCIF, CIF, 4CIF and 16CIF. It is also possible to negotiate a custom picture format. For all of these picture formats, the luminance sampling structure is dx pixels per line, dy lines per picture in an orthogonal arrangement. Sampling of each of the two colour difference components is at dx/2 pixels per line, dy/2 lines per picture, orthogonal. The values of dx, dy, dx/2 and dy/2 are given in Table 2 for each of the standardized picture formats.

Table 2/H.263 – Number of pixels per line and number of lines for each of the standardized H.263 picture formats

Picture format	Number of pixels for luminance (dx)	Number of lines for luminance (dy)	Number of pixels for chrominance (dx/2)	Number of lines for chrominance (dy/2)
sub-QCIF	128	96	64	48
QCIF	176	144	88	72
CIF	352	288	176	144
4CIF	704	576	352	288
16CIF	1408	1152	704	576

For all picture formats, colour difference samples are sited such that their block boundaries coincide with luminance block boundaries as shown in Figure 2. The pixel aspect ratio is the same for each of the standardised picture formats and is the same as defined for QCIF and CIF in Recommendation H.261: (288/3):(352/4), which simplifies to 12:11 in relatively prime numbers. The picture area covered by all of the standardized picture formats except the sub-QCIF picture format has an aspect ratio of 4:3.

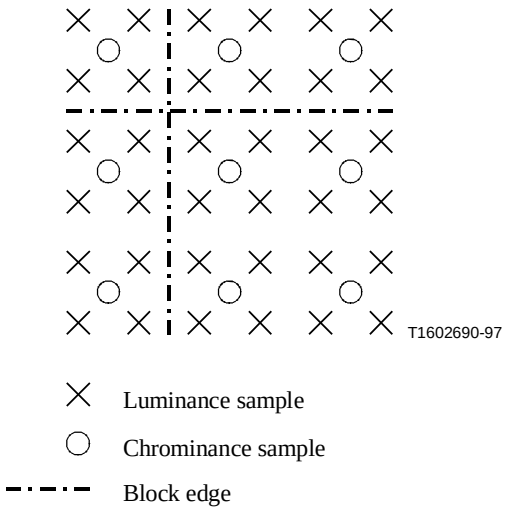


Figure 2/H.263 – Positioning of luminance and chrominance samples

Custom picture formats can have a custom pixel aspect ratio as described in Table 3, if the custom pixel aspect ratio use is first negotiated by external means. Custom picture formats can have any number of lines and any number of pixels per line, provided that the number of lines is divisible by four and is in the range [4, ..., 1152], and provided that the number of pixels per line is also divisible by four and is in the range [4, ..., 2048]. For picture formats having a width or height that is not divisible by 16, the picture is decoded in the same manner as if the width or height had the next larger size that would be divisible by 16 and then the picture is cropped at the right and the bottom to the proper width and height for display purposes only.

Table 3/H.263 – Custom pixel aspect ratios

Pixel aspect ratio	Pixel width:Pixel height
Square	1:1
CIF	12:11
525-type for 4:3 picture	10:11
CIF for 16:9 picture	16:11
525-type for 16:9 picture	40:33
Extended PAR	m:n, m and n are relatively prime

All decoders and encoders shall be able to operate using the CIF picture clock frequency. Some decoders and encoders may also support custom picture clock frequencies. All decoders shall be able to operate using the sub-QCIF picture format. All decoders shall also be able to operate using the QCIF picture format. Some decoders may also operate with CIF, 4CIF or 16CIF, or custom picture formats. Encoders shall be able to operate with one of the picture formats sub-QCIF and QCIF. The

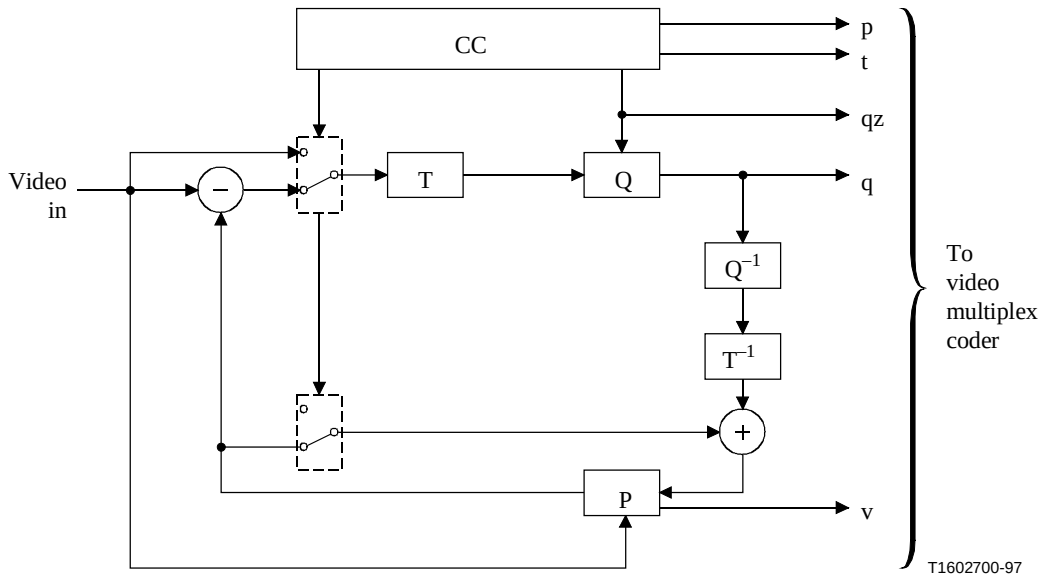
encoders determine which of these two formats are used, and are not obliged to be able to operate with both. Some encoders can also operate with CIF, 4CIF, 16CIF, or custom picture formats. Which optional formats and which picture clock frequencies can be handled by the decoder is signalled by external means, for example Recommendation H.245. For a complete overview of possible picture formats and video coding algorithms, refer to the terminal description, for example Recommendation H.324.

NOTE – For CIF, the number of pixels per line is compatible for practical purposes with sampling the active portions of the luminance and colour difference signals from 525- or 625-line sources at 6.75 and 3.375 MHz respectively. These frequencies have a simple relationship to those in ITU-R Recommendation BT.601-5.

Means shall be provided to restrict the maximum picture rate of encoders by having a minimum number of non-transmitted pictures between transmitted ones. Selection of this minimum number shall be by external means (for example, Recommendation H.245). For the calculation of the minimum number of non-transmitted pictures in PB-frames mode, the P-picture and the B-picture of a PB-frames unit are taken as two separate pictures.

4.2 Video source coding algorithm

The source coder is shown in generalized form in Figure 3. The main elements are prediction, block transformation and quantization.



T	Transform
Q	Quantizer
P	Picture Memory with motion compensated variable delay
CC	Coding control
p	Flag for INTRA/INTER
t	Flag for transmitted or not
qz	Quantizer indication
q	Quantizing index for transform coefficients
v	Motion vector

Figure 3/H.263 – Source coder

4.2.1 GOBs, slices, macroblocks and blocks

Each picture is divided either into Groups Of Blocks (GOBs) or into slices.

A Group Of Blocks (GOB) comprises of up to k * 16 lines, where k depends on the number of lines in the picture format and depends on whether the optional Reduced-Resolution Update mode is in use (see Annex Q). The dependencies are shown in Table 4. If the number of lines is less than or equal to 400 and the optional Reduced-Resolution Update mode is not in use, then k = 1. If the number of lines is less than or equal to 800 and the optional Reduced-Resolution Update mode is in use or the number of lines is more than 400, then k = 2. If the number of lines is more than 800, then k = 4. When using custom picture sizes, the number of lines in the last (bottom-most) GOB may be less than k * 16 if the number of lines in the picture is not divisible by k * 16. However, every GOB in each of the standardized picture formats has k * 16 lines, as the number of lines in each standardized picture format is an integer multiple of k * 16. Thus, for example, if the optional Reduced-Resolution mode is not in use, the number of GOBs per picture is 6 for sub-QCIF, 9 for QCIF, and 18 for CIF, 4CIF and 16CIF. The GOB numbering is done by use of vertical scan of the GOBs, starting with the upper GOB (number 0) and ending with the bottom-most GOB. An example of the arrangement of GOBs in a picture is given for the CIF picture format in Figure 4. Data for each GOB consists of a GOB header (may be empty) followed by data for macroblocks. Data for GOBs is transmitted per GOB in increasing GOB number.

Table 4/H.263 – Parameter k for GOB size definition

Number of Lines dy	Value of k when not in RRU mode	Value of k when in RRU mode
4,…,400	1	2
404,…,800	2	2
804,…,1152	4	4

The Slice Structured mode is described in Annex K. Slices are similar to GOBs in that they are a multi-macroblock layer of the syntax, but slices have a more flexible shape and usage than GOBs, and slices may appear in the bitstream in any order, under certain conditions.

0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

Figure 4/H.263 – Arrangement of Groups of Blocks in a CIF picture

Each GOB is divided into macroblocks. The macroblock structure depends on whether the optional Reduced-Resolution Update (RRU) mode is in use (see Annex Q). Unless in RRU mode, each macroblock relates to 16 pixels by 16 lines of Y and the spatially corresponding 8 pixels by 8 lines of C_B and C_R. Further, a macroblock consists of four luminance blocks and the two spatially corresponding colour difference blocks as shown in Figure 5. Each luminance or chrominance block thus relates to 8 pixels by 8 lines of Y, C_B or C_R. Unless in RRU mode, a GOB comprises one macroblock row for sub-QCIF, QCIF and CIF, two macroblock rows for 4CIF and four macroblock rows for 16CIF.

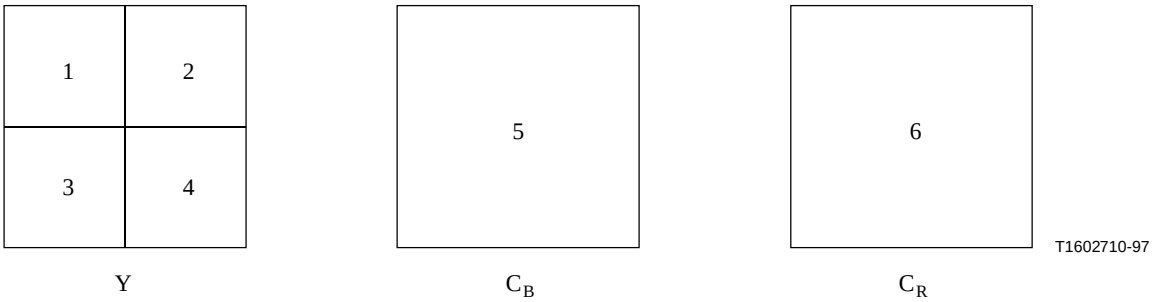


Figure 5/H.263 – Arrangement of blocks in a macroblock

When in RRU mode, a macroblock relates to 32 pixels by 32 lines of Y and the spatially corresponding 16 pixels by 16 lines of C_B and C_R, and each luminance or chrominance block relates to 16 pixels by 16 lines of Y, C_B or C_R. Furthermore, a GOB comprises one macroblock row for CIF and 4CIF, and two macroblock rows for 16CIF.

The macroblock numbering is done by use of horizontal scan of the macroblock rows from left to right, starting with the upper macroblock row and ending with the lower macroblock row. Data for the macroblocks is transmitted per macroblock in increasing macroblock number. Data for the blocks is transmitted per block in increasing block number (see Figure 5).

The criteria for choice of mode and transmitting a block are not subject to recommendation and may be varied dynamically as part of the coding control strategy. Transmitted blocks are transformed and resulting coefficients are quantized and entropy coded.

4.2.2 Prediction

The primary form of prediction is inter-picture and may be augmented by motion compensation (see 4.2.3). The coding mode in which temporal prediction is applied is called INTER; the coding mode is called INTRA if no temporal prediction is applied. The INTRA coding mode can be signalled at the picture level (INTRA for I-pictures or INTER for P-pictures) or at the macroblock level in P-pictures. In the optional PB-frames mode, B-pictures are always coded in INTER mode. The B-pictures are partly predicted bidirectionally (refer to Annex G).

In total, H.263 has seven basic picture types (of which only the first two are mandatory) which are defined primarily in terms of their prediction structure:

1) INTRA: A picture having no reference picture(s) for prediction (also called an I-picture);
2) INTER: A picture using a temporally previous reference picture (also called a P-picture);
3) PB: A frame representing two pictures and having a temporally previous reference picture (see Annex G);
4) Improved PB: A frame functionally similar but normally better than a PB-frame (see Annex M);

5) B: A picture having two reference pictures, one of which temporally precedes the B-picture and one of which temporally succeeds the B-picture and has the same picture size (see Annex O);

6) EI: A picture having a temporally simultaneous reference picture which has either the same or a smaller picture size (see Annex O); and

7) EP: A picture having two reference pictures, one of which temporally precedes the EP-picture and one of which is temporally simultaneous and has either the same or a smaller picture size (see Annex O).

As used herein, a "reference" or "anchor" picture is a picture that contains data which can be used by reference as a basis for the decoding of another picture. This use by reference is also known as "prediction", although it sometimes may actually indicate use in a reverse-temporal direction.

4.2.3 Motion compensation

The decoder will accept one vector per macroblock or, if the Advanced Prediction mode or the Deblocking Filter mode is used, one or four vectors per macroblock (see Annexes F and J). If the PB-frames mode is used, one additional delta vector can be transmitted per macroblock for adaptation of the motion vectors for prediction of the B-macroblock. Similarly, an Improved PB-frame macroblock (see Annex M) can include an additional forward motion vector. B-picture macroblocks (see Annex O) can be transmitted together with a forward and a backward motion vector, and EP-pictures can be transmitted with a forward motion vector.

Both horizontal and vertical components of the motion vectors have integer or half integer values. In the default prediction mode, these values are restricted to the range [–16, 15.5] (this is also valid for the forward and backward motion vector components for B-pictures).

In the Unrestricted Motion Vector mode, however, the maximum range for vector components is increased. If PLUSPTYPE is absent, the range is [–31.5, 31.5], with the restriction that only values that are within a range of [–16, 15.5] around the predictor for each motion vector component can be reached if the predictor is in the range [–15.5, 16]. If PLUSPTYPE is absent and the predictor is outside [–15.5, 16], all values within the range [–31.5, 31.5] with the same sign as the predictor plus the zero value can be reached. If PLUSPTYPE is present, the motion vector values are less restricted (see also Annex D).

In the Reduced-Resolution Update mode, the motion vector range is enlarged to approximately double size, and each vector component is restricted to have only a half-integer or zero value. Therefore, the range of each motion vector component is [–31.5, 30.5] in the default Reduced-Resolution Update mode (see Annex Q) and a larger range if the Unrestricted Motion Vector mode is also used (see also Annex D).

A positive value of the horizontal or vertical component of the motion vector signifies that the prediction is formed from pixels in the referenced picture which are spatially to the right or below the pixels being predicted.

Motion vectors are restricted such that all pixels referenced by them are within the coded picture area, except when the Unrestricted Motion Vector mode, the Advanced Prediction mode, the Advanced Prediction mode, or the Deblocking Filter mode is used (see Annexes D, F, and J), or in B- and EP-pictures of the Temporal, SNR, and Spatial Scalability mode (see Annex O).

4.2.4 Quantization

Unless the optional Advanced INTRA Coding mode or Modified Quantization mode is in use, the number of quantizers is 1 for the first coefficient of INTRA blocks and 31 for all other coefficients. Within a macroblock the same quantizer is used for all coefficients except the first one of INTRA

blocks. The decision levels are not defined. The first coefficient of INTRA blocks is nominally the transform dc value uniformly quantized with a step size of 8. Each of the other 31 quantizers use equally spaced reconstruction levels with a central dead-zone around zero and with a step size of an even value in the range 2 to 62. For the exact formulas, refer to 6.2. For quantization using the Advanced INTRA Coding mode, refer to Annex I. For quantization using the Modified Quantization mode, refer to Annex T.

NOTE – For the smaller quantization step sizes, the full dynamic range of the transform coefficients cannot be represented unless the optional Modified Quantization mode is in use.

4.3 Coding control

Several parameters may be varied to control the rate of generation of coded video data. These include processing prior to the source coder, the quantizer, block significance criterion and temporal subsampling. The proportions of such measures in the overall control strategy are not subject to recommendation.

When invoked, temporal subsampling is performed by discarding complete pictures.

A decoder can signal its preference for a certain tradeoff between spatial and temporal resolution of the video signal. The encoder shall signal its default tradeoff at the beginning of the call and shall indicate whether it is capable of responding to decoder requests to change this tradeoff. The transmission method for these signals is by external means (for example, Recommendation H.245).

4.4 Forced updating

This function is achieved by forcing the use of the INTRA mode of the coding algorithm. The update pattern is not defined. To control the accumulation of inverse transform mismatch error, each macroblock shall be coded in INTRA mode at least once every 132 times when coefficients are transmitted for this macroblock in P-pictures. A similar requirement applies when using optional EP-pictures (see Annex O), for which each macroblock shall be coded in an INTRA or upward mode at least once every 132 times when coefficients are transmitted for the macroblock.

4.5 Byte alignment of start codes

Byte alignment of start codes is achieved by inserting a stuffing codeword consisting of less than 8 zero-bits before the start code such that the first bit of the start code is the first (most significant) bit of a byte. A start code is therefore byte aligned if the position of its most significant bit is a multiple of 8 bits from the first bit in the H.263 bitstream. All picture, slice, and EOSBS start codes shall be byte aligned, and GOB and EOS start codes may be byte aligned.

NOTE 1 – The number of bits spent for a certain picture is variable but always a multiple of 8 bits.

NOTE 2 – H.324 requires H.263 encoders to align picture start codes with the start of logical information units passed to the Adaptation Layer (AL_SDU's).

5 Syntax and semantics

The video syntax is arranged in a hierarchical structure with four primary layers. From top to bottom the layers are:

- Picture;
- Group of Blocks, or slice, or video picture segment;
- Macroblock;
- Block.

The syntax diagram is shown in Figure 6. A guide for interpretation of the diagram consists of the following:

1) Arrow paths show the possible flows of syntax elements. Any syntax element which has zero length is considered absent for arrow path diagramming purposes (thus, for example, there is an arrow path bypassing PSTUF despite the mandatory nature the PSTUF field since the length of the PSTUF field may be zero).

2) Abbreviations and semantics for each syntax element are as defined in later clauses.

3) The set of syntax elements and arrow paths shown using thick solid lines denotes the syntax flow of the "baseline" mode of operation, without the use of any optional enhancements. (This syntax was also present in the Version 1 of this Recommendation, and remains unchanged in any way.)

4) The set of syntax elements and arrow paths shown using thick dotted lines denotes the additional elements in the syntax flow of the optional enhancements which have been present in both Version 1 and Version 2 of this Recommendation. (This syntax remains unchanged in any way.)

5) The set of syntax elements and arrow paths shown using thin solid lines denotes the additional new elements in the syntax flow of the optional enhancements which are specific to the additional optional features added in Version 2. (This syntax was not present in Version 1.)

6) Syntax element fields shown with square-edged boundaries indicate fixed-length fields, and those with rounded boundaries indicate variable-length fields. One syntax element (DQUANT) is shown with both types of boundaries, because it can have either a variable or fixed length.

7) A fixed-length field is defined to be a field for which the length of the field is not dependent on the data in the content of the field itself. The length of this field is either always the same, or is determined by the prior data in the syntax flow.

8) The term "layer" is used to refer to any part of the syntax which can be understood and diagrammed as a distinct entity.

Unless specified otherwise, the most significant bit is transmitted first. This is bit 1 and is the left most bit in the code tables in this Recommendation. Unless specified otherwise, all unused or spare bits are set to "1". Spare bits shall not be used until their functions are specified by the ITU-T.

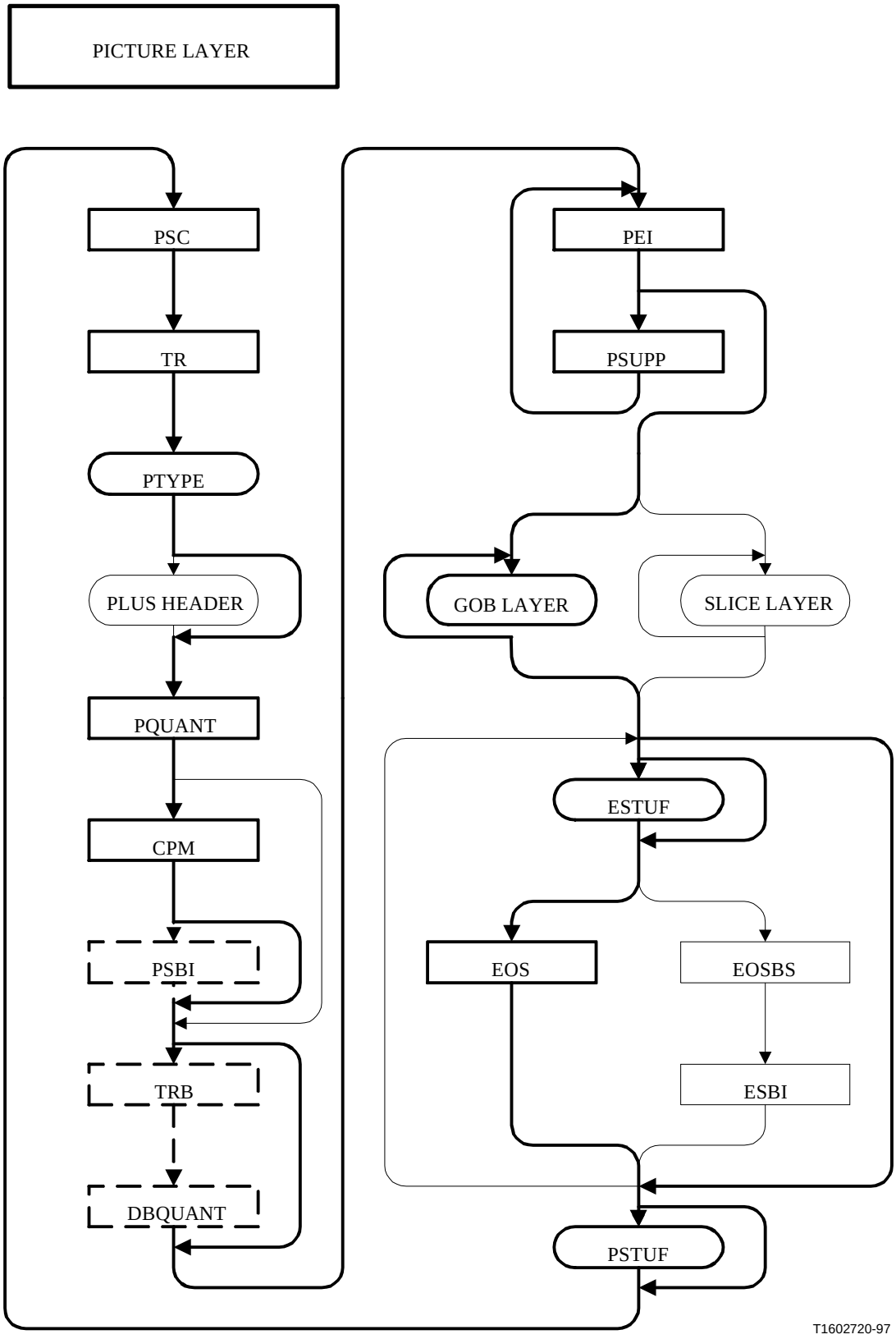


Figure 6/H.263 (part 1 of 7) – Syntax diagram for the video bitstream

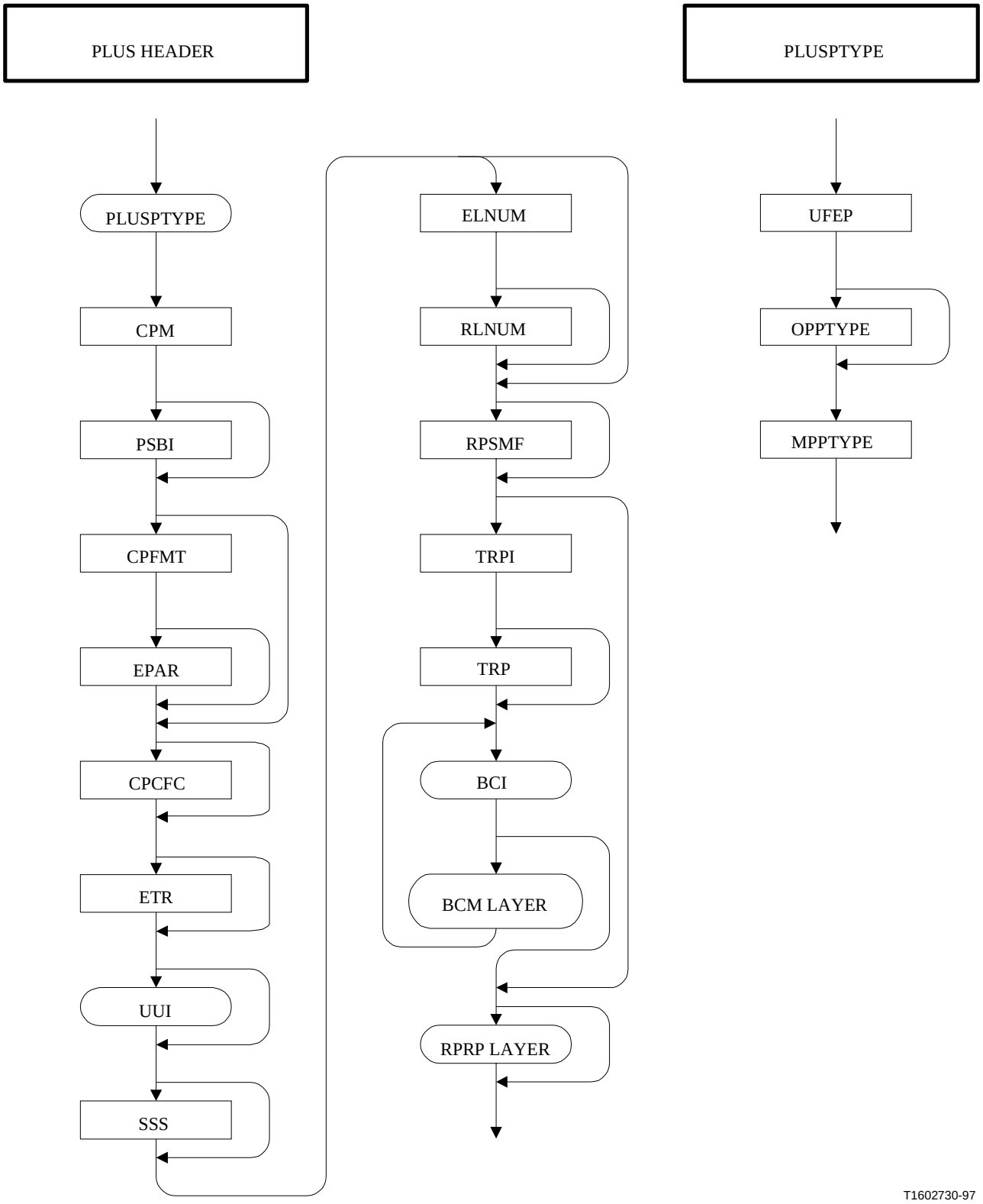


Figure 6/H.263 (part 2 of 7) – Syntax diagram for the video bitstream

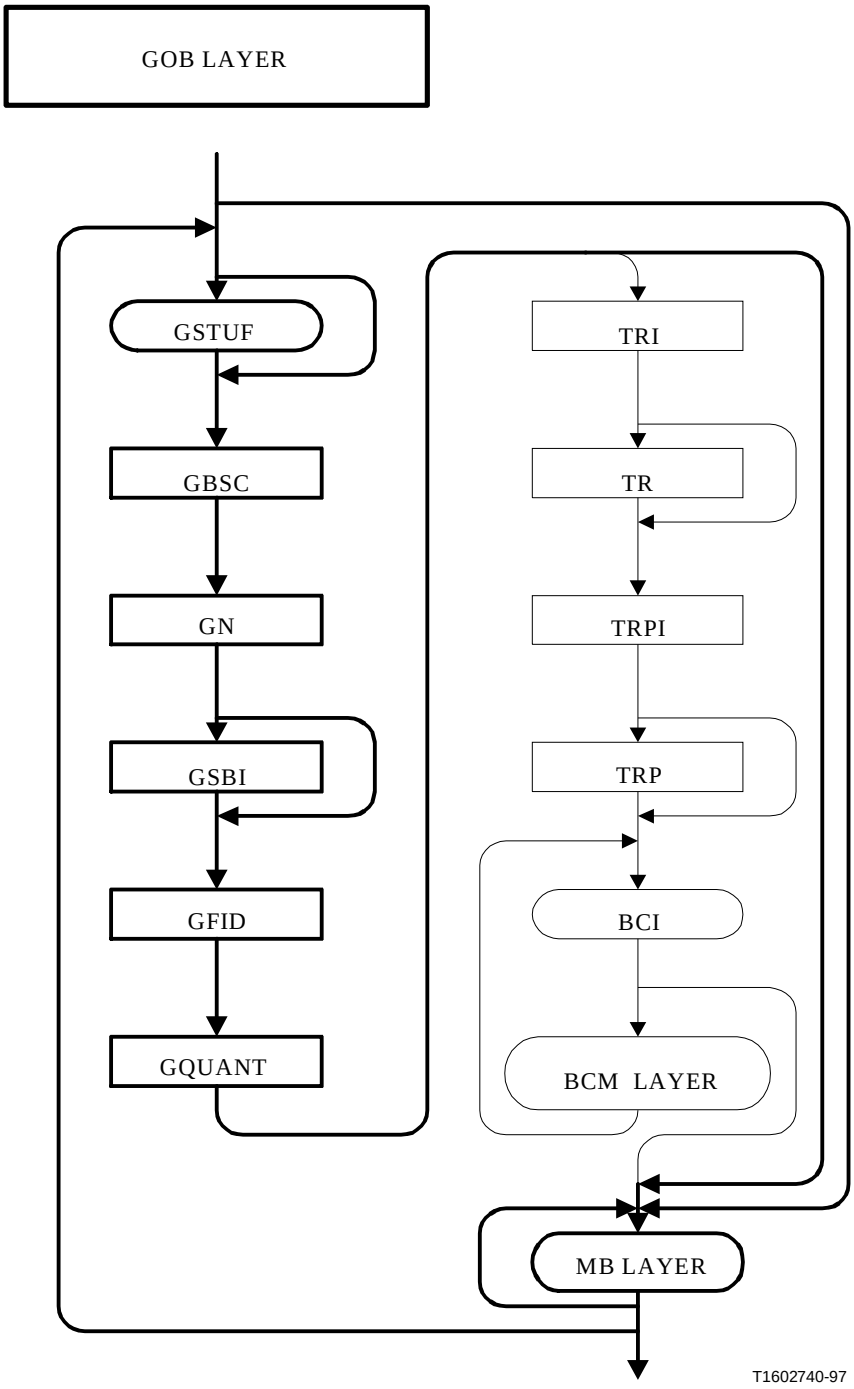


Figure 6/H.263 (part 3 of 7) – Syntax diagram for the video bitstream

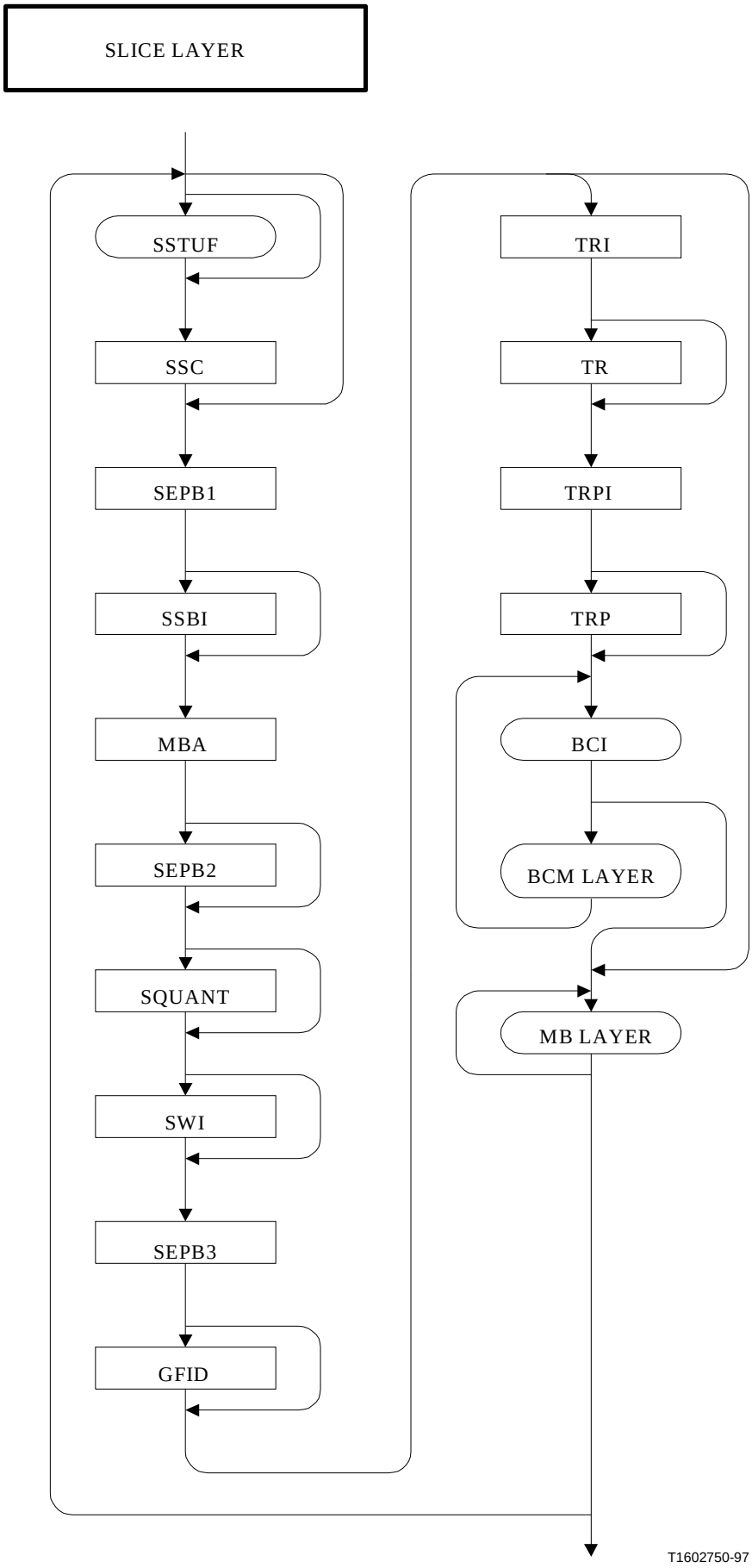


Figure 6/H.263 (part 4 of 7) – Syntax diagram for the video bitstream

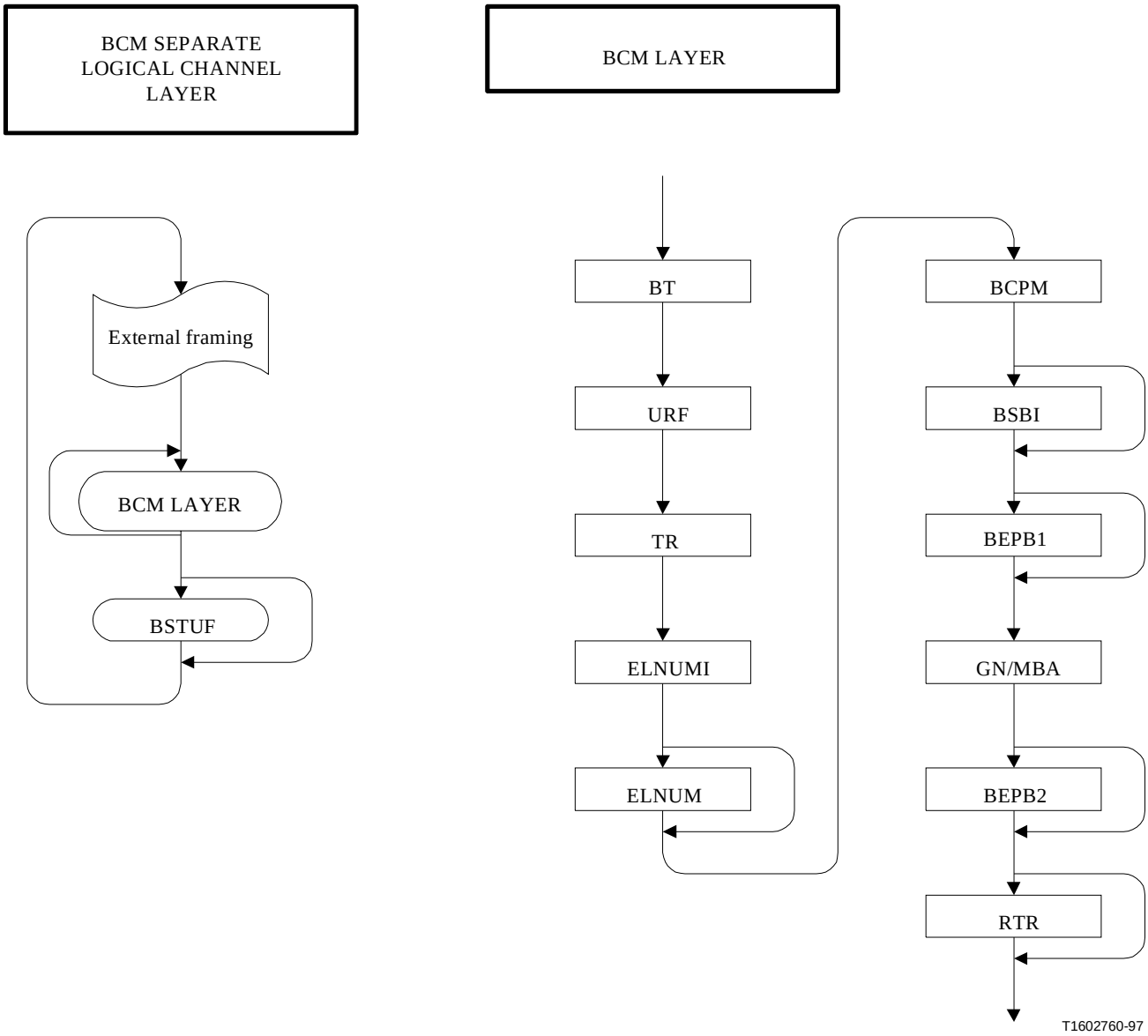


Figure 6/H.263 (part 5 of 7) – Syntax diagram for the video bitstream

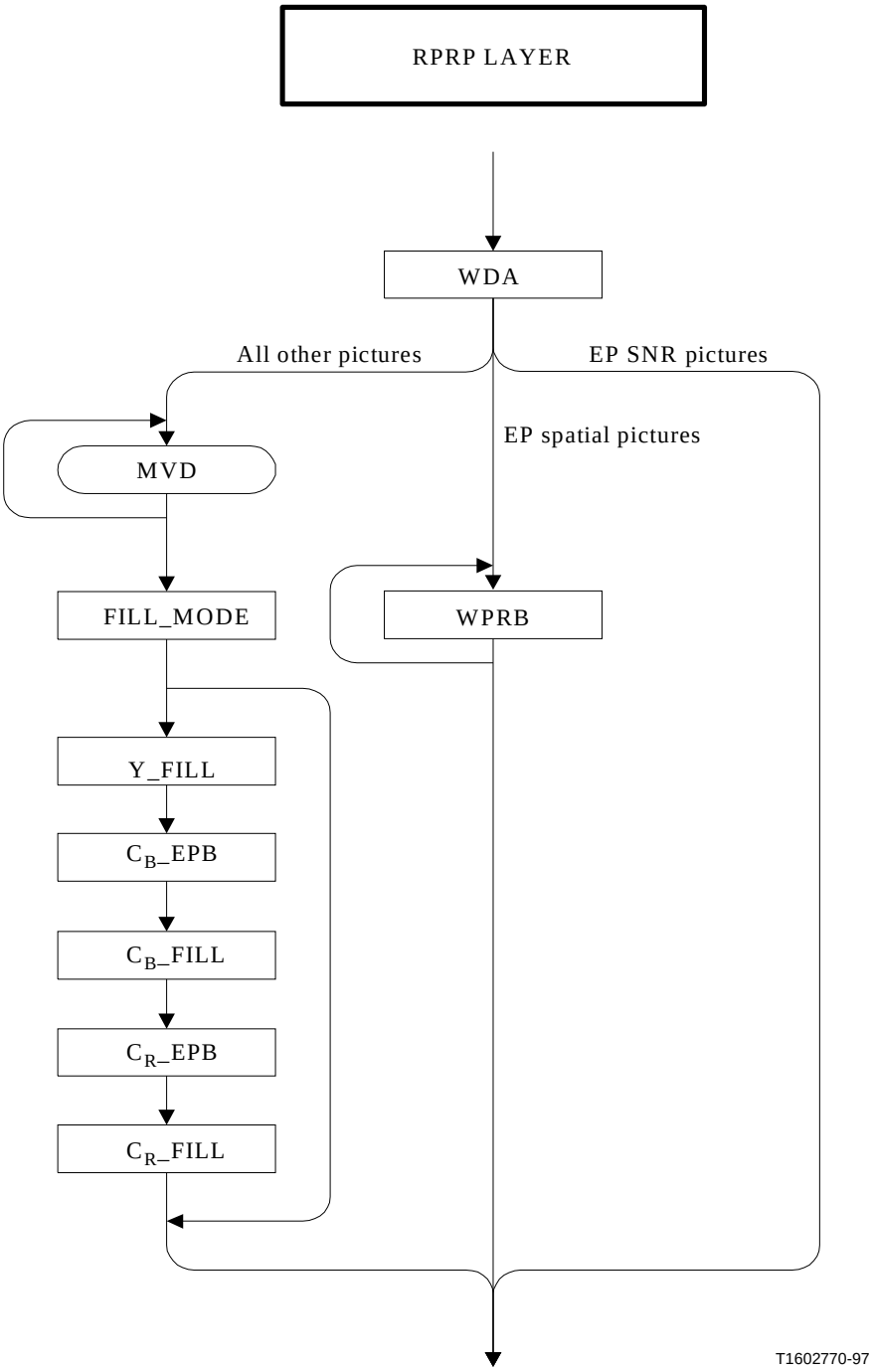


Figure 6/H.263 (part 6 of 7) – Syntax diagram for the video bitstream

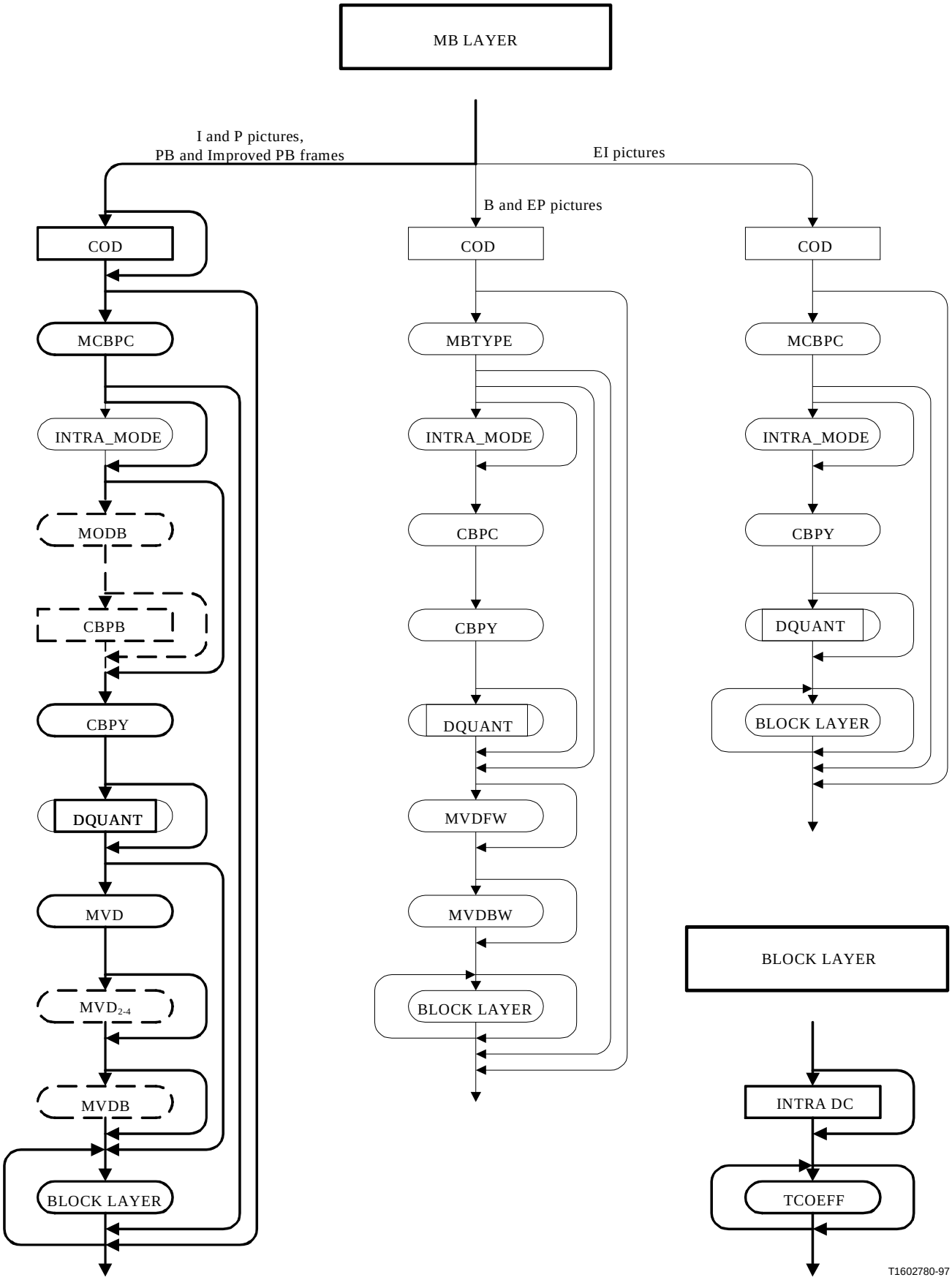


Figure 6/H.263 (part 7 of 7) – Syntax diagram for the video bitstream

5.1 Picture layer

Data for each picture consists of a picture header followed by data for Group of Blocks or for slices, eventually followed by an optional end-of-sequence code and stuffing bits. The structure is shown in Figure 7 for pictures that do not include the optional PLUSPTYPE data field. PSBI is only present if indicated by CPM. TR_B and DBQUANT are only present if PTYPE indicates use of the "PB-frame" mode (unless the PLUSPTYPE field is present and the use of DBQUANT is indicated therein).

The optional PLUSPTYPE data field is present when so indicated in bits 6-8 of PTYPE. When present, an additional set of data is included in the bitstream, which immediately follows PTYPE and precedes PQUANT. In addition, the CPM and PSBI fields are moved forward in the picture header when PLUSPTYPE is present, so that they appear immediately after PLUSPTYPE rather than being located after PQUANT. The format for the additional data following PLUSPTYPE is shown in Figure 8. All fields in this additional picture header data after PLUSPTYPE are optional, depending on whether their presence is indicated in PLUSPTYPE. When the Slice Structured mode (see Annex K) is in use, slices are substituted for GOBs in the location shown in Figure 7.

Combinations of PSUPP and PEI may not be present, and may be repeated when present. EOS and EOSBS+ESBI may not be present, while ESTUF may be present only if EOS or EOSBS is present. EOS shall not be repeated unless at least one picture start code appears between each pair of EOS codes. Picture headers for dropped pictures are not transmitted.

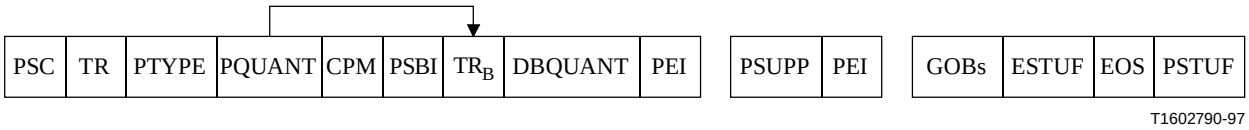


Figure 7/H.263 – Structure of picture layer (without optional PLUSPTYPE-related fields)

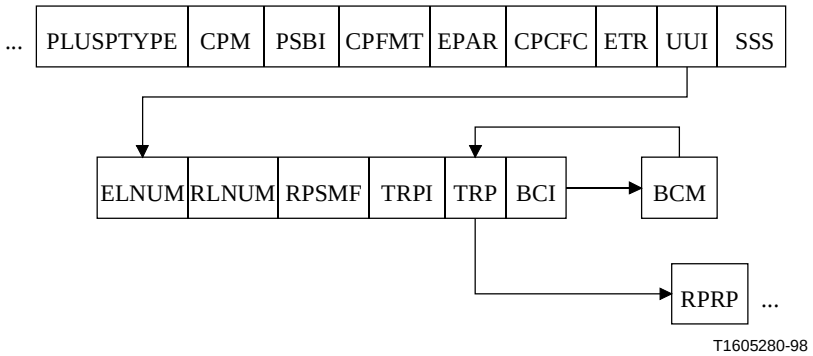


Figure 8/H.263 – Structure of optional PLUSPTYPE-related fields (located immediately after PTYPE when present)

5.1.1 Picture Start Code (PSC) (22 bits)

PSC is a word of 22 bits. Its value is 0000 0000 0000 0000 1 00000. All picture start codes shall be byte aligned. This shall be achieved by inserting PSTUF bits as necessary before the start code such that the first bit of the start code is the first (most significant) bit of a byte.

5.1.2 Temporal Reference (TR) (8 bits)

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. The interpretation of TR depends on the active picture clock frequency. Under the standard CIF picture clock frequency, TR is an 8-bit number which can have 256 possible values. The arithmetic is performed with only the eight LSBs. If a custom picture clock frequency is signalled in use, Extended TR in 5.1.8 and TR form a 10-bit number where TR stores the eight Least Significant Bits (LSBs) and ETR stores the two Most Significant Bits (MSBs). The arithmetic in this case is performed with the ten LSBs. In the optional PB-frames or Improved PB-frames mode, TR only addresses P-pictures; for the temporal reference for the B-picture part of PB or Improved PB frames, refer to 5.1.22.

5.1.3 Type Information (PTYPE) (Variable Length)

Information about the complete picture:

– Bit 1: Always "1", in order to avoid start code emulation.

– Bit 2: Always "0", for distinction with Recommendation H.261.

– Bit 3: Split screen indicator, "0" off, "1" on.

– Bit 4: Document camera indicator, "0" off, "1" on.

– Bit 5: Full Picture Freeze Release, "0" off, "1" on.

– Bits 6-8: Source Format, "000" forbidden, "001" sub-QCIF, "010" QCIF, "011" CIF, "100" 4CIF, "101" 16CIF, "110" reserved, "111" extended PTYPE.

If bits 6-8 are not equal to "111", which indicates an extended PTYPE (PLUSPTYPE), the following five bits are also present in PTYPE:

– Bit 9: Picture Coding Type, "0" INTRA (I-picture), "1" INTER (P-picture).

– Bit 10: Optional Unrestricted Motion Vector mode (see Annex D), "0" off, "1" on.

– Bit 11: Optional Syntax-based Arithmetic Coding mode (see Annex E), "0" off, "1" on.

– Bit 12: Optional Advanced Prediction mode (see Annex F), "0" off, "1" on.

– Bit 13: Optional PB-frames mode (see Annex G), "0" normal I- or P-picture, "1" PB-frame.

Split screen indicator is a signal that indicates that the upper and lower half of the decoded picture could be displayed side by side. This bit has no direct effect on the encoding or decoding of the picture.

Full Picture Freeze Release is a signal from an encoder which responds to a request for packet retransmission (if not acknowledged) or fast update request (see also Annex C) or picture freeze request (see also Annex L) and allows a decoder to exit from its freeze picture mode and display the decoded picture in the normal manner.

If bits 6-8 indicate a different source format than in the previous picture header, the current picture shall be an I-picture, unless an extended PTYPE is indicated in bits 6-8 and the capability to use the optional Reference Picture Resampling mode (see Annex P) has been negotiated externally (for example Recommendation H.245).

Bits 10-13 refer to optional modes that are only used after negotiation between encoder and decoder (see also Annexes D, E, F and G, respectively). If bit 9 is set to "0", bit 13 shall be set to "0" as well.

Bits 6-8 shall not have a value of "111" which indicates the presence of an extended PTYPE (PLUSPTYPE) unless the capability has been negotiated externally (for example Recommendation H.245) to allow the use of a custom source format or one or more of the other optional modes

available only by the use of an extended PTYPE (see Annexes I through K and M through T). Whenever bit 6-8 do not have a value of "111", all of the additional modes available only by the use of an extended PTYPE shall be considered to have been set to an "off" state and shall be inferred to remain "off" unless explicitly switched on later in the bitstream.

5.1.4 Plus PTYPE (PLUSPTYPE) (Variable Length)

A codeword of 12 or 30 bits which is present only if the presence of extended PTYPE is indicated in bits 6-8 of PTYPE.

PLUSPTYPE is comprised of up to three subfields: UFEP, OPPTYPE, and MPPTYPE. OPPTYPE is present only if UFEP has a particular value.

5.1.4.1 Update Full Extended PTYPE (UFEP) (3 bits)

A fixed length codeword of 3 bits which is present only if "extended PTYPE" is indicated in PTYPE bits 6-8. When set to "000", it indicates that only those extended PTYPE fields which need to be signalled in every picture header (MPPTYPE) are included in the current picture header. When set to "001", it indicates that all extended PTYPE fields are included in the current picture header. If the picture type is INTRA or EI, this field shall be set to "001".

In addition, if PLUSPTYPE is present in each of a continuing sequence of pictures, this field shall be set to "001" at least as often as specified by a five-second or five-picture timeout period, whichever allows a larger interval of time. More specifically, the timeout period requires UFEP = "001" to appear in the PLUSPTYPE field (if PLUSPTYPE is present in every intervening picture) of the first picture header with temporal reference indicating a time interval greater than or equal to five seconds since the last occurrence of UFEP = "001", or of the fifth picture after the last occurrence of UFEP = "001" (whichever requirement allows a longer period of time as measured by temporal reference).

Encoders should set UFEP to "001" more often in error-prone environments. Values of UFEP other than "000" and "001" are reserved.

5.1.4.2 The Optional Part of PLUSPTYPE (OPPTYPE) (18 bits)

If UFEP is "001", then the following bits are present in PLUSPTYPE:

- Bits 1-3 Source Format, "000" reserved, "001" sub-QCIF, "010" QCIF, "011" CIF, "100" 4CIF, "101" 16CIF, "110" custom source format, "111" reserved;
- Bit 4 Optional Custom PCF, "0" CIF PCF, "1" custom PCF;
- Bit 5 Optional Unrestricted Motion Vector (UMV) mode (see Annex D), "0" off, "1" on;
- Bit 6 Optional Syntax-based Arithmetic Coding (SAC) mode (see Annex E), "0" off, "1" on;
- Bit 7 Optional Advanced Prediction (AP) mode (see Annex F), "0" off, "1" on;
- Bit 8 Optional Advanced INTRA Coding (AIC) mode (see Annex I), "0" off, "1" on;
- Bit 9 Optional Deblocking Filter (DF) mode (see Annex J), "0" off, "1" on;
- Bit 10 Optional Slice Structured (SS) mode (see Annex K), "0" off, "1" on;
- Bit 11 Optional Reference Picture Selection (RPS) mode (see Annex N), "0" off, "1" on;
- Bit 12 Optional Independent Segment Decoding (ISD) mode (see Annex R), "0" off, "1" on;
- Bit 13 Optional Alternative INTER VLC (AIV) mode (see Annex S), "0" off, "1" on;

– Bit 14 Optional Modified Quantization (MQ) mode (see Annex T), "0" off, "1" on;

– Bit 15 Equal to "1" to prevent start code emulation;

– Bit 16 Reserved, shall be equal to "0";

– Bit 17 Reserved, shall be equal to "0";

– Bit 18 Reserved, shall be equal to "0".

5.1.4.3 The mandatory part of PLUSPTYPE when PLUSPTYPE present (MPPTYPE) (9 bits)

Regardless of the value of UFEP, the following 9 bits are also present in PLUSPTYPE:

– Bits 1-3 Picture Type Code:

"000" I-picture (INTRA),

"001" P-picture (INTER),

"010" Improved PB-frame (see Annex M),

"011" B-picture (see Annex O),

"100" EI-picture (see Annex O),

"101" EP-picture (see Annex O),

"110" Reserved,

"111" Reserved;

– Bit 4 Optional Reference Picture Resampling (RPR) mode (see Annex P), "0" off, "1" on;

– Bit 5 Optional Reduced-Resolution Update (RRU) mode (see Annex Q), "0" off, "1" on;

– Bit 6 Rounding Type (RTYPE) (see 6.1.2);

– Bit 7 Reserved, shall be equal to "0";

– Bit 8 Reserved, shall be equal to "0";

Bit 9 Equal to "1" to prevent start code emulation.

The encoder should control the rounding type so that P-pictures, Improved PB-frames, and EP-pictures have different values for bit 6 (Rounding Type for P-pictures) from their reference pictures for motion compensation. Bit 6 can have an arbitrary value if the reference picture is an I- or an EI-picture. Bit 6 can be set to "1" only when bits 1-3 indicate a P-picture, Improved PB-frame, or EP-picture. For other types of pictures, this bit shall always be set to "0".

5.1.4.4 The semantics of PLUSPTYPE

The mandatory part of PLUSPTYPE consists of features which are likely to be changed on a picture-by-picture basis. Primarily, these are the bits that indicate the picture type among I, P, Improved PB, B, EI, and EP. (Note that the PB-frames mode of Annex G cannot be used with PLUSPTYPE present – the Improved PB-frames mode of Annex M should be used instead.) However, they also include indications for the use of the RPR and RRU modes, as these may change from picture to picture as well.

Features that are likely to remain in use rather than being changed from one picture to another (except in obvious ways as discussed in 5.1.4.5) have been placed in the optional part of PLUSPTYPE. When UFEP is 000, the missing mode information is inferred from the type of picture and from the mode information sent in a previous PLUSPTYPE with UFEP equal to 001.

If PLUSPTYPE is present but UFEP is 000, then:

1) For a P-picture or Improved PB-frame (see Annex M), the pixel aspect ratio, picture width, and picture height are unchanged from those of the reference picture.

2) For a temporal-scalability B-picture (see Annex O) in an enhancement layer, the Reference Layer Number (RLNUM) is the same as the Enhancement Layer Number (ELNUM) if the last picture sent in the enhancement layer was an EI- or EP-picture. If the last picture sent in the enhancement layer was a B-picture, the reference layer number is the same as the reference layer number of the last B-picture. The pixel aspect ratio, picture width and picture height are unchanged from those of the temporally subsequent reference layer picture.

   Note that if temporally surrounding EI- or EP-pictures exist in the same enhancement layer as the B-picture, RLNUM (explicit or implied) shall always be equal to ELNUM. Note also that the pixel aspect ratio, picture width and picture height of a B-picture (explicit or implied) shall always be equal to those of its temporally subsequent reference layer picture.

3) For a SNR/Spatial scalability EP-picture (see Annex O), the pixel aspect ratio, picture width and picture height are unchanged from those of the temporally previous reference picture in the same enhancement layer.

5.1.4.5 Mode restrictions for certain picture types and mode inference rules

Certain modes do not apply to certain types of pictures. Particularly, these restrictions apply:

1) The following modes do not apply within I (INTRA) pictures: Unrestricted Motion Vector (see Annex D), Advanced Prediction (see Annex F), Alternative INTER VLC (see Annex S), Reference Picture Resampling (see Annex P), and Reduced-Resolution Update (see Annex Q).

2) The following modes do not apply within B-pictures (see Annex O): Syntax-based Arithmetic Coding (see Annex E), Deblocking Filter (see Annex J), and Advanced Prediction (see Annex F).

3) The following modes do not apply within EI-pictures (see Annex O): Unrestricted Motion Vector (see Annex D), Syntax-based Arithmetic Coding (see Annex E), Advanced Prediction (see Annex F), Reference Picture Resampling (see Annex P), Reduced-Resolution Update (see Annex Q), and Alternative INTER VLC (see Annex S).

4) The following modes do not apply within EP-pictures (see Annex O): Syntax-based Arithmetic Coding (see Annex E) and Advanced Prediction (see Annex F).

One or more of the modes listed in the above four-item list may have a mode flag having a value "1" in the optional part of PLUSPTYPE within a picture of a type that is prohibited for that mode (types I, B, EI, or EP). This condition is allowed and shall be interpreted subject to the mode inference rules which follow in the next paragraph.

Mode states are subject to the following mode inference rules:

1) Once a mode flag has been set to "1" in the optional part of PLUSPTYPE, the current picture and each subsequent picture in the bitstream shall be assigned a state of "on" for that mode.

2) An inferred state of "off" shall be assigned to any mode which does not apply within a picture having the current picture type code. However, each subsequent picture in the bitstream shall have an inferred state of "on" for that mode (unless this too results in an obvious conflict – which shall be resolved in the same way). In the case of layered scalable bitstreams (see Annex O), the mode state shall be inferred only from within the same layer of the bitstream.

3) The inference of state shall continue until a picture in the same layer that either contains the optional part of PLUSPTYPE or does not contain PLUSPTYPE at all is sent. If a new picture containing the optional part of PLUSPTYPE is sent, the state sent in the new message shall override the old state. If a picture is sent which does not contain PLUSPTYPE (a picture in which bits 6-8 of PTYPE is not "111"), a state of "off" shall be assigned to all modes not explicitly set to "on" in the PTYPE field, and all modes shall continue to have an inferred state of "off" until a new picture containing the optional part of PLUSPTYPE is sent.

4) Two modes do not require mode state inference, since the mode flags for these modes appear in the mandatory part of PLUSPTYPE. These are the Reference Picture Resampling mode (Annex P) and the Reduced-Resolution Update mode (Annex Q). The mode flag for either of these modes shall not be set unless the current picture allows the use of the mode. For example, the Reduced-Resolution Update mode bit shall not be set in an INTRA picture.

5.1.4.6 Mode interaction restrictions

Certain modes cannot be used in combination with certain other modes.

1) The Syntax-based Arithmetic Coding mode (see Annex E) shall not be used with the Alternative INTER VLC mode (see Annex S) or the Modified Quantization mode (see Annex T).

2) If PLUSPTYPE is present, the Unrestricted Motion Vector mode (see Annex D) shall not be used with the Syntax-based Arithmetic Coding mode (see Annex E).

3) The Independent Segment Decoding mode (see Annex R) shall not be used with the Reference Picture Resampling mode (see Annex P).

4) The Independent Segment Decoding mode (see Annex R) shall not be used with the Slice Structured mode without the simultaneous use of the Rectangular Slice submode of the Slice Structured mode (see Annex K).

5.1.4.7 The picture header location of CPM (1 bit) and PSBI (2 bits)

The location of the CPM and PSBI fields in the picture header depends on whether or not PLUSPTYPE is present (see 5.1.20 and 5.1.21). If PLUSPTYPE is present, then CPM follows immediately after PLUSPTYPE in the picture header. If PLUSPTYPE is not present, then CPM follows immediately after PQUANT in the picture header. PSBI always follows immediately after CPM (if CPM = "1").

5.1.5 Custom Picture Format (CPFMT) (23 bits)

A fixed length codeword of 23 bits that is present only if the use of a custom picture format is signalled in PLUSPTYPE and UFEP is ’001’. When present, CPFMT consists of:

– Bits 1-4 Pixel Aspect Ratio Code: A 4-bit index to the PAR value in Table 5. For extended PAR, the exact pixel aspect ratio shall be specified in EPAR (see 5.1.6);

– Bits 5-13 Picture Width Indication: Range [0, ..., 511]; Number of pixels per line = (PWI + 1) * 4;

– Bit 14 Equal to "1" to prevent start code emulation;

– Bits 15-23 Picture Height Indication: Range [1, ..., 288]; Number of lines = PHI * 4.

Table 5/H.263 – PAR code definition

PAR code	Pixel aspect ratios
0000	Forbidden
0001	1:1 (Square)
0010	12:11 (CIF for 4:3 picture)
0011	10:11 (525-type for 4:3 picture)
0100	16:11 (CIF stretched for 16:9 picture)
0101	40:33 (525-type stretched for 16:9 picture)
0110-1110	Reserved
1111	Extended PAR

5.1.6 Extended Pixel Aspect Ratio (EPAR) (16 bits)

A fixed length codeword of 16 bits that is present only if CPFMT is present and extended PAR is indicated therein. When present, EPAR consists of:

– Bits 1-8 PAR Width: "0" is forbidden. The natural binary representation of the PAR width;

– Bits 9-16 PAR Height: "0" is forbidden. The natural binary representation of the PAR height.

The PAR Width and PAR Height shall be relatively prime.

5.1.7 Custom Picture Clock Frequency Code (CPCFC) (8 bits)

A fixed length codeword of 8 bits that is present only if PLUSPTYPE is present and UFEP is 001 and a custom picture clock frequency is signalled in PLUSPTYPE. When present, CPCFC consists of:

– Bit 1 Clock Conversion Code: "0" indicates a clock conversion factor of 1000 and "1" indicates 1001;

– Bits 2-8 Clock Divisor: "0" is forbidden. The natural binary representation of the value of the clock divisor.

The custom picture clock frequency is given by 1 800 000/(clock divisor * clock conversion factor) Hz.

The temporal reference counter shall count in units of the inverse of the picture clock frequency, in seconds. When the PCF changes from that specified for the previous picture, the temporal reference for the current picture is measured in terms of the prior PCF, so that the new PCF takes effect only for the temporal reference interpretation of future pictures.

5.1.8 Extended Temporal Reference (ETR) (2 bits)

A fixed length codeword of 2 bits which is present only if a custom picture clock frequency is in use (regardless of the value of UFEP). It is the two MSBs of the 10-bit number defined in 5.1.2.

5.1.9 Unlimited Unrestricted Motion Vectors Indicator (UUI) (Variable length)

A variable length codeword of 1 or 2 bits that is present only if the optional Unrestricted Motion Vector mode is indicated in PLUSPTYPE and UFEP is 001. When UUI is present it indicates the effective limitation of the range of the motion vectors being used.

– UUI = "1" The motion vector range is limited according to Tables D.1 and D.2.

– UUI = "01" The motion vector range is not limited except by the picture size.

5.1.10 Slice Structured Submode bits (SSS) (2 bits)

A fixed length codeword of 2 bits which is present only if the optional Slice Structured mode (see Annex K) is indicated in PLUSPTYPE and UFEP is 001. If the Slice Structured mode is in use but UFEP is not 001, the last values sent for SSS shall remain in effect.

– Bit 1 Rectangular Slices, "0" indicates free-running slices, "1" indicates rectangular slices;

– Bit 2 Arbitrary Slice Ordering, "0" indicates sequential order, "1" indicates arbitrary order.

5.1.11 Enhancement Layer Number (ELNUM) (4 bits)

A fixed length codeword of 4 bits which is present only if the optional Temporal, SNR, and Spatial Scalability mode is in use (regardless of the value of UFEP). The particular enhancement layer is identified by an enhancement layer number, ELNUM. Picture correspondence between layers is achieved via the temporal reference. Picture size is either indicated within each enhancement layer using the existing source format fields or is inferred by the relationship to the reference layer. The first enhancement layer above the base layer is designated as Enhancement Layer Number 2, and the base layer has number 1.

5.1.12 Reference Layer Number (RLNUM) (4 bits)

A fixed length codeword of 4 bits which is present only if the optional Temporal, SNR, and Spatial Scalability mode is in use (see Annex O) and UFEP is 001. The layer number for the pictures used as reference anchors is identified by a Reference Layer Number (RLNUM). Time correspondence between layers is achieved via the temporal reference.

Note that for B-pictures in an enhancement layer having temporally surrounding EI- or EP-pictures which are present in the same enhancement layer, RLNUM shall be equal to ELNUM (see Annex O).

5.1.13 Reference Picture Selection Mode Flags (RPSMF) (3 bits)

A fixed length codeword of 3 bits that is present only if the Reference Picture Selection mode is in use and UFEP is 001. When present, RPSMF indicates which type of back-channel messages are needed by the encoder. If the Reference Picture Selection mode is in use but RPSMF is not present, the last value of RPSMF that was sent shall remain in effect.

– 100: neither ACK nor NACK signals needed;

– 101: need ACK signals to be returned;

– 110: need NACK signals to be returned;

– 111: need both ACK and NACK signals to be returned;

– 000-011: Reserved.

5.1.14 Temporal Reference for Prediction Indication (TRPI) (1 bit)

A fixed length codeword of 1 bit that is present only if the optional Reference Picture Selection mode is in use (regardless of the value of UFEP). When present, TRPI indicates the presence of the following TRP field:

– 0: TRP field is not present;

– 1: TRP field is present.

TRPI shall be 0 whenever the picture header indicates an I- or EI-picture.

5.1.15 Temporal Reference for Prediction (TRP) (10 bits)

When present (as indicated in TRPI), TRP indicates the Temporal Reference which is used for prediction of the encoding, except for in the case of B-pictures. For B-pictures, the picture having the temporal reference TRP is used for the prediction in the forward direction. (Prediction in the reverse-temporal direction always uses the immediately temporally subsequent picture.) TRP is a ten-bit number. If a custom picture clock frequency was not in use for the reference picture, the two MSBs of TRP are zero and the LSBs contain the eight-bit TR found in the picture header of the reference picture. If a custom picture clock frequency was in use for the reference picture, TRP is a ten-bit number consisting of the concatenation of ETR and TR from the reference picture header.

When TRP is not present, the most recent temporally previous anchor picture shall be used for prediction, as when not in the Reference Picture Selection mode. TRP is valid until the next PSC, GSC, or SSC.

5.1.16 Back-Channel message Indication (BCI) (Variable length)

A variable length field of one or two bits that is present only if the optional Reference Picture Selection mode is in use. When set to "1", this signals the presence of the following optional video Back-Channel Message (BCM) field. "01" indicates the absence or the end of the video back-channel message field. Combinations of BCM and BCI may not be present, and may be repeated when present. BCI shall be set to "01" if the videomux submode of the optional Reference Picture Selection mode is not in use.

5.1.17 Back-Channel Message (BCM) (Variable length)

The Back-Channel message with syntax as specified in N.4.2, which is present only if the preceding BCI field is present and is set to "1".

5.1.18 Reference Picture Resampling Parameters (RPRP) (Variable length)

A variable length field that is present only if the optional Reference Picture Resampling mode bit is set in PLUSPTYPE. This field carries the parameters of the Reference Picture Resampling mode (see Annex P). Note that the Reference Picture Resampling mode can also be invoked implicitly by the occurrence of a picture header for an INTER coded picture having a picture size which differs from that of the previous encoded picture, in which case the RPRP field is not present and the Reference Picture Resampling mode bit is not set.

5.1.19 Quantizer Information (PQUANT) (5 bits)

A fixed length codeword of 5 bits which indicates the quantizer QUANT to be used for the picture until updated by any subsequent GQUANT or DQUANT. The codewords are the natural binary representations of the values of QUANT which, being half the step sizes, range from 1 to 31.

5.1.20 Continuous Presence Multipoint and Video Multiplex (CPM) (1 bit)

A codeword of 1 bit that signals the use of the optional Continuous Presence Multipoint and Video Multiplex mode (CPM); "0" is off, "1" is on. For the use of CPM, refer to Annex C. CPM follows immediately after PLUSPTYPE if PLUSPTYPE is present, but follows PQUANT in the picture header if PLUSPTYPE is not present.

5.1.21 Picture Sub-Bitstream Indicator (PSBI) (2 bits)

A fixed length codeword of 2 bits that is only present if Continuous Presence Multipoint and Video Multiplex mode is indicated by CPM. The codewords are the natural binary representation of the sub-bitstream number for the picture header and all following information until the next Picture or GOB start code (see also Annex C). PSBI follows immediately after CPM if CPM is "1" (the location of CPM and PSBI in the picture header depend on whether PLUSPTYPE is present).

5.1.22 Temporal Reference for B-pictures in PB-frames (TR_B) (3/5 bits)

TR_B is present if PTYPE or PLUSPTYPE indicates "PB-frame" or "Improved PB-frame" (see also Annexes G and M) and indicates the number of non-transmitted or non-reference pictures (at 29.97 Hz or the custom picture clock frequency indicated in CPCFC) since the last P- or I-picture or P-part of a PB-or Improved PB-frame and before the B-picture part of the PB- or Improved PB-frame. The codeword is the natural binary representation of the number of non-transmitted pictures plus one. It is 3 bits long for standard CIF picture clock frequency and is extended to 5 bits when a custom picture clock frequency is in use. The maximum number of non-transmitted pictures is 6 for the standard CIF picture clock frequency and 30 when a custom picture clock frequency is used.

5.1.23 Quantization information for B-pictures in PB-frames (DBQUANT) (2 bits)

DBQUANT is present if PTYPE or PLUSPTYPE indicates "PB-frame" or "Improved PB-frame" (see also Annexes G and M). In the decoding process a quantization parameter QUANT is obtained for each macroblock. With PB-frames QUANT is used for the P-block, while for the B-block a different quantization parameter BQUANT is used. QUANT ranges from 1 to 31. DBQUANT indicates the relation between QUANT and BQUANT as defined in Table 6. In this table, "/" means division by truncation. BQUANT ranges from 1 to 31; if the value for BQUANT resulting from Table 6 is greater than 31, it is clipped to 31.

Table 6/H.263 – DBQUANT codes and relation between QUANT and BQUANT

DBQUANT	BQUANT
00	$(5 \times \text{QUANT})/4$
01	$(6 \times \text{QUANT})/4$
10	$(7 \times \text{QUANT})/4$
11	$(8 \times \text{QUANT})/4$

5.1.24 Extra Insertion Information (PEI) (1 bit)

A bit which when set to "1" signals the presence of the following optional data field.

5.1.25 Supplemental Enhancement Information (PSUPP) (0/8/16 ... bits)

If PEI is set to "1", then 9 bits follow consisting of 8 bits of data (PSUPP) and then another PEI bit to indicate if a further 9 bits follow and so on. Encoders shall use PSUPP as specified in Annex L.

Decoders which do not support the extended capabilities described in Annex L shall be designed to discard PSUPP if PEI is set to 1. This enables backward compatibility for the extended capabilities of Annex L so that a bitstream which makes use of the extended capabilities can also be used without alteration by decoders which do not support those capabilities.

5.1.26 Stuffing (ESTUF) (Variable length)

A codeword of variable length consisting of less than 8 zero-bits. Encoders may insert this codeword directly before an EOS codeword. Encoders shall insert this codeword as necessary to attain mandatory byte alignment directly before an EOSBS codeword. If ESTUF is present, the last bit of ESTUF shall be the last (least significant) bit of a byte, so that the start of the EOS or EOSBS codeword is byte aligned. Decoders shall be designed to discard ESTUF. See Annex C for a description of EOSBS and its use.

5.1.27 End Of Sequence (EOS) (22 bits)

A codeword of 22 bits. Its value is 0000 0000 0000 0000 1 11111. It is up to the encoder to insert this codeword or not. EOS may be byte aligned. This can be achieved by inserting ESTUF before the EOS code such that the first bit of the EOS code is the first (most significant) bit of a byte. EOS shall not be repeated unless at least one picture start code appears between each pair of EOS codes.

5.1.28 Stuffing (PSTUF) (Variable length)

A codeword of variable length consisting of less than 8 zero-bits. Encoders shall insert this codeword for byte alignment of the next PSC. The last bit of PSTUF shall be the last (least significant) bit of a byte, so that the video bitstream including PSTUF is a multiple of 8 bits from the first bit in the H.263 bitstream. Decoders shall be designed to discard PSTUF.

If for some reason the encoder stops encoding pictures for a certain time-period and resumes encoding later, PSTUF shall be transmitted before the encoder stops, to prevent that the last up to 7 bits of the previous picture are not sent until the coder resumes coding.

5.2 Group of Blocks Layer

Data for each Group of Blocks (GOB) consists of a GOB header followed by data for macroblocks. The structure is shown in Figure 9. Each GOB contains one or more rows of macroblocks. For the first GOB in each picture (with number 0), no GOB header shall be transmitted. For all other GOBs, the GOB header may be empty, depending on the encoder strategy. A decoder can signal the remote encoder to transmit only non-empty GOB headers by external means, for example Recommendation H.245. GSTUF may be present when GBSC is present. GN, GFID and GQUANT are present when GBSC is present. GSBI is present when CPM is "1" in the Picture header.

GSTUF	GBSC	GN	GSBI	GFID	GQUANT	Macroblock Data

Figure 9/H.263 – Structure of GOB layer

5.2.1 Stuffing (GSTUF) (Variable length)

A codeword of variable length consisting of less than 8 zero-bits. Encoders may insert this codeword directly before a GBSC codeword. If GSTUF is present, the last bit of GSTUF shall be the last (least significant) bit of a byte, so that the start of the GBSC codeword is byte aligned. Decoders shall be designed to discard GSTUF.

5.2.2 Group of Block Start Code (GBSC) (17 bits)

A word of 17 bits. Its value is 0000 0000 0000 0000 1. GOB start codes may be byte aligned. This can be achieved by inserting GSTUF before the start code such that the first bit of the start code is the first (most significant) bit of a byte.

5.2.3 Group Number (GN) (5 bits)

A fixed length codeword of 5 bits. The bits are the binary representation of the number of the Group of Blocks. For the GOB with number 0, the GOB header including GSTUF, GBSC, GN, GSBI, GFID and GQUANT is empty; as group number 0 is used in the PSC. Group numbers 1 through 17 are used in GOB headers of the standard picture formats. Group numbers 1 through 24 are used in GOB headers of custom picture formats. Group numbers 16 through 28 are emulated in the slice header (see Annex K) when CPM = "0", and Group Numbers 25-27 and 29 are emulated in the slice header (see Annex K) when CPM = "1". Group number 31 is used in the EOS code, and group number 30 is used in the EOSBS code.

5.2.4 GOB Sub-Bitstream Indicator (GSBI) (2 bits)

A fixed length codeword of 2 bits that is only present if CPM is "1" in the picture header. The codewords are the natural binary representation of the sub-bitstream number for the GOB header and all following information until the next Picture or GOB start code (see also Annex C).

5.2.5 GOB Frame ID (GFID) (2 bits)

A fixed length codeword of 2 bits. GFID shall have the same value in every GOB (or slice) header of a given picture. Moreover, if PTYPE as indicated in a picture header is the same as for the previous transmitted picture, GFID shall have the same value as in that previous picture, provided PLUSPTYPE is not present. However, if PTYPE in a certain picture header differs from the PTYPE in the previous transmitted picture header, the value for GFID in that picture shall differ from the value in the previous picture.

If PLUSPTYPE is present, the value of GFID shall be the same as that for the previous picture (in the same layer) if the PTYPE, and PLUSPTYPE, and all of the present fields among CPFMT, EPAR, CPCFC, SSS, ELNUM, RLNUM, UUI, RPSMF, and RPRP remain in effect as for the previous picture; otherwise, GFID shall be different from that for the previous picture.

5.2.6 Quantizer Information (GQUANT) (5 bits)

A fixed length codeword of 5 bits which indicates the quantizer QUANT to be used for the remaining part of the picture until updated by any subsequent GQUANT or DQUANT. The codewords are the natural binary representations of the values of QUANT which, being half the step sizes, range from 1 to 31.

5.3 Macroblock layer

Data for each macroblock consists of a macroblock header followed by data for blocks. The structure is shown in Figure 10. COD is only present in pictures that are not of type 'INTRA', for each macroblock in these pictures. MCBPC is present when indicated by COD or when the picture is of type 'INTRA'. MODB is present for MB-type 0-4 if PTYPE indicates "PB-frame". CBPY, DQUANT, MVD and MVD_{2-4} are present when indicated by MCBPC. CBPB and MVDB are only present if indicated by MODB. Block Data is present when indicated by MCBPC and CBPY. MVD_{2-4} are only present when in Advanced Prediction mode (refer to Annex F) or Deblocking Filter mode (refer to Annex J). MODB, CBPB and MVDB are only present in PB-frames mode (refer to Annex G). For coding of the symbols in the Syntax-based Arithmetic Coding mode, refer to Annex E. For coding of the macroblock layer in B-, EI-, and EP-pictures, see Annex O.

COD	MCBPC	MODB	CBPB	CBPY	DQUANT	MVD	MVD_2	MVD_3	MVD_4	MVDB	Block Data

Figure 10/H.263 – Structure of macroblock layer

5.3.1 Coded macroblock indication (COD) (1 bit)

A bit which when set to "0" signals that the macroblock is coded. If set to "1", no further information is transmitted for this macroblock; in that case the decoder shall treat the macroblock as an INTER macroblock with motion vector for the whole block equal to zero and with no coefficient data. COD is only present in pictures that are not of type "INTRA", for each macroblock in these pictures.

NOTE – In Advanced Prediction mode (see Annex F), overlapped block motion compensation is also performed if COD is set to "1"; and in Deblocking Filter mode (see Annex J), the deblocking filter can also affect the values of some pixels of macroblocks having COD is set to "1".

5.3.2 Macroblock type & Coded Block Pattern for Chrominance (MCBPC) (Variable length)

MCBPC is a variable length codeword giving information about the macroblock type and the coded block pattern for chrominance. The codewords for MCBPC are given in Tables 7 and 8. MCBPC is always included in coded macroblocks.

Table 7/H.263 – VLC table for MCBPC (for I-pictures)

Index	MB type	CBPC (56)	Number of bits	Code
0	3	00	1	1
1	3	01	3	001
2	3	10	3	010
3	3	11	3	011
4	4	00	4	0001
5	4	01	6	0000 01
6	4	10	6	0000 10
7	4	11	6	0000 11
8	Stuffing	–	9	0000 0000 1

Table 8/H.263 – VLC table for MCBPC (for P-pictures)

Index	MB type	CBPC (56)	Number of bits	Code
0	0	00	1	1
1	0	01	4	0011
2	0	10	4	0010
3	0	11	6	0001 01
4	1	00	3	011
5	1	01	7	0000 111
6	1	10	7	0000 110
7	1	11	9	0000 0010 1
8	2	00	3	010
9	2	01	7	0000 101
10	2	10	7	0000 100
11	2	11	8	0000 0101
12	3	00	5	0001 1
13	3	01	8	0000 0100
14	3	10	8	0000 0011
15	3	11	7	0000 011
16	4	00	6	0001 00
17	4	01	9	0000 0010 0
18	4	10	9	0000 0001 1
19	4	11	9	0000 0001 0
20	Stuffing	–	9	0000 0000 1
21	5	00	11	0000 0000 010
22	5	01	13	0000 0000 0110 0
23	5	10	13	0000 0000 0111 0
24	5	11	13	0000 0000 0111 1

An extra codeword is available in the tables for bit stuffing. This codeword should be discarded by decoders. If an Improved PB-frame is indicated by MPPTYPE bits 1-3 and Custom Source Format is indicated in OPPTYPE bits 1-3, then MBA shall not indicate stuffing before the first macroblock of the picture (in order to prevent start code emulation).

The macroblock type gives information about the macroblock and which data elements are present. Macroblock types and included elements are listed in Tables 9 and 10. Macroblock type 5 (indices 21-24 in Table 8) shall not be present unless an extended PTYPE (PLUSPTYPE) is present in the picture header and either the Advanced Prediction mode (see Annex F) or the Deblocking Filter mode (see Annex J) is in use, and shall not be present for the first macroblock of a picture. Also, encoders shall not allow an MCBPC code for macroblock type 5 to immediately follow seven consecutive zeros in the bitstream (as can be caused by particular INTRADC codes followed by COD = 0), in order to prevent start code emulation. Codes for macroblock type 5 can be preceded by stuffing when necessary to fulfill this requirement (for macroblocks other than the first of a picture).

Table 9/H.263 – Macroblock types and included data elements for normal pictures

Picture type	MB type	Name	COD	MCBPC	CBPY	DQUANT	MVD	MVD_{2-4}
INTER	Not coded	–	X					
INTER	0	INTER	X	X	X		X	
INTER	1	INTER+Q	X	X	X	X	X	
INTER	2	INTER4V	X	X	X		X	X
INTER	3	INTRA	X	X	X			
INTER	4	INTRA+Q	X	X	X	X		
INTER	5	INTER4V+Q	X	X	X	X	X	X
INTER	Stuffing	–	X	X				
INTRA	3	INTRA		X	X			
INTRA	4	INTRA+Q		X	X	X		
INTRA	Stuffing	–		X				
NOTE – "X" means that the item is present in the macroblock.								

Table 10/H.263 – Macroblock types and included data elements for PB-frames

Picture type	MB type	Name	COD	MCBPC	MODB	CBPY	CBPB	DQUANT	MVD	MVDB	MVD_{2-4}
INTER	Not coded	–	X								
INTER	0	INTER	X	X	X	X	(X)		X	(X)	
INTER	1	INTER+Q	X	X	X	X	(X)	X	X	(X)	
INTER	2	INTER4V	X	X	X	X	(X)		X	(X)	X
INTER	3	INTRA	X	X	X	X	(X)		X	(X)	
INTER	4	INTRA+Q	X	X	X	X	(X)	X	X	(X)	
INTER	5	INTER4V+Q	X	X	X	X	(X)	X	X	(X)	X
INTER	Stuffing	–	X	X							
NOTE 1 – "X" means that the item is present in the macroblock. NOTE 2 – CBPB and MVDB are only present if indicated by MODB. NOTE 3 – B-blocks are always coded in INTER mode, even if the macroblock type of the PB-macroblock indicates INTRA.											

The coded block pattern for chrominance signifies C_B and/or C_R blocks when at least one non-INTRADC transform coefficient is transmitted (INTRADC is the dc-coefficient for INTRA blocks, see 5.4.1), unless the optional Advanced INTRA Coding mode is in use. $CBPC_N$ = 1 if any non-INTRADC coefficient is present for block N, else 0, for $CBPC_5$ and $CBPC_6$ in the coded block pattern. If Advanced INTRA Coding is in use, the usage is similar, but the INTRADC coefficient is indicated in the same way as the other coefficients (see Annex I). Block numbering is given in Figure 5. When MCBPC = Stuffing, the remaining part of the macroblock layer is skipped. In this case, the preceding COD = 0 is not related to any coded or not-coded macroblock and therefore the macroblock number is not incremented. For P-pictures, multiple stuffings are accomplished by multiple sets of COD = 0 and MCBPC = Stuffing. See Tables 7 and 8.

5.3.3 Macroblock mode for B-blocks (MODB) (Variable length)

MODB is present for MB-type 0-4 if PTYPE indicates "PB-frame" and is a variable length codeword indicating whether CBPB is present (indicates that B-coefficients are transmitted for this macroblock) and/or MVDB is present. In Table 11 the codewords for MODB are defined. MODB is coded differently for Improved PB-frames, as specified in Annex M.

Table 11/H.263 – VLC table for MODB

Index	CBPB	MVDB	Number of bits	Code
0			1	0
1		X	2	10
2	X	X	2	11
NOTE – "X" means that the item is present in the macroblock.				

5.3.4 Coded Block Pattern for B-blocks (CBPB) (6 bits)

CBPB is only present in PB-frames mode if indicated by MODB. $CBPB_N$ = 1 if any coefficient is present for B-block N, else 0, for each bit $CBPB_N$ in the coded block pattern. Block numbering is given in Figure 5, the utmost left bit of CBPB corresponding with block number 1.

5.3.5 Coded Block Pattern for luminance (CBPY) (Variable length)

Variable length codeword giving a pattern number signifying those Y blocks in the macroblock for which at least one non-INTRADC transform coefficient is transmitted (INTRADC is the dc-coefficient for INTRA blocks, see 5.4.1), unless the Advanced INTRA Coding mode is in use. If Advanced INTRA Coding is in use, INTRADC is indicated in the same manner as the other coefficients (see Annex I).

$CBPY_N$ = 1 if any non-INTRADC coefficient is present for block N, else 0, for each bit $CBPY_N$ in the coded block pattern. Block numbering is given in Figure 5, the utmost left bit of CBPY corresponding with block number 1. For a certain pattern $CBPY_N$, different codewords are used for INTER and INTRA macroblocks as defined in Table 13.

5.3.6 Quantizer Information (DQUANT) (2 bits/Variable Length)

If the Modified Quantization mode is not in use, DQUANT is a two-bit code to define a change in QUANT. In Table 12 the differential values for the different codewords are given. QUANT ranges from 1 to 31; if the value for QUANT after adding the differential value is less than 1 or greater than 31, it is clipped to 1 and 31 respectively. If the Modified Quantization mode is in use, DQUANT is a variable length codeword as specified in Annex T.

Table 12/H.263 – DQUANT codes and differential values for QUANT

Index	Differential value	DQUANT
0	–1	00
1	–2	01
2	1	10
3	2	11

Table 13/H.263 – VLC table for CBPY

Index	CBPY(INTRA) (12, 34)	CBPY(INTER) (12, 34)	Number of bits	Code
0	00 00	11 11	4	0011
1	00 01	11 10	5	0010 1
2	00 10	11 01	5	0010 0
3	00 11	11 00	4	1001
4	01 00	10 11	5	0001 1
5	01 01	10 10	4	0111
6	01 10	10 01	6	0000 10
7	01 11	10 00	4	1011
8	10 00	01 11	5	0001 0
9	10 01	01 10	6	0000 11
10	10 10	01 01	4	0101
11	10 11	01 00	4	1010
12	11 00	00 11	4	0100
13	11 01	00 10	4	1000
14	11 10	00 01	4	0110
15	11 11	00 00	2	11

5.3.7 Motion Vector Data (MVD) (Variable length)

MVD is included for all INTER macroblocks (in PB-frames mode also for INTRA macroblocks) and consists of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component. Variable length codes are given in Table 14. If the Unrestricted Motion Vector mode is used and PLUSPTYPE is present, motion vectors are coded using Table D.3 instead of Table 14 (see Annex D).

Table 14/H.263 – VLC table for MVD

Index	Vector	Differences	Bit number	Codes
0	–16	16	13	0000 0000 0010 1
1	–15.5	16.5	13	0000 0000 0011 1
2	–15	17	12	0000 0000 0101
3	–14.5	17.5	12	0000 0000 0111
4	–14	18	12	0000 0000 1001
5	–13.5	18.5	12	0000 0000 1011
6	–13	19	12	0000 0000 1101
7	–12.5	19.5	12	0000 0000 1111
8	–12	20	11	0000 0001 001
9	–11.5	20.5	11	0000 0001 011
10	–11	21	11	0000 0001 101
11	–10.5	21.5	11	0000 0001 111
12	–10	22	11	0000 0010 001
13	–9.5	22.5	11	0000 0010 011
14	–9	23	11	0000 0010 101
15	–8.5	23.5	11	0000 0010 111
16	–8	24	11	0000 0011 001
17	–7.5	24.5	11	0000 0011 011
18	–7	25	11	0000 0011 101
19	–6.5	25.5	11	0000 0011 111
20	–6	26	11	0000 0100 001
21	–5.5	26.5	11	0000 0100 011
22	–5	27	10	0000 0100 11
23	–4.5	27.5	10	0000 0101 01
24	–4	28	10	0000 0101 11
25	–3.5	28.5	8	0000 0111
26	–3	29	8	0000 1001
27	–2.5	29.5	8	0000 1011
28	–2	30	7	0000 111
29	–1.5	30.5	5	0001 1
30	–1	31	4	0011
31	–0.5	31.5	3	011
32	0		1	1
33	0.5	–31.5	3	010
34	1	–31	4	0010
35	1.5	–30.5	5	0001 0
36	2	–30	7	0000 110
37	2.5	–29.5	8	0000 1010
38	3	–29	8	0000 1000
39	3.5	–28.5	8	0000 0110
40	4	–28	10	0000 0101 10
41	4.5	–27.5	10	0000 0101 00
42	5	–27	10	0000 0100 10
43	5.5	–26.5	11	0000 0100 010
44	6	–26	11	0000 0100 000
45	6.5	–25.5	11	0000 0011 110

Table 14/H.263 – VLC table for MVD (*concluded*)

Index	Vector	Differences	Bit number	Codes
46	7	–25	11	0000 0011 100
47	7.5	–24.5	11	0000 0011 010
48	8	–24	11	0000 0011 000
49	8.5	–23.5	11	0000 0010 110
50	9	–23	11	0000 0010 100
51	9.5	–22.5	11	0000 0010 010
52	10	–22	11	0000 0010 000
53	10.5	–21.5	11	0000 0001 110
54	11	–21	11	0000 0001 100
55	11.5	–20.5	11	0000 0001 010
56	12	–20	11	0000 0001 000
57	12.5	–19.5	12	0000 0000 1110
58	13	–19	12	0000 0000 1100
59	13.5	–18.5	12	0000 0000 1010
60	14	–18	12	0000 0000 1000
61	14.5	–17.5	12	0000 0000 0110
62	15	–17	12	0000 0000 0100
63	15.5	–16.5	13	0000 0000 0011 0

5.3.8 Motion Vector Data ($MVD_{2\text{-}4}$) (Variable length)

The three codewords $MVD_{2\text{-}4}$ are included if indicated by PTYPE and by MCBPC, and consist each of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component of each vector. Variable length codes are given in Table 14. $MVD_{2\text{-}4}$ are only present when in Advanced Prediction mode (see Annex F) or Deblocking Filter mode (see Annex J).

5.3.9 Motion Vector Data for B-macroblock (MVDB) (Variable length)

MVDB is only present in PB-frames or Improved PB-frames mode if indicated by MODB, and consists of a variable length codeword for the horizontal component followed by a variable length codeword for the vertical component of each vector. Variable length codes are given in Table 14. For the use of MVDB, refer to Annexes G and M.

5.4 Block layer

If not in PB-frames mode, a macroblock comprises four luminance blocks and one of each of the two colour difference blocks (see Figure 5). The structure of the block layer is shown in Figure 11. INTRADC is present for every block of the macroblock if MCBPC indicates macroblock type 3 or 4 (see Tables 7 and 8). TCOEF is present if indicated by MCBPC or CBPY.

In PB-frames mode, a macroblock comprises twelve blocks. First the data for the six P-blocks is transmitted as in the default H.263 mode, then the data for the six B-blocks. INTRADC is present for every P-block of the macroblock if MCBPC indicates macroblock type 3 or 4 (see Tables 7 and 8). INTRADC is not present for B-blocks. TCOEF is present for P-blocks if indicated by MCBPC or CBPY. TCOEF is present for B-blocks if indicated by CBPB.

For coding of the symbols in the Syntax-based Arithmetic Coding mode, refer to Annex E.

INTRADC	TCOEF

Figure 11/H.263 – Structure of block layer

5.4.1 DC coefficient for INTRA blocks (INTRADC) (8 bits)

A codeword of 8 bits. The code 0000 0000 is not used. The code 1000 0000 is not used, the reconstruction level of 1024 being coded as 1111 1111 (see Table 15).

Table 15/H.263 – Reconstruction levels for INTRA-mode DC coefficient

Index	FLC	Reconstruction level into inverse transform
0	0000 0001 (1)	8
1	0000 0010 (2)	16
2	0000 0011 (3)	24
.	. .	.
.	. .	.
126	0111 1111 (127)	1016
127	1111 1111 (255)	1024
128	1000 0001 (129)	1032
.	. .	.
.	. .	.
252	1111 1101 (253)	2024
253	1111 1110 (254)	2032

5.4.2 Transform Coefficient (TCOEF) (Variable length)

The most commonly occurring EVENTs are coded with the variable length codes given in Table 16. The last bit "s" denotes the sign of the level, "0" for positive and "1" for negative.

An EVENT is a combination of a last non-zero coefficient indication (LAST; "0": there are more non-zero coefficients in this block, "1": this is the last non-zero coefficient in this block), the number of successive zeros preceding the coded coefficient (RUN), and the non-zero value of the coded coefficient (LEVEL).

The remaining combinations of (LAST, RUN, LEVEL) are coded with a 22-bit word consisting of 7 bits ESCAPE, 1 bit LAST, 6 bits RUN and 8 bits LEVEL. Use of this 22-bit word for encoding the combinations listed in Table 16 is not prohibited. For the 8-bit word for LEVEL, the code 0000 0000 is forbidden, and the code 1000 0000 is forbidden unless the Modified Quantization mode is in use (see Annex T). The codes for RUN and for LEVEL are given in Table 17.

Table 16/H.263 – VLC table for TCOEF

INDEX	LAST	RUN	|LEVEL|	BITS	VLC CODE
0	0	0	1	3	10s
1	0	0	2	5	1111s
2	0	0	3	7	0101 01s
3	0	0	4	8	0010 111s
4	0	0	5	9	0001 1111s
5	0	0	6	10	0001 0010 1s
6	0	0	7	10	0001 0010 0s
7	0	0	8	11	0000 1000 01s
8	0	0	9	11	0000 1000 00s
9	0	0	10	12	0000 0000 111s
10	0	0	11	12	0000 0000 110s
11	0	0	12	12	0000 0100 000s
12	0	1	1	4	110s
13	0	1	2	7	0101 00s
14	0	1	3	9	0001 1110s
15	0	1	4	11	0000 0011 11s
16	0	1	5	12	0000 0100 001s
17	0	1	6	13	0000 0101 0000s
18	0	2	1	5	1110s
19	0	2	2	9	0001 1101s
20	0	2	3	11	0000 0011 10s
21	0	2	4	13	0000 0101 0001s
22	0	3	1	6	0110 1s
23	0	3	2	10	0001 0001 1s
24	0	3	3	11	0000 0011 01s
25	0	4	1	6	0110 0s
26	0	4	2	10	0001 0001 0s
27	0	4	3	13	0000 0101 0010s
28	0	5	1	6	0101 1s
29	0	5	2	11	0000 0011 00s
30	0	5	3	13	0000 0101 0011s
31	0	6	1	7	0100 11s
32	0	6	2	11	0000 0010 11s
33	0	6	3	13	0000 0101 0100s
34	0	7	1	7	0100 10s
35	0	7	2	11	0000 0010 10s
36	0	8	1	7	0100 01s
37	0	8	2	11	0000 0010 01s
38	0	9	1	7	0100 00s
39	0	9	2	11	0000 0010 00s
40	0	10	1	8	0010 110s
41	0	10	2	13	0000 0101 0101s
42	0	11	1	8	0010 101s
43	0	12	1	8	0010 100s
44	0	13	1	9	0001 1100s
45	0	14	1	9	0001 1011s

Table 16/H.263 – VLC table for TCOEF (*continued*)

INDEX	LAST	RUN	|LEVEL|	BITS	VLC CODE
46	0	15	1	10	0001 0000 1s
47	0	16	1	10	0001 0000 0s
48	0	17	1	10	0000 1111 1s
49	0	18	1	10	0000 1111 0s
50	0	19	1	10	0000 1110 1s
51	0	20	1	10	0000 1110 0s
52	0	21	1	10	0000 1101 1s
53	0	22	1	10	0000 1101 0s
54	0	23	1	12	0000 0100 010s
55	0	24	1	12	0000 0100 011s
56	0	25	1	13	0000 0101 0110s
57	0	26	1	13	0000 0101 0111s
58	1	0	1	5	0111s
59	1	0	2	10	0000 1100 1s
60	1	0	3	12	0000 0000 101s
61	1	1	1	7	0011 11s
62	1	1	2	12	0000 0000 100s
63	1	2	1	7	0011 10s
64	1	3	1	7	0011 01s
65	1	4	1	7	0011 00s
66	1	5	1	8	0010 011s
67	1	6	1	8	0010 010s
68	1	7	1	8	0010 001s
69	1	8	1	8	0010 000s
70	1	9	1	9	0001 1010s
71	1	10	1	9	0001 1001s
72	1	11	1	9	0001 1000s
73	1	12	1	9	0001 0111s
74	1	13	1	9	0001 0110s
75	1	14	1	9	0001 0101s
76	1	15	1	9	0001 0100s
77	1	16	1	9	0001 0011s
78	1	17	1	10	0000 1100 0s
79	1	18	1	10	0000 1011 1s
80	1	19	1	10	0000 1011 0s
81	1	20	1	10	0000 1010 1s
82	1	21	1	10	0000 1010 0s
83	1	22	1	10	0000 1001 1s
84	1	23	1	10	0000 1001 0s
85	1	24	1	10	0000 1000 1s
86	1	25	1	11	0000 0001 11s
87	1	26	1	11	0000 0001 10s
88	1	27	1	11	0000 0001 01s
89	1	28	1	11	0000 0001 00s
90	1	29	1	12	0000 0100 100s
91	1	30	1	12	0000 0100 101s
92	1	31	1	12	0000 0100 110s
93	1	32	1	12	0000 0100 111s
94	1	33	1	13	0000 0101 1000s

Table 16/H.263 – VLC table for TCOEF (*concluded*)

INDEX	LAST	RUN	|LEVEL|	BITS	VLC CODE
95	1	34	1	13	0000 0101 1001s
96	1	35	1	13	0000 0101 1010s
97	1	36	1	13	0000 0101 1011s
98	1	37	1	13	0000 0101 1100s
99	1	38	1	13	0000 0101 1101s
100	1	39	1	13	0000 0101 1110s
101	1	40	1	13	0000 0101 1111s
102	ESCAPE			7	0000 011

Table 17/H.263 – FLC table for RUNS and LEVELS

Index	Run	Code
0	0	000 000
1	1	000 001
2	2	000 010
.	.	.
.	.	.
63	63	111 111

Index	Level	Code
–	–128	see text
0	–127	1000 0001
.	.	.
125	–2	1111 1110
126	–1	1111 1111
–	0	FORBIDDEN
127	1	0000 0001
128	2	0000 0010
.	.	.
253	127	0111 1111

6 Decoding process

6.1 Motion compensation

In this subclause, the motion compensation for the default H.263 prediction mode is described. For a description of motion compensation in the Unrestricted Motion Vector mode, refer to Annex D. For a description of motion compensation in the Advanced Prediction mode, refer to Annex F. For a description of motion compensation in the Reduced-Resolution Update mode refer to Annex Q.

6.1.1 Differential motion vectors

The macroblock vector is obtained by adding predictors to the vector differences indicated by MVD (see Table 14 and Table D.3). For differential coding with four vectors per macroblock, refer to Annex F. In case of one vector per macroblock, the candidate predictors for the differential coding are taken from three surrounding macroblocks as indicated in Figure 12. The predictors are calculated separately for the horizontal and vertical components.

In the special cases at the borders of the current GOB, slice, or picture, the following decision rules are applied in increasing order:

1) When the corresponding macroblock was coded in INTRA mode (if not in PB-frames mode with bidirectional prediction) or was not coded (COD = 1), the candidate predictor is set to zero.

2) The candidate predictor MV1 is set to zero if the corresponding macroblock is outside the picture or the slice (at the left side).

3) Then, the candidate predictors MV2 and MV3 are set to MV1 if the corresponding macroblocks are outside the picture (at the top) or outside the GOB (at the top) if the GOB header of the current GOB is non-empty; or outside the slice when in Slice Structured mode.

4) Then, the candidate predictor MV3 is set to zero if the corresponding macroblock is outside the picture (at the right side).

For each component, the predictor is the median value of the three candidate predictors for this component.

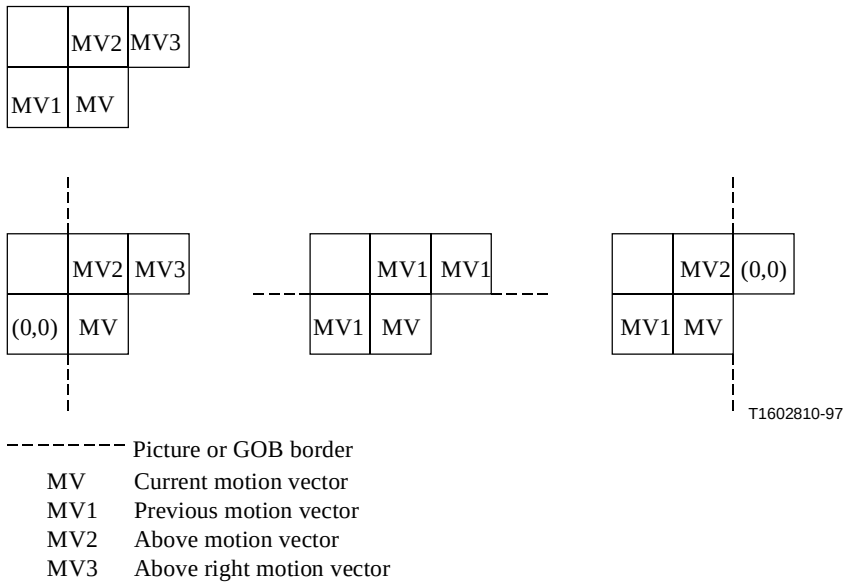


Figure 12/H.263 – Motion vector prediction

Advantage is taken of the fact that the range of motion vector component values is constrained. Each VLC word for MVD represents a pair of difference values. Only one of the pair will yield a macroblock vector component falling within the permitted range [–16, 15.5]. A positive value of the horizontal or vertical component of the motion vector signifies that the prediction is formed from pixels in the previous picture which are spatially to the right or below the pixels being predicted. If the unrestricted motion vector mode (see Annex D) is used, the decoding of motion vectors shall be performed as specified in D.2.

The motion vector is used for all pixels in all four luminance blocks in the macroblock. Motion vectors for both chrominance blocks are derived by dividing the component values of the macroblock vector by two, due to the lower chrominance format. The component values of the resulting quarter pixel resolution vectors are modified towards the nearest half pixel position as indicated in Table 18.

Table 18/H.263 – Modification of quarter-pixel resolution chrominance vector components

Quarter-pixel position	0	1/4	1/2	3/4	1
Resulting position	0	1/2	1/2	1/2	1

6.1.2 Interpolation for subpixel prediction

Half pixel values are found using bilinear interpolation as described in Figure 13. "/" indicates division by truncation.

The value of RCONTROL is equal to the value of the rounding type (RTYPE) bit (bit 6) in MPPTYPE (see 5.1.4.3), when the Source Format field (bits 6-8) in PTYPE indicates "extended PTYPE". Otherwise RCONTROL has an implied value of 0. Regardless of the RTYPE bit, the value of RCONTROL is set to 0 for the B-part of Improved PB frames (see Annex M).

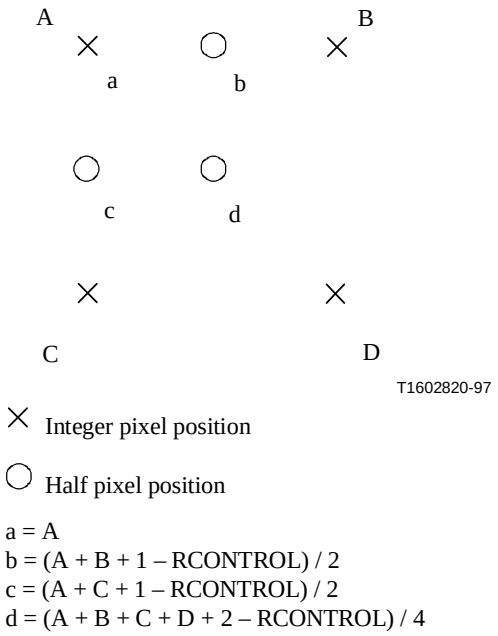


Figure 13/H.263 – Half-pixel prediction by bilinear interpolation

6.2 Coefficients decoding

6.2.1 Inverse quantization

The inverse quantization process is described in this subclause, except for when the optional Advanced INTRA Coding mode is in use (see Annex I). If LEVEL = "0", the reconstruction level REC = "0". The reconstruction level of INTRADC is given by Table 15. The reconstruction levels of all non-zero coefficients other than the INTRADC one are given by the following formulas:

$$|REC| = QUANT \cdot (2 \cdot |LEVEL| + 1) \qquad \text{if QUANT = "odd"}$$

$$|REC| = QUANT \cdot (2 \cdot |LEVEL| + 1) - 1 \qquad \text{if QUANT = "even"}$$

Note that this process disallows even valued numbers. This has been found to prevent accumulation of IDCT mismatch errors. After calculation of |REC|, the sign is added to obtain REC: $REC = sign(LEVEL) \cdot |REC|$

Sign(LEVEL) is given by the last bit of the TCOEF code (see Table 16) or by Table 17.

6.2.2 Clipping of reconstruction levels

After inverse quantization, the reconstruction levels of all coefficients other than the INTRADC one are clipped to the range –2048 to 2047.

6.2.3 Zigzag positioning

The quantized transform coefficients are placed into an 8 × 8 block according to the sequence given in Figure 14, unless the optional Advanced INTRA Coding mode is in use (see Annex I). Coefficient 1 is the dc-coefficient.

1	2	6	7	15	16	28	29
3	5	8	14	17	27	30	43
4	9	13	18	26	31	42	44
10	12	19	25	32	41	45	54
11	20	24	33	40	46	53	55
21	23	34	39	47	52	56	61
22	35	38	48	51	57	60	62
36	37	49	50	58	59	63	64

Figure 14/H.263 – Zigzag positioning of quantized transform coefficients

6.2.4 Inverse transform

After inverse quantization and zigzag of coefficients, the resulting 8 × 8 blocks are processed by a separable two-dimensional inverse discrete cosine transform of size 8 by 8. The output from the inverse transform ranges from –256 to +255 after clipping to be represented with 9 bits. The transfer function of the inverse transform is given by:

$$f(x,y) = \frac{1}{4}\sum_{u=0}^{7}\sum_{v=0}^{7} C(u)C(v)F(u,v)\cos\left[\pi(2x+1)\frac{u}{16}\right]\cos\left[\pi(2y+1)\frac{v}{16}\right]$$

with $u, v, x, y = 0, 1, 2, ..., 7$

where:

x, y = spatial coordinates in the pixel domain,

u, v = coordinates in the transform domain;

$C(u)$ = $1/\sqrt{2}$ for $u = 0$, otherwise 1;

$C(v)$ = $1/\sqrt{2}$ for $v = 0$, otherwise 1.

NOTE – Within the block being transformed, $x = 0$ and $y = 0$ refer to the pixel nearest the left and top edges of the picture respectively.

The arithmetic procedures for computing the inverse transform are not defined, but should meet the error tolerance specified in Annex A.

6.3 Reconstruction of blocks

6.3.1 Summation

After motion compensation and coefficients decoding (inverse transform included), a reconstruction is formed for each luminance and chrominance block. For INTRA blocks, the reconstruction is equal to the result of the inverse transformation. For INTER blocks, the reconstruction is formed by

summing the prediction and the result of the inverse transformation. The summation is performed on a pixel basis. For the summation in the Reduced-Resolution Update mode, refer to Annex Q.

6.3.2 Clipping

To prevent quantization distortion of transform coefficient amplitudes causing arithmetic overflow in the encoder and decoder loops, clipping functions are inserted. The clipper operates after the summation of prediction and reconstructed prediction error on resulting pixel values less than 0 or greater than 255, changing them to 0 and 255 respectively.

ANNEX A

Inverse transform accuracy specification

A.1 Generate random integer pixel data values in the range –L to +H according to the random number generator given below ("C" version). Arrange into 8 by 8 blocks. Data set of 10 000 blocks should each be generated for (L = 256, H = 255), (L = H = 5) and (L = H = 300).

A.2 For each 8 by 8 block, perform a separable, orthonormal, matrix multiply, forward discrete cosine transform using at least 64-bit floating point accuracy.

$$F(u,v) = \frac{1}{4} C(u) C(v) \sum_{x=0}^{7} \sum_{y=0}^{7} f(x,y) \cos\left[\pi(2x+1)\frac{u}{16}\right] \cos\left[\pi(2y+1)\frac{v}{16}\right]$$

with $u, v, x, y = 0, 1, 2, ..., 7$

where:

x, y	=	spatial coordinates in the pixel domain;
u, v	=	coordinates in the transform domain;
$C(u)$	=	$1/\sqrt{2}$ for $u = 0$, otherwise 1;
$C(v)$	=	$1/\sqrt{2}$ for $v = 0$, otherwise 1.

A.3 For each block, round the 64 resulting transformed coefficients to the nearest integer values. Then clip them to the range –2048 to +2047. This is the 12-bit input data to the inverse transform.

A.4 For each 8 by 8 block of 12-bit data produced by A.3, perform a separable, orthonormal, matrix multiply, inverse discrete cosine transform (IDCT) using at least 64-bit floating point accuracy. Round the resulting pixels to the nearest integer and clip to the range –256 to +255. These blocks of 8×8 pixels are the reference IDCT output data.

A.5 For each 8 by 8 block produced by A.3, apply the IDCT under test and clip the output to the range –256 to +255. These blocks of 8×8 pixels are the test IDCT output data.

A.6 For each of the 64 IDCT output pixels, and for each of the 10 000 block data sets generated above, measure the peak, mean and mean square error between the reference and the test data.

A.7
- For any pixel, the peak error should not exceed 1 in magnitude.
- For any pixel, the mean square error should not exceed 0.06.
- Overall, the mean square error should not exceed 0.02.
- For any pixel, the mean error should not exceed 0.015 in magnitude.
- Overall, the mean error should not exceed 0.0015 in magnitude.

A.8 All zeros in shall produce all zeros out.

A.9 Re-run the measurements using exactly the same data values of A.1, but change the sign on each pixel.

"C" program for random number generation

```
/* L and H shall be long, that is 32 bits */
long rand(L,H)
long     L,H;
{
     static long randx = 1;                    /* long is 32 bits            */
     static double z = (double) 0x7fffffff;
     long i,j;
     double   x;                               /* double is 64 bits          */
     randx = (randx * 1103515245) + 12345;
     i = randx & 0x7ffffffe;                   /* keep 30 bits               */
     x = ( (double)i ) /  z;                   /* range 0 to 0.99999 ...     */
     x *= (L+H+1);                             /* range 0 to < L+H+1         */
     j = x;                                    /* truncate to integer        */
     return(j – L);                            /* range –L to H              */
}
```

ANNEX B

Hypothetical Reference Decoder

The Hypothetical Reference Decoder (HRD) is defined as follows:

B.1 The HRD and the encoder have the same clock frequency as well as the same picture clock frequency, and are operated synchronously.

B.2 The HRD receiving buffer size is (B + BPPmaxKb * 1024 bits) where (BPPmaxKb * 1024) is the maximum number of bits per picture that has been negotiated for use in the bitstream (see 3.6). The value of B is defined as follows:

$$B = 4 \cdot R_{max} / PCF$$

where PCF is the effective picture clock frequency, and R_{max} is the maximum video bit rate during the connection in bits per second. The effective picture clock frequency is the standard CIF picture clock frequency unless a custom PCF is specified in the CPCFC field of the picture header. This value for B is a minimum. An encoder may use a larger value for B, provided the larger number is first negotiated by external means, for example Recommendation H.245.

The value for R_{max} depends on the system configuration (for example GSTN or ISDN, single or multi-link) and may be equal to the maximum bit rate supported by the physical link. Negotiation of R_{max} is done by external means (for example, Recommendation H.245).

B.3 The HRD is initially empty.

B.4 The HRD buffer is examined at picture clock intervals (1000/PCF ms). If at least one complete coded picture is in the buffer, then all the data for the earliest picture in bitstream order is instantaneously removed (e.g. at t_{n+1} in Figure B.1). Immediately after removing the above data the buffer occupancy must be less than B. This is a requirement on the coder output bitstream including coded picture data and MCBPC and STUF stuffing but not error correction framing bits, fill indicator (Fi), fill bits or error correction parity information described in Annex H.

For the purposes of this definition, unless the optional Temporal, SNR, and Spatial Scalability mode is in use, a complete coded picture is one normal I- or P-picture, or a PB-frame or Improved PB-frame.

When the Temporal, SNR, and Spatial Scalability mode is in use (see Annex O), each enhancement layer is given an additional HRD, for which a complete coded picture is one EI-, EP-, or B-picture. The base layer buffer shall hold the bits of the picture header as they arrive, until a sufficient amount of the picture header has arrived to determine whether the picture is a base layer or enhancement layer picture, and the number of the enhancement layer. When it can be determined that the arriving picture belongs to an enhancement layer, all bits for that picture shall be instantly transferred to the appropriate enhancement layer HRD, and any later bits which arrive continue to be placed into the enhancement layer HRD until a sufficient amount of some new picture header has arrived to determine that the bitstream should again be re-routed into another HRD buffer. The process of enhancement layer identification is instantaneous and asynchronous, independent of the picture clock interval checking times.

To meet this requirement the number of bits for the $(n+1)$th coded picture d_{n+1} must satisfy:

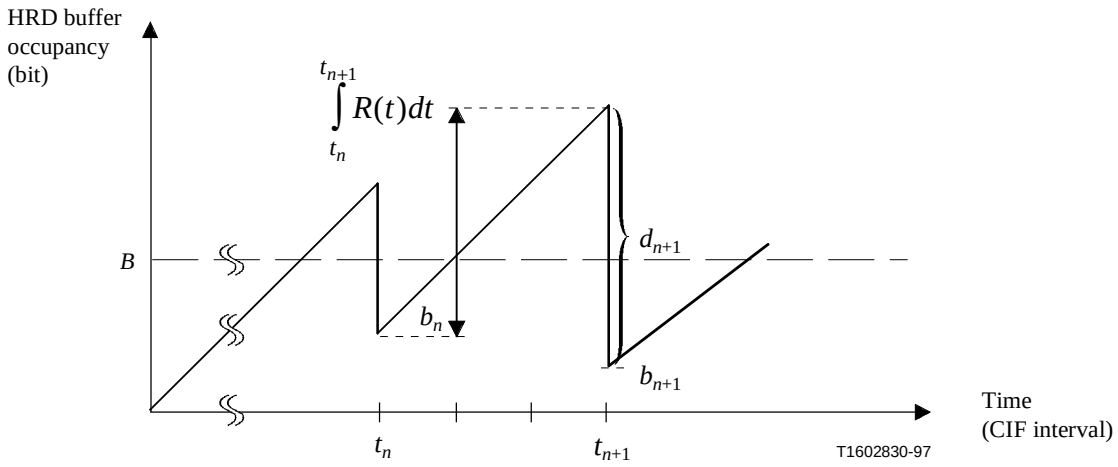
$$d_{n+1} \geq b_n + \int_{t_n}^{t_{n+1}} R(t)dt - B$$

where:

b_n is the buffer occupancy just after time t_n;

t_n is the time the nth coded picture is removed from the HRD buffer;

$R(t)$ is the video bit rate at time t.



NOTE – Time $(t_{n+1} - t_n)$ is an integer number of CIF picture periods (1/29.97, 2/29.97, 3/29.97,...).

Figure B.1/H.263 – HRD buffer occupancy

ANNEX C

Considerations for multipoint

The following facilities are provided to support switched multipoint operation.

C.1 Freeze picture request

Causes the decoder to freeze its displayed picture until a freeze picture release signal is received or a time-out period of at least six seconds has expired. The transmission of this signal is by external means (for example, Recommendation H.245). Note that a similar command may also be sent using supplemental enhancement information within the picture header of the video bitstream (see L.4).

C.2 Fast update request

Causes the encoder to encode its next picture in INTRA mode with coding parameters such as to avoid buffer overflow. The transmission method for this signal is by external means (for example Recommendation H.245).

C.3 Freeze picture release

A signal from an encoder which has responded to a fast update request and allows a decoder to exit from its freeze picture mode and display decoded pictures in the normal manner. This signal is transmitted by PTYPE (see 5.1.3) in the picture header of the first picture coded in response to the fast update request.

C.4 Continuous Presence Multipoint and Video Multiplexing (CPM)

NOTE – Not used for Recommendation H.324.

In this Recommendation a negotiable Continuous Presence Multipoint and Video Multiplexing mode is provided in which up to four independent H.263 bitstreams can be multiplexed as independent "Sub-Bitstreams" in one new video bitstream with use of the PSBI, GSBI, SSBI, and ESBI fields. Capability exchange for this mode is done by external means (for example Recommendation H.242). Reference Picture Selection back-channel data for responding to independent Sub-Bitstreams is supported using the BCPM and BSBI fields.

When in CPM mode, the CPM field shall be set to "1" in each of the independent H.263 Sub-Bitstreams. Sub-Bitstreams are identified by a stream identifier number using the Sub-Bitstream Indicators (SBIs) in the Picture and GOB or slice and EOSBS headers of each H.263 bitstream. The SBI indicates the number of the H.263 bitstream to which that header and all following information until the next Picture or GOB header or slice header in the composed video bitstream belongs.

Each Sub-Bitstream is considered as a normal H.263 bitstream and shall therefore comply with the capabilities that are exchanged by external means. The information for the different H.263 bitstreams is not transmitted in any special predefined order, an SBI can have any value independent from preceding SBIs and the picture rates for the different H.263 bitstreams may be different. The information in each individual bitstream is also completely independent from the information in the other bitstreams. For example, the GFID codewords in one Sub-Bitstream are not influenced by GFID or PTYPE codewords in other Sub-Bitstreams. Similarly, the mode state inference rules when using an extended picture type (PLUSPTYPE) in the picture header and all other aspects of the video bitstream operation shall operate independently and separately for each Sub-Bitstream.

As a matter of convention, the Sub-Bitstream with the lowest Sub-Bitstream identifier number (sent in SBI) is considered to have the highest priority in situations in which some conflict of resource

requirements may necessitate a choice of priority (unless a different priority convention is established by external means).

In order to mark the end of each Sub-Bitstream of the CPM mode, a syntax is provided as shown in Figure C.1, provided the ability to send this added syntax is first negotiated by external means (while CPM operation was defined in Version 1 of this Recommendation, the end of Sub-Bitstream syntax was added in Version 2 and thus is not considered a part of Version 1 CPM operation). The end of Sub-Bitstream syntax (ESTUF + EOSBS + ESBI) marks the end of each Sub-Bitstream, rather than the end of the entire stream as done by an EOS code.

NOTE – No ability to negotiate CPM Sub-Bitstream operation as defined herein for Recommendation H.263 was adopted into any ITU-T Recommendations for terminals (such as Recommendation H.324) prior to the creation of Version 2 of this Recommendation. Thus any external negotiation of CPM operation adopted into a future H-Series terminal Recommendation shall imply support for the end of Sub-Bitstream syntax unless otherwise specified in the H-Series terminal Recommendation.

There are three parts to the end of Sub-Bitstream syntax. Following mandatory byte alignment using ESTUF, an EOSBS codeword of 23 bits is sent (corresponding to a GOB header with GN = 30, which is otherwise unused in the syntax, followed by a single zero-valued bit which is reserved for future use). The EOSBS codeword is then followed by a two-bit ESBI codeword indicating which Sub-Bitstream is affected. This pair of codewords signifies that the sending of data for the associated Sub-Bitstream has ended and that any subsequent data sent for the same Sub-Bitstream shall be entirely independent from that which came before the EOSBS. In particular, the next picture for the Sub-Bitstream after the EOSBS code shall not be an INTER picture or any other picture type which can use forward temporal prediction (an I- or EI-picture is allowed, but a P-picture, PB-frame, Improved PB-frame, B-picture, or EP-picture is not).

The syntax of EOSBS and ESBI is described in the following subclauses. ESTUF is described in 5.1.26.

ESTUF	EOSBS	ESBI

Figure C.1/H.263 – Syntax diagram for End of Sub-Bitstream Indicators

C.4.1 End Of Sub-Bitstream code (EOSBS) (23 bits)

The EOSBS code is a codeword of 23 bits. Its value is 0000 0000 0000 0000 1 11110 0. It is up to the encoder whether to insert this codeword or not. EOSBS should not be sent unless at least one picture header has previously been sent for the same Sub-Bitstream indicated in the following ESBI field, and shall not be sent unless the capability to send EOSBS has been negotiated by external means. EOSBS codes shall be byte aligned. This is achieved by inserting ESTUF before the EOSBS start code such that the first bit of the EOSBS start code is the first (most significant) bit of a byte (see 5.1.26).

The EOSBS code indicates that the sending of data for the indicated Sub-Bitstream has stopped and the Sub-Bitstream has been declared over, until re-started by issuance of another picture start code for that Sub-Bitstream. Subsequent pictures with the same Sub-Bitstream identifier number (ESBI) shall be completely independent of and shall not depend in any way on the pictures which were sent prior to the EOSBS code.

Control and other information associated with the video bitstream in general without specification of which Sub-Bitstreams these codes are meant to apply (such as a Freeze Picture Request or a Fast Update Request sent in H.242) should be presumed to apply to all of the *active* Sub-Bitstreams only. A Sub-Bitstream is considered active if at least one picture start code has been received for the

Sub-Bitstream and the last data sent which was applicable to that Sub-Bitstream was not an EOS or EOSBS + ESBI.

C.4.2 Ending Sub-Bitstream Indicator (ESBI) (2 bits)

ESBI is a fixed length codeword of two bits which follows immediately after EOSBS. It indicates the Sub-Bitstream number of the ending Sub-Bitstream. Its value is the natural two-bit binary representation of the Sub-Bitstream number.

ANNEX D

Unrestricted Motion Vector mode

This annex describes the optional Unrestricted Motion Vector mode of this Recommendation. The capability of this H.263 mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in PTYPE or PLUSPTYPE.

The range of motion vectors and the VLC table used for coding the motion vector differences for the Unrestricted Motion Vector mode depend on whether the PLUSPTYPE field of the picture header is present. When PLUSPTYPE is present, the range of motion vectors also depends on the picture size and the value of the UUI field in the picture header.

D.1 Motion vectors over picture boundaries

In the default prediction mode of this Recommendation, motion vectors are restricted such that all pixels referenced by them are within the coded picture area (see 4.2.3). In the Unrestricted Motion Vector mode however this restriction is removed and therefore motion vectors *are* allowed to point outside the picture. When a pixel referenced by a motion vector is outside the coded picture area, an edge pixel is used instead. This edge pixel is found by limiting the motion vector to the last full-pixel position inside the coded picture area. Limitation of the motion vector is performed on a pixel basis and separately for each component of the motion vector.

For example, if the Unrestricted Motion Vector mode is used for a QCIF picture, the referenced pixel value for the luminance component is given by the following formula:

$$\mathrm{Rumv}(x, y) = R(x', y')$$

where:

x, y, x', y' = spatial coordinates in the pixel domain;

$\mathrm{Rumv}(x, y)$ = pixel value of the referenced picture at (x, y) when in Unrestricted Motion Vector mode;

$R(x', y')$ = pixel value of the referenced picture at (x′, y′) when in Unrestricted Motion Vector mode;

$$x' \begin{cases} = 0 & \text{if } x < 0; \\ = 175 & \text{if } x > 175; \\ = x & \text{otherwise;} \end{cases}$$

$$y' \begin{cases} = 0 & \text{if } y < 0; \\ = 143 & \text{if } y > 143; \\ = y & \text{otherwise;} \end{cases}$$

and the coded picture area of R(x′, y′) is $0 \le x' \le 175$, $0 \le y' \le 143$. The given boundaries are integer pixel positions; however, (x′, y′) can also be a half-pixel position within these boundaries.

D.1.1 Restrictions for motion vector values

If PLUSPTYPE is present in the picture header, the motion vector values are restricted such that no element of the 16 × 16 or (8 × 8) region that is selected shall have a horizontal or vertical distance more than 15 pixels outside the coded picture area. Note that this is a smaller extrapolation range than when PLUSPTYPE is not present.

NOTE 1 – When PLUSPTYPE is absent, the extrapolation range is a maximum of 31.5 pixels outside the coded picture area when the Unrestricted Motion Vector mode is used, and 16 pixels outside the coded picture area when the Advanced Prediction mode (see Annex F) is used without the Unrestricted Motion Vector mode.

NOTE 2 – When the Advanced Prediction mode (see Annex F) is in use, the motion vector for each 16 × 16 or (8 × 8) region affects a larger areas, due to overlapped block motion compensation. This can cause the effective extrapolation range to increase for the "remote" motion vectors of the Advanced Prediction mode, since the amount of overlapping (4 pixels, or 8 pixels when the Reduced-Resolution Update mode is also in use) adds to the amount of extrapolation required (even though the range of values allowed for each motion vector remains the same as when the Advanced Prediction mode is not in use).

D.2 Extension of the motion vector range

In the default prediction mode, the values for both horizontal and vertical components of the motion vectors are restricted to the range [–16, 15.5] (this is also valid for the forward and backward motion vector components for B-pictures). In the Unrestricted Motion Vector mode, however, the maximum range for vector components is extended.

If the PLUSPTYPE field is not present in the picture header, the motion vector range is extended to [–31.5, 31.5], with the restriction that only values that are within a range of [–16, 15.5] around the predictor for each motion vector component can be reached if the predictor is in the range [–15.5, 16]. If the predictor is outside [–15.5, 16], all values within the range [–31.5, 31.5] with the same sign as the predictor plus the zero value can be reached. So, if MV_c is the motion vector component and P_c is the predictor for it, then:

$$-31.5 \le MV_c \le 0 \qquad if\ -31.5 \le P_c \le -16$$

$$-16 + P_c \le MV_c \le 15.5 + P_c \qquad if\ -15.5 \le P_c \le 16$$

$$0 \le MV_c \le 31.5 \qquad if\ \ 16.5 \le P_c \le 31.5$$

In the Unrestricted Motion Vector mode, the interpretation of Table 14 for MVD, $MVD_{2\text{-}4}$ and MVDB is as follows:

- If the predictor for the motion vector component is in the range [–15.5, 16], only the first column of vector differences applies.
- If the predictor for the motion vector component is outside the range [–15.5, 16], the vector difference from Table 14 shall be used that results in a vector component inside the range [–31.5, 31.5] with the same sign as the predictor (including zero).

The predictor for MVD and $MVD_{2\text{-}4}$ is defined as the median value of the vector components MV1, MV2 and MV3 as defined in 6.1.1 and F.2. For MVDB, the predictor $P_c = (TR_B \times MV)/TR_D$, where MV represents a vector component for an 8 * 8 luminance block in a P-picture (see also G.4).

If PLUSPTYPE is present, the motion vector range does not depend on the motion vector prediction value. If the UUI field is set to "1" the motion vector range depends on the picture format. For standardized picture formats up to CIF the range is [–32, 31.5], for those up to 4CIF the range is

[–64, 63.5], and for those up to 16CIF the range is [–128, 127.5], and for even larger custom picture formats the range is [–256, 255.5]. The horizontal and vertical motion vector ranges may be different for custom picture formats. The horizontal and vertical ranges are specified in Tables D.1 and D.2.

Table D.1/H.263 – Horizontal motion vector range when PLUSPTYPE present and UUI = 1

Picture width	Horizontal motion vector range
4, …, 352	[–32, 31.5]
356, …, 704	[–64, 63.5]
708, …, 1408	[–128, 127.5]
1412, …, 2048	[–256, 255.5]

Table D.2/H.263 – Vertical motion vector range when PLUSPTYPE present and UUI = 1

Picture height	Vertical motion vector range
4, …, 288	[–32, 31.5]
292, …, 576	[–64, 63.5]
580, …, 1152	[–128, 127.5]

In the Reduced-Resolution Update mode, the specified range applies to the pseudo motion vectors. This implies that the resulting actual motion vector range is enlarged to approximately double size (see also Annex Q).

If UUI is set to "01", the motion vectors are not limited except by their distance to the coded area border as explained in D.1.1. The same limitation applies to the actual motion vectors (not just the pseudo motion vectors) in the Reduced-Resolution Update mode.

To encode the motion vectors when PLUSPTYPE is present, Table D.3 is used to encode the difference between the motion vector and the motion vector prediction. Every entry in Table D.3 has a single value (in contrast to Table 14). The motion vector range and the use of Table D.3 to encode motion vector data apply to all picture types when PLUSPTYPE is present.

Motion vectors differences are always coded as a pair of a horizontal and a vertical component. If a pair equals (0.5, 0.5) six consecutive zeros are produced. To prevent start code emulation, this occurrence shall be followed by one bit set to "1". This corresponds to sending one additional zero motion vector component.

Table D.3/H.263 – Motion Vector Table used when PLUSPTYPE present

Absolute value of vector difference in half-pixel units	Number of bits	Codes
0	1	1
1	3	0s0
"x_0"+2 (2:3)	5	$0x_01s0$
"x_1x_0"+4 (4:7)	7	$0x_11x_01s0$
"$x_2x_1x_0$"+8 (8:15)	9	$0x_21x_11x_01s0$
"$x_3x_2x_1x_0$"+16 (16:31)	11	$0x_31x_21x_11x_01s0$
"$x_4x_3x_2x_1x_0$"+32 (32:63)	13	$0x_41x_31x_21x_11x_01s0$
"$x_5x_4x_3x_2x_1x_0$"+64 (64:127)	15	$0x_51x_41x_31x_21x_11x_01s0$
"$x_6x_5x_4x_3x_2x_1x_0$"+128 (128:255)	17	$0x_61x_51x_41x_31x_21x_11x_01s0$
"$x_7x_6x_5x_4x_3x_2x_1x_0$"+256 (256:511)	19	$0x_71x_61x_51x_41x_31x_21x_11x_01s0$
"$x_8x_7x_6x_5x_4x_3x_2x_1x_0$"+512 (512:1023)	21	$0x_81x_71x_61x_51x_41x_31x_21x_11x_01s0$
"$x_9x_8x_7x_6x_5x_4x_3x_2x_1x_0$"+1024 (1024:2047)	23	$0x_91x_81x_71x_61x_51x_41x_31x_21x_11x_01s0$
"$x_{10}x_9x_8x_7x_6x_5x_4x_3x_2x_1x_0$"+2048 (2048:4095)	25	$0x_{10}1x_91x_81x_71x_61x_51x_41x_31x_21x_11x_01s0$

Table D.3 is a regularly constructed reversible table. Each row represents an interval of motion vector differences in half-pixel units. The bits "…x_1x_0" denote all bits following the leading "1" in the binary representation of the absolute value of the motion vector difference. The bit "s" denotes the sign of the motion vector difference, "0" for positive and "1" for negative. The binary representation of the motion vector difference is interleaved with bits that indicate if the code continues or ends. For example, the motion vector difference –13 has sign s = 1 and binary representation $1x_2x_1x_0$ = 1101. It is encoded as 0 $x_2$1 $x_1$1 $x_0$1 s0 = 0 11 01 11 10. The 0 in the second position of the last group of two bits indicates the end of the code.

ANNEX E

Syntax-based Arithmetic Coding mode

E.1 Introduction

In the Variable Length Coding/Decoding (VLC/VLD) as described in clause 5, a symbol is VLC encoded using a specific table based on the syntax of the coder. This table typically stores lengths and values of the VLC code words. The symbol is mapped to an entry of the table in a table look-up operation, and then the binary code word specified by the entry is sent out normally to a buffer for transmitting to the receiver. In VLD decoding, the received bitstream is matched entry by entry in a specific table based on the syntax of the coder. This table must be the same as the one used in the encoder for encoding the current symbol. The matched entry in the table is then mapped back to the corresponding symbol which is the end result of the VLD decoder and is then used for recovering the video pictures. This VLC/VLD process implies that each symbol must be encoded into a fixed integral number of bits. Removing this restriction of fixed integral number of bits for symbols can lead to reductions of resulting bit rates, which can be achieved by arithmetic coding.

This annex describes the optional Syntax-based Arithmetic Coding (SAC) mode of this Recommendation. In this mode, all the corresponding variable length coding/decoding operations of this Recommendation are replaced with arithmetic coding/decoding operations. The capability of this H.263 mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in PTYPE.

E.2 Specification of SAC encoder

In SAC mode, a symbol is encoded by using a specific array of integers (or a model) based on the syntax of the coder and by calling the following procedure which is specified in C language.

```
#define  q1  16384
#define  q2  32768
#define  q3  49152
#define  top 65535

static long  low, high, opposite_bits, length;
void     encode_a_symbol(int index, int cumul_freq[ ])
{
      length = high – low + 1;
      high = low – 1 + (length * cumul_freq[index]) / cumul_freq[0];
      low += (length * cumul_freq[index+1]) / cumul_freq[0];
      for ( ; ; ) {
         if (high < q2) {
            send out a bit "0" to PSC_FIFO;
            while (opposite_bits > 0) {
               send out a bit "1" to PSC_FIFO;
               opposite_bits––;
            }
         }
         else if (low >= q2) {
            send out a bit "1" to PSC_FIFO;
            while (opposite_bits > 0) {
               send out a bit "0" to PSC_FIFO;
               opposite_bits––;
            }
            low –= q2;
            high –= q2;
         }
         else if (low >= q1 && high < q3) {
            opposite_bits += 1;
            low –= q1;
            high –= q1;
         }
         else break;

         low *= 2;
         high = 2 * high+1;
      }
}
```

The values of `low`, `high` and `opposite_bits` are initialized to `0`, `top` and `0`, respectively. `PSC_FIFO` is a FIFO for buffering the output bits from the arithmetic encoder. The model is specified through `cumul_freq[ ],` and the symbol is specified using its index in the model.

E.3 Specification of SAC decoder

In SAC decoder, a symbol is decoded by using a specific model based on the syntax and by calling the following procedure which is specified in C language.

```
static long    low, high, code_value, bit, length, index, cum;
int   decode_a_symbol(int cumul_freq[ ])
{
      length = high – low + 1;
      cum = (–1 + (code_value – low + 1) * cumul_freq[0]) / length;
      for (index = 1; cumul_freq[index] > cum; index++);
      high = low – 1 + (length * cumul_freq[index–1]) / cumul_freq[0];
      low += (length * cumul_freq[index]) / cumul_freq[0];
      for ( ; ; ) {
         if (high < q2);
         else if (low >= q2) {
            code_value -= q2;
            low –= q2;
            high –= q2;
         }
         else if (low >= q1 && high < q3) {
            code_value –= q1;
            low –= q1;
            high –= q1;
         }
         else break;

         low *= 2;
         high = 2 * high + 1;
         get bit from PSC_FIFO;
         code_value = 2 * code_value + bit;
      }
      return (index–1);
}
```

Again the model is specified through `cumul_freq[ ]`. The decoded symbol is returned through its index in the model. `PSC_FIFO` is a FIFO for buffering the incoming bitstream. The decoder is initialized to start decoding an arithmetic coded bitstream by calling the following procedure.

```
void  decoder_reset( )
{
      code_value = 0;
      low = 0;
      high = top;
      for (int i = 1;   i <= 16;   i++) {
         get bit from PSC_FIFO;
         code_value = 2 * code_value + bit;
      }
}
```

E.4 Syntax

As in VLC table mode of this Recommendation, the syntax of the symbols is partitioned into four layers: Picture, Group of Blocks, Macroblock and Block. The syntax of the top three layers remain exactly the same. The syntax of the Block layer also remains quite similar, but is illustrated in Figure E.1.

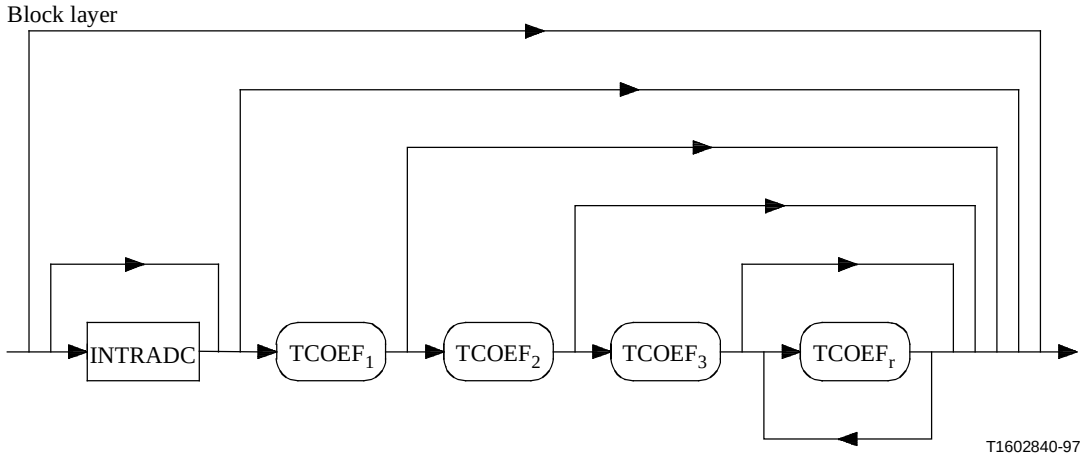


Figure E.1/H.263 – Structure of SAC Block layer

In Figure E.1, TCOEF1, TCOEF2, TCOEF3 and TCOEFr are Last-Run-Level symbols as defined in 5.4.2, and are the possible 1st, 2nd, 3rd and rest of the symbols, respectively. TCOEF1, TCOEF2, TCOEF3 and TCOEFr are only present when one, two, three or more coefficients are present in the block layer, respectively.

E.5 PSC_FIFO

PSC_FIFO in encoder or decoder is a FIFO of size > 17 bits. In PSC_FIFO of encoder, illegal emulations of PSC and GBSC are located and are avoided by stuffing a "1" after each successive appearance of 14 "0"s (which are not part of PSC or GBSC). In PSC_FIFO of the decoder, the first "1" after each string of 14 "0"s is deleted; if instead a string of 14 "0"s is followed by a "0", it indicates that a legal PSC or GBSC is detected. The exact location of the PSC or GBSC is determined by the next "1" following the string of zeros.

E.6 Header layer symbols

The header layers of the syntax are considered to be those syntactical elements above the block and macroblock layers (see Figure 6 and the syntax specification in the text). The header levels of the basic Version 1 syntax can form three possible strings, (PSTUF)--PSC--TR--PTYPE--PQUANT--CPM--(PSBI)--(TRB-DBQUANT)--PEI--(PSUPP--PEI--...), (GSTUF)--GBSC--GN--(GSBI)--GFID--GQUANT, and (ESTUF)--(EOS)--(PSTUF). In the revised syntax of Version 2, the header levels of the syntax can have other structures (see Figure 6 and the syntax specification in the text). The header level syntax strings are directly sent to PSC_FIFO as in the normal VLC table mode of this Recommendation at encoder side, and are directly sent out from PSC_FIFO in the decoder after a legal PSC, GBSC, SSC, EOS, or EOSBS is detected.

If a header is not the first in a video session, the arithmetic encoder needs to be reset before sending the header by calling the following procedure. This procedure shall also be called at the end of a video session if (ESTUF)--EOS [or (ESTUF)--EOSBS for the Sub-Bitstream for which the last header was sent] is not sent.

```
void encoder_flush( )
{
      opposite_bits++;
      if (low < q1) {
         send out a bit "0" to PSC_FIFO;
         while (opposite_bits > 0) {
            send out a bit "1" to PSC_FIFO;
            opposite_bits--;
         }
      }
      else {
         send out a bit "1" to PSC_FIFO;
         while (opposite_bits > 0) {
            send out a bit "0" to PSC_FIFO;
            opposite_bits--;
         }
      }
      low = 0;
      high = top;
}
```

In the decoder, after each fixed length symbol string, procedure **`decoder_reset`** is called.

E.7 Macroblock and Block layer symbols

Models for the macroblock and block layer symbols are included in E.8. The indices as given in the VLC tables of clause 5 are used for the indexing of the integers in the models.

The model for COD in P-pictures is named cumf_COD. The index for COD being "0" is 0, and is 1 for COD being "1". The model for MCBPC in P-pictures is named cumf_MCBPC_no4MVQ unless PLUSPTYPE is present in the picture header and either the Advanced Prediction mode (Annex F) or the Deblocking Filter mode (Annex J) is in use, in which case the model is named cumf_MCBPC_4MVQ The indexes for MCBPC are defined in Table 7 for I-pictures and Table 8 for P-pictures. The model for MCBPC in I-pictures is named by cumf_MCBPC_intra.

The model for MODB is cumf_MODB_G if Annex G is used or cumf_MODB_M if Annex M is used. The indexes for MODB are defined in Table 11 or Table M.1, respectively. The model for CBPBn, n = 1, 2, ..., 4, is cumf_YCBPB, and the model for CBPBn, n = 5, 6, is cumf_UVCBPB, with index 0 for CBPBn = 0 and index 1 for CBPBn = 1.

The model for CBPY is cumf_CBPY in INTER macroblocks and cumf_CBPY_intra in INTRA macroblocks. The model for DQUANT is cumf_DQUANT. The indexing for CBPY and DQUANT is defined in Tables 13 and 12, respectively.

The model for MVD, $MVD_{2\text{-}4}$ and MVDB is cumf_MVD and the model for INTRADC is cumf_INTRADC. The indexing is defined in Tables 14 and 15, respectively.

A non-escaped TCOEF consists of a symbol for TCOEF1/2/3/r followed by a symbol, SIGN, for the sign of the TCOEF. The models for TCOEF1, TCOEF2, TCOEF3 and TCOEFr in INTER blocks are cumf_TCOEF1, cumf_TCOEF2, cumf_TCOEF3, cumf_TCOEFr. The models for INTRA blocks are cumf_TCOEF1_intra, cumf_TCOEF2_intra, cumf_TCOEF3_intra, cumf_TCOEFr_intra. For all TCOEFs the indexing is defined in Table 16. The model for SIGN is cumf_SIGN. The indexing for SIGN is 0 for positive sign and 1 for negative sign.

The models for LAST, RUN, LEVEL after ESCAPE are cumf_LAST (cumf_LAST_intra), cumf_RUN (cumf_RUN_intra), cumf_LEVEL (cumf_LEVEL_intra) for INTER (INTRA) blocks. The indexing for LAST is 0 for LAST = 0 and 1 for LAST = 1, while the indexing for RUN and LEVEL is defined in Table 17.

The model for INTRA_MODE is cumf_INTRA_AC_DC. The indexing is defined in Table I.1.

E.8 SAC models

int cumf_COD[3]={16383, 6849, 0};

int cumf_MCBPC_no4MVQ[22]={16383, 4105, 3088, 2367, 1988, 1621, 1612, 1609, 1608, 496, 353, 195, 77, 22, 17, 12, 5, 4, 3, 2, 1, 0};

int cumf_MCBPC_4MVQ[26]={16383, 6880, 6092, 5178, 4916, 3965, 3880, 3795, 3768, 1491, 1190, 889, 655, 442, 416, 390, 360, 337, 334, 331, 327, 326, 88, 57, 26, 0};

int cumf_MCBPC_intra[10]={16383, 7410, 6549, 5188, 442, 182, 181, 141, 1, 0};

int cumf_MODB_G[4]={16383, 6062, 2130, 0};

int cumf_MODB_M[7] = {16383, 6717, 4568, 2784, 1370, 655, 0};

int cumf_YCBPB[3]={16383, 6062, 0};

int cumf_UVCBPB[3]={16383, 491, 0};

int cumf_CBPY[17]={16383, 14481, 13869, 13196, 12568, 11931, 11185, 10814, 9796, 9150, 8781, 7933, 6860, 6116, 4873, 3538, 0};

int cumf_CBPY_intra[17]={16383, 13619, 13211, 12933, 12562, 12395, 11913, 11783, 11004, 10782, 10689, 9928, 9353, 8945, 8407, 7795, 0};

int cumf_DQUANT[5]={16383, 12287, 8192, 4095, 0};

int cumf_MVD[65]={16383, 16380, 16369, 16365, 16361, 16357, 16350, 16343, 16339, 16333, 16326, 16318, 16311, 16306, 16298, 16291, 16283, 16272, 16261, 16249, 16235, 16222, 16207, 16175, 16141, 16094, 16044, 15936, 15764, 15463, 14956, 13924, 11491, 4621, 2264, 1315, 854, 583, 420, 326, 273, 229, 196, 166, 148, 137, 123, 114, 101, 91, 82, 76, 66, 59, 53, 46, 36, 30, 26, 24, 18, 14, 10, 5, 0};

int cumf_INTRADC[255]={16383, 16380, 16379, 16378, 16377, 16376, 16370, 16361, 16360, 16359, 16358, 16357, 16356, 16355, 16343, 16238, 16237, 16236, 16230, 16221, 16220, 16205, 16190, 16169, 16151, 16130, 16109, 16094, 16070, 16037, 16007, 15962, 15938, 15899, 15854, 15815, 15788, 15743, 15689, 15656, 15617, 15560, 15473, 15404, 15296, 15178, 15106, 14992, 14868, 14738, 14593, 14438, 14283, 14169, 14064, 14004, 13914, 13824, 13752, 13671, 13590, 13515, 13458, 13380, 13305, 13230, 13143, 13025, 12935, 12878, 12794, 12743, 12656, 12596, 12521, 12443, 12359, 12278, 12200, 12131, 12047, 12002, 11948, 11891, 11828, 11744, 11663, 11588, 11495, 11402, 11288, 11204, 11126, 11039, 10961, 10883, 10787, 10679, 10583, 10481, 10360, 10227, 10113, 9961, 9828, 9717, 9584, 9485, 9324, 9112, 9019, 8908, 8766, 8584, 8426, 8211, 7920, 7663, 7406, 7152, 6904, 6677, 6453, 6265, 6101, 5904, 5716, 5489, 5307, 5056, 4850, 4569, 4284, 3966, 3712, 3518, 3342, 3206, 3048, 2909, 2773, 2668, 2596, 2512, 2370, 2295, 2232, 2166, 2103, 2022, 1956, 1887, 1830, 1803, 1770, 1728, 1674, 1635, 1599, 1557, 1500, 1482, 1434, 1389, 1356, 1317, 1284, 1245, 1200, 1179, 1140, 1110, 1092, 1062, 1044, 1035, 1014, 1008, 993, 981, 954, 936, 912, 894, 876, 864, 849, 828, 816, 801, 792, 777, 756, 732, 690, 660, 642, 615, 597, 576, 555, 522, 489, 459, 435, 411, 405, 396, 387, 375, 360, 354, 345, 344, 329, 314, 293, 278, 251, 236, 230, 224, 215, 214, 208, 199, 193, 184, 178, 169, 154, 127, 100, 94, 73, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 20, 19, 18, 17, 16, 15, 9, 0};

int cumf_TCOEF1[104]={16383, 13455, 12458, 12079, 11885, 11800, 11738, 11700, 11681, 11661, 11651, 11645, 11641, 10572, 10403, 10361, 10346, 10339, 10335, 9554, 9445, 9427, 9419, 9006, 8968, 8964, 8643, 8627, 8624, 8369, 8354, 8352, 8200, 8192, 8191, 8039, 8036, 7920, 7917, 7800, 7793, 7730, 7727, 7674, 7613, 7564, 7513, 7484, 7466, 7439, 7411, 7389, 7373, 7369, 7359, 7348,

7321, 7302, 7294, 5013, 4819, 4789, 4096, 4073, 3373, 3064, 2674, 2357, 2177, 1975, 1798, 1618, 1517, 1421, 1303, 1194, 1087, 1027, 960, 890, 819, 758, 707, 680, 656, 613, 566, 534, 505, 475, 465, 449, 430, 395, 358, 335, 324, 303, 295, 286, 272, 233, 215, 0};

int cumf_TCOEF2[104]={16383, 13582, 12709, 12402, 12262, 12188, 12150, 12131, 12125, 12117, 12113, 12108, 12104, 10567, 10180, 10070, 10019, 9998, 9987, 9158, 9037, 9010, 9005, 8404, 8323, 8312, 7813, 7743, 7726, 7394, 7366, 7364, 7076, 7062, 7060, 6810, 6797, 6614, 6602, 6459, 6454, 6304, 6303, 6200, 6121, 6059, 6012, 5973, 5928, 5893, 5871, 5847, 5823, 5809, 5796, 5781, 5771, 5763, 5752, 4754, 4654, 4631, 3934, 3873, 3477, 3095, 2758, 2502, 2257, 2054, 1869, 1715, 1599, 1431, 1305, 1174, 1059, 983, 901, 839, 777, 733, 683, 658, 606, 565, 526, 488, 456, 434, 408, 380, 361, 327, 310, 296, 267, 259, 249, 239, 230, 221, 214, 0};

int cumf_TCOEF3[104]={16383, 13532, 12677, 12342, 12195, 12112, 12059, 12034, 12020, 12008, 12003, 12002, 12001, 10586, 10297, 10224, 10202, 10195, 10191, 9223, 9046, 8999, 8987, 8275, 8148, 8113, 7552, 7483, 7468, 7066, 7003, 6989, 6671, 6642, 6631, 6359, 6327, 6114, 6103, 5929, 5918, 5792, 5785, 5672, 5580, 5507, 5461, 5414, 5382, 5354, 5330, 5312, 5288, 5273, 5261, 5247, 5235, 5227, 5219, 4357, 4277, 4272, 3847, 3819, 3455, 3119, 2829, 2550, 2313, 2104, 1881, 1711, 1565, 1366, 1219, 1068, 932, 866, 799, 750, 701, 662, 605, 559, 513, 471, 432, 403, 365, 336, 312, 290, 276, 266, 254, 240, 228, 223, 216, 206, 199, 192, 189, 0};

int cumf_TCOEFr[104]={16383, 13216, 12233, 11931, 11822, 11776, 11758, 11748, 11743, 11742, 11741, 11740, 11739, 10203, 9822, 9725, 9691, 9677, 9674, 8759, 8609, 8576, 8566, 7901, 7787, 7770, 7257, 7185, 7168, 6716, 6653, 6639, 6276, 6229, 6220, 5888, 5845, 5600, 5567, 5348, 5327, 5160, 5142, 5004, 4900, 4798, 4743, 4708, 4685, 4658, 4641, 4622, 4610, 4598, 4589, 4582, 4578, 4570, 4566, 3824, 3757, 3748, 3360, 3338, 3068, 2835, 2592, 2359, 2179, 1984, 1804, 1614, 1445, 1234, 1068, 870, 739, 668, 616, 566, 532, 489, 453, 426, 385, 357, 335, 316, 297, 283, 274, 266, 259, 251, 241, 233, 226, 222, 217, 214, 211, 209, 208, 0};

int cumf_TCOEF1_intra[104]={16383, 13383, 11498, 10201, 9207, 8528, 8099, 7768, 7546, 7368, 7167, 6994, 6869, 6005, 5474, 5220, 5084, 4964, 4862, 4672, 4591, 4570, 4543, 4397, 4337, 4326, 4272, 4240, 4239, 4212, 4196, 4185, 4158, 4157, 4156, 4140, 4139, 4138, 4137, 4136, 4125, 4124, 4123, 4112, 4111, 4110, 4109, 4108, 4107, 4106, 4105, 4104, 4103, 4102, 4101, 4100, 4099, 4098, 4097, 3043, 2897, 2843, 1974, 1790, 1677, 1552, 1416, 1379, 1331, 1288, 1251, 1250, 1249, 1248, 1247, 1236, 1225, 1224, 1223, 1212, 1201, 1200, 1199, 1198, 1197, 1196, 1195, 1194, 1193, 1192, 1191, 1190, 1189, 1188, 1187, 1186, 1185, 1184, 1183, 1182, 1181, 1180, 1179, 0};

int cumf_TCOEF2_intra[104]={16383, 13242, 11417, 10134, 9254, 8507, 8012, 7556, 7273, 7062, 6924, 6839, 6741, 6108, 5851, 5785, 5719, 5687, 5655, 5028, 4917, 4864, 4845, 4416, 4159, 4074, 3903, 3871, 3870, 3765, 3752, 3751, 3659, 3606, 3580, 3541, 3540, 3514, 3495, 3494, 3493, 3474, 3473, 3441, 3440, 3439, 3438, 3425, 3424, 3423, 3422, 3421, 3420, 3401, 3400, 3399, 3398, 3397, 3396, 2530, 2419, 2360, 2241, 2228, 2017, 1687, 1576, 1478, 1320, 1281, 1242, 1229, 1197, 1178, 1152, 1133, 1114, 1101, 1088, 1087, 1086, 1085, 1072, 1071, 1070, 1069, 1068, 1067, 1066, 1065, 1064, 1063, 1062, 1061, 1060, 1059, 1058, 1057, 1056, 1055, 1054, 1053, 1052, 0};

int cumf_TCOEF3_intra[104]={16383, 12741, 10950, 10071, 9493, 9008, 8685, 8516, 8385, 8239, 8209, 8179, 8141, 6628, 5980, 5634, 5503, 5396, 5327, 4857, 4642, 4550, 4481, 4235, 4166, 4151, 3967, 3922, 3907, 3676, 3500, 3324, 3247, 3246, 3245, 3183, 3168, 3084, 3069, 3031, 3030, 3029, 3014, 3013, 2990, 2975, 2974, 2973, 2958, 2943, 2928, 2927, 2926, 2925, 2924, 2923, 2922, 2921, 2920, 2397, 2298, 2283, 1891, 1799, 1591, 1445, 1338, 1145, 1068, 1006, 791, 768, 661, 631, 630, 615, 592, 577, 576, 561, 546, 523, 508, 493, 492, 491, 476, 475, 474, 473, 472, 471, 470, 469, 468, 453, 452, 451, 450, 449, 448, 447, 446, 0};

int cumf_TCOEFr_intra[104]={16383, 12514, 10776, 9969, 9579, 9306, 9168, 9082, 9032, 9000, 8981, 8962, 8952, 7630, 7212, 7053, 6992, 6961, 6940, 6195, 5988, 5948, 5923, 5370, 5244, 5210, 4854, 4762, 4740, 4384, 4300, 4288, 4020, 3968, 3964, 3752, 3668, 3511, 3483, 3354, 3322, 3205, 3183, 3108, 3046, 2999, 2981, 2974, 2968, 2961, 2955, 2949, 2943, 2942, 2939, 2935, 2934, 2933, 2929, 2270, 2178, 2162, 1959, 1946, 1780, 1651, 1524, 1400, 1289, 1133, 1037, 942, 849, 763, 711, 591, 521, 503, 496, 474, 461, 449, 442, 436, 426, 417, 407, 394, 387, 377, 373, 370, 367, 366, 365, 364, 363, 362, 358, 355, 352, 351, 350, 0};

int cumf_SIGN[3]={16383, 8416, 0};

int cumf_LAST[3]={16383, 9469, 0};

int cumf_LAST_intra[3]={16383, 2820, 0};

int cumf_RUN[65]={16383, 15310, 14702, 13022, 11883, 11234, 10612, 10192, 9516, 9016, 8623, 8366, 7595, 7068, 6730, 6487, 6379, 6285, 6177, 6150, 6083, 5989, 5949, 5922, 5895, 5828, 5774, 5773, 5394, 5164, 5016, 4569, 4366, 4136, 4015, 3867, 3773, 3692, 3611, 3476, 3341, 3301, 2787, 2503, 2219, 1989, 1515, 1095, 934, 799, 691, 583, 435, 300, 246, 206, 125, 124, 97, 57, 30, 3, 2, 1, 0};

int cumf_RUN_intra[65]={16383, 10884, 8242, 7124, 5173, 4745, 4246, 3984, 3034, 2749, 2607, 2298, 966, 681, 396, 349, 302, 255, 254, 253, 206, 159, 158, 157, 156, 155, 154, 153, 106, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0};

int cumf_LEVEL[255]={16383, 16382, 16381, 16380, 16379, 16378, 16377, 16376, 16375, 16374, 16373, 16372, 16371, 16370, 16369, 16368, 16367, 16366, 16365, 16364, 16363, 16362, 16361, 16360, 16359, 16358, 16357, 16356, 16355, 16354, 16353, 16352, 16351, 16350, 16349, 16348, 16347, 16346, 16345, 16344, 16343, 16342, 16341, 16340, 16339, 16338, 16337, 16336, 16335, 16334, 16333, 16332, 16331, 16330, 16329, 16328, 16327, 16326, 16325, 16324, 16323, 16322, 16321, 16320, 16319, 16318, 16317, 16316, 16315, 16314, 16313, 16312, 16311, 16310, 16309, 16308, 16307, 16306, 16305, 16304, 16303, 16302, 16301, 16300, 16299, 16298, 16297, 16296, 16295, 16294, 16293, 16292, 16291, 16290, 16289, 16288, 16287, 16286, 16285, 16284, 16283, 16282, 16281, 16280, 16279, 16278, 16277, 16250, 16223, 16222, 16195, 16154, 16153, 16071, 15989, 15880, 15879, 15878, 15824, 15756, 15674, 15606, 15538, 15184, 14572, 13960, 10718, 7994, 5379, 2123, 1537, 992, 693, 611, 516, 448, 421, 380, 353, 352, 284, 257, 230, 203, 162, 161, 160, 133, 132, 105, 104, 103, 102, 101, 100, 99, 98, 97, 96, 95, 94, 93, 92, 91, 90, 89, 88, 87, 86, 85, 84, 83, 82, 81, 80, 79, 78, 77, 76, 75, 74, 73, 72, 71, 70, 69, 68, 67, 66, 65, 64, 63, 62, 61, 60, 59, 58, 57, 56, 55, 54, 53, 52, 51, 50, 49, 48, 47, 46, 45, 44, 43, 42, 41, 40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0};

int cumf_LEVEL_intra[255]={16383, 16379, 16378, 16377, 16376, 16375, 16374, 16373, 16372, 16371, 16370, 16369, 16368, 16367, 16366, 16365, 16364, 16363, 16362, 16361, 16360, 16359, 16358, 16357, 16356, 16355, 16354, 16353, 16352, 16351, 16350, 16349, 16348, 16347, 16346, 16345, 16344, 16343, 16342, 16341, 16340, 16339, 16338, 16337, 16336, 16335, 16334, 16333, 16332, 16331, 16330, 16329, 16328, 16327, 16326, 16325, 16324, 16323, 16322, 16321, 16320, 16319, 16318, 16317, 16316, 16315, 16314, 16313, 16312, 16311, 16268, 16267, 16224, 16223, 16180, 16179, 16136, 16135, 16134, 16133, 16132, 16131, 16130, 16129, 16128, 16127, 16126, 16061, 16018, 16017, 16016, 16015, 16014, 15971, 15970, 15969, 15968, 15925, 15837, 15794, 15751, 15750, 15749, 15661, 15618, 15508, 15376, 15288, 15045, 14913, 14781, 14384, 13965, 13502, 13083, 12509, 12289, 12135, 11892, 11738, 11429, 11010, 10812, 10371, 9664, 9113, 8117, 8116, 8028, 6855, 5883, 4710, 4401, 4203, 3740, 3453, 3343, 3189, 2946, 2881, 2661, 2352, 2132, 1867, 1558, 1382, 1250, 1162, 1097, 1032, 967, 835, 681, 549, 439, 351, 350, 307, 306, 305, 304,

303, 302, 301, 300, 299, 298, 255, 212, 211, 210, 167, 166, 165, 164, 163, 162, 161, 160, 159, 158, 115, 114, 113, 112, 111, 68, 67, 66, 65, 64, 63, 62, 61, 60, 59, 58, 57, 56, 55, 54, 53, 52, 51, 50, 49, 48, 47, 46, 45, 44, 43, 42, 41, 40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0};

int cumf_INTRA_AC_DC[4]={16383, 9229, 5461, 0};

ANNEX F

Advanced Prediction mode

F.1 Introduction

This annex describes the optional Advanced Prediction mode of this Recommendation, including overlapped block motion compensation and the possibility of four motion vectors per macroblock. The capability of this mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in PTYPE. In the Advanced Prediction mode, motion vectors are allowed to cross picture boundaries as is the case in the Unrestricted Motion Vector mode (for the description of this technique, refer to D.1). The extended motion vector range feature of the Unrestricted Motion Vector mode is not automatically included in the Advanced Prediction mode, and only is active if the Unrestricted Motion Vector mode is selected. If the Advanced Prediction mode is used in combination with the PB-frames mode, overlapped motion compensation is only used for prediction of the P-pictures, not for the B-pictures.

F.2 Four motion vectors per macroblock

In this Recommendation, one motion vector per macroblock is used except when in Advanced Prediction mode or Deblocking Filter mode. In this mode, the one/four vectors decision is indicated by the MCBPC codeword for each macroblock. If only one motion vector is transmitted for a certain macroblock, this is defined as four vectors with the same value. If MCBPC indicates that four motion vectors are transmitted for the current macroblock, the information for the first motion vector is transmitted as the codeword MVD and the information for the three additional motion vectors is transmitted as the codewords $MVD_{2\text{-}4}$ (see also 5.3.7 and 5.3.8).

The vectors are obtained by adding predictors to the vector differences indicated by MVD and $MVD_{2\text{-}4}$ in a similar way as when only one motion vector per macroblock is present, according to the decision rules given in 6.1.1. Again the predictors are calculated separately for the horizontal and vertical components. However, the candidate predictors MV1, MV2 and MV3 are redefined as indicated in Figure F.1. If only one vector per macroblock is present, MV1, MV2 and MV3 are defined as for the 8 * 8 block numbered 1 in Figure 5 (this definition is given in the upper left of the four sub-figures of Figure F.1).

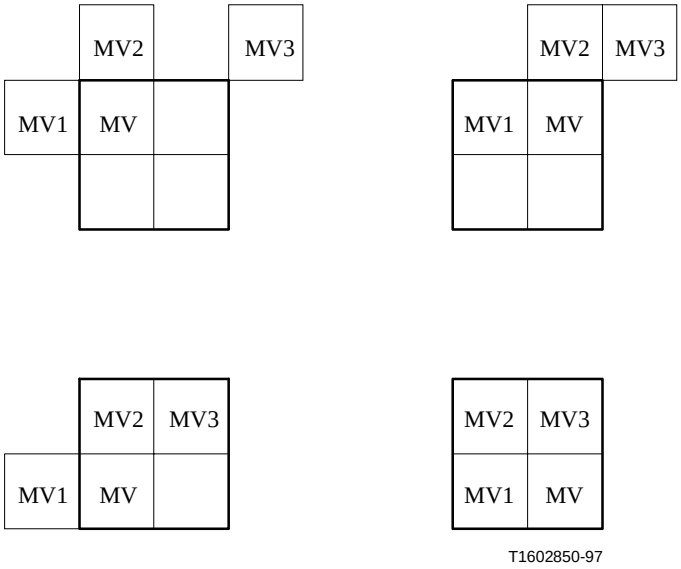


Figure F.1/H.263 – Redefinition of the candidate predictors MV1, MV2 and MV3 for each of the luminance blocks in a macroblock

If four vectors are used, each of the motion vectors is used for all pixels in one of the four luminance blocks in the macroblock. The numbering of the motion vectors is equivalent to the numbering of the four luminance blocks as given in Figure 5. Motion vector MVD_{CHR} for both chrominance blocks is derived by calculating the sum of the four luminance vectors and dividing this sum by 8; the component values of the resulting sixteenth pixel resolution vectors are modified towards the nearest half-pixel position as indicated in Table F.1.

Table F.1/H.263 – Modification of sixteenth pixel resolution chrominance vector components

Sixteenth pixel position	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	/16
Resulting position	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	2	/2

Half-pixel values are found using bilinear interpolation as described in 6.1.2. In Advanced Prediction mode, the prediction for luminance is obtained by overlapped motion compensation as described in F.3. The prediction for chrominance is obtained by applying the motion vector MVD_{CHR} to all pixels in the two chrominance blocks (as it is done in the default prediction mode).

F.3 Overlapped motion compensation for luminance

Each pixel in an 8 * 8 luminance prediction block is a weighted sum of three prediction values, divided by 8 (with rounding). In order to obtain the three prediction values, three motion vectors are used: the motion vector of the current luminance block, and two out of four "remote" vectors:

- the motion vector of the block at the left or right side of the current luminance block;
- the motion vector of the block above or below the current luminance block.

For each pixel, the remote motion vectors of the blocks at the two nearest block borders are used. This means that for the upper half of the block the motion vector corresponding to the block above the current block is used, while for the lower half of the block the motion vector corresponding to the block below the current block is used (see Figure F.3). Similarly, for the left half of the block the motion vector corresponding to the block at the left side of the current block is used, while for the

right half of the block the motion vector corresponding to the block at the right side of the current block is used (see Figure F.4).

Let *(x,y)* be a position in a picture measured in integer pixel units.

Let *(m,n)* be an integer block index in a picture, as given by:

$$m = x / 8 \qquad \text{and} \qquad n = y / 8,$$

where "/" denotes division with truncation.

Let *(i,j)* be an integer pixel location in an 8×8 block, given by:

$$i = x - m \cdot 8 \qquad \text{and} \qquad j = y - n \cdot 8,$$

resulting in:

$$(x,y) = (m \cdot 8 + i,\ n \cdot 8 + j).$$

Let $(MV^k{}_x, MV^k{}_y)$ be a motion vector, which may contain full-pixel or half pixel offsets, with $k = 0$, 1, or 2. For example, $(MV^k{}_x, MV^k{}_y)$ can be equal to (–7.0, 13.5). Here, $(MV^0{}_x, MV^0{}_y)$ denotes the motion vector for the current block *(m,n)*, $(MV^1{}_x, MV^1{}_y)$ denotes the motion vector of the block either above or below, and $(MV^2{}_x, MV^2{}_y)$ denotes the motion vector either to the left or right of the current block *(m,n)* as defined above.

Then the creation of each pixel, *P(x,y)*, in an 8×8 luminance prediction block with block index *(m,n)* is governed by the following equation:

$$P(x,y) = (q(x,y) \cdot H_0(i,j) + r(x,y) \cdot H_1(i,j) + s(x,y) \cdot H_2(i,j) + 4)/8,$$

where *q(x,y), r(x,y)* and *s(x,y)* are the prediction values taken from the referenced picture as defined by:

$$q(x,y) = p(x + MV^0{}_x, y + MV^0{}_y),$$

$$r(x,y) = p(x + MV^1{}_x, y + MV^1{}_y),$$

$$s(x,y) = p(x + MV^2{}_x, y + MV^2{}_y),$$

where $p(x + MV^k{}_x, y + MV^k{}_y)$ is the prediction value at position $(x + MV^k{}_x, y + MV^k{}_y)$ in the referenced picture. Note that $(x + MV^k{}_x, y + MV^k{}_y)$ may be outside the picture and can be at a full or half-pixel position. In cases using half-pixel motion vectors, $p(x + MV^k{}_x, y + MV^k{}_y)$ refers to the value obtained after the interpolation process described in 6.1.2 is applied.

The matrices $H_0(i,j)$, $H_1(i,j)$ and $H_2(i,j)$ are defined in Figures F.2, F.3 and F.4, where *(i, j)* denotes the column and row, respectively, of the matrix.

When neither the Slice Structured mode (see Annex K) nor the Independent Segment Decoding mode (see Annex R) are in use, remote motion vectors from other video picture segments are used in the same way as remote motion vectors inside the current GOB. If either the Slice Structured mode or the Independent Segment Decoding mode are in use, the remote motion vectors corresponding to blocks from other video picture segments are set to the motion vector of the current block, regardless of the other conditions described in the next paragraph. (See Annex R for the definition of a video picture segment.)

If one of the surrounding macroblocks was not coded, the corresponding remote motion vector is set to zero. If one of the surrounding blocks was INTRA coded, the corresponding remote motion vector is replaced by the motion vector for the current block except when in PB-frames mode. In this case (INTRA block in PB-frame mode), the INTRA block's motion vector is used (also see Annex G). If the current block is at the border of the picture and therefore a surrounding block is not present, the corresponding remote motion vector is replaced by the current motion vector. In all cases, if the current block is at the bottom of the macroblock (for block number 3 or 4, see Figure 5), the remote motion vector corresponding with an 8 * 8 luminance block in the macroblock below the current macroblock is replaced by the motion vector for the current block.

The weighting values for the prediction are given in Figures F.2, F.3 and F.4.

4	5	5	5	5	5	5	4
5	5	5	5	5	5	5	5
5	5	6	6	6	6	5	5
5	5	6	6	6	6	5	5
5	5	6	6	6	6	5	5
5	5	6	6	6	6	5	5
5	5	5	5	5	5	5	5
4	5	5	5	5	5	5	4

Figure F.2/H.263 – Weighting values, H_0, for prediction with motion vector of current luminance block

2	2	2	2	2	2	2	2
1	1	2	2	2	2	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
1	1	2	2	2	2	1	1
2	2	2	2	2	2	2	2

Figure F.3/H.263 – Weighting values, H_1, for prediction with motion vectors of the luminance blocks on top or bottom of current luminance block

2	1	1	1	1	1	1	2
2	2	1	1	1	1	2	2
2	2	1	1	1	1	2	2
2	2	1	1	1	1	2	2
2	2	1	1	1	1	2	2
2	2	1	1	1	1	2	2
2	2	1	1	1	1	2	2
2	1	1	1	1	1	1	2

Figure F.4/H.263 – Weighting values, H_2, for prediction with motion vectors of the luminance blocks to the left or right of current luminance block

ANNEX G

PB-frames mode

G.1 Introduction

This annex describes the optional PB-frames mode of this Recommendation. The capability of this mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in PTYPE.

A PB-frame consists of two pictures being coded as one unit. The name PB comes from the name of picture types in Recommendation H.262 where there are P-pictures and B-pictures. Thus, a PB-frame consists of one P-picture which is predicted from the previous decoded P-picture and one B-picture which is predicted both from the previous decoded P-picture and the P-picture currently being decoded. The name B-picture was chosen because parts of B-pictures may be bidirectionally predicted from the past and future pictures. The prediction process is illustrated in Figure G.1.

An improved version of the PB-frames mode, termed the "Improved PB-frames mode," is described in Annex M. The PB-frames mode as described in this annex is retained herein only for purposes of compatibility with systems designed prior to the adoption of the Improved PB-frames mode. For this reason, the PB-frames mode as described in this annex cannot be used with the additional features of the syntax which require the use of PLUSPTYPE.

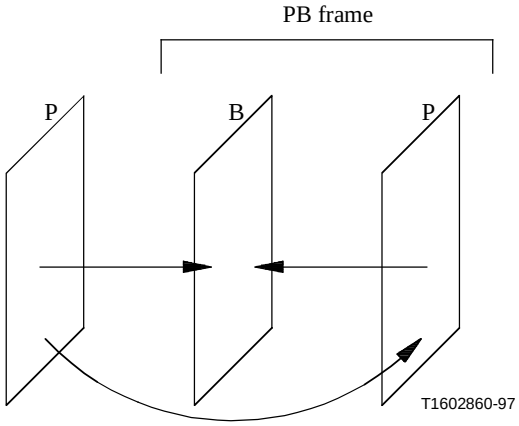


Figure G.1/H.263 – Prediction in PB-frames mode

G.2 PB-frames and INTRA blocks

When PB-frames are used, the coding mode INTRA has the following meaning (see also 5.3.2):

- The P-blocks are INTRA coded.
- The B-blocks are INTER coded with prediction as for an INTER block.

If PB-frames are used, Motion Vector Data (MVD) is included also for INTRA macroblocks in pictures for which PTYPE indicates "INTER". In this case, the vector is used for the B-blocks only. The codewords $MVD_{2\text{-}4}$ are never used for INTRA (see also Table 10). When in both the Advanced Prediction mode and the PB-frames mode, and one of the surrounding blocks was coded in INTRA mode, the corresponding remote motion vector is not replaced by the motion vector for the current block. Instead, the remote "INTRA" motion vector is used.

G.3 Block layer

In a PB-frame, a macroblock comprises twelve blocks. First, the data for the six P-blocks is transmitted as in the default H.263 mode, then the data for the six B-blocks (see also 5.4). The structure of the block layer is shown in Figure 11. INTRADC is present for every P-block of the macroblock if MCBPC indicates macroblock type 3 or 4 (see Tables 7 and 8). INTRADC is not present for B-blocks. TCOEF is present for P-blocks if indicated by MCBPC or CBPY; TCOEF is present for B-blocks if indicated by CBPB.

G.4 Calculation of vectors for the B-picture in a PB-frame

The vectors for the B-picture are calculated as follows (see also 6.1.1). Assume we have a vector component MV in half-pixel units to be used in the P-picture (MV represents a vector component for an 8 * 8 luminance block; if only one vector per macroblock is transmitted, MV has the same value for each of the four 8 * 8 luminance blocks). For prediction of the B-picture we need both forward and backward vector components MV_F and MV_B. These forward and backward vector components are derived from MV and eventually enhanced by a delta vector given by MVDB.

- TR_D: The increment of the temporal reference TR (or the combined extended temporal reference ETR and temporal reference TR in an Improved PB frame when a custom picture clock frequency is in use) from the last picture header (see 5.1.2). If TR_D is negative, then $TR_D = TR_D + d$ where d = 256 for CIF picture frequency and 1024 for any custom picture clock frequency.
- TR_B: See 5.1.2.

Assume that MV_D is the delta vector component given by MVDB and corresponding with vector component MV. If MVDB is not present, MV_D is set to zero. If MVDB is present, the same MV_D given by MVDB is used for each of the four luminance B-blocks within the macroblock.

Now, MV_F and MV_B are given in half-pixel units by the following formulas:

$$MV_F = (TR_B \times MV) / TR_D + MV_D$$

$$MV_B = ((TR_B - TR_D) \times MV) / TR_D \qquad \text{if } MV_D \text{ is equal to } 0$$

$$MV_B = MV_F - MV \qquad \text{if } MV_D \text{ is unequal to } 0$$

where "/" means division by truncation. It is assumed that the scaling reflects the actual position in time of P- and B-pictures. Advantage is taken of the fact that the range of values for MV_F is constrained. Each VLC word for MVDB represents a pair of difference values. Only one of the pair will yield a value for MV_F falling within the permitted range (default [–16, 15.5]; in Unrestricted Motion Vector mode [–31.5, 31.5]). The formulas for MV_F and MV_B are also used in the case of INTRA blocks where the vector data is used only for predicting B-blocks.

For chrominance blocks, MV_F is derived by calculating the sum of the four corresponding luminance MV_F vectors and dividing this sum by 8; the resulting sixteenth pixel resolution vector components are modified towards the nearest half-pixel position as indicated in Table F.1. MV_B for chrominance is derived by calculating the sum of the four corresponding luminance MV_B vectors and dividing this sum by 8; the resulting sixteenth pixel resolution vector components are modified towards the nearest half-pixel position as indicated in Table F.1.

A positive value of the horizontal or vertical component of the motion vector signifies that the prediction is formed from pixels in the referenced picture which are spatially to the right or below the pixels being predicted.

G.5 Prediction of a B-block in a PB-frame

In this subclause a block means an 8 × 8 block. The following procedure applies for luminance as well as chrominance blocks. First, the forward and backward vectors are calculated. It is assumed that the P-macroblock (luminance and chrominance) is first decoded, reconstructed and clipped (see 6.3.2). This macroblock is called P_{REC}. Based on P_{REC} and the prediction for P_{REC}, the prediction for the B-block is calculated.

The prediction of the B-block has two modes that are used for different parts of the block:

- For pixels where the backward vector – MV_B – points inside P_{REC}, use bidirectional prediction. This is obtained as the average of the forward prediction using MV_F relative to the previous decoded picture, and the backward prediction using MV_B relative to P_{REC}. The average is calculated by dividing the sum of the two predictions by two (division by truncation).
- For all other pixels, forward prediction using MV_F relative to the previous decoded picture is used.

Figure G.2 indicates which part of a block is predicted bidirectionally (shaded part of the B-block) and which part with forward prediction only (rest of the B-block).

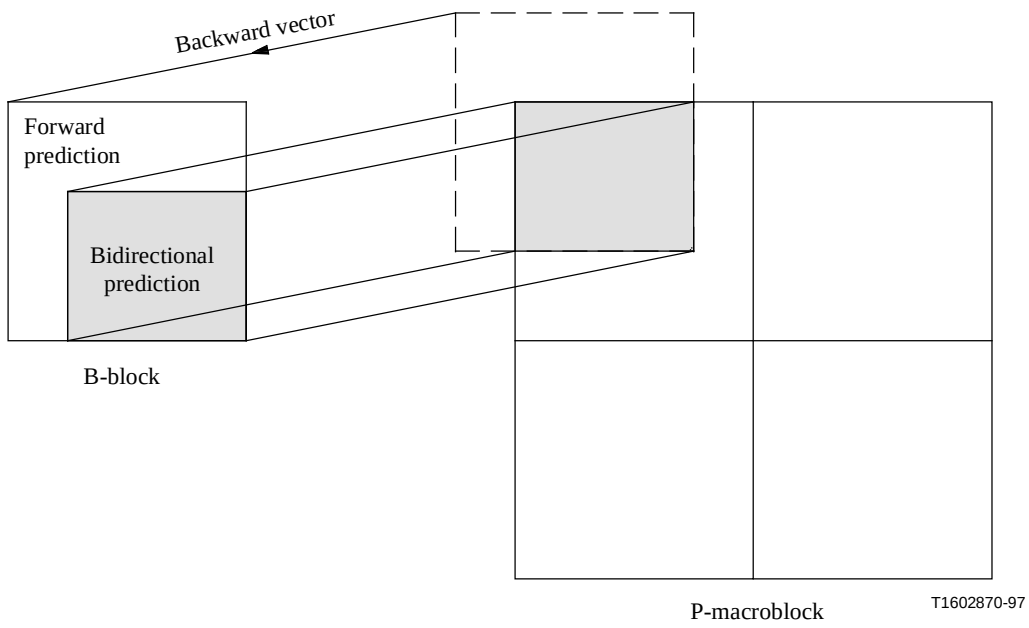


Figure G.2/H.263 – Forward and bidirectional prediction for a B-block

Bidirectional prediction is used for pixels where the backward vector – MV_B – points inside P_{REC}. These pixels are defined by the following procedures which are specified in C language.

Definitions:

nh	Horizontal position of block within a macroblock (0 or 1).
nv	Vertical position of block within a macroblock (0 or 1).
mh(nh,nv)	Horizontal vector component of block (nh,nv) in half-pixel units.
mv(nh,nv)	Vertical vector component of block (nh,nv) in half-pixel units.
mhc	Horizontal chrominance vector component.
mvc	Vertical chrominance vector component.

Procedure for luminance

```
for (nh = 0; nh <= 1; nh++) {
      for (nv = 0; nv <= 1; nv++) {
         for (i = nh * 8 + max(0,(–mh(nh,nv)+1)/2 – nh * 8);
               i <= nh * 8 + min(7,15–(mh(nh,nv)+1)/2 – nh * 8); i++) {
            for (j = nv * 8 + max(0,(–mv(nh,nv)+1)/2 – nv * 8);
               j <= nv * 8 + min(7,15–(mv(nh,nv)+1)/2 – nv * 8); j++) {
               predict pixel (i,j) bidirectionally
            }
         }
      }
}
```

Procedure for chrominance

```
for (i = max(0,(–mhc+1)/2); i <= min(7,7–(mhc+1)/2); i++) {
      for (j = max(0,(–mvc+1)/2); j <= min(7,7–(mvc+1)/2); j++) {
         predict pixel (i,j) bidirectionally;
      }
}
```

Pixels not predicted bidirectionally are predicted with forward prediction only.

ANNEX H

Forward error correction for coded video signal

H.1 Introduction

This annex describes an optional forward error correction method (code and framing) for transmission of H.263 encoded video data. This forward error correction may be used in situations where no forward error correction is provided by external means, for example at the multiplex or system level. It is not used for Recommendation H.324. Both the framing and the forward error correction code are the same as in Recommendation H.261.

H.2 Error correction framing

To allow the video data and error correction parity information to be identified by a decoder, an error correction framing pattern is included. This pattern consists of multiframes of eight frames, each frame comprising 1 bit framing, 1 bit fill indicator (Fi), 492 bits of coded data (or fill all 1s) and 18 bits parity (see Figure H.1). For each multiframe the frame alignment pattern formed by the framing bits of the eight individual frames is:

$$(S_1S_2S_3S_4S_5S_6S_7S_8) = (00011011)$$

The fill indicator (Fi) can be set to zero by an encoder. In this case 492 consecutive fill bits (fill all 1s) are used instead of 492 bits of coded data. This may be used for stuffing data (see 3.6).

H.3 Error correcting code

The error correction code is a BCH (511, 493) forward error correction code. Use of this by the decoder is optional. The parity is calculated against a code of 493 bits, comprising 1 bit fill indicator (Fi) and 492 bits of coded video data.

The generator polynomial is:

$$g(x) = (x9 + x4 + 1)(x9 + x6 + x4 + x3 + 1)$$

Example: for the input data of "01111 ... 11" (493 bits) the resulting correction parity bits are "011011010100011011" (18 bits).

H.4 Relock time for error corrector framing

Three consecutive error correction frame alignment patterns (24 bits) should be received before frame lock is deemed to have been achieved. The decoder should be designed such that frame lock will be re-established within 34 000 bits after an error corrector framing phase change.

NOTE – This assumes that the video data does not contain three correctly phased emulations of the error correction framing sequence during the relocking period.

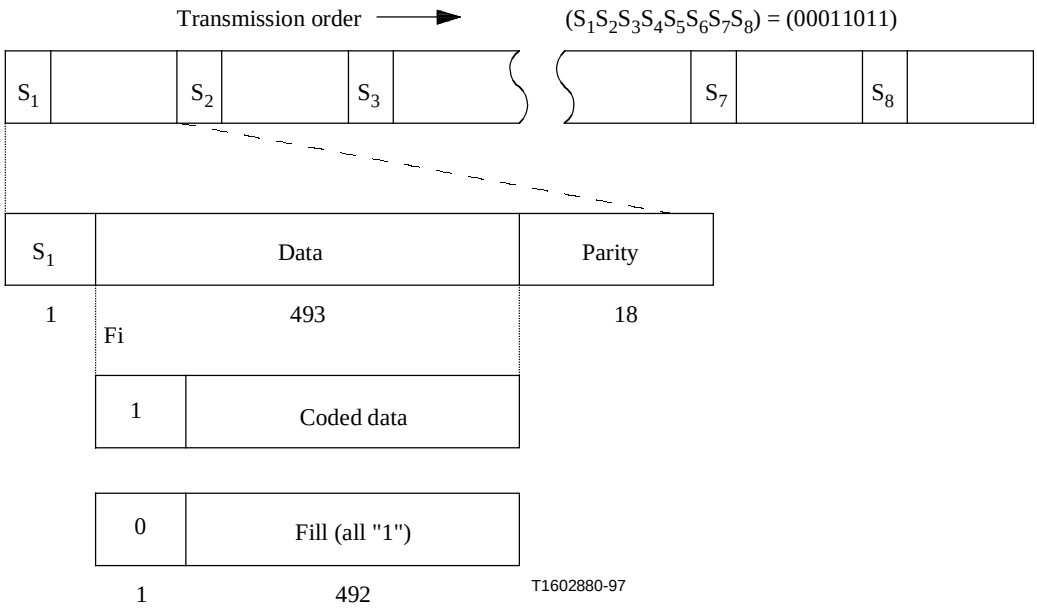


Figure H.1/H.263 – Error correcting frame

ANNEX I

Advanced INTRA Coding mode

This annex describes the optional Advanced INTRA Coding mode of this Recommendation. The capability of this H.263 mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in the PLUSPTYPE field of the picture header.

I.1 Introduction

This optional mode alters the decoding of macroblocks of type "INTRA" (macroblocks of other types are not affected). The coding efficiency of INTRA macroblocks is improved by using:

1) INTRA-block prediction using neighbouring INTRA blocks for the same component (Y, C_B, or C_R);
2) modified inverse quantization for INTRA coefficients; and
3) a separate VLC for INTRA coefficients.

A particular INTRA-coded block may be predicted from the block above the current block being decoded, from the block to the left of the current block being decoded, or from both. Special cases exist for situations in which the neighbouring blocks are not INTRA coded or are not in the same video picture segment. Block prediction always uses data from the same luminance or color difference component (Y, C_B, or C_R) as the block being decoded. In prediction, DC coefficients are always predicted in some manner. The first row of AC coefficients may be predicted from those in the block above, or the first column of AC coefficients may be predicted from those in the block to the left, or only the DC coefficient may be predicted as an average from the block above and the block to the left, as signalled on a macroblock-by-macroblock basis. The remaining AC coefficients are never predicted. Inverse quantization of the INTRADC coefficient is modified to allow a varying quantization step size, unlike in the main text of this Recommendation where a fixed step size of 8 is used for INTRADC coefficients. Inverse quantization of all INTRA coefficients is performed without a "dead-zone" in the quantizer reconstruction spacing.

I.2 Syntax

When using the Advanced INTRA Coding mode, the macroblock layer syntax is altered as specified in Figure I.1. The syntax as shown in Figure I.1 is the same as that defined in 5.3 except for the insertion of an additional INTRA_MODE field for INTRA macroblocks. INTRA_MODE is present only when MCBPC indicates a macroblock of type INTRA (macroblock type 3 or 4). The prediction mode is coded using the variable length code shown in Table I.1. One prediction mode is transmitted per INTRA macroblock.

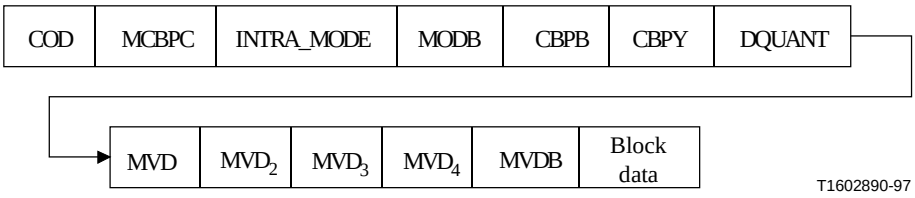


Figure I.1/H.263 – Structure of macroblock layer

Table I.1/H.263 – VLC for INTRA_MODE

Index	Prediction Mode	VLC
0	0 (DC Only)	0
1	1 (Vertical DC & AC)	10
2	2 (Horizontal DC & AC)	11

I.3 Decoding process

Two scans in addition to the zigzag scan are employed. The two added scans are shown in Figure I.2 parts a) and b), and the zigzag scan is shown in Figure 14.

1	2	3	4	11	12	13	14
5	6	9	10	18	17	16	15
7	8	20	19	27	28	29	30
21	22	25	26	31	32	33	34
23	24	35	36	43	44	45	46
37	38	41	42	47	48	49	50
39	40	51	52	57	58	59	60
53	54	55	56	61	62	63	64

a) Alternate-Horizontal scan

1	5	7	21	23	37	39	53
2	6	8	22	24	38	40	54
3	9	20	25	35	41	51	55
4	10	19	26	36	42	52	56
11	18	27	31	43	47	57	61
12	17	28	32	44	48	58	62
13	16	29	33	45	49	59	63
14	15	30	34	46	50	60	64

b) Alternate-Vertical scan (as in Recommendation H.262)

Figure I.2/H.263 – Alternate DCT scanning patterns for Advanced INTRA coding

For INTRA-coded blocks, if Prediction Mode = 0, the zigzag scan shown in Figure 14 is selected for all blocks in the macroblock, otherwise, the prediction direction is used to select a scan for the macroblock.

Prediction Mode = 1 uses the vertically adjacent block in forming a prediction. This prediction mode is designed for INTRA blocks which are dominated by stronger horizontal frequency content, so the vertically adjacent block is used to predict the horizontal frequency content of the current block, with a prediction of zero for all coefficients representing vertical AC content. Then the scanning pattern is chosen to scan the stronger horizontal frequencies prior to the vertical ones, using the Alternate-Horizontal scan.

Prediction Mode = 2 uses the horizontally adjacent block in forming a prediction. This prediction mode is designed for INTRA blocks which are dominated by stronger vertical frequency content, so the horizontally adjacent block is used to predict the vertical frequency content of the current block, with a prediction of zero for all coefficients representing horizontal AC content. Then the scanning pattern is chosen to scan the stronger vertical frequencies prior to the horizontal ones, using the Alternate-Vertical scan.

For non-INTRA blocks, the 8 × 8 blocks of transform coefficients are scanned with "zigzag" scanning as shown in Figure 14.

A separate VLC table is used for all INTRADC and INTRA AC coefficients. This table is specified in Table I.2. Note that the VLC codeword entries used in Table I.2 are the same as those used in the normal TCOEF table (Table 16) used when Advanced INTRA coding is not in use, but with a different interpretation of LEVEL and RUN (without altering LAST).

Table I.2/H.263 – VLC for INTRA TCOEF

INDEX	LAST	RUN	|LEVEL|	BITS	VLC CODE
0	0	0	1	3	10s
1	0	1	1	5	1111s
2	0	3	1	7	0101 01s
3	0	5	1	8	0010 111s
4	0	7	1	9	0001 1111s
5	0	8	1	10	0001 0010 1s
6	0	9	1	10	0001 0010 0s
7	0	10	1	11	0000 1000 01s
8	0	11	1	11	0000 1000 00s
9	0	4	3	12	0000 0000 111s
10	0	9	2	12	0000 0000 110s
11	0	13	1	12	0000 0100 000s
12	0	0	2	4	110s
13	0	1	2	7	0101 00s
14	0	1	4	9	0001 1110s
15	0	1	5	11	0000 0011 11s
16	0	1	6	12	0000 0100 001s
17	0	1	7	13	0000 0101 0000s
18	0	0	3	5	1110s
19	0	3	2	9	0001 1101s
20	0	2	3	11	0000 0011 10s
21	0	3	4	13	0000 0101 0001s
22	0	0	5	6	0110 1s
23	0	4	2	10	0001 0001 1s
24	0	3	3	11	0000 0011 01s
25	0	0	4	6	0110 0s

Table I.2/H.263 – VLC for INTRA TCOEF (*continued*)

INDEX	LAST	RUN	|LEVEL|	BITS	VLC CODE
26	0	5	2	10	0001 0001 0s
27	0	5	3	13	0000 0101 0010s
28	0	2	1	6	0101 1s
29	0	6	2	11	0000 0011 00s
30	0	0	25	13	0000 0101 0011s
31	0	4	1	7	0100 11s
32	0	7	2	11	0000 0010 11s
33	0	0	24	13	0000 0101 0100s
34	0	0	8	7	0100 10s
35	0	8	2	11	0000 0010 10s
36	0	0	7	7	0100 01s
37	0	2	4	11	0000 0010 01s
38	0	0	6	7	0100 00s
39	0	12	1	11	0000 0010 00s
40	0	0	9	8	0010 110s
41	0	0	23	13	0000 0101 0101s
42	0	2	2	8	0010 101s
43	0	1	3	8	0010 100s
44	0	6	1	9	0001 1100s
45	0	0	10	9	0001 1011s
46	0	0	12	10	0001 0000 1s
47	0	0	11	10	0001 0000 0s
48	0	0	18	10	0000 1111 1s
49	0	0	17	10	0000 1111 0s
50	0	0	16	10	0000 1110 1s
51	0	0	15	10	0000 1110 0s
52	0	0	14	10	0000 1101 1s
53	0	0	13	10	0000 1101 0s
54	0	0	20	12	0000 0100 010s
55	0	0	19	12	0000 0100 011s
56	0	0	22	13	0000 0101 0110s
57	0	0	21	13	0000 0101 0111s
58	1	0	1	5	0111s
59	1	14	1	10	0000 1100 1s
60	1	20	1	12	0000 0000 101s
61	1	1	1	7	0011 11s
62	1	19	1	12	0000 0000 100s
63	1	2	1	7	0011 10s
64	1	3	1	7	0011 01s
65	1	0	2	7	0011 00s
66	1	5	1	8	0010 011s
67	1	6	1	8	0010 010s
68	1	4	1	8	0010 001s
69	1	0	3	8	0010 000s
70	1	9	1	9	0001 1010s
71	1	10	1	9	0001 1001s
72	1	11	1	9	0001 1000s
73	1	12	1	9	0001 0111s
74	1	13	1	9	0001 0110s

Table I.2/H.263 – VLC for INTRA TCOEF (*concluded*)

INDEX	LAST	RUN	|LEVEL|	BITS	VLC CODE
75	1	8	1	9	0001 0101s
76	1	7	1	9	0001 0100s
77	1	0	4	9	0001 0011s
78	1	17	1	10	0000 1100 0s
79	1	18	1	10	0000 1011 1s
80	1	16	1	10	0000 1011 0s
81	1	15	1	10	0000 1010 1s
82	1	2	2	10	0000 1010 0s
83	1	1	2	10	0000 1001 1s
84	1	0	6	10	0000 1001 0s
85	1	0	5	10	0000 1000 1s
86	1	4	2	11	0000 0001 11s
87	1	3	2	11	0000 0001 10s
88	1	1	3	11	0000 0001 01s
89	1	0	7	11	0000 0001 00s
90	1	2	3	12	0000 0100 100s
91	1	1	4	12	0000 0100 101s
92	1	0	9	12	0000 0100 110s
93	1	0	8	12	0000 0100 111s
94	1	21	1	13	0000 0101 1000s
95	1	22	1	13	0000 0101 1001s
96	1	23	1	13	0000 0101 1010s
97	1	7	2	13	0000 0101 1011s
98	1	6	2	13	0000 0101 1100s
99	1	5	2	13	0000 0101 1101s
100	1	3	3	13	0000 0101 1110s
101	1	0	10	13	0000 0101 1111s
102	ESCAPE			7	0000 011

Depending on the value of INTRA_MODE, either one or eight coefficients are prediction residuals that must be added to a predictor as described below. Figure I.3 shows three 8 × 8 blocks of final reconstructed DCT levels for the same component (Y, C_B, or C_R), labelled RecA'(u,v), RecB'(u,v) and RecC'(u,v), where u and v are column (horizontal) and row (vertical) indices, respectively. The reconstruction process differs from the processing described in 6.2.1. INTRADC residuals are reconstructed differently by use of a variable step size, as opposed to using Table 15, and then a predictor is added to the residual values to obtain the final coefficient reconstruction value. INTRA coefficients other than INTRADC are also reconstructed differently than in 6.2.1, using a reconstruction spacing without a "dead-zone" and then in some cases adding a predictor to obtain the final coefficient reconstruction value. The block may contain both DC and AC prediction residuals.

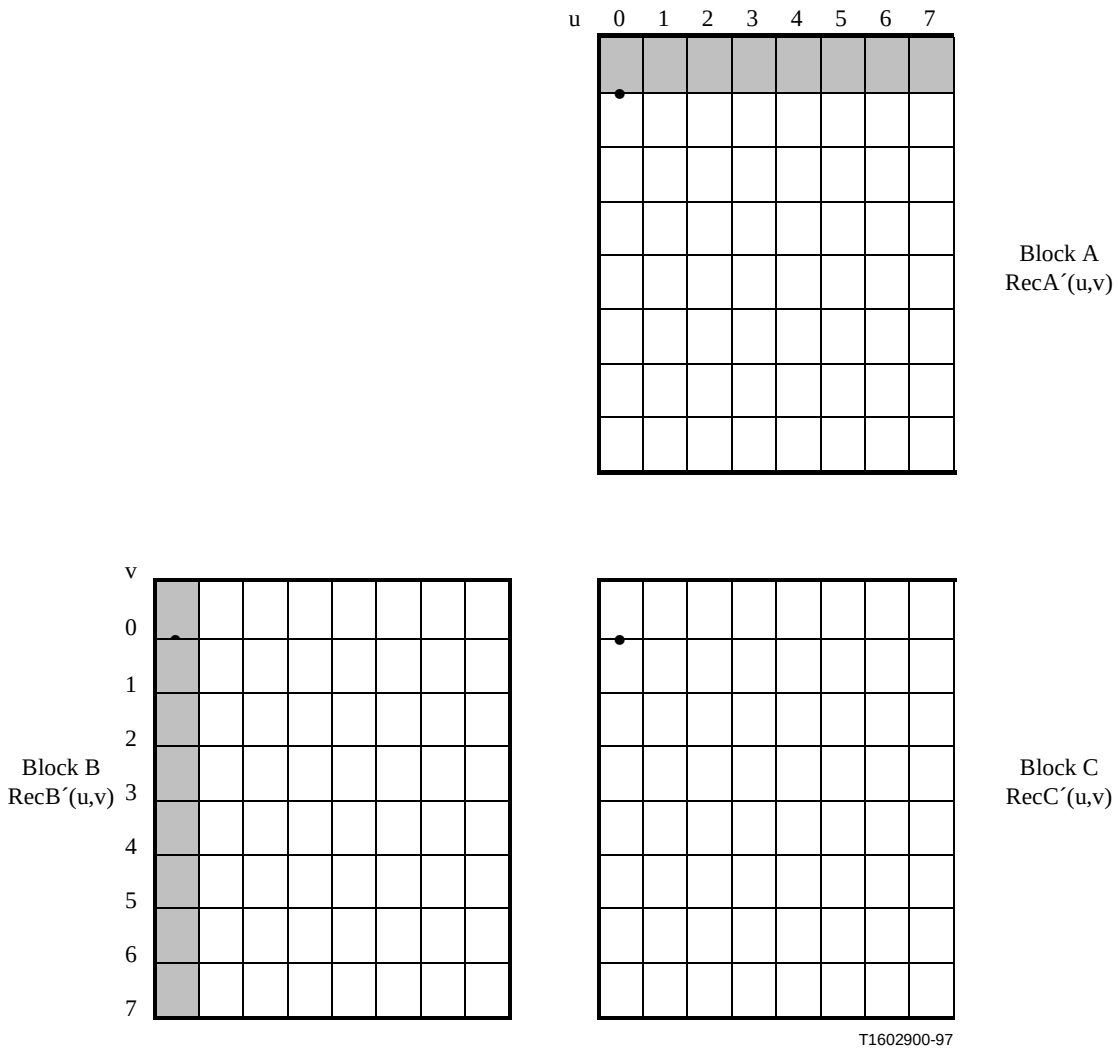


Figure I.3/H.263 – Three neighbouring blocks in the DCT domain

The definitions of MCBPC and CBPY are changed when Advanced INTRA coding is in use. When Advanced INTRA coding is in use, INTRADC transform coefficients are no longer handled as a separate case, but are instead treated in the same way as the AC coefficients in regard to MCBPC and CBPY. This means that a zero INTRADC will not be coded as a LEVEL, but will simply increase the run for the following AC coefficients.

The inverse quantization process for the B-part of an Improved PB frame (see Annex M) is not altered by the use of the Advanced INTRA coding mode.

Define RecC(u,v) to be the reconstructed coefficient *residuals* of the current block. For all INTRA coefficients, the reconstructed residual value is obtained by:

$$RecC(u,v) = 2 * QUANT * LEVEL(u,v) \qquad u = 0, \ldots, 7, v = 0, \ldots, 7.$$

NOTE – LEVEL(u,v) denotes a quantity having both a magnitude and a sign in the above equation.

Define RecC´(u,v) to be the *final* reconstructed coefficient values of the current block (after adjustments for prediction, oddification as described below, and clipping). The final reconstructed coefficient values RecC´(u,v) are recovered by adding RecC(u,v) to the appropriate prediction as signalled in the INTRA_MODE field, altering the least-significant bit if needed for oddification of the DC coefficient, and clipping.

RecA´(u,v) denotes the *final* reconstructed coefficient values for the block immediately above the current block. RecB´(u,v) denotes the *final* reconstructed coefficient values of the block immediately to the left of the current block.

The ability to use the reconstructed coefficient values for blocks A and B in the prediction of the coefficient values for block C depends on whether blocks A and B are in the same video picture segment as block C. A block is defined to be "in the same video picture segment" as another block only if the following conditions are fulfilled:

1) The relevant block is within the boundary of the picture, and

2) If not in Slice Structured mode (see Annex K), the relevant block is either within the same GOB or no GOB header is present for the current GOB, and

3) If in Slice Structured mode, the relevant block is within the same slice.

The block C to be decoded is predicted only from INTRA blocks within the same video picture segment as block C, as shown below.

If Prediction Mode = 0 is used (DC prediction only) and blocks A and B are both INTRA blocks within the same video picture segment as block C, then the DC coefficient of block C is predicted from the average (with truncation) of the DC coefficients of blocks A and B. If only one of the two blocks A and B is an INTRA block within the same video picture segment as block C, then the DC coefficient of only this one of the two blocks is used as the predictor for Prediction Mode = 0. If neither of the two blocks A and B are INTRA blocks within the same video picture segment as block C, then the prediction uses the value of 1024 as the predictor for the DC coefficient.

If Prediction Mode = 1 or 2 (vertical DC & AC or horizontal DC & AC prediction) and the referenced block (block A or block B) is not an INTRA block within the same video picture segment as block C, then the prediction uses the value of 1024 as the predictor for the DC coefficient and the value of 0 as the predictor for the AC coefficients of block C.

A process of "oddification" is applied to the DC coefficient in order to minimize the impact of IDCT mismatch errors. Certain values of coefficients can cause a round-off error mismatch between different IDCT implementations, especially certain values of the (0,0), (0,4), (4,0), and (4,4) coefficients. For example, a DC coefficient of 8k + 4 for some integer k results in an inverse-transformed block having a constant value k + 0.5, for which slight errors can cause rounding in different directions on different implementations.

Define the clipAC() function to indicate clipping to the range –2048 to 2047. Define the clipDC() function to indicate clipping to the range 0 to 2047. Define the oddifyclipDC(x) function as:

```
If (x is even) {
    result = clipDC(x+1)
} else {
    result = clipDC(x)
}
```

The reconstruction for each INTRA prediction mode is then specified as follows, in which the operator "/" is defined as division by truncation:

Mode 0: DC prediction only.

RecC´(u,v) = clipAC(RecC(u,v)) (u,v) ≠ (0,0), u = 0, …, 7, v = 0, …, 7.

If (block A and block B are both INTRA coded and are both in the same video picture segment as block C) {

    tempDC = RecC(0,0) + (RecA´(0,0) + RecB´(0,0)) / 2

} else {

```
    If (block A is INTRA coded and is in the same video picture segment as block C) {
        tempDC = RecC(0,0) + RecA´(0,0)
    } else {
        If (block B is INTRA coded and is in the same video picture segment as block C) {
            tempDC = RecC(0,0) + RecB´(0,0)
        } else {
            tempDC = RecC(0,0) + 1024
        }
    }
}
RecC'(0,0) = oddifyclipDC( tempDC )
```

Mode 1: DC and AC prediction from the block above.

```
If (block A is INTRA coded and is in the same video picture segment as block C) {
    tempDC = RecC(0,0) + RecA´(0,0)
    RecC´(u,0) = clipAC( RecC(u,0) + RecA´(u,0) )        u = 1, …, 7,
    RecC´(u,v) = clipAC( RecC(u,v) )                     u = 0, …, 7, v = 1, …, 7.
} else {
    tempDC = RecC(0,0) + 1024
    RecC´(u,v) = clipAC( RecC(u,v) )                     (u,v) ≠ (0,0), u = 0, …,7, v = 0, …, 7
}
RecC´(0,0) = oddifyclipDC( tempDC )
```

Mode 2: DC and AC prediction from the block to the left.

```
If (block B is INTRA coded and is in the same video picture segment as block C) {
    tempDC = RecC(0,0) + RecB´(0,0)
    RecC´(0,v) = clipAC( RecC(0,v) + RecB´(0,v) )        v = 1, …, 7,
    RecC´ (u,v) = clipAC( RecC(u,v) )                    u = 1, …, 7, v = 0, …, 7.
} else {
    tempDC = RecC(0,0) + 1024
    RecC´(u,v) = clipAC( RecC(u,v) )                     (u,v) ≠ (0,0), u = 0, …, 7, v = 0, …, 7
}
RecC'(0,0) = oddifyclipDC( tempDC )
```

ANNEX J

Deblocking Filter mode

J.1 Introduction

This annex describes the use of an optional block edge filter within the coding loop. The main purpose of the block edge filter is to reduce blocking artifacts. The filtering is performed on 8 × 8 block edges. Motion vectors may have either 8 × 8 or 16 × 16 resolution (see J.2). The processing described in this annex applies only for the P-, I-, EP-, or EI-pictures or the P-picture part of an Improved PB-frame. (Possible filtering of B-pictures or the B-picture part of an Improved PB-frame is not a matter for standardization; however, some type of filtering is recommended for improved picture quality.) The capability of this mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in the PLUSPTYPE field of the picture header.

J.2 Relation to UMV and AP modes (Annexes D and F)

The use of the deblocking filter mode has similar effects on picture quality as Overlapped Block Motion Compensation (OBMC) as defined in Annex F when used alone. When both techniques are used together, a further improvement in picture quality can be obtained. The Advanced Prediction mode (see also Annex F) consists of three elements:

1) four motion vectors per macroblock as defined in F.2;
2) overlapped motion compensation for luminance as defined in F.3;
3) motion vectors over picture boundaries as defined in D.1.

In order for the Deblocking Filter mode to be able to provide maximum performance when complexity considerations may prevent use of the OBMC part of the Advanced Prediction mode, the Deblocking Filter mode includes the ability to use four motion vectors per macroblock and motion vectors over picture boundaries.

In summary, the three options defined in Annexes D, F and J contain the following five coding elements:

1) motion vectors over picture boundaries (D.1);
2) extension of motion vector range (D.2);
3) four motion vectors per macroblock (F.2);
4) overlapped motion compensation for luminance (F.3);
5) deblocking edge filter (J.3).

Table J.1 indicates which of the five elements are turned on depending on which of the three options defined in Annexes D, F and J are turned on.

Table J.1/H.263 – Feature Elements for UMV, AP, and DF modes

Unrestricted Motion Vector mode	Advanced Prediction mode	Deblocking Filter mode	Motion vectors over picture boundaries	Extension of motion vector range	Four motion vectors per macroblock	Overlapped motion compensation for luminance	Deblocking edge filter
OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
OFF	OFF	ON	ON	OFF	ON	OFF	ON
OFF	ON	OFF	ON	OFF	ON	ON	OFF
OFF	ON	ON	ON	OFF	ON	ON	ON
ON	OFF	OFF	ON	ON	OFF	OFF	OFF
ON	OFF	ON	ON	ON	ON	OFF	ON
ON	ON	OFF	ON	ON	ON	ON	OFF
ON	ON	ON	ON	ON	ON	ON	ON

J.3 Definition of the deblocking edge filter

The filter operations are performed across 8 × 8 block edges at the encoder as well as on the decoder side. The reconstructed image data (the sum of the prediction and reconstructed prediction error) are clipped to the range of 0 to 255 as described in 6.3.2. Then the filtering is applied, which alters the picture that is to be stored in the picture store for future prediction. The filtering operations include an additional clipping to ensure that resulting pixel values stay in the range 0...255. No filtering is performed across a picture edge, and when the Independent Segment Decoding mode is in use, no

filtering is performed across slice edges when the Slice Structured mode is in use (see Annexes K and R) or across the top boundary of GOBs having GOB headers present when the Slice Structured mode is not in use (see Annex R). Chrominance as well as luminance data are filtered.

When the mode described in this annex is used together with the Improved PB-frames mode of Annex M, the backward prediction of the B-macroblock is based on the reconstructed P-macroblock (named P_{REC} in G.5) after the clipping operation but before the deblocking edge filter operations. The forward prediction of the B-macroblock is based on the filtered version of the previous decoded picture (the same picture data that are used for prediction of the P-macroblock).

The deblocking filter operates using a set of four (clipped) pixel values on a horizontal or vertical line of the reconstructed picture, denoted as A, B, C and D, of which A and B belong to one block called block1 and C and D belong to a neighbouring block called block2 which is to the right of or below block1. Figure J.1 shows examples for the position of these pixels.

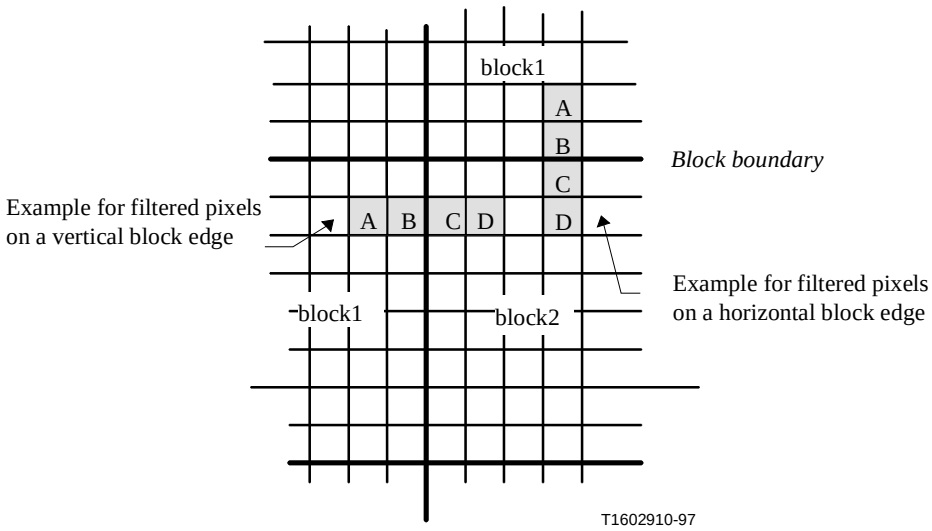


Figure J.1/H.263 – Examples of positions of filtered pixels

One or both of the following conditions must be fulfilled in order to apply the filter across a particular edge:

– Condition 1: block1 belongs to a coded macroblock (COD==0 || MB-type == INTRA); or

– Condition 2: block2 belongs to a coded macroblock (COD==0 || MB-type == INTRA).

If filtering is to be applied across the edge, A, B, C, and D shall be replaced by A1, B1, C1, D1 where:

B1 = clip(B + d1)

C1 = clip(C – d1)

A1 = A – d2

D1 = D + d2

d = (A–4B+4C–D) / 8

d1 = UpDownRamp(d, STRENGTH)

d2 = clipd1((A – D) / 4, d1/2)

UpDownRamp(x, STRENGTH) = SIGN(x) * (MAX(0, abs(x)–MAX(0, 2*(abs(x) – STRENGTH))))

STRENGTH depends on QUANT and determines the amount of filtering. The relation between STRENGTH and QUANT is given in Table J.2.

QUANT = quantization parameter used for block2 if block2 belongs to a coded macroblock, or

QUANT = quantization parameter used for block1 if block2 does not belong to a coded macroblock (but block1 does).

Table J.2/H.263 – Relationship between QUANT and STRENGTH of filter

QUANT	STRENGTH	QUANT	STRENGTH
1	1	17	8
2	1	18	8
3	2	19	8
4	2	20	9
5	3	21	9
6	3	22	9
7	4	23	10
8	4	24	10
9	4	25	10
10	5	26	11
11	5	27	11
12	6	28	11
13	6	29	12
14	7	30	12
15	7	31	12
16	7		

The function clip(x) is defined according to 6.3.2, and the function clipd1(x, lim) clips x to the range ± abs(lim). The symbol "/" denotes division by truncation toward zero.

Figure J.2 shows how the value of d1 varies as a function of d. As a result, the filter has an effect only if d is smaller than 2*STRENGTH (and different from zero). This is to prevent the filtering of strong true edges in the picture content. However, if the Reduced-Resolution Update mode is in use, STRENGTH is set to infinity, and as a result, the value of d1 is always equal to the value of d (see Q.7.2).

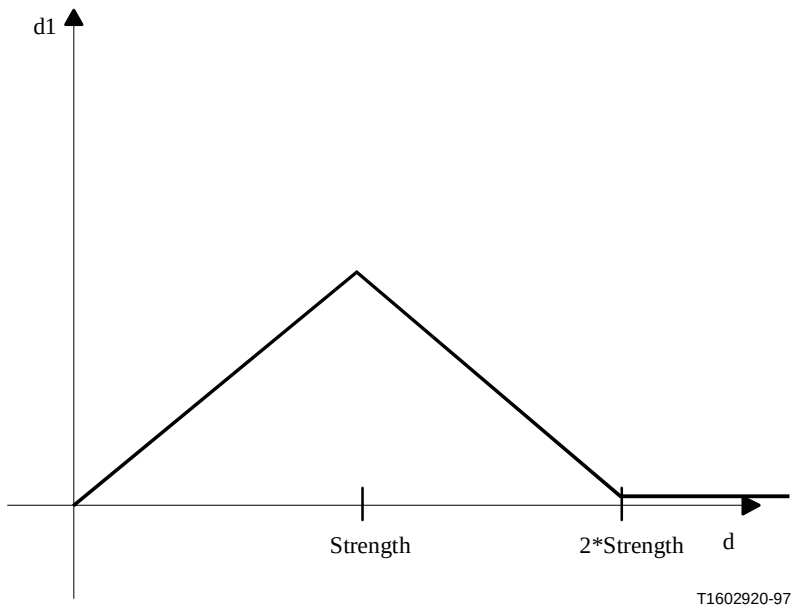


Figure J.2/H.263 – Parameter d1 as a function of parameter d for deblocking filter mode

The definition of d1 is designed to ensure that small mismatches between the encoder and decoder will remain small and will not build up over multiple pictures of a video sequence. This would be a problem, for example, with a condition that simply switches the filter on or off, because a mismatch of only ±1 for d could then cause the filter to be switched on at the encoder side and off at the decoder side, or vice versa.

Due to rounding effects, the order of edges where filtering is performed must be specified.

Filtering across horizontal edges:

Basically this process is assumed to take place first. More precisely, the pixels $\begin{pmatrix} A \\ B \\ C \\ D \end{pmatrix}$ that are used in filtering across a horizontal edge shall not have been influenced by previous filtering across a vertical edge.

Filtering across vertical edges:

Before filtering across a vertical edge using pixels (A, B, C, D), all modifications of pixels (A, B, C, D) resulting from filtering across a horizontal edge shall have taken place.

Note that if one or more of the pixels (A, B, C, D) taking part in a filtering process are outside of a picture, no filtering takes place. Also, if the Independent Segment Decoding mode is in use (see Annex R) and one or more of the pixels (A, B, C, D) taking part in a filtering process are in different video picture segments (see I.3 concerning when a block is considered to be in the same video picture segment), no filtering is performed.

ANNEX K

Slice Structured mode

K.1 Introduction

This annex describes the optional Slice Structured mode of this Recommendation. The capability of this H.263 mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in the PLUSPTYPE field of the picture header. In order to facilitate optimal usage in a number of environments, this mode contains two submodes which are also capable of being signalled by external means (for example, Recommendation H.245). These two submodes are used to indicate whether or not rectangular slices will be used and/or whether the slices will be transmitted in sequential order or sent in an arbitrary order.

A slice is defined as a slice header followed by consecutive macroblocks in scanning order. An exception is for the slice that immediately follows the picture start code in the bitstream for a picture (which is not necessarily the slice starting with macroblock 0). In this case only part of the slice header is transmitted as described in K.2. The slice layer defines a video picture segment, and is used in place of the GOB layer in this optional mode. A slice video picture segment starts at a macroblock boundary in the picture and contains a number of macroblocks. Different slices within the same picture shall not overlap with each other, and every macroblock shall belong to one and only one slice.

This mode contains two submodes, which are signalled in the SSS field of the picture header:

1) The Rectangular Slice submode (RS): When RS is in use, the slice shall occupy a rectangular region of width specified by the SWI parameter of the slice header in units of macroblocks, and contains a number of macroblocks in scanning order within the rectangular region. When the Rectangular Slice submode is not in use, the SWI field is not present in the slice header and a slice contains a number of macroblocks in scanning order within the picture as a whole.

2) The Arbitrary Slice Ordering submode (ASO): When ASO is in use, the slices may appear in any order within the bitstream. When ASO is not in use, the slices must be sent in the (unique) order for which the MBA field of the slice header is strictly increasing from each slice to each subsequent slice in the picture.

Slice boundaries are treated differently from simple macroblock boundaries in order to allow slice header locations within the bitstream to act as resynchronization points for bit error and packet loss recovery and in order to allow out-of-order slice decoding within a picture. Thus, no data dependencies can cross the slice boundaries within the current picture, except for the Deblocking Filter mode which, when in use without the Independent Segment Decoding mode, filters across the boundaries of the blocks in the picture. However, motion vectors within a slice can cause data dependencies which cross the slice boundaries in the reference picture used for prediction purposes, unless the optional Independent Segment Decoding mode is in use.

The following rules are adopted to ensure that slice boundary locations can act as resynchronization points and to ensure that slices can be sent out of order without causing additional decoding delays:

1) The prediction of motion vector values are the same as if a GOB header were present (see 6.1.1), preventing the use of motion vectors of blocks outside the current slice for the prediction of the values of motion vectors within the slice.

2) The Advanced INTRA Coding mode (see Annex I) treats the slice boundary as if it were a picture boundary with respect to the prediction of INTRA block DCT coefficient values.

3) The assignment of remote motion vectors for use in overlapped block motion compensation within the Advanced Prediction mode also prevents the use of motion vectors of blocks outside the current slice for use as remote motion vectors (see F.3).

K.2 Structure of slice layer

The structure of the slice layer of the syntax is shown in Figure K.1 for all slices except the slice that immediately follows the picture start code in the bitstream for a picture. For the slice following the picture start code, only the emulation prevention bits (SEPB1, SEPB3, and conditionally SEPB2 as specified below), the MBA field and, when in the RS submode, also the SWI field are included.

SSTUF	SSC	SEPB1	SSBI	MBA	SEPB2	SQUANT	SWI	SEPB3	GFID	Macroblock Data

Figure K.1/H.263 – Structure of slice layer

Refer to 5.2.5 for GFID, and to 5.3 for description of Macroblock layer.

K.2.1 Stuffing (SSTUF) (Variable length)

A codeword of variable length consisting of less than 8 bits. Encoders shall insert this codeword directly before an SSC codeword whenever needed to ensure that SSC is byte aligned. If SSTUF is present, the last bit of SSTUF shall be the last (least significant) bit of a byte, so that the start of the SSC codeword is byte aligned. Decoders shall be designed to discard SSTUF. Notice that 0 is used for stuffing within SSTUF.

K.2.2 Slice Start Code (SSC) (17 bits)

A word of 17 bits. Its value is 0000 0000 0000 0000 1. Slice start codes shall be byte aligned. This can be achieved by inserting SSTUF before the start code such that the first bit of the start code is the first (most significant) bit of a byte. The slice start code is not present for the slice which follows the picture start code.

K.2.3 Slice Emulation Prevention Bit 1 (SEPB1) (1 bit)

A single bit always having the value of "1", which is included to prevent start code emulation.

K.2.4 Slice Sub-Bitstream Indicator (SSBI) (4 bits)

A codeword of length four bits which is present only when CPM = "1" in the picture header. SSBI indicates the Sub-Bitstream number for the slice for Continuous Presence Multipoint and Video Multiplex operation, as described in Annex C. The mapping from the value of SSBI to the Sub-Bitstream number is shown in Table K.1. SSBI is not present for the slice which follows the picture start code.

Table K.1/H.263 – Values of SSBI and associated Sub-Bitstream numbers

Sub-Bitstream number	SSBI field value	GN value emulated
0	1001	25
1	1010	26
2	1011	27
3	1101	29

K.2.5 Macroblock Address (MBA) (5/6/7/9/11/12/13/14 bits)

A codeword having a length that is dependent on the current picture size and whether the Reduced-Resolution Update mode is in effect (see Annex Q). The bits are the binary representation of the macroblock number of the first macroblock in the current slice as counted from the beginning of the picture in scanning order, starting with macroblock number 0 at the upper left corner. MBA uniquely identifies which macroblock in the picture the current slice starts with. Codeword lengths for this codeword are provided in Table K.2. For custom picture sizes, the field width is given by the first entry in the table that has an equal or larger number of macroblocks, and the maximum value is the number of macroblocks in the current picture minus one. When in the Reduced-Resolution Update mode, the relevant picture size is the lower resolution update picture size rather than the picture size indicated in the picture header (see Annex Q).

Table K.2/H.263 – Specification of MBA parameter

	Default		**RRU mode**	
Picture format	**Max value**	**Field width**	**Max value**	**Field width**
sub-QCIF	47	6	11	5
QCIF	98	7	29	6
CIF	395	9	98	7
4CIF	1583	11	395	9
16CIF	6335	13	1583	11
2048×1152	9215	14	2303	12

K.2.6 Slice Emulation Prevention Bit 2 (SEPB2) (1 bit)

A single bit always having the value "1", which is included under certain conditions to prevent start code emulation. For slices other than the one following the picture start code, SEPB2 is included only if the MBA field width is greater than 11 bits and CPM = "0" in the picture header, or if the MBA field width is greater than 9 bits and CPM = "1" in the picture header. For the slice following the picture start code, SEPB2 is included only if the Rectangular Slice submode is in use.

K.2.7 Quantizer Information (SQUANT) (5 bits)

A fixed length codeword of five bits which indicates the quantizer QUANT to be used for that slice until updated by any subsequent DQUANT. The codewords are the natural binary representations of the values of QUANT which, being half the step sizes, range from 1 to 31. SQUANT is not present for the slice which follows the picture start code.

K.2.8 Slice Width Indication in Macroblocks (SWI) (3/4/5/6/7 bits)

A codeword which is present only if the Rectangular Slice submode is active, and having a length which depends on the current picture size and whether the Reduced-Resolution Update mode is active, as specified in Table K.3. For custom picture sizes, the field width is given by the next standard format size which is equal or larger in width (QCIF, CIF, …), and the maximum value is the total number of macroblocks across the picture minus one. The last row of the table indicates the field width for picture sizes wider than 16CIF. SWI refers to the width of the current rectangular slice having its first macroblock (upper left) specified by MBA. The calculation of the actual slice width is given by

$$\text{Actual Slice Width} = \text{SWI} + 1$$

When in the Reduced-Resolution Update mode, the relevant picture size is that of the lower resolution picture size for the update information, rather than the picture size indicated in the picture header.

Table K.3/H.263 – Specification of SWI parameter

	Default		RRU mode	
Picture format	**Max value**	**Field width**	**Max value**	**Field width**
sub-QCIF	7	4	3	3
QCIF	10	4	5	3
CIF	21	5	10	4
4CIF	43	6	21	5
16CIF	87	7	43	6
1412...2048 pixels wide	127	7	63	6

K.2.9 Slice Emulation Prevention Bit 3 (SEPB3) (1 bit)

A single bit always having the value of "1" in order to prevent start code emulation.

ANNEX L

Supplemental Enhancement Information Specification

L.1 Introduction

This annex describes the format of the supplemental enhancement information sent in the PSUPP field of the picture layer of this Recommendation. The capability of a decoder to provide any or all of the enhanced capabilities described in this annex may be signalled by external means (for example Recommendation H.245). Decoders which do not provide the enhanced capabilities may simply discard any PSUPP information bits that appear in the bitstream. The presence of this supplemental enhancement information is indicated in PEI, and an additional PEI bit is inserted between every octet of PSUPP data, as described in 5.1.24 and 5.1.25.

In this annex, a distinction is made between the "decoded picture" and the "displayed picture". For purposes of this annex, the "displayed picture" is a picture having the same picture format as specified for the current picture by the picture layer of the video bitstream syntax. The "displayed picture" is constructed as described in this annex from the decoded picture, the prior displayed picture, the supplementary enhancement information described herein, and in some cases partly from a background picture which is externally controlled.

L.2 PSUPP format

The PSUPP data consists of a four-bit function type indication FTYPE, followed by a four-bit parameter data size specification DSIZE, followed by DSIZE octets of function parameter data, optionally followed by another function type indication, and so on. One function type indication value is defined as an escape code to provide for future extensibility to allow definition of more than fifteen different functions. A decoder which receives a function type indication which it does not support can discard the function parameter data for that function and then check for a subsequent

function type indication which may be supported. The defined FTYPE values are shown in Table L.1.

Table L.1/H.263 – FTYPE function type values

0	Reserved
1	Do Nothing
2	Full-Picture Freeze Request
3	Partial-Picture Freeze Request
4	Resizing Partial-Picture Freeze Request
5	Partial-Picture Freeze-Release Request
6	Full-Picture Snapshot Tag
7	Partial-Picture Snapshot Tag
8	Video Time Segment Start Tag
9	Video Time Segment End Tag
10	Progressive Refinement Segment Start Tag
11	Progressive Refinement Segment End Tag
12	Chroma Key Information
13	Reserved
14	Reserved
15	Extended Function Type

L.3 Do Nothing

No action is requested by the Do Nothing function. This function is used to prevent start code emulation. Whenever the last five or more bits of the final octet of the previous PSUPP octet are all zero and no additional PSUPP function requests are to be sent, the Do Nothing function shall be inserted into PSUPP to prevent the possibility of start code emulation. The Do Nothing function may also be sent when it is not required by rule expressed in the previous sentence. DSIZE shall be zero for the Do Nothing function.

L.4 Full-Picture Freeze Request

The full-picture freeze request function indicates that the contents of the entire prior displayed video picture shall be kept unchanged, without updating the displayed picture using the contents of the current decoded picture. The displayed picture shall then remain unchanged until the freeze picture release bit in the current PTYPE or in a subsequent PTYPE is set to 1, or until timeout occurs, whichever comes first. The request shall lapse due to timeout after five seconds or five pictures, whichever is a longer period of time. The timeout can be prevented by the issuance of another full-picture freeze request prior to or upon expiration of the timeout period (e.g. repeating the request in the header of the first picture with temporal reference indicating a time interval greater than or equal to five seconds since issuance, or in the header of the fifth picture after issuance). DSIZE shall be zero for the full-picture freeze request function.

L.5 Partial-Picture Freeze Request

The partial-picture freeze request function indicates that the contents of a specified rectangular area of the prior displayed video picture should be kept unchanged, without updating the specified area of the displayed picture using the contents of the current decoded picture. The specified area of the displayed picture shall then remain unchanged until the freeze picture release bit in the current

PTYPE or in a subsequent PTYPE is set to 1, until a partial-picture freeze-release request affecting the specified area is received, until the source format specified in a picture header differs from that of previous picture headers, or until timeout occurs, whichever comes first. Any change in the picture source format shall act as a freeze release for all active partial-picture freeze requests. The request shall lapse due to timeout after five seconds or five pictures, whichever is a longer period of time. The timeout can be prevented by the issuance of an identical partial-picture freeze request prior to or upon expiration of the timeout period (e.g. repeating the request in the header of the first picture with temporal reference indicating a time interval greater than or equal to five seconds since issuance, or in the header of the fifth picture after issuance). DSIZE shall be equal to 4 for the partial-picture freeze request. The four octets of PSUPP that follow contain the horizontal and vertical location of the upper left corner of the frozen picture rectangle, and the width and height of the rectangle, respectively, using eight bits each and expressed in units of eight pixels. For example, a 24-pixel wide and 16 pixel tall area in the upper left corner of the video display is specified by the four parameters (0, 0, 3, 2).

L.6 Resizing Partial-Picture Freeze Request

The resizing partial-picture freeze request function indicates that the contents of a specified rectangular area of the prior displayed video picture should be resized to fit into a smaller part of the displayed video picture, which should then be kept unchanged, without updating the specified area of the displayed picture using the contents of the current decoded picture. The specified area of the displayed picture shall then remain unchanged until the freeze release bit in the current PTYPE or in a subsequent PTYPE is set to 1, until a partial-picture freeze-release request affecting the specified area is received, until the source format specified in a picture header differs from that of previous picture headers, or until timeout occurs, whichever comes first. Any change in the picture source format shall act as a freeze release for all active resizing partial-picture freeze requests. The request shall lapse due to timeout after five seconds or five pictures, whichever is a longer period of time. The timeout can be prevented by the issuance of a partial-picture freeze request for the affected area of the displayed picture prior to or upon expiration of the timeout period (e.g. issuing a partial-picture freeze request in the header of the first picture with temporal reference indicating a time interval greater than or equal to five seconds since issuance, or in the header of the fifth picture after issuance). DSIZE shall be equal to 8 for the resizing partial-picture freeze request. The eight octets of PSUPP data that follow contain 32 bits used to specify the rectangular region of the affected area of the displayed picture, and then 32 bits used to specify the corresponding rectangular region of the affected area of the decoded picture. The width and height of the rectangular region in the decoded picture shall both be equal to 2^i times the width and height specified for the rectangular region in the displayed picture, where i is an integer in the range of 1 to 8. The location and size of each of these two rectangular regions is specified using the same format as such a region is specified in the partial-picture freeze request function.

L.7 Partial-Picture Freeze-Release Request

The partial-picture freeze-release request function indicates that the contents of a specified rectangular area of the displayed video picture shall be updated by the current and subsequent decoded pictures. DSIZE shall be equal to 4 for the partial-picture freeze-release request. The four octets of PSUPP data that follow specify a rectangular region of the displayed picture in the same format as such a region is specified in the partial-picture freeze request function.

L.8 Full-Picture Snapshot Tag

The full-picture snapshot tag function indicates that the current picture is labelled for external use as a still-image snapshot of the video content. DSIZE shall be equal to 4 for the full-picture snapshot

tag function. The four octets of PSUPP data that follow specify a snapshot identification number for external use.

L.9 Partial-Picture Snapshot Tag

The partial-picture snapshot tag function indicates that a specified rectangular area of the current picture is labelled for external use as a still-image snapshot of the video content. DSIZE shall be equal to 8 for the partial-picture snapshot tag function. The first four octets of PSUPP data that follow specify a snapshot identification number for external use, and the remaining four octets of PSUPP data that follow specify a rectangular region of the decoded picture in the same format as such a region is specified in the partial-picture freeze request function.

L.10 Video Time Segment Start Tag

The video time segment start tag function indicates that the beginning of a specified sub-sequence of video data is labelled as a useful section of video content for external use, starting with the current picture. The tagged sub-sequence of video data shall continue until stopped by the receipt of a matching video time segment end tag function or until timeout, whichever comes first. The tagged sub-sequence shall end due to timeout after five seconds or five pictures, whichever is a longer period of time. The timeout can be prevented by the issuance of an identical video time segment start tag function prior to or upon expiration of the timeout period (e.g. repeating the video time segment start tag function in the header of the first picture with temporal reference indicating a time interval greater than or equal to five seconds since issuance, or in the header of the fifth picture after issuance). DSIZE shall be equal to 4 for the video time segment start tag function. The four octets of PSUPP data that follow specify a video time segment identification number for external use.

L.11 Video Time Segment End Tag

The video time segment end tag function indicates that the end of a specified sub-sequence of video data is labelled as a useful section of video content for external use, ending with the previous picture. DSIZE shall be equal to 4 for the video time segment start tag function. The four octets of PSUPP data that follow specify a video time segment identification number for external use.

L.12 Progressive Refinement Segment Start Tag

The progressive refinement segment start tag function indicates the beginning of a specified sub-sequence of video data which is labelled as the current picture followed by a sequence of zero or more pictures of refinement of the quality of the current picture, rather than as a representation of a continually moving scene. The tagged sub-sequence of video data shall continue until stopped by the receipt of a matching progressive refinement segment end tag function or until timeout, whichever comes first. The tagged sub-sequence shall end due to timeout after five seconds or five pictures, whichever is a longer period of time. The timeout can be prevented by the issuance of an identical progressive refinement segment start tag function prior to or upon expiration of the timeout period (e.g. repeating the progressive refinement start tag function in the header of the first picture with temporal reference indicating a time interval greater than or equal to five seconds since issuance, or in the header of the fifth picture after issuance). DSIZE shall be equal to 4 for the video time segment start tag function. The four octets of PSUPP data that follow specify a progressive refinement segment identification number for external use.

L.13 Progressive Refinement Segment End Tag

The progressive refinement segment end tag function indicates the end of a specified sub-sequence of video data which is labelled as an initial picture followed by a sequence of zero or more pictures

of the refinement of the quality of the initial picture, and ending with the previous picture. DSIZE shall be equal to 4 for the video time segment start tag function. The four octets of PSUPP data that follow specify a progressive refinement identification number for external use.

L.14 Chroma Keying Information

The Chroma Keying Information Function (CKIF) indicates that the "chroma keying" technique is used to represent "transparent" and "semi-transparent" pixels in the decoded video pictures. When being presented on the display, "transparent" pixels are not displayed. Instead, a background picture which is either a prior reference picture or is an externally controlled picture is revealed. Semi-transparent pixels are displayed by blending the pixel value in the current picture with the corresponding value in the background picture. One octet is used to indicate the keying color value for each component (Y, C_B, or C_R) which is used for chroma keying. To represent pixels that are to be "semi-transparent", two threshold values, denoted as T_1 and T_2, are used. Let α denote the transparency of a pixel; $\alpha = 255$ indicates that the pixel is opaque, and $\alpha = 0$ indicates that the pixel is transparent. For other values of α, the resulting value for a pixel should be a weighted combination of the pixel value in the current picture and the pixel value from the background picture (which is specified externally). The values of α may be used to form an image that is called an "alpha map." Thus, the resulting value for each component may be:

$$[\alpha \cdot X + (255 - \alpha) \cdot Z] / 255$$

where X is the decoded pixel component value (for Y, C_B, or C_R), and Z is the corresponding pixel component value from the background picture.

The α value can be calculated as follows. First, the distance of the pixel color from the key color value is calculated:

$$d = A_Y (X_Y - K_Y)^2 + A_B (X_B - K_B)^2 + A_R - K_R)^2$$

in which X_Y, X_B, and X_R are the Y, C_B, and C_R values of the decoded pixel color, K_Y, K_B, and K_R are the corresponding key color parameters, and A_Y, A_B, and A_R. are keying flag bits which indicate which color components are used as keys. Once the distance d is calculated, the α value may be computed as specified in the following pseudo-code:

```
for each pixel
   if      (d<T1) then α = 0;
   else if (d>T2) then α = 255;
   else α = [255·(d-T1)]/(T2-T1)
```

However, the precise method for performing the chroma keying operation in the decoder is not specified herein, since normative specification of the method is not needed for interoperability. The process described here is provided for illustration purposes in order to convey the intended interpretation of the data parameters.

Since the derived α value is simply a function of X_Y, X_B, and X_R, a Look-Up Table (LUT) can be built to achieve the above operation. Such an LUT has $2^{8\times N}$ entries corresponding to all pixel values, where N is the number of color components used as keys. Each entry in the LUT would then contain the corresponding α value.

DSIZE shall be in the range of 1 to 9 (inclusive) for chroma keying information, according to the amount of data sent with the CKIF. No more than one CKIF shall be sent with a picture.

The first octet following the DSIZE octet shall contain the representation order of the current picture – streams having a lower representation order are assumed to form the background picture for streams having a higher representation order.

If DSIZE is greater than one, the next octet after the representation order octet shall be used to send six flag bits defined as:

bit 1: A_Y: A flag bit indicating the presence of a K_Y key parameter for luminance Y values

bit 2: A_B: A flag bit indicating the presence of a K_B key parameter for chroma C_B values

bit 3: A_R: A flag bit indicating the presence of a K_R key parameter for chroma C_R values

bit 4: A_1: A flag bit indicating the presence of a T_1 threshold parameter for transparency

bit 5: A_2: A flag bit indicating the presence of a T_2 threshold parameter for opacity

bit 6: RPB: A flag bit indicating the use of the reference picture as a background picture

bit 7: reserved

bit 8: reserved

DSIZE shall be equal to 1 or shall be equal to 2 plus the number of flag bits among A_Y, A_B, and A_R which are set to 1, plus 2 times the number of bits among A_1 and A_2 which are set to 1. If DSIZE is greater than 1, then an additional octet shall be sent to specify the value of each color component for each of the flag bits A_Y, A_B, and A_R which are set to one and two additional octets shall be sent to specify each of the flagged threshold values among T_1 and T_2. These octets shall follow in the same order as the flag bits.

If DSIZE is equal to 1, or if all three keying color flag bits A_Y, A_B, and A_R, are zero, the keying flag bits A_Y, A_B, and A_R and keying colours K_Y, K_B, and K_R which were used for the previous keyed picture should also be used for the current picture. If no previous values have been sent for the video sequence, the default keying flag bits A_Y = 1, A_B = 1, and A_R = 1 and the default key colours K_Y = 50, K_B = 220, and K_R = 100 should be used as the previous values.

If DSIZE is equal to 1, or if both of the keying threshold flag bits A_1 and A_2 are zero, the keying threshold values T_1 and T_2 which were used for the previous keyed picture should also be used for the current picture. If no previous values have been sent for the video sequence, the default threshold values T_1 = 48 and T_2 = 75 should be used as the previous values.

In the portion where the pixels are "semi-transparent" (i.e. when $T_1 < d < T_2$), the decoded pixels typically contain the chroma key color in components where chroma keys are used. This may result in certain color artifacts. To address this problem, these pixel values may be adjusted before they are blended with the background color. Such a correction process may be applied to color components being used in the chroma key operation as indicated by the flag bits. The process is as follows:

$$X' = K + \left(T_2 / d\right)\left(X - K\right)$$

where X is the original decoded pixel component value, and X' is the corrected value.

Since the adjusted pixel values X'_Y, X'_B, and X'_R are functions of X_Y, X_B, and X_R, the color correction can be achieved by using an LUT. This LUT would have 2^{8N} entries corresponding to all pixel values, where N is the number of color components used as keys. Each entry would then contain the corresponding corrected values.

If the Reference Picture Background (RPB) flag bit is set to "1", this indicates that the temporally previous reference picture (prior to any Annex P resampling performed for the current picture) should be held as the (opaque) background of the current picture and of all subsequent chroma keyed pictures, until replaced by the arrival of another picture having an RPB flag set to "1". If the current picture has no temporally previous reference picture (i.e if the current picture is a picture of type

INTRA or EI), the picture to which the RPB flag bit refers is the picture which would normally have been the reference picture if the current picture were of type INTER or EP as appropriate. If the RPB flag bit is set to "0", this indicates that background should remain as previously controlled (either under external control or using a reference picture which was previously stored upon receipt of a prior picture having RPB set to "1").

The use of the chroma keying which is invoked by the issuance of the chroma keying information function shall start with the current picture and shall continue until a subsequent picture of type INTRA or EI occurs or until a timeout period expires, whichever comes first. The use of chroma keying shall end due to timeout after five seconds or five pictures, whichever is a longer period of time. The timeout can be prevented by the issuance of an identical chroma keying information function prior to or upon expiration of the timeout period (e.g. repeating the chroma keying information function in the header of the first picture with temporal reference indicating a time interval greater than or equal to five seconds since issuance, or in the header of the fifth picture after issuance). The encoder shall send sufficient information with the chroma keying information function for complete resynchronization to occur with each picture of type INTRA or EI and within each timeout interval (it shall not rely on using stored or default values of the key colours or thresholds).

L.15 Extended Function Type

The extended function type indication is used to signal that the following PSUPP octet contains an extended function. The usage of extended functions is reserved for the ITU to have a later ability to define a larger number of backward-compatible PSUPP data functions. DSIZE shall be equal to zero for the extended function type indication. In order to allow backward compatibility of future use of the extended function type indication, decoders shall treat the second set of four bits in the octet which follows the extended function type indication as a DSIZE value indicating the number of subsequent octets of PSUPP that are to be skipped for extended function parameter data, which may be followed by additional FTYPE indications.

ANNEX M

Improved PB-frames mode

M.1 Introduction

This annex describes an optional Improved PB-frames mode of this Recommendation. It is therefore considered to be advantageous to use the present Improved PB-frames mode instead of the PB-frames mode defined in Annex G. The capability of this mode is signalled by external means (for example, Recommendation H.245). The use of this mode is indicated in the PLUSPTYPE field of the picture header.

Most parts of this option are similar to the PB-frame option defined in Annex G.

To avoid confusion with B-pictures as defined in Annex O, the terms B-picture, B-macroblock, and B-block will not be used in this annex. Instead, we will use the notation B_{PB} to mean the "B-part" of an Improved PB-frame. When reference is made to Annex G, B-picture and B-block shall be read as B_{PB}-picture and B_{PB}-block.

The main difference between the PB-frames mode and the Improved PB-frames mode is that in the Improved PB-frames mode, the B_{PB}-macroblock has available a forward and a backward prediction mode in addition to the bidirectional prediction mode. In this annex, MVDB (when present) refers to a forward motion vector. (Note that, in Annex G, MVDB was used to refer to an enhancement of the

downscaled forward and backward vectors for bidirectional prediction, rather than a distinct forward motion vector.)

All the differences from Annex G are identified in this annex. When nothing is indicated, it means that the same procedure as described in Annex G is used.

M.2 B_{PB}-macroblock prediction modes

There are three different ways of coding a B_{PB}-macroblock. The different coding modes are signalled by the parameter MODB. The B_{PB}-macroblock coding modes are:

M.2.1 Bidirectional prediction

In the bidirectional prediction mode, prediction uses the reference pictures before and after the B_{PB}-picture (in the case of a sequence of Improved PB-frames, this means the P-picture part of the temporally previous Improved PB-frame and the P-picture part of the current Improved PB-frame). This prediction is equivalent to the prediction defined in Annex G when $MV_D = 0$. Notice that in this mode (and only in this mode), Motion Vector Data (MVD) of the PB-macroblock must be included even if the P-macroblock is INTRA coded. (Notice the difference between MVD – motion vector data – and MV_D – delta vector – defined in Annex G.)

M.2.2 Forward prediction

In the forward prediction mode, the vector data contained in MVDB are used for forward prediction from the previous reference picture (an INTRA or INTER picture, or the P-picture part of a PB or Improved PB-frame). This means that there is always only one 16×16 vector for the B_{PB}-macroblock in this prediction mode.

A simple predictor is used for coding of the forward motion vector. The rule for this predictor is that if the current macroblock is not at the far left edge of the picture or slice and the macroblock to the left has a forward motion vector, then the predictor of the forward motion vector for the current macroblock is set to the value of the forward motion vector of the block to the left; otherwise, the predictor is set to zero. The difference between the predictor and the desired motion vector is then VLC coded in the same way as vector data to be used for the P-picture (MVD).

Concerning motion vectors over picture boundaries defined in D.1, the described technique also applies for the forward B_{PB}-vector if this feature is in use (this applies for forward as well as for bidirectional prediction mode).

M.2.3 Backward prediction

In the backward prediction mode, the prediction of the B_{PB} macroblock is identical to P_{REC} (defined in G.5). No motion vector data is used for the backward prediction.

M.3 Calculation of vectors for bidirectional prediction of a the B-macroblock

In case bidirectional prediction is used, the scaled forward and backward vectors are calculated as described in Annex G when $MV_D = 0$.

M.4 MODB table

A new definition for MODB (replacing Table 11) is shown in Table M.1. It indicates the possible coding modes for a B_{PB}-block.

Table M.1/H.263 – MODB table for Improved PB-frames mode

Index	CBPB	MVDB	Number of bits	Code	Coding mode
0			1	0	Bidirectional prediction
1	x		2	10	Bidirectional prediction
2		x	3	110	Forward prediction
3	x	x	4	1110	Forward prediction
4			5	11110	Backward prediction
5	x		5	11111	Backward prediction
NOTE – The symbol "x" indicates that the associated syntax element is present.					

ANNEX N

Reference Picture Selection mode

N.1 Introduction

This annex describes the optional Reference Picture Selection mode of this Recommendation, which operates using a modified interframe prediction method called "NEWPRED." The capability of this H.263 mode is signalled by external means (for example, Recommendation H.245). The amount of additional picture memory accommodated in the decoder may also be signalled by external means to help the memory management at the encoder. This mode can use backward channel messages sent from a decoder to an encoder to inform the encoder which part of which pictures have been correctly decoded at the decoder. The use of this mode is indicated in the PLUSPTYPE field of the picture header. This mode has two back-channel mode switches which define whether a backward channel is used and what kind of messages are returned on that backward channel from the decoder, and has another submode defined in terms of the channel for the backward channel messages.

The two back-channel mode switches of this mode determine the type of messages sent on the back-channel, specifying whether ACK (Acknowledgment messages), or NACK (Non-Acknowledgment messages) are sent. Together, the two switches define four basic methods of operation:

1) NEITHER, in which no back-channel data is returned from the decoder to the encoder;
2) ACK, in which the decoder returns only acknowledgment messages;
3) NACK, in which the decoder returns only non-acknowledgment messages; and
4) ACK+NACK, in which the decoder returns both acknowledgment and non-acknowledgment messages.

The specific type of messages to be sent as outlined above is indicated in the picture header.

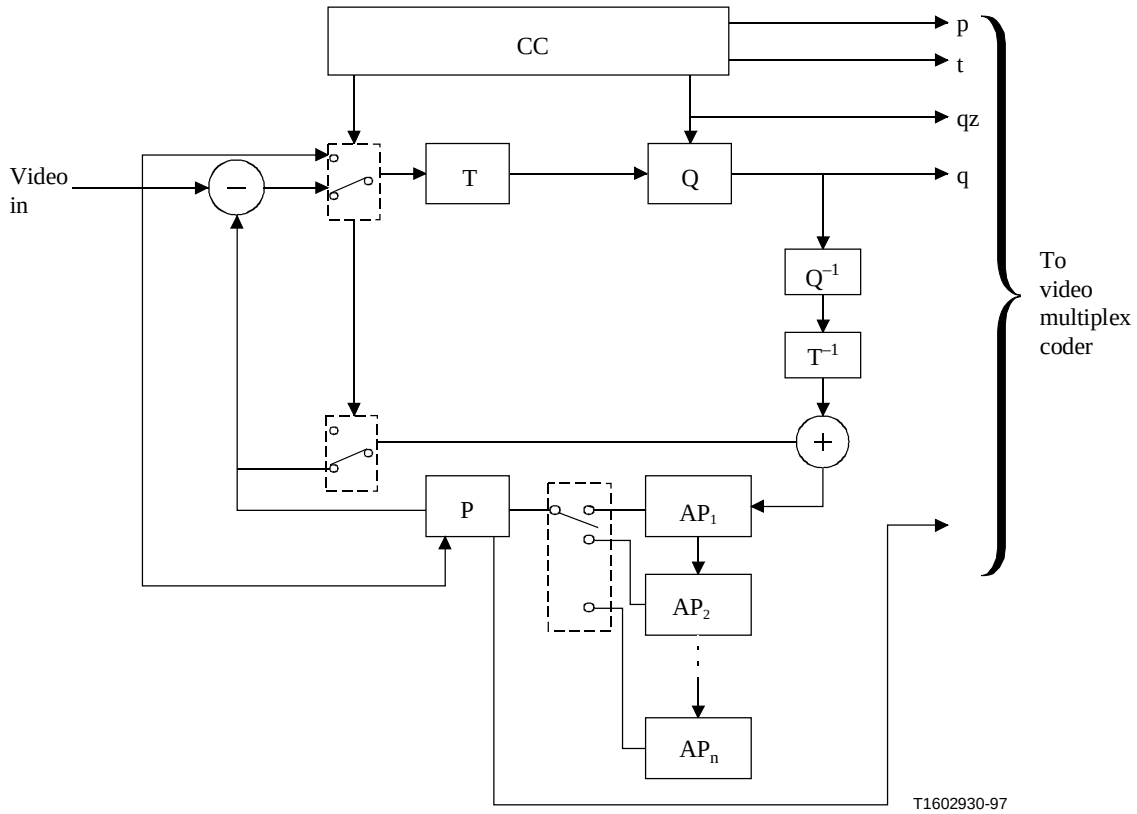
There are also two methods of operation in terms of the channel for backward channel messages:

1) Separate Logical Channel mode: This method of operation delivers back-channel data through a separate logical channel in the multiplex layer of the system, and
2) VideoMux mode: This method of operation delivers back-channel data for received video within the forward video data of a video stream of encoded data.

This annex specifies a syntax for the backward channel messages as well as for forward-channel data.

N.2 Video source coding algorithm

The source coder of this mode is shown in generalized form in Figure N.1. This figure shows a structure which uses a number of picture memories. The source coder may select one of the picture memories to suppress the temporal error propagation due to the inter-frame coding. The Independent Segment Decoding mode (see Annex R), which treats boundaries of GOBs with non-empty headers or slices as picture boundaries, can be used to avoid error propagation due to motion compensation across the boundaries of the GOBs or slices when this mode is applied to a smaller unit than a picture, such as a GOB or slice. The information to signal which picture is selected for prediction is included in the encoded bitstream. The strategy used by the encoder to select the picture to be used for prediction is out of the scope of this Recommendation.



T	Transform
Q	Quantizer
P	Picture Memory with motion compensated variable delay
AP	Additional Picture Memory
CC	Coding control
p	Flag for INTRA/INTER
t	Flag for transmitted or not
qz	Quantizer indication
q	Quantizing index for transform coefficients
v	Motion vector

Figure N.1/H.263 – Source coder for NEWPRED

N.3 Channel for back-channel messages

This mode has two methods of operation in terms of the type of channel for back-channel messages. One is the separate logical channel mode and the other is the videomux mode. The separate logical channel mode is a preferred mode and delivers the back-channel message defined in N.4.2 through the dedicated logical channel. The videomux mode is prepared for the system which cannot set up

the separate extra channel for the back-channel messages due to the restriction of the number of channels' combinations. The videomux mode delivers the back-channel messages through the same logical channel with the forward video data in the opposite direction.

N.3.1 Separate logical channel mode

The separate logical channel mode delivers back-channel messages through a dedicated logical channel opened only for the purpose of the back-channel messages. The association mechanism with the forward channel which delivers video data is provided by external means (for example, Recommendation H.245). Separate logical channel operation requires an external framing mechanism for synchronization of the messages within the back channel, as the back-channel syntax defined herein contains no synchronization flag words.

N.3.2 Videomux mode

The videomux mode delivers the back-channel messages through the same logical channel with the forward video data in the opposite direction. The syntax of the multiplexed bitstream is described in N.4.1. The back-channel messages may be inserted by using the Back-Channel message Indication (BCI) in the GOB or slice header.

N.4 Syntax

N.4.1 Forward channel

The syntax for the forward-channel data which conveys the compressed video signal is altered only in the Group of Blocks (GOB) or slice layer.

The syntax of the GOB layer is illustrated in Figure N.2. The fields of TRI, TR, TRPI, TRP, BCI, and BCM are added to Figure 9.

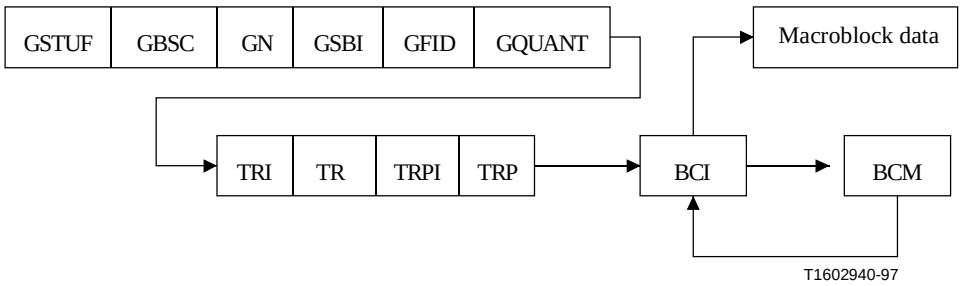


Figure N.2/H.263 – Structure of GOB layer for NEWPRED

When the optional Slice Structured mode (see Annex K) is in use, the syntax of the slice layer is modified in the same way as the GOB layer. The syntax is illustrated Figure N.3.

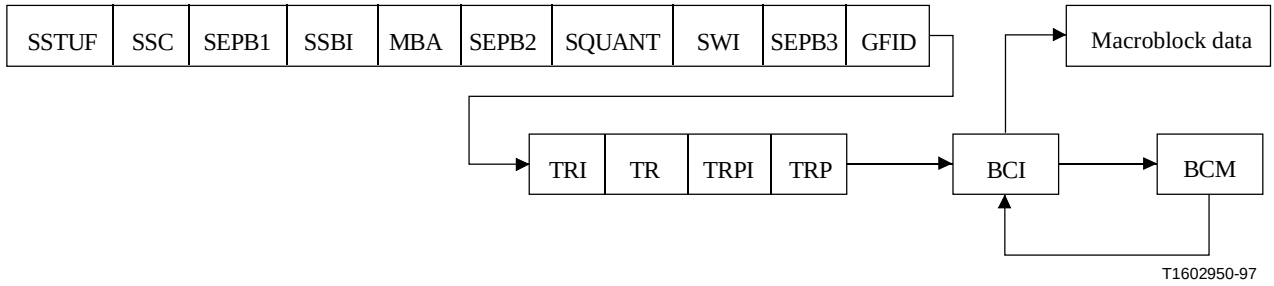


Figure N.3/H.263 – Structure of slice layer for NEWPRED

N.4.1.1 Temporal Reference Indicator (TRI) (1 bit)

TRI indicates whether or not the following TR field is present.

0: TR field is not present.

1: TR field is present.

N.4.1.2 Temporal Reference (TR) (8/10 bits)

When present, TR is an eight-bit number unless a custom picture clock frequency is in use, in which case it is a ten-bit number consisting of the concatenation of ETR and TR of the picture header.

N.4.1.3 Temporal Reference for Prediction Indicator (TRPI) (1 bit)

TRPI indicates whether or not the following TRP field is present.

0: TRP field is not present.

1: TRP field is present.

TRPI shall be equal to zero whenever the picture is an I- or EI-picture.

N.4.1.4 Temporal Reference for Prediction (TRP) (10 bits)

When present (as indicated in TRPI), TRP indicates the Temporal Reference which is used for prediction of the encoding, except in the case of B-pictures and the B-picture part of an Improved PB-frame. For B-pictures or the B-picture part of an Improved PB-frame, the picture having the temporal reference TRP is used for the prediction in the forward direction. (Prediction in the reverse-temporal direction always uses the immediately temporally subsequent picture.) TRP is a ten-bit number. If a custom picture clock frequency was not in use for the reference picture, the two MSBs of TRP are zero and the LSBs contain the eight-bit TR found in the picture header of the reference picture. If a custom picture clock frequency was in use for the reference picture, TRP is a ten-bit number consisting of the concatenation of ETR and TR from the reference picture header.

When TRP is not present, the most recent temporally previous anchor picture shall be used for prediction, as when not in the Reference Picture Selection mode. TRP is valid until the next PSC, GSC, or SSC.

N.4.1.5 Back-Channel message Indication (BCI) (Variable length)

This field contains one or two bits; when set to "1", it signals the presence of the following video Back-Channel Message (BCM) field. Otherwise, the field value is "01", which indicates the absence or the end of the video back-channel message field. Combinations of BCM and BCI may not be present, and may be repeated when present. BCI shall always be set to "01" if the videomux mode is not in use.

N.4.1.6 Back-Channel Message (BCM) (Variable length)

The Back-Channel Message having syntax as defined in N.4.2, which is present only if the preceding BCI field is set to "1".

N.4.2 Back-Channel Message (BCM) syntax

The syntax for the back-channel which conveys the acknowledgment/non-acknowledgment messages is illustrated in Figure N.4. This message is returned from a decoder to an encoder in order to tell whether a forward-channel data was correctly decoded or not.

BT	URF	TR	ELNUMI	ELNUM	BCPM	BSBI	BEPB1	GN/MBA	BEPB2	RTR	BSTUF

Figure N.4/H.263 – Structure of Back-Channel Message (BCM) syntax for NEWPRED

N.4.2.1 Back-channel message Type (BT) (2 bits)

Back-channel message type indicates if the corresponding part of the encoded message is correctly decoded or not. Which type of message is required for the encoder is indicated in the picture header of the forward channel.

00: Reserved for future use.

01: Reserved for future use.

10: NACK. This indicates the erroneous decoding of the corresponding part of the forward-channel data.

11: ACK. This indicates the correct decoding of the corresponding part of the forward-channel data.

N.4.2.2 Unreliable Flag (URF) (1 bit)

The Unreliable Flag is set to 1 when a reliable value for TR or GN/MBA is not available to the decoder. (When BT is NACK, a reliable TR may not be available at the decoder.)

0: Reliable.

1: Unreliable.

N.4.2.3 Temporal Reference (TR) (10 bits)

Temporal reference contains the TR information of the video picture segment for which the ACK/NACK is indicated in the back-channel message.

NOTE – The meaning of the term "video picture segment" as used herein is defined in Annex R. If a custom picture clock frequency was not in use for the reference picture, the two MSBs of TR are zero and the LSBs contain the eight-bit TR found in the picture header of the reference picture. If a custom picture clock frequency was in use for the reference picture, TR is a ten-bit number consisting of the concatenation of ETR and TR from the reference picture header.

N.4.2.4 Enhancement Layer Number Indication (ELNUMI) (1 bit)

The enhancement layer number indication is "0" unless the optional Temporal, SNR and Spatial Scalability mode (Annex O) is used in the forward-channel data and some enhancement layers of the forward channel are combined on one logical channel and the back-channel message refers to an enhancement layer (rather than the base layer), in which case the enhancement layer number indication shall be "1".

N.4.2.5 Enhancement Layer Number (ELNUM) (4 bits)

Enhancement layer number is present if and only if ELNUMI is "1", in which case it contains the layer number of the enhancement layer referred to in the back-channel message.

N.4.2.6 BCPM (1 bit)

BCPM is "0" unless the CPM mode is used in the forward-channel data, in which case it is "1". If BCPM is "1", this indicates that BSBI is present.

N.4.2.7 Back-channel Sub-Bitstream Indicator (BSBI) (2 bits)

A fixed length codeword of 2 bits that is only present if BCPM is "1". The BSBI is the natural binary representation of the appropriate Sub-Bitstream number in the forward-channel data for which the ACK/NACK message is indicated in the back-channel message as described in 5.2.4 and in Annex C.

N.4.2.8 Back-channel Emulation Prevention Bit 1 (BEPB1) (1 bit)

A field which is present if and only if the videomux mode is in use. This field is always set to "1" to prevent a start code emulation.

N.4.2.9 GOB Number/Macroblock Address (GN/MBA) (5/6/7/9/11/12/13/14 bits)

A GOB number or macroblock address is present in this field. If the optional Slice Structured mode (see Annex K) is not in use, this field contains the GOB number of the beginning of the video picture segment for which the NACK/ACK message is indicated in the back-channel message. If the optional Slice Structured mode is in use, this field contains the macroblock address of the beginning of the slice for which the NACK/ACK message is indicated in the back-channel message. The length of this field is the length specified elsewhere in this Recommendation for GN or MBA.

N.4.2.10 Back-channel Emulation Prevention Bit 2 (BEPB2) (1 bit)

A field which is present if and only if the videomux mode is in use. This field is always set to "1" to prevent a start code emulation.

N.4.2.11 Requested Temporal Reference (RTR) (10 bits)

Requested temporal reference is present only if BT is NACK. RTR indicates the requested temporal reference of the GOB or slice associated with the NACK. Typically, it is the TR of the last correctly decoded video picture segment of the corresponding position at the decoder. If a custom picture clock frequency was not in use for the requested reference picture, the two MSBs of RTR are zero and the LSBs contain the eight-bit TR found in the picture header of the requested reference picture. If a custom picture clock frequency was in use for the requested reference picture, RTR is a ten-bit number consisting of the concatenation of ETR and TR from the requested reference picture header.

N.4.2.12 Stuffing (BSTUF) (Variable length)

This field is present if and only if the separate logical channel mode is in use and the back-channel message is the last in an external frame. BSTUF consists of a codeword of variable length consisting of zero or more bits of value "0". This field is only present at the end of an external frame.

N.5 Decoder process

The decoder of this mode may need an additional number of picture memories to store the correctly decoded video signals and their Temporal Reference (TR) information. The decoder uses the stored picture for which the TR is TRP as the reference picture for inter-frame decoding instead of the last decoded picture, if the TRP field exists in the forward-channel data. When the picture for which the

TR is TRP is not available at the decoder, the decoder may send a forced INTRA update signal to the encoder by external means (for example, Recommendation H.245). Unless a different frame storage policy is negotiated by external means, correctly decoded video picture segments shall be stored into memory for use as later reference pictures on a first-in, first-out basis as shown in Figure N.1 (except for B-pictures, which are not used as reference pictures), and video picture segments which are detected as having been incorrectly decoded should not replace correctly decoded ones in this memory area.

An Acknowledgment message (ACK) and a Non-Acknowledgment message (NACK) are defined as back-channel messages. An ACK may be returned when the decoder decodes a video picture segment successfully. NACKs may be returned when the decoder fails to decode a video picture segment, and may continue to be returned until the decoder gets the expected forward channel data which includes the requested TRP or an INTRA update. Which types of message shall be sent is indicated in the RPSMF field of the picture header of the forward-channel data.

In a usage scenario known as "Video Redundancy Coding", the Reference Picture Selection mode may be used by some encoders in a manner in which more than one representation is sent for the pictured scene at the same temporal instant (usually using different reference pictures). In such a case in which the Reference Picture Selection mode is in use and in which adjacent pictures in the bitstream have the same temporal reference, the decoder shall regard this occurrence as an indication that redundant copies have been sent of approximately the same pictured scene content, and shall decode and use the first such received picture while discarding the subsequent redundant picture(s).

ANNEX O

Temporal, SNR, and Spatial Scalability mode

This annex describes the optional mode of this Recommendation in support of Temporal, SNR, and Spatial Scalability. This mode may also be used in conjunction with error control schemes. The capability of this mode and the extent to which its features are supported is signaled by external means (for example, Recommendation H.245). The use of this mode is indicated in PLUSPTYPE.

O.1 Overview

Scalability allows for the decoding of a sequence at more than one quality level. This is done by using a hierarchy of pictures and enhancement pictures partitioned into one or more layers. There are three types of pictures used for scalability: B-, EI-, and EP-pictures, as explained below. Each of these has an enhancement layer number ELNUM that indicates to which layer it belongs, and a reference layer number RLNUM that indicates which layer is used for its prediction. The lowest layer is called the base layer, and has layer number 1.

Scalability is achieved by three basic methods: temporal, SNR, and spatial enhancement.

O.1.1 Temporal scalability

Temporal scalability is achieved using bidirectionally predicted pictures, or B-pictures. B-pictures allow prediction from either or both a previous and subsequent reconstructed picture in the reference layer. This property generally results in improved compression efficiency as compared to that of P-pictures. These B-pictures differ from the B-picture part of a PB- (or Improved PB-) frame (see Annexes G and M) in that they are separate entities in the bitstream: they are not syntactically intermixed with a subsequent P- (or EP-) picture.

B-pictures (and the B-part of PB- or Improved PB-frames) are not used as reference pictures for the prediction of any other pictures. This property allows for B-pictures to be discarded if necessary without adversely affecting any subsequent pictures, thus providing temporal scalability. Figure O.1 illustrates the predictive structure of P- and B-pictures.

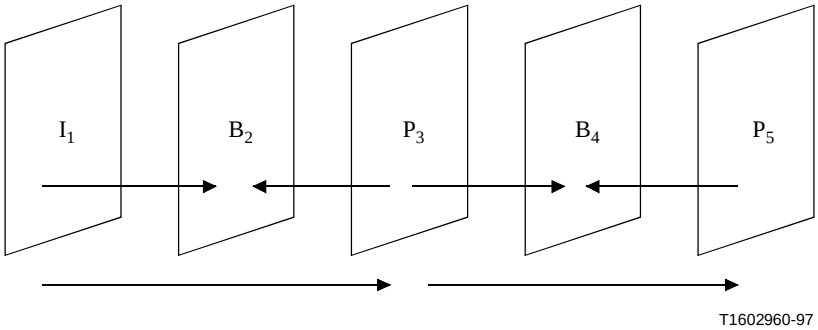


Figure O.1/H.263 – Illustration of B-picture prediction dependencies

The location of B-pictures in the bitstream is in a data-dependence order rather than in strict temporal order. (This rule is consistent with the ordering of other pictures in the bitstream, but for all picture types other than the B-picture, no such conflict arises between the data-dependence order and the temporal order.) For example, if the pictures of a video sequence were numbered 1, 2, 3, …, then the bitstream order of the encoded pictures would be I_1, P_3, B_2, P_5, B_4, …, where the subscript refers to the original picture number (as illustrated in Figure O.1).

There is no limit to the number of B-pictures that may be inserted between pairs of reference pictures in the reference layer (other than what is necessary to prevent temporal ambiguity from overflows of the temporal reference field in the picture header). However, a 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 layer picture.

Motion vectors are allowed to extend beyond the picture boundaries of B-pictures.

O.1.2 SNR scalability

The other basic method to achieve scalability is through spatial/SNR enhancement. Spatial scalability and SNR scalability are equivalent except for the use of interpolation as is described shortly. Because compression introduces artifacts and distortions, the difference between a reconstructed picture and its original in the encoder is (nearly always) a nonzero-valued picture, containing what can be called the coding error. Normally, this coding error is lost at the encoder and never recovered. With SNR scalability, these coding error pictures can also be encoded and sent to the decoder, producing an enhancement to the decoded picture. The extra data serves to increase the signal-to-noise ratio of the video picture, and hence, the term SNR scalability. Figure O.2 illustrates the data flow for SNR scalability. The vertical arrows from the lower layer illustrate that the picture in the enhancement layer is predicted from a reconstructed approximation of that picture in the reference (lower) layer.

If prediction is only formed from the lower layer, then the enhancement layer picture is referred to as an EI-picture. It is possible, however, to create a modified bidirectionally predicted picture using both a prior enhancement layer picture and a temporally simultaneous lower layer reference picture. This type of picture is referred to as an EP-picture or "Enhancement" P-picture. The prediction flow for EI- and EP-pictures is shown in Figure O.2. (Although not specifically shown in Figure O.2, an

EI-picture in an enhancement layer may have a P-picture as its lower layer reference picture, and an EP-picture may have an I-picture as its lower-layer enhancement picture.)

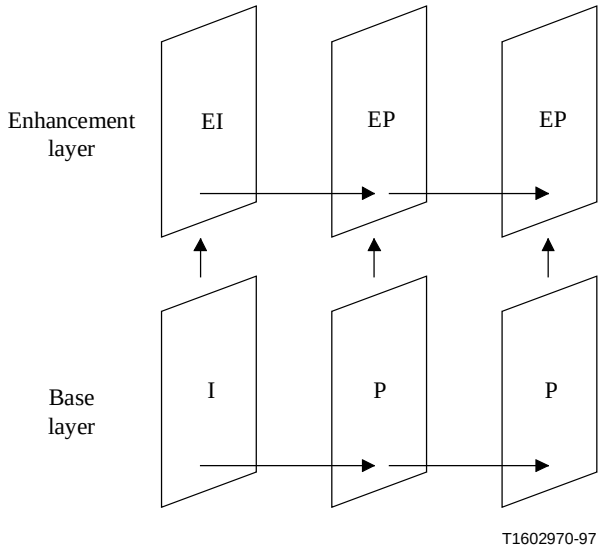


Figure O.2/H.263 – Illustration of SNR scalability

For both EI- and EP-pictures, the prediction from the reference layer uses no motion vectors. However, as with normal P-pictures, EP-pictures use motion vectors when predicting from their temporally prior reference picture in the same layer.

O.1.3 Spatial scalability

The third and final scalability method in the Temporal, SNR, and Spatial Scalability mode is spatial scalability, which is closely related to SNR scalability. The only difference is that before the picture in the reference layer is used to predict the picture in the spatial enhancement layer, it is interpolated by a factor of two either horizontally or vertically (1-D spatial scalability), or both horizontally and vertically (2-D spatial scalability). The interpolation filters for this operation are defined in O.6. For a decoder to be capable of some forms of spatial scalability, it may also need to be capable of custom picture formats. For example, if the base layer is sub-QCIF (128 × 96), the 2-D spatial enhancement layer picture would be 256 × 192, which does not correspond to a standard picture format. Another example would be if the base layer were QCIF (176 × 144), with the standard pixel aspect ratio of 12:11. A 1-D horizontal spatial enhancement layer would then correspond to a picture format of 352 × 144 with a pixel aspect ratio of 6:11. Thus a custom picture format would have to be used for the enhancement layer in these cases. An example which does not require a custom picture format would be the use of a QCIF base layer with a CIF 2-D spatial enhancement layer. Spatial scalability is illustrated in Figure O.3.

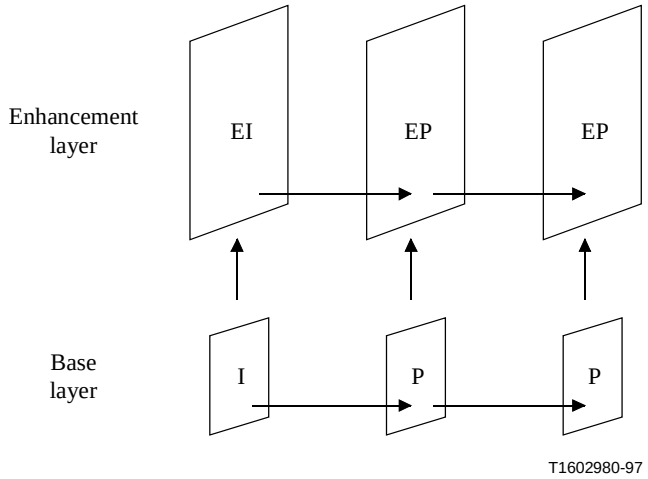


Figure O.3/H.263 – Illustration of spatial scalability

Other than requiring an upsampling process to increase the size of the reference layer picture prior to its use as a reference for the encoding process, the processing and syntax for a spatial scalability picture is functionally identical to that for an SNR scalability picture.

Since there is very little syntactical distinction between pictures using SNR scalability and pictures using spatial scalability, the pictures used for either purpose are called EI- and EP-pictures.

The picture in the base layer which is used for upward prediction in an EI- or EP-picture may be an I-picture, a P-picture, or the P-part of a PB- or Improved PB-frame (but shall not be a B-picture or the B-part of a PB- or Improved PB-frame).

O.1.4 Multilayer scalability

It is possible not only for B-pictures to be temporally inserted between pictures of types I, P, PB, and Improved PB, but also between pictures of types EI and EP, whether these consist of SNR or spatial enhancement pictures. It is also possible to have more than one SNR or spatial enhancement layer in conjunction with a base layer. Thus, a multilayer scalable bitstream can be a combination of SNR layers, spatial layers, and B-pictures. The size of a picture cannot decrease, however, with increasing layer number. It can only stay the same or increase by a factor of two in one or both dimensions. Figure O.4 illustrates a multilayer scalable bitstream.

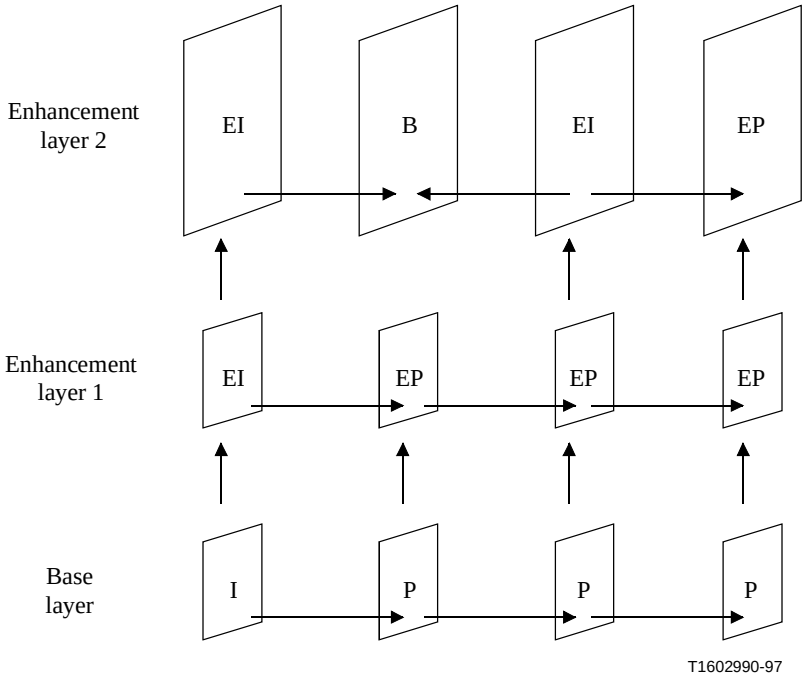


Figure O.4/H.263 – Illustration of multilayer scalability

In the case of multilayer scalability, the picture in a reference layer which is used for upward prediction in an EI- or EP-picture may be a I-, P-, EI-, or EP-picture, or may be the P-part of a PB- or Improved PB-frame in the base layer (but shall not be a B-picture or the B-part of a PB- or Improved PB-frame).

As with the two-layer case, B-pictures may occur in any layer. However, any picture in an enhancement layer which is temporally simultaneous with a B-picture in its reference layer must be a B-picture or the B-picture part of an PB- or Improved PB-frame. This is to preserve the disposable nature of B-pictures. Note, however, that B-pictures may occur in layers that have no corresponding picture in lower layers. This allows an encoder to send enhancement video with a higher picture rate than the lower layers.

The enhancement layer number and the reference layer number for each enhancement picture (B-, EI-, or EP-) are indicated in the ELNUM and RLNUM fields, respectively, of the picture header (when present). See the inference rules described in 5.1.4.4 for when these fields are not present. If a B-picture appears in an enhancement layer in which temporally surrounding SNR or spatial scalability pictures also appear, the Reference Layer Number (RLNUM) of the B-picture shall be the same as the Enhancement Layer Number (ELNUM).

The picture height, width, and pixel aspect ratio of a B-picture shall always be equal to those of its temporally subsequent reference layer picture.

O.2 Transmission order of pictures

Pictures which are dependent on other pictures shall be located in the bitstream after the pictures on which they depend.

The bitstream syntax order is specified such that for reference pictures (i.e. picture having types I, P, EI, or EP, or the P-part of PB or Improved PB), the following two rules shall be obeyed:

1) All reference pictures with the same temporal reference shall appear in the bitstream in increasing enhancement layer order (since each lower layer reference picture is needed to decode the next higher layer reference picture).

2) All temporally simultaneous reference pictures as discussed in item 1) above shall appear in the bitstream prior to any B-pictures for which any of these reference pictures is the first temporally subsequent reference picture in the reference layer of the B-picture (in order to reduce the delay of decoding all reference pictures which may be needed as references for B-pictures).

Then, the B-pictures with earlier temporal references shall follow (temporally ordered within each enhancement layer).

The bitstream location of each B-picture shall comply with the following rules:

1) Its bitstream location shall be after that of its first temporally subsequent reference picture in the reference layer (since the decoding of the B-picture generally depends on the prior decoding of that reference picture).

2) Its bitstream location shall be after that of all reference pictures that are temporally simultaneous with the first temporally subsequent reference picture in the reference layer (in order to reduce the delay of decoding all reference pictures which may be needed as references for B-pictures).

3) Its bitstream location shall precede the location of any additional temporally subsequent pictures other than B-pictures in its reference layer (since to allow otherwise would increase picture-storage memory requirements for the reference layer pictures).

4) Its bitstream location shall be after that of all EI- and EP-pictures that are temporally simultaneous with the first temporally subsequent reference picture.

5) Its bitstream location shall precede the location of all temporally subsequent pictures within its same enhancement layer (since to allow otherwise would introduce needless delay and increase picture-storage memory requirements for the enhancement layer).

Figure O.5 illustrates two allowable picture transmission orders given by the rules above for the layering structure shown therein (with numbers in dotted-line boxes indicating the bitstream order, separated by commas for the two alternatives).

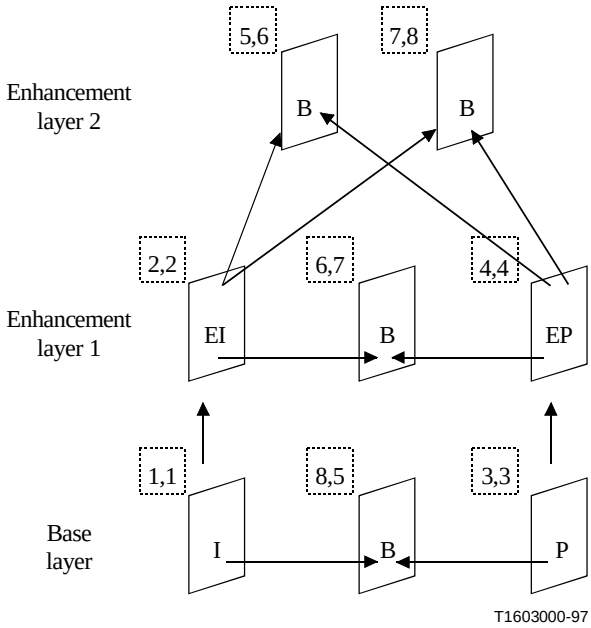


Figure O.5/H.263 – Example of picture transmission order

O.3 Picture layer syntax

The Enhancement Layer Number (ELNUM) (see 5.1.11) is always present in any enhancement (B, EI, or EP) picture and shall not be present in I- or P-pictures, or in PB- or Improved PB-frames. The Reference Layer Number (RLNUM) (see 5.1.12) is present for some enhancement pictures and is inferred for others, as described in 5.1.12.

There is exactly one base layer, and it has ELNUM and RLNUM equal to 1. The RLNUM gives the enhancement layer number of the forward and backward reference pictures for B-pictures, for the upward reference picture for EI- and EP-pictures. The reference pictures of the base layer may consist of I, PB, Improved PB, and P-pictures, none of which include ELNUM or RLNUM in the picture header (their implied values are 1).

For B-pictures, RLNUM must be less or equal to ELNUM, while for EI- and EP-pictures, RLNUM must be smaller than ELNUM.

ELNUM may be different from the layer number used at the system level. Since B-pictures have no other pictures dependent on themselves, they may even be put in a separate enhancement layer by system components external to this Recommendation (for example, Recommendations H.245 and H.223). Moreover, it is up to the implementor as to whether the enhancement pictures are sent in separate video channels or remain multiplexed together with the base layer pictures.

As stated in 5.1.4.5, the Deblocking Filter mode (see Annex J) does not apply within B-pictures. This is because B-pictures are not used for the prediction of any other pictures, and thus the application of a deblocking filter to these pictures is entirely a post-processing technique which is outside the scope of this Recommendation. However, the use of some type of deblocking filter for B-pictures is encouraged, and a filter such as that described in Annex J may in fact be a good design to use for that purpose.

The Temporal Reference (TR) (see 5.1.2) is defined exactly as for I- and P-pictures.

There shall be no TR_B (see 5.1.22) or DBQUANT (see 5.1.23) fields in the picture header of B-, EI- or EP-pictures.

O.4 Macroblock layer syntax

The macroblock layer syntax for B- and EP-pictures is the same, since each uses two reference pictures in a similar way. However, the interpretation varies slightly depending on the picture type. Figure O.6 indicates the B and EP syntax. The MBTYPE field indicates whether there is direct-mode prediction, forward prediction, backward/upward prediction, or bidirectional prediction. The MBTYPE is defined differently for B- and EP-pictures as described below.

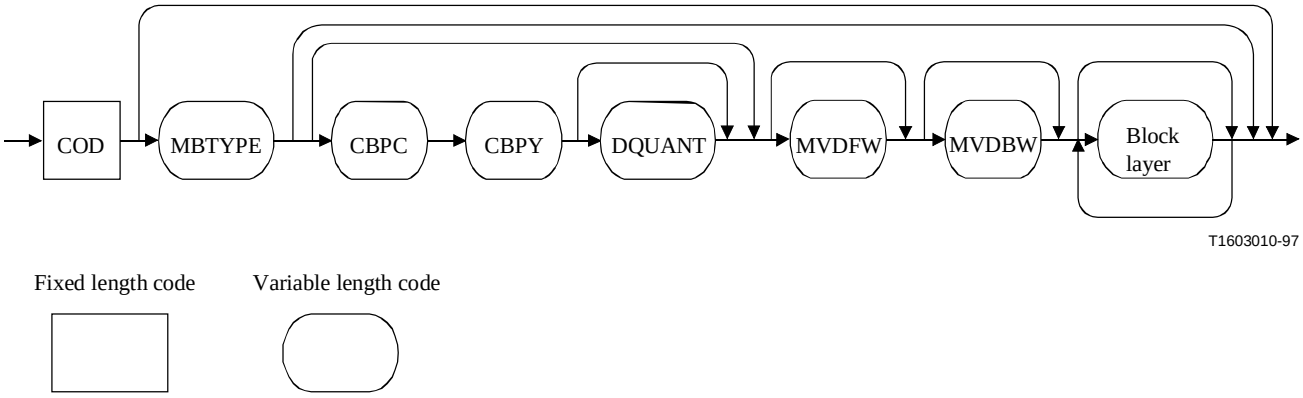


Figure O.6/H.263 – Macroblock syntax for EP- and B-pictures

The direct prediction mode is only available for B-pictures. It is a bidirectional prediction mode similar to the bidirectional mode in Improved PB-frames mode (Annex M). The only difference is that there is no restriction on which pixels can be backward predicted since the complete backward prediction image is known at the decoder. Bidirectional mode uses separate motion vectors for forward and backward prediction. In both direct and bidirectional mode, the prediction pixel values are calculated by averaging the forward and backward prediction pixels. The average is calculated by dividing the sum of the two predictions by two (division by truncation). In direct mode, when there are four motion vectors in the reference macroblock, then all four motion vectors are used as in Improved PB-frames mode (Annex M).

For B-pictures, forward prediction means prediction from a previous reference picture in the reference layer. Backward prediction means prediction from a temporally subsequent reference picture in the reference layer.

For EP-pictures, forward prediction means prediction from a previous EI- or EP-picture in the same layer, while upward prediction is used to mean prediction from the temporally simultaneous (possibly interpolated) reference picture in the reference layer. No motion vector is used for the upward prediction (which is syntactically in the same place as backward prediction for B-pictures), although one can be used for the forward prediction.

The macroblock syntax for EI-pictures is slightly different. As shown in Figure O.7, the MBTYPE and CBPC are combined into an MCBPC field. No forward prediction is used, only upward prediction from the temporally simultaneous reference picture in the reference layer. No motion vector is used.

In B- and EP-pictures, motion vectors over picture boundaries may be used as described in D.1 (although extension of the motion vector range as described in D.2 is only active if the Unrestricted Motion Vector mode is also in use).

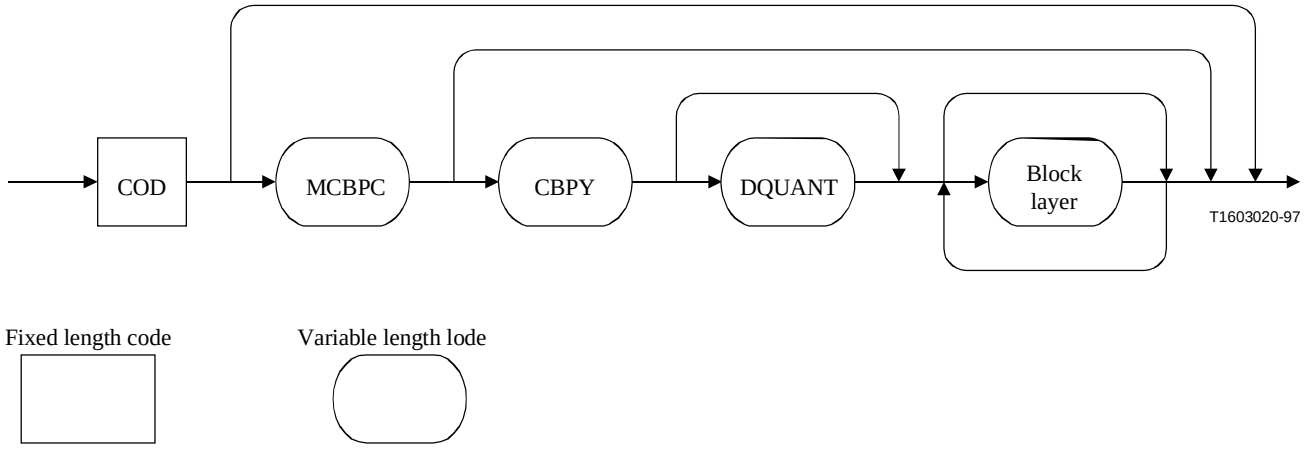


Figure O.7/H.263 – Macroblock syntax for EI-pictures

O.4.1 Coded macroblock indication (COD) (1 bit)

A bit which, when set to "0", signals that the macroblock is coded. If set to "1", no further information is transmitted for this macroblock and the macroblock is handled as "skipped" as described below.

O.4.2 MBTYPE/MCBPC (VLC)

There are different MBTYPE tables for B- and EP-pictures. For EI-pictures, there is instead a MCBPC table. Table O.1 is the MBTYPE table for B-pictures. Table O.2 is the MBTYPE table for EP-pictures. Table O.3 is the MCBPC table for EI-pictures.

For B-pictures, the "Direct (skipped)" prediction type indicates that neither MBTYPE, nor any data, is transmitted in the macroblock and that the decoder derives forward and backward motion vectors and the corresponding bidirectional prediction. This is signaled by the COD bit. The "Forward (no texture)", the "Backward (no texture)", and the "Bi-dir (no texture)" prediction types for a B-picture indicate forward, backward, and bi-directional prediction with no coefficients, and with one transmitted motion vector for forward and backward prediction, and two transmitted motion vectors for bidirectional prediction.

For EP-pictures, the "Forward (skipped)" prediction type indicates that no additional data is sent for the macroblock, so that the decoder should use forward prediction with a zero motion vector and no coefficients. The "Upward (no texture)" and "Bi-dir (no texture)" prediction types for an EP-picture indicate upward and bidirectional prediction with no coefficients, and with zero motion vector(s).

For EI-pictures, the "Upward (skipped)" prediction type indicates that no additional data is sent for the macroblock, so that the decoder should use upward prediction with a zero motion vector and no coefficients.

Table O.1/H.263 – MBTYPE VLC codes for B-pictures

Index	Prediction type	MVDFW	MVDBW	CBPC + CBPY	DQUANT	MBTYPE	Bits
–	Direct (skipped)					(COD = 1)	0
0	Direct			X		11	2
1	Direct + Q			X	X	0001	4
2	Forward (no texture)	X				100	3
3	Forward	X		X		101	3
4	Forward + Q	X		X	X	0011 0	5
5	Backward (no texture)		X			010	3
6	Backward		X	X		011	3
7	Backward + Q		X	X	X	0011 1	5
8	Bi-dir (no texture)	X	X			0010 0	5
9	Bi-dir	X	X	X		0010 1	5
10	Bi-dir + Q	X	X	X	X	0000 1	5
11	INTRA			X		0000 01	6
12	INTRA + Q			X	X	0000 001	7
13	Stuffing					0000 0000 1	9

Table O.2/H.263 – MBTYPE VLC codes for EP-pictures

Index	Prediction type	MVDFW	MVDBW	CBPC + CBPY	DQUANT	MBTYPE	Bits
–	Forward (skipped)					(COD = 1)	0
0	Forward	X		X		1	1
1	Forward + Q	X		X	X	001	3
2	Upward (no texture)					010	3
3	Upward			X		011	3
4	Upward + Q			X	X	0000 1	5
5	Bi-dir (no texture)					0001 0	5
6	Bi-dir	X		X		0001 1	5
7	Bi-dir + Q	X		X	X	0000 01	6
8	INTRA			X		0000 001	7
9	INTRA + Q			X	X	0000 0001	8
10	Stuffing					0000 0000 1	9

Table O.3/H.263 – MCBPC VLC codes for EI-pictures

Index	Prediction type	Code block pattern (56)	CBPY	DQUANT	MCBPC	Bits
–	Upward (skipped)				(COD = 1)	0
0	Upward	00	X		1	1
1	Upward	01	X		001	3
2	Upward	10	X		010	3
3	Upward	11	X		011	3
4	Upward + Q	00	X	X	0001	4
5	Upward + Q	01	X	X	0000 001	7
6	Upward + Q	10	X	X	0000 010	7
7	Upward + Q	11	X	X	0000 011	7
8	INTRA	00	X		0000 0001	8
9	INTRA	01	X		0000 1001	8
10	INTRA	10	X		0000 1010	8
11	INTRA	11	X		0000 1011	8
12	INTRA+Q	00	X	X	0000 1100	8
13	INTRA+Q	01	X	X	0000 1101	8
14	INTRA+Q	10	X	X	0000 1110	8
15	INTRA+Q	11	X	X	0000 1111	8
16	Stuffing				0000 0000 1	9

O.4.3 Coded Block Pattern for Chrominance (CBPC) (Variable length)

When present, CBPC indicates the coded block pattern for chrominance blocks as described in Table O.4. CBPC is present only for EP- and B-pictures, when its presence is indicated by MBTYPE (see Tables O.1 and O.2).

Table O.4/H.263 – CBPC VLC codes

Index	Code block pattern (56)	CBPC	Bits
0	00	0	1
1	01	10	2
2	10	111	3
3	11	110	3

O.4.4 Coded Block Pattern for Luminance (CBPY) (Variable length)

When present, CBPY indicates which blocks in the luminance portion of the macroblock are present. CBPY is present only when its presence is indicated by MBTYPE (see Tables O.1, O.2 and O.3). CBPY is coded as described in 5.3.5 and in Table 13. Upward predicted macroblocks in EI- and EP-pictures, bidirectional predicted macroblocks in EP-pictures, and INTRA macroblocks in EI-, EP-, and B-pictures use the CBPY definition for INTRA macroblocks, and other macroblock types in EI-, EP-, and B-pictures use the CBPY definition for INTER macroblocks.

O.4.5 Quantizer Information (DQUANT) (2 bits/Variable length)

DQUANT is used as in other picture macroblock types. See 5.3.6 and Annex T.

O.4.6 Motion vector data (MVDFW, MVDBW) (Variable length)

MVDFW is the motion vector data for the forward vector, if present. MVDBW is the motion vector data for the backward vector, if present (allowed only in B-pictures). The variable length codewords are given in Table 14, or in Table D.3 if the Unrestricted Motion Vector mode is used (see Annex D).

O.5 Motion vector decoding

O.5.1 Differential motion vectors

Motion vectors for forward, backward or bidirectionally predicted blocks are differentially encoded. To recover the macroblock motion vectors, a prediction is added to the motion vector differences. The predictions are formed in a similar manner to that described in 6.1.1, except 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. The same decision rules apply for the special cases at picture, GOB or slice borders as described in 6.1.1. If a neighboring macroblock does not have a motion vector of the same type (forward or backward), the candidate predictor for that macroblock is zero for that motion vector type.

O.5.2 Motion vectors in direct mode

For macroblocks coded in direct mode, no vector differences are transmitted. Instead, the forward and backward motion vectors are directly computed from the temporally consecutive P-vector as described in G.4 with the restriction that MV_D is always zero. These derived vectors are not used for prediction of other motion vectors.

O.6 Interpolation filters

The method by which a picture is interpolated for 2-D spatial scalability is shown in Figures O.8 and O.9. The first figure shows the interpolation for interior pixels, while the second one shows the interpolation close to picture boundaries. This is the same technique used in Annex Q and in some cases in Annex P. The method by which a picture is interpolated for 1-D spatial scalability is shown in Figures O.10 and O.11. Figure O.10 shows the interpolation for interior pixels in the horizontal direction. The interpolation for the vertical direction is analogous. Figure O.11 shows the interpolation for pixels at picture boundaries. Again, the interpolation for the vertical direction is analogous. Again, this is the same technique used in some cases in Annex P.

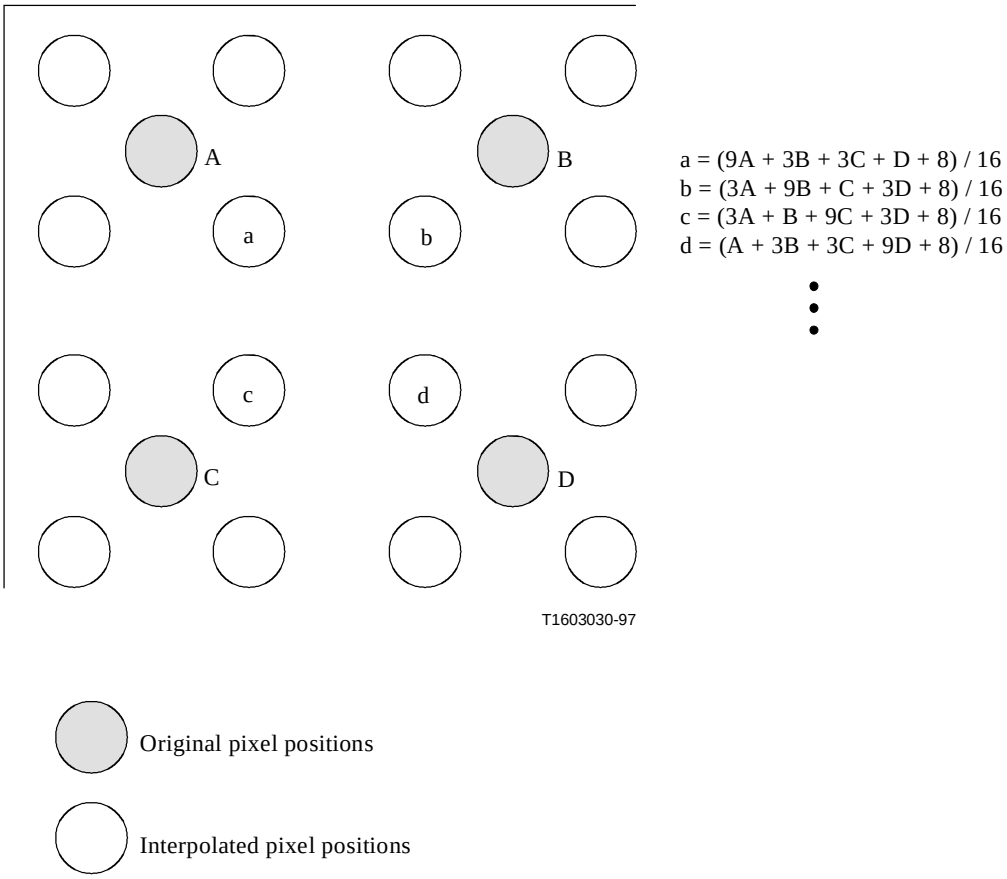


Figure O.8/H.263 – Method for interpolating pixels for 2-D scalability

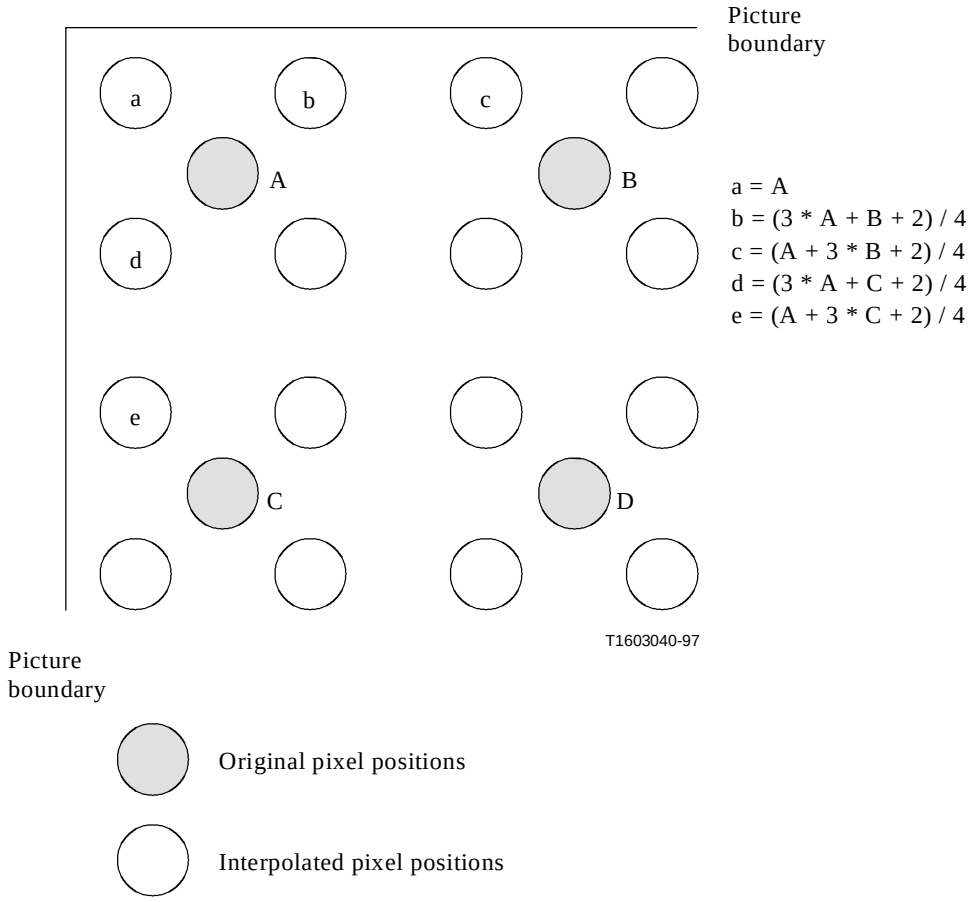


Figure O.9/H.263 – Method for 2-D interpolation at boundaries

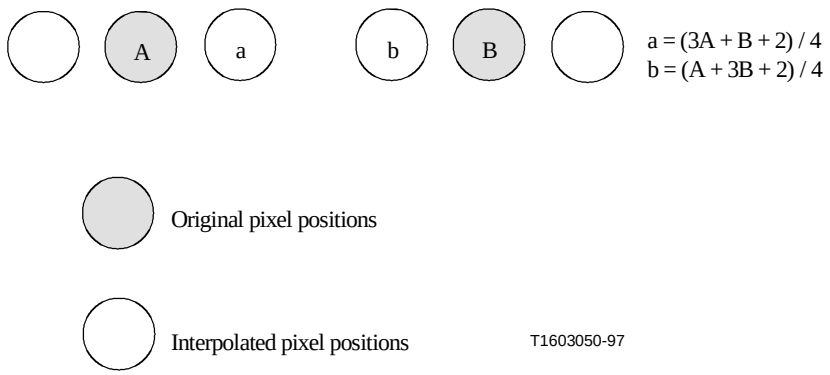


Figure O.10/H.263 – Method for interpolating pixels for 1-D scalability

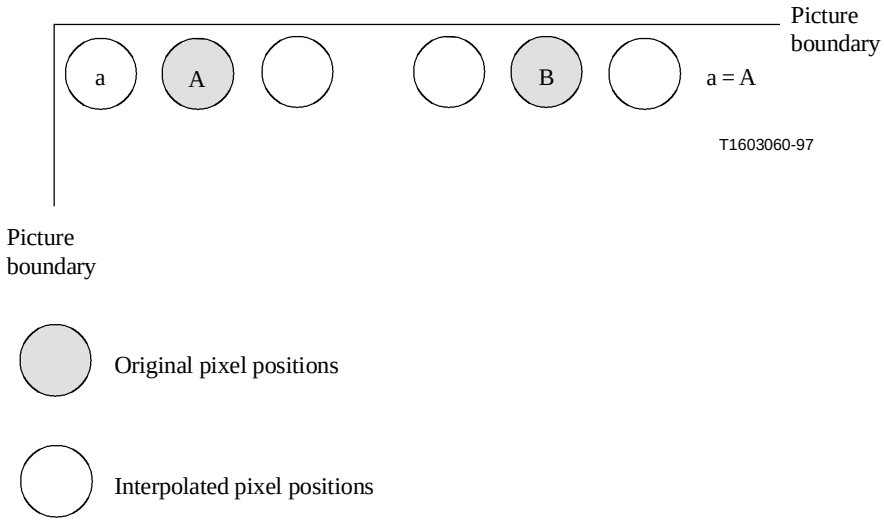


Figure O.11/H.263 – Method for 1-D interpolation at picture boundaries

ANNEX P

Reference picture resampling

P.1 Introduction

This annex describes the use and syntax of a resampling process which can be applied to the previous decoded reference picture in order to generate a "warped" picture for use in predicting the current picture. This resampling syntax can specify the relationship of the current picture to a prior picture having a different source format, and can also specify a "global motion" warping alteration of the shape, size, and location of the prior picture with respect to the current picture. In particular, the Reference Picture Resampling mode can be used to adaptively alter the resolution of pictures during encoding. A fast algorithm is used to generate bilinear interpolation coefficients. The capability to use this mode and the extent to which its features are supported is negotiated externally (for example, Recommendation H.245). This mode may be used in restricted scenarios that may be defined during capability negotiation (e.g. to support only factor-of-four picture resizing, to support only half-pixel resolution picture warping, or to support arbitrary image size resizing and displacements).

NOTE – The default image transformation between pictures of differing resolutions is defined to maintain the spatial alignment of the edges of the picture area and of the relative locations of the luminance and chrominance samples. This may have implications on the design of any resampling operations used for generating pictures of various resolutions at the encoder and for displaying pictures of various resolutions after decoding (particularly regarding shifts in spatial location caused by phase shifts induced in resampling). Also, since this mode can be used for dynamic adaptive picture resolution changes, operation with this mode may benefit from external negotiation to display the decoded picture at a higher resolution than its encoded picture size, in order to allow switching between encoded picture sizes without resizing the picture display.

If the Reference Picture Resampling bit in the PLUSPTYPE field is not set, but PLUSPTYPE is present and the picture is an INTER, B, or EP-picture or an Improved PB-frame, and the picture size differs from that of the temporally previous encoded picture, this condition invokes Reference Picture Resampling with warping parameters (see P.2.2) set equal to zero, fill mode (see P.2.3) set to *clip*, and displacement accuracy (see P.2.1) set to $\frac{1}{16}$-pixel accuracy. This causes the resampling process to easily act as a predictively-encoded change in picture resolution. In simple factor-of-four

resolution change cases such as transitions between CIF and 4CIF, the resampling process reduces to the same simple filter used for Spatial Scalability (Annex O) or for Reduced-Resolution Update (Annex Q), except for the application of rounding control.

If the picture is an EP-picture and the Reference Picture Resampling bit is set in the PLUSPTYPE field of the picture header of the reference layer, this bit shall also be set in the picture header of the EP-picture in the enhancement layer.

If a B-picture uses the Reference Picture Resampling mode, the resampling process shall be applied to the temporally previous anchor picture and not to the temporally subsequent one. The temporally previous anchor picture to which the resampling process is applied shall be the decoded picture (i.e. prior to any resampling applied by Reference Picture Resampling if this mode is also invoked for the subsequent reference picture). The temporally subsequent anchor picture shall have the same picture size as the B-picture.

If the Reference Picture Resampling mode is invoked for an Improved PB-frame, one set of warping parameters is sent and the resampled reference picture is used as the reference for both the B- and P-parts of the Improved PB-frame.

The Reference Picture Resampling is defined in terms of the displacement of the four corners of the current picture area. For the luminance field of the current picture with horizontal size H and vertical size V, four conceptual motion vectors $\underline{v}^{00}$, $\underline{v}^{H0}$, $\underline{v}^{0V}$, and $\underline{v}^{HV}$, are defined for the upper left, upper right, lower left, and lower right corners of the picture, respectively. These vectors describe how to move the corners of the current picture to map them onto the corresponding corners of the previous decoded picture, as shown in Figure P.1. The units of these vectors are the same as those in the reference picture grid. To generate a vector $\underline{v}(x,y)$ at some real-valued location (x, y) in the interior of the current picture, an approximation to bilinear interpolation is used, *i.e.* as in:

$$\underline{v}(x,y)=\left(1-\frac{y}{V}\right)\left[\left(1-\frac{x}{H}\right)\underline{v}^{00}+\left(\frac{x}{H}\right)\underline{v}^{H0}\right]+\left(\frac{y}{V}\right)\left[\left(1-\frac{x}{H}\right)\underline{v}^{0V}+\left(\frac{x}{H}\right)\underline{v}^{HV}\right]$$

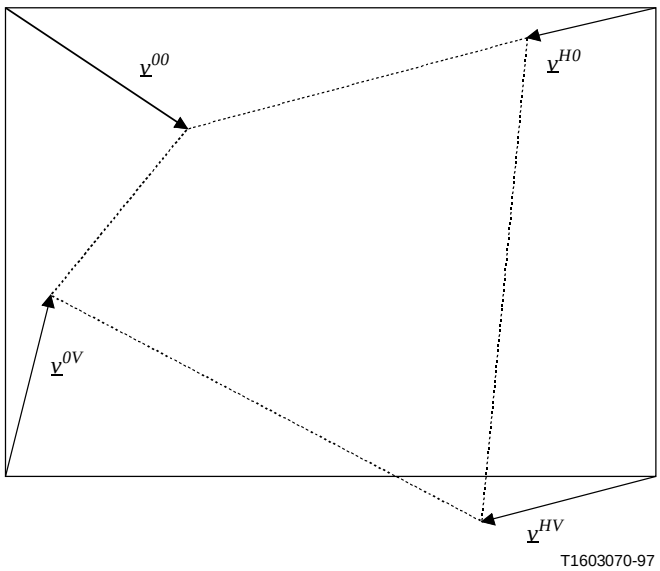


Figure P.1/H.263 – Example of conceptual motion vectors used for warping

The horizontal size H and vertical size V of the current picture, and the horizontal size H_R and vertical size V_R of the reference picture are those indicated by the picture header, regardless of

whether these values are divisible by 16 or not. If the picture width or height is not divisible by 16, the additional area shall be generated by adding pixels to the resampled picture using the same fill mode as used in the resampling process.

For the simplicity of description, the resampling vectors $\underline{r}^0$, $\underline{r}^x$, $\underline{r}^y$ and $\underline{r}^{xy}$ are defined as:

$$\underline{r}^0 = \underline{v}^{00}$$

$$\underline{r}^x = \underline{v}^{H0} - \underline{v}^{00}$$

$$\underline{r}^y = \underline{v}^{0V} - \underline{v}^{00}$$

$$\underline{r}^{xy} = \underline{v}^{00} - \underline{v}^{H0} - \underline{v}^{0V} + \underline{v}^{HV}$$

Using this definition, the equation for bilinear interpolation is rewritten as:

$$\underline{v}(x,y) = \underline{r}^0 + \left(\frac{x}{H}\right)\underline{r}^x + \left(\frac{y}{V}\right)\underline{r}^y + \left(\frac{x}{H}\right)\left(\frac{y}{V}\right)\underline{r}^{xy}$$

For warping purposes, it is assumed that the coordinates of the upper left corner of the picture area are (x, y) = (0,0) and that each pixel has unit height and width, so that the centers of the pixels lie at the points $(x,y) = \left(i_L + \frac{1}{2}, j_L + \frac{1}{2}\right)$ for i_L = 0, …, H – 1 and j_L = 0, …, V – 1, where the L subscript indicates that i_L and j_L pertain to the luminance field. (As the pixel aspect ratio is usually constant or the conversion of the aspect ratio is performed by this resampling, there is no need to consider the actual pixel aspect ratio for these purposes.) Using this convention, the x- and y-displacements at the locations of interest in the luminance field of the reference picture are:

$$v_x(i_L, j_L) = \frac{1}{HV}\left[HVr_x^0 + \left(i_L + \frac{1}{2}\right)Vr_x^x + \left(j_L + \frac{1}{2}\right)Hr_x^y + \left(i_L + \frac{1}{2}\right)\left(j_L + \frac{1}{2}\right)r_x^{xy}\right]$$

$$v_y(i_L, j_L) = \frac{1}{HV}\left[HVr_y^0 + \left(i_L + \frac{1}{2}\right)Vr_y^x + \left(j_L + \frac{1}{2}\right)Hr_y^y + \left(i_L + \frac{1}{2}\right)\left(j_L + \frac{1}{2}\right)r_y^{xy}\right]$$

Because all positions and phases must be computed relative to the center of the upper-left corner pixel, which has the coordinate (x, y) = $\left(\frac{1}{2}, \frac{1}{2}\right)$, the quantities of primary interest are:

$$x_R(i_L, j_L) - \frac{1}{2} = \left(i_L + \frac{1}{2}\right) + v_x(i_L, j_L) - \frac{1}{2}$$

$$= \frac{1}{HV}\left[HVr_x^0 + \left(i_L + \frac{1}{2}\right)(HV + Vr_x^x) + \left(j_L + \frac{1}{2}\right)Hr_x^y + \left(i_L + \frac{1}{2}\right)\left(j_L + \frac{1}{2}\right)r_x^{xy}\right] - \frac{1}{2}$$

$$y_R(i_L, j_L) - \frac{1}{2} = \left(i_L + \frac{1}{2}\right) + v_y(i_L, j_L) - \frac{1}{2}$$

$$= \frac{1}{HV}\left[HVr_y^0 + \left(j_L + \frac{1}{2}\right)Vr_y^x + \left(j_L + \frac{1}{2}\right)(HV + Hr_y^y) + \left(i_L + \frac{1}{2}\right)\left(j_L + \frac{1}{2}\right)r_y^{xy}\right] - \frac{1}{2}$$

Once a location has been determined in the prior decoded reference picture using an approximation of these equations, bilinear interpolation as specified later in this annex shall be used to generate a value for the resampled pixel.

Each resampling vector can be decomposed into two components, with the first component describing the geometrical warping and the second component accounting for any difference in size between the predicted picture (horizontal size H and vertical size V) and the reference picture (horizontal size H_R and vertical size V_R). This decomposition is as follows:

$$\underline{v}^{00} = \underline{v}^{00}_{warp} + \underline{v}^{00}_{size} = \underline{v}^{00}_{warp} + (0,0)$$
$$\underline{v}^{H0} = \underline{v}^{H0}_{warp} + \underline{v}^{H0}_{size} = \underline{v}^{H0}_{warp} + (H_R - H, 0)$$
$$\underline{v}^{0V} = \underline{v}^{0V}_{warp} + \underline{v}^{0V}_{size} = \underline{v}^{0V}_{warp} + (0, V_R - V)$$
$$\underline{v}^{HV} = \underline{v}^{HV}_{warp} + \underline{v}^{HV}_{size} = \underline{v}^{HV}_{warp} + (H_R - H, V_R - V)$$

P.2 Syntax

Whenever the reference picture resampling bit is set in the PLUSTPYPE field of the picture header, the RPRP field of the picture header includes parameters which control the Reference Picture Resampling process. This includes a two-bit Warping Displacement Accuracy (WDA) field, may include eight warping parameters or one-bit warping parameter refinements, and includes a fill mode, as described in this subclause.

P.2.1 Warping Displacement Accuracy (WDA) (2 bits)

A two-bit warping displacement accuracy field WDA appears first in the RPRP field of the bitstream, and indicates the accuracy of the displacements for each pixel. A value of "10" indicates that the *x*- and *y*-displacements for each pixel are quantized to half-pixel accuracy. A value of "11" indicates that the displacements are quantized to $\frac{1}{16}$-pixel accuracy. The use of other values is reserved.

P.2.2 Warping parameters (Variable length)

When the Reference Picture Resampling parameters are sent for an INTER or B-picture, or an Improved PB-frame, eight warping parameters are included in the picture header using the variable length code (VLC) shown in Table D.3. For an EP-picture using SNR scalability, the warping parameters of the lower layer are used and no warping parameters are transmitted. If the Reference Picture Resampling bit is set in the PLUSPTYPE field of the picture header for an EP-picture using spatial scalability, the warping parameters of the lower layer are refined to the accuracy needed for the current layer by multiplying the warping parameter for each up-sampled dimension (warping parameters with subscript *x* and/or *y*) of the lower layer by two and adding the value of one additional bit that is sent in place of the associated warping parameter to define the least significant bit of the warping parameter.

The eight integer warping parameters (or their one-bit refinements) are sent in the following order:

$$w^0_x, w^0_y, w^x_x, w^x_y, w^y_x, w^y_y, w^{xy}_x, \text{ and } w^{xy}_y$$

When not a one-bit refinement, these parameters are sent in a similar manner as motion vector differences in the Unrestricted Motion Vector mode when PLUSPTYPE is present, using Table D.3 with no restriction on the range of the parameters (i.e. a range of –4095 to +4095). As when encoding motion vector difference pairs, an emulation prevention bit shall be added as needed after each pair of warping parameters is sent, such that if the all-zero codeword (the value +1 in half-pixel units) of Table D.3 is used for both warping parameters in the pair

(w_x^0 and w_y^0, w_x^x and w_y^y, or w_x^{xy} and w_y^{xy}) the pair of codewords is followed by a single bit equal to 1 to prevent start code emulation.

These eight warping parameters are interpreted as picture corner displacements relative to the displacements that would be induced by removing the resizing component of the resampling vectors. The warping parameters are scaled to represent half-pixel offsets in the luminance field of the current picture, and the range for the values of these paramenters is –4095 to +4095. The warping parameters are defined using the resampling vectors by the relations:

$$w_x^0 = 2r_x^0 \qquad w_y^0 = 2r_y^0$$

$$w_x^x = 2\left(r_x^x - (H_R - H)\right) \qquad w_y^x = 2r_y^x$$

$$w_x^y = 2r_x^y \qquad w_y^y = 2\left(r_y^y - (V_R - V)\right)$$

$$w_x^y = 2r_x^y \qquad w_y^{xy} = 2r_y^{xy}$$

P.2.3 Fill Mode (FILL_MODE) (2 bits)

For an INTER or B-picture or an Improved PB-frame, immediately following the VLC-coded warping parameters in the picture header are two bits which define the fill-mode action to be taken for the values of pixels for which the calculated location in the reference picture lies outside of the reference picture area. The meaning of these two bits is shown in Table P.1 and their location is shown in Figure P.2. For an EP-picture, the fill-mode action is the same as that for the reference layer, and the two fill-mode bits are not sent.

Table P.1/H.263 – Fill mode bits/action

fill-mode bits	fill action
0 0	*color*
0 1	*black*
1 0	*gray*
1 1	*clip*

If the fill mode is *clip*, the coordinates of locations in the prior reference picture are independently limited as in the Unrestricted Motion Vector mode so that pixel values outside of the prior reference picture area are estimated by extrapolation from the values of pixels at the image border. If the fill mode is *black*, luminance samples outside of the prior reference picture area are assigned a value of Y = 16 and chrominance samples are assigned a value of $C_B = C_R = 128$. If the fill mode is *gray*, luminance and chrominance values are assigned a value of $Y = C_B = C_R = 128$. If the fill mode is *color*, then additional fields are sent to specify a fill color, as described in the next subclause.

P.2.4 Fill Color Specification (Y_FILL, C_B_EPB, C_B_FILL, C_R_EPB, C_R_FILL) (26 bits)

If the fill mode is *color* and the picture is not an EP-picture, then the fill-mode bits are followed in the bitstream by three eight-bit integers, *Y_fill*, C_B_ *fill*, and C_R_ *fill*, which specify a fill color precisely. Between these three eight-bit integers are two emulation prevention bits (C_B_EPB and C_R_EPB) each of which is equal to 1. The format of this color specification, which is present only when the fill mode is *color*, is shown in Figure P.2. Each eight-bit integer field is sent using its

natural representation. For an EP-picture, the fill-mode action (and fill color) is the same as that for the reference layer, and the fill color specification is not sent.

FILL_MODE	Y_FILL	C_B_EPB	C_B_FILL	C_R_EPB	C_R_FILL

Figure P.2/H.263 – Format of fill mode and fill color specification data

P.3 Resampling algorithm

The method described in this subclause shall be mathematically equal in result to that used to generate the samples of the resampled reference picture. Using the integer warping parameters $w_x^0, w_y^0, w_x^x, w_y^x, w_x^y, w_y^y, w_x^{xy}$, and w_y^{xy} integer parameters u_x^{00}, u_y^{00}, u_x^{H0}, u_y^{H0}, u_x^{0V}, u_y^{0V}, u_x^{HV}, and u_y^{HV} which denote the *x*- and *y*-displacements at the corners of the luminance field in $\frac{1}{32}$-pixel accuracy (the actual displacements are obtained by dividing these values by 32) are defined as:

$$u_x^{00} = 16 w_x^0 \qquad u_y^{00} = 16 w_y^0$$

$$u_x^{H0} = 16\left(w_x^0 + w_x^x + 2\left(H_R - H\right)\right) \qquad u_y^{H0} = 16\left(w_y^0 + w_y^x\right)$$

$$u_x^{0V} = 16\left(w_x^0 + w_x^y\right) \qquad u_y^{0V} = 16\left(w_y^0 + w_y^y + 2\left(V_R - V\right)\right)$$

$$u_x^{HV} = 16\left(w_x^0 + w_x^x + w_x^y + w_x^{xy} + 2\left(H_R - H\right)\right) \qquad u_y^{HV} = 16\left(w_y^0 + w_y^x + w_y^y + w_y^{xy} + 2\left(V_R - V\right)\right)$$

Next, *H´* and *V´*, which denote the horizontal and vertical size of the *virtual frame*, are defined as the smallest integers that satisfy the following condition:

$$H' \geq H,\ V' \geq V,\ H' = 2^m,\ V' = 2^n,\ m \text{ and } n \text{ are positive integers}$$

By applying bilinear extrapolation to the corner vectors of the luminance field, the integer parameters u_x^{LT}, u_y^{LT}, u_x^{RT}, u_y^{RT}, u_x^{LB}, u_y^{LB}, u_x^{RB}, and u_y^{RB} which denote the *x*- and *y*-displacements of the luminance field at the *virtual points* (*x*, *y*) = (0, 0), (*H´*, 0), (0, *V´*), and (*H´*, *V´*) in $\frac{1}{32}$-pixel accuracy (the actual displacements are obtained by dividing these values by 32) are defined as:

$$u_x^{LT} = u_x^{00} \qquad u_y^{LT} = u_y^{00}$$

$$u_x^{RT} = \left((H - H')u_x^{00} + H' u_x^{H0}\right) // H \qquad u_y^{RT} = \left((H - H')u_y^{00} + H' u_y^{H0}\right) // H$$

$$u_x^{LB} = \left((V - V')u_x^{00} + V' u_x^{0V}\right) // V \qquad u_y^{LB} = \left((V - V')u_y^{00} + V' u_y^{0V}\right) // V$$

$$u_x^{RB} = \left((V - V')\left((H - H')u_x^{00} + H' u_x^{H0}\right) + V'\left((H - H')u_x^{0V} + H' u_x^{HV}\right)\right) // (HV)$$

$$u_y^{RB} = \left((V - V')\left((H - H')u_y^{00} + H' u_y^{H0}\right) + V'\left((H - H')u_y^{0V} + H' u_y^{HV}\right)\right) // (HV)$$

where "//" denotes integer division that rounds the quotient to the nearest integer, and rounds half integer values away from 0.

In the remainder of this annex, it is assumed that the centers of the pixels lie at the points $(x, y) = \left(i + \frac{1}{2}, j + \frac{1}{2}\right)$ for both the luminance and chrominance fields. Integer parameters *i*, *j* are defined as:

- $i = 0, \ldots, H - 1$ and $j = 0, \ldots, V - 1$ for luminance, and
- $i = 0, \ldots, \frac{H}{2} - 1$ and $j = 0, \ldots, \frac{V}{2} - 1$ for chrominance.

This implies that different coordinate systems are used for luminance and chrominance as shown in Figure P.3. Using the coordinate system for chrominance, the integer parameters u_x^{LT}, u_y^{LT}, u_x^{RT}, u_y^{RT}, u_x^{LB}, u_y^{LB}, u_x^{RB}, and u_y^{RB} defined above can also be regarded as the *x*- and *y*-displacements of the chrominance field at virtual points (*x*, *y*) = (0, 0), (*H*´/2, 0), (0, *V*´/2), and (*H*´/2, *V*´/2) in $\frac{1}{64}$-pixel accuracy (the actual displacements are obtained by dividing these values by 64). Using these parameters and an additional parameter *S*, which is defined as 2 for luminance and as 1 for chrominance, the resampling algorithm for the luminance and chrominance fields are defined using common equations.

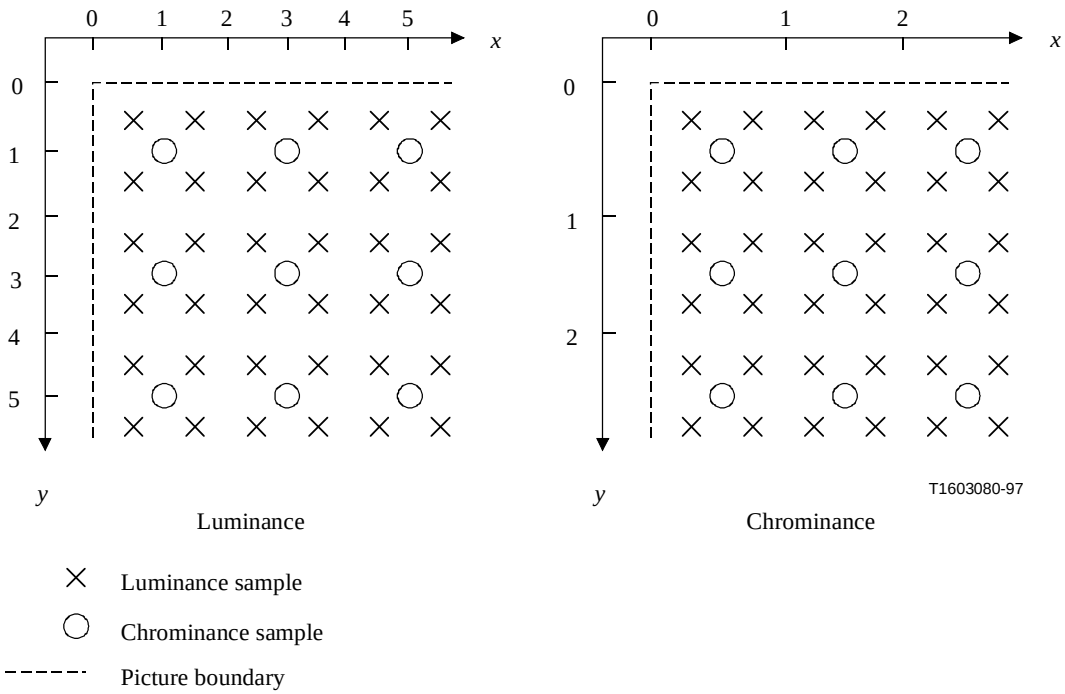


Figure P.3/H.263 – Coordinate systems for luminance and chrominance fields

The integer parameters $u_x^L(j)$, $u_y^L(j)$, $u_x^R(j)$, and $u_y^R(j)$ which denote the *x*- and *y*-displacements of the picture field at (*x*, *y*) = (0, $j + \frac{1}{2}$) and (*SH*´/2, $j + \frac{1}{2}$) in $\frac{s}{64}$-pixel accuracy (the actual displacements are obtained by dividing these values by 64/*S*) are defined using one dimensional linear interpolation as:

$$u_x^L(j)=\left((SV'-2j-1)u_x^{LT}+(2j+1)u_x^{LB}\right)//(SV') \quad u_y^L(j)=\left((SV'-2j-1)u_y^{LT}+(2j+1)u_y^{LB}\right)//(SV')$$

$$u_x^R(j)=\left((SV'-2j-1)u_x^{RT}+(2j+1)u_x^{RB}\right)//(SV') \quad u_y^R(j)=\left((SV'-2j-1)u_y^{RT}+(2j+1)u_y^{RB}\right)//(SV')$$

where "//" denotes integer division that rounds the quotient to the nearest integer, and rounds half integer values away from 0.

Finally, the parameters that specify the transformed position in the reference picture become:

$$I_R(i,j)=Pi+\left((SH'-2i-1)u_x^L(j)+(2i+1)u_x^R(j)+32H'/P\right)///(64H'/P)$$

$$J_R(i,j)=Pj+\left((SH'-2i-1)u_y^L(j)+(2i+1)u_y^R(j)+32H'/P\right)///(64H'/P)$$

$$i_R(i,j)=I_R(i,j)///P \qquad j_R(i,j)=J_R(i,j)///P$$

$$\varnothing_x=I_R(i,j)-\left(I_R(i,j)///P\right)P \qquad \varnothing_y=J_R(i,j)-\left(J_R(i,j)///P\right)P$$

where

"///" integer division with truncation towards the negative infinity;

"/" integer division (in this case resulting in no loss of accuracy);

P accuracy of *x*- and *y*-displacements (*P* = 2 when WDA = "10" and *P* = 16 when WDA = "11" or is absent, see P.2.1 for the definition of WDA);

$\left(\frac{I_R(i,j)}{P}+\frac{1}{2},\frac{J_R(i,j)}{P}+\frac{1}{2}\right)$ (*x*, *y*) location of the transformed position (both $I_R(i,j)$ and $J_R(i,j)$ are integers);

$\left(i_R(i,j)+\frac{1}{2},j_R(i,j)+\frac{1}{2}\right)$ (*x*, *y*) location of the sampling point near the transformed position (both $i_R(i,j)$ and $j_R(i,j)$ are integers);

$(\varnothing_x,\varnothing_y)$ bilinear interpolation coefficients of the transformed position (both $\varnothing_x$ and $\varnothing_y$ are integers).

The computation of this equation can be simplified by replacing the divisions by shift operations, since $64H'/P = 2^{m+2}$ when $P = 16$ and $64H'/P = 2^{m+5}$ when $P = 2$.

Using these parameters, the sample value, $E_P(i, j)$, of the pixel located at $(x,y)=\left(i+\frac{1}{2},j+\frac{1}{2}\right)$ in the resampled picture is obtained using bilinear interpolation by:

$$E_P(i,j)=\Big((P-\varnothing_y)\big((P-\varnothing_x)E_R(i_R,j_R)+\varnothing_x E_R(i_R+1,j_R)\big)$$

$$+\varnothing_y\big((P-\varnothing_x)E_R(i_R,j_R+1)+\varnothing_x E_R(i_R+1,j_R+1)\big)+P^2/2-1+RCRPR\Big)/P^2$$

where "/" denotes division by truncation. i_R and j_R are simplified notations for $i_R(i,j)$ and $j_R(i,j)$, and $E_R(i_R,j_R)$ denotes the sample value of the pixel located at $(x,y)=\left(i_R+\frac{1}{2},j_R+\frac{1}{2}\right)$ in the reference picture after extrapolation using the proper fill mode if necessary. The value of parameter RCRPR is defined as follows:

- For a B-picture (or the B-part of an Improved PB-frame) which has a P-picture as its temporally subsequent anchor picture, RCRPR is equal to the rounding type (RTYPE) bit in

MPPTYPE (see 5.1.4.3) of this temporally subsequent P-picture. This implies that for Improved PB-frames, RCRPR has the same value for the P-part and the B-part.

- For other types of pictures, RCRPR is equal to the RTYPE bit of the current picture.

P.4 Example of implementation

In this subclause, an implementation example of the algorithm described in the previous subclause is provided as pseudo-code.

P.4.1 Displacements of virtual points

When a large picture is coded, a straightforward implementation of the equation for obtaining parameters u_x^{RB} and u_y^{RB} shown in P.3 may necessitate the usage of variables requiring more that 32 bits for their binary representation. For systems which cannot easily use 64-bit integer or floating point registers, an example of an algorithm which does not require variables with more than 32 bits for the calculation of u_x^{RB} and u_y^{RB} is shown below.

Since H, V, H', and V' are divisible by 4, the definition of u_x^{RB} can be rewritten as:

$$u_x^{RB} = \left((V_Q - V_Q')\left((H_Q - H_Q')u_x^{00} + H_Q' u_x^{H0}\right) + V_Q'\left((H_Q - H_Q')u_x^{0V} + H_Q' u_x^{HV}\right)\right) // A$$

where $H_Q = H/4$, $V_Q = V/4$, $H_Q' = H'/4$, $V_Q' = V'/4$, $A = H_Q V_Q$, and "//" denotes integer division that rounds the quotient to the nearest integer, and rounds half integer values away from 0. Next, parameters T_T and T_B are defined as:

$$T_T = (H_Q - H_Q')u_x^{00} + H_Q' u_x^{H0}$$
$$T_B = (H_Q - H_Q')u_x^{0V} + H_Q' u_x^{HV}$$

for simplicity of description. Using operator "///" which denotes integer division with truncation towards the negative infinity, and operator "%" which is defined as $a \% b = a - (a /// b)\, b$, the value of u_x^{RB} can be obtained via the following pseudo-code:

```
q = (VQ - VQ´)*(TT /// A)+ VQ´*(TB /// A) + ((VQ - VQ´)*(TT % A)+ VQ´
    *(TB % A)) /// A;
r = ((VQ - VQ´)*(TT % A)+ VQ´ *(TB % A)) % A;
if (q < 0)
  uxRB = q+(r+(A-1)/2)/A;
else
  uxRB = q+(r+A/2)/A;
```

The value of u_y^{RB} can also be calculated using this algorithm.

P.4.2 Resampling algorithm

To simplify the description of the algorithm, a function `prior_sample` is defined. Its purpose is to generate a pixel value for any integer location (i_p, j_p) relative to the prior reference picture sampling grid:

```
clip(xmin, x, xmax) {
  if (x < xmin) {
    return xmin;
  } else if (x > xmax) {
    return xmax;
```

```
        } else {
          return x;
        }
      }
prior_sample (ip, jp) {
    if (FILL_MODE = clip) {
      ic = clip (0, ip, S*HR /2-1);
      jc = clip (0, jp, S*VR /2-1);
      return prior_ref[ic, jc];
    } else {
      if ((ip < 0) OR (ip > S*HR /2-1) or (jp < 0) OR (jp > S*VR /2-1) {
        return fill_value;
      } else {
        return prior_ref[ip,jp];
      }
    }
}
```

In the pseudo-code, `prior_ref[`i, j`]` indicates the sample in column i and row j in the temporally previous reference picture.

Next, a filter function that implements the bilinear interpolation described in P.3 is defined. It is assumed that all arguments of the following function are integers and that the bilinear interpolation coefficients, $Ø_x$ and $Ø_y$, are quantized in the range 0, …, P–1 (inclusive).

$$\texttt{filter}(x_0, y_0, \varnothing_x, \varnothing_y)\ \{$$

$$\texttt{return}\ [(P-\varnothing_y)\cdot((P-\varnothing_x)\cdot \texttt{prior\_sample}(x_0, y_0)+\varnothing_x\cdot \texttt{prior\_sample}(x_0+1, y_0))+$$

$$\varnothing_y\cdot((P-\varnothing_x)\cdot \texttt{prior\_sample}(x_0, y_0+1)+\varnothing_x\cdot \texttt{prior\_sample}(x_0+1, y_0+1))+$$

$$P^2/2-1+RCRPR]/P^2;$$

$$\}$$

Finally, the method for warping the reference picture to generate a prediction for the current picture can be specified in terms of these functions. The pixels of the prediction picture can be generated in a raster scan order. It is assumed that the values $u_x^L(j)$, $u_y^L(j)$, $u_x^R(j)$, and $u_y^R(j)$ are already calculated and loaded into variables u_x^L, u_y^L, u_x^R, and u_y^R. Defining parameter D as $D = 64H'/P$ and noting that $H' = 2^m$, the sample values of the pixels in the j th line of the resampled field (the topmost line is defined as the 0th line) is obtained by the following pseudo-code:

a_x^i = D * P + 2 * $(u_x^R - u_x^L)$;

a_y^i = 2 * $(u_y^R - u_y^L)$;

a_x = u_x^L * S * 2^m + $(u_x^R - u_x^L)$; + D / 2;

a_y = j * D * P + u_y^L * S * 2^m + $(u_y^R - u_y^L)$; + D / 2;

for (i = 0; i < S * H / 2; i++) {

  I_R = a_x /// D;

  J_R = a_y /// D;

  i_R = I_R /// P;

```
        jR = JR /// P;
        Øx = IR – (iR * P);
        Øy = JR – (jR * P);
        new_ref[i, j] = filter(iR, jR, Øx, Øy);
        ax += axi;
        ay += ayi;
}
```

where all the variables used in this code are integer variables and `new_ref[i, j]` indicates the sample generated for column *i* and row *j* in the resampled reference picture. According to the definition of the parameters, all the divisions in this code can be replaced by binary shift operations. For example, when *P* = 16:

```
        IR = ax /// D;
        JR = ay /// D;
        iR = IR /// P;
        jR = JR /// P;
        Øx = IR – (iR * P);
        Øy = JR – (jR * P);
```

can be rewritten, assuming that a_x, a_y, I_R, and J_R are binary-coded integer variables in two's complement representation, as:

```
        IR = ax >> (m+2);
        JR = ay >> (m+2);
        iR = IR >> 4;
        jR = JR >> 4;
        Øx = IR & 15;
        Øy = JR & 15;
```

where ">> N_{shift}" denotes a right arithmetic binary shift by N_{shift} bits (N_{shift} is a positive integer), and "&" denotes a bit-wise AND operation.

P.5 Factor-of-4 resampling

Factor-of-4 resampling, which converts both the horizontal and vertical size of the picture by a factor of 2 or $\frac{1}{2}$, is a special case of the resampling algorithm described in P.3. The simplified description of the resampling algorithm for this special case is provided in this subclause.

The value of the parameter RCRPR used in Figures P.4 to P.6 is determined by the Rounding Type (RTYPE) bit in MPPTYPE (see 5.1.4.3) as described in P.3. Additionally, "/" in the figures indicates division by truncation.

P.5.1 Factor-of-4 upsampling

The pixel value interpolation method used in factor-of-4 upsampling for internal pixels are shown in Figure P.4. By assuming the existence of pixels outside the picture according to the selected fill mode (see P.2.3 and P.2.4), the same interpolation method is applied for boundary pixels. The interpolation method for boundary pixels when *clip* is selected as the fill mode is shown in Figure P.5. Since precise factor-of-4 upsampling requires x- and y-displacements with at least

$\frac{1}{4}$-pixel accuracy, the Warping Displacement Accuracy (WDA) field specified in P.2.1 must be set to "11" or the resampling must be implicitly invoked in order to use this upsampling method.

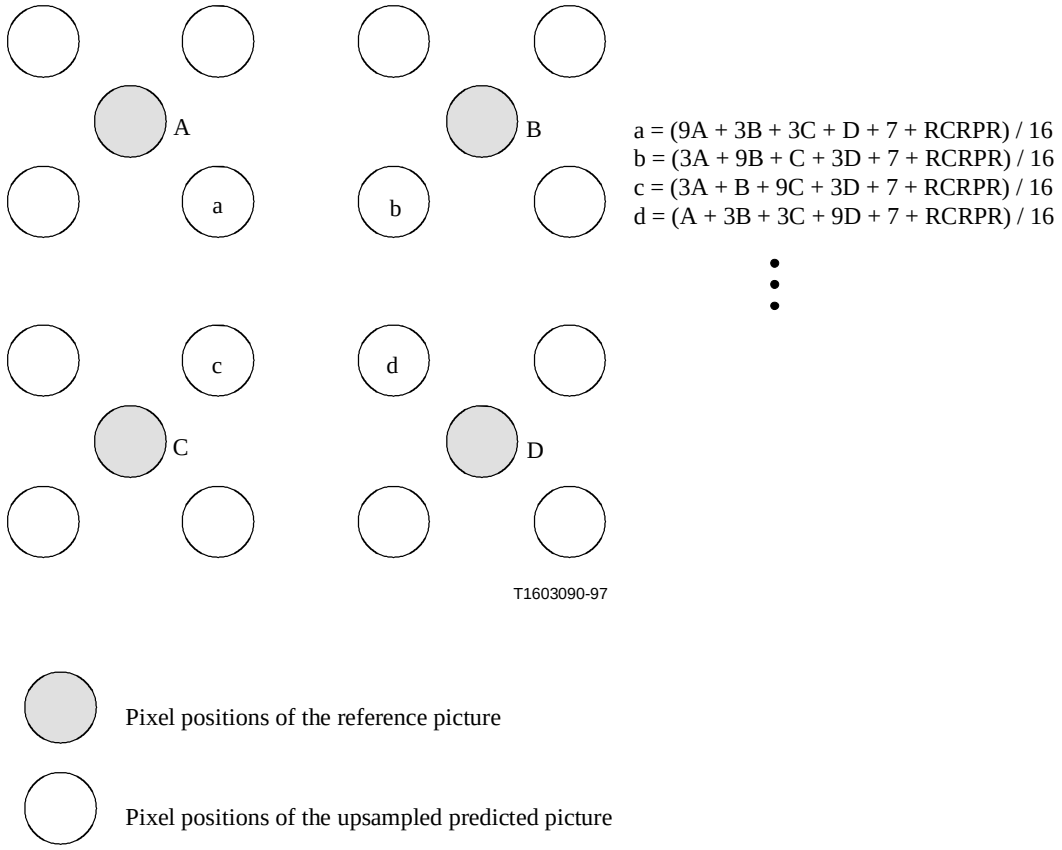


Figure P.4/H.263 – Factor-of-4 upsampling for pixels inside the picture

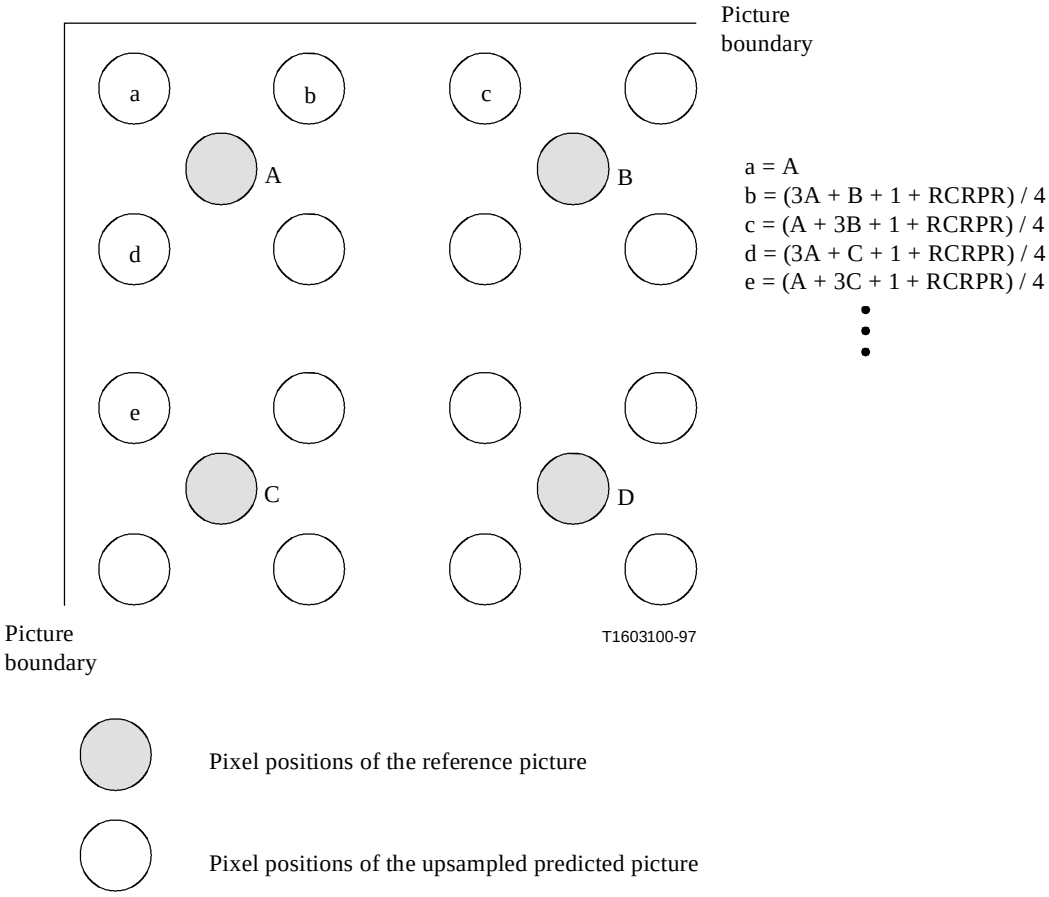


Figure P.5/H.263 – Factor-of-4 upsampling for pixels at the picture boundary (fill mode = *clip*)

P.5.2 Factor-of-4 downsampling

The pixel value interpolation method for factor-of-4 downsampling is shown in Figure P.6. Since x- and y-displacements with $\frac{1}{2}$-pixel accuracy is sufficient for precise factor-of-4 downsampling, both "10" and "11" are allowed as the value of the displacement accuracy (WDA) field (if present) specified in P.2.1.

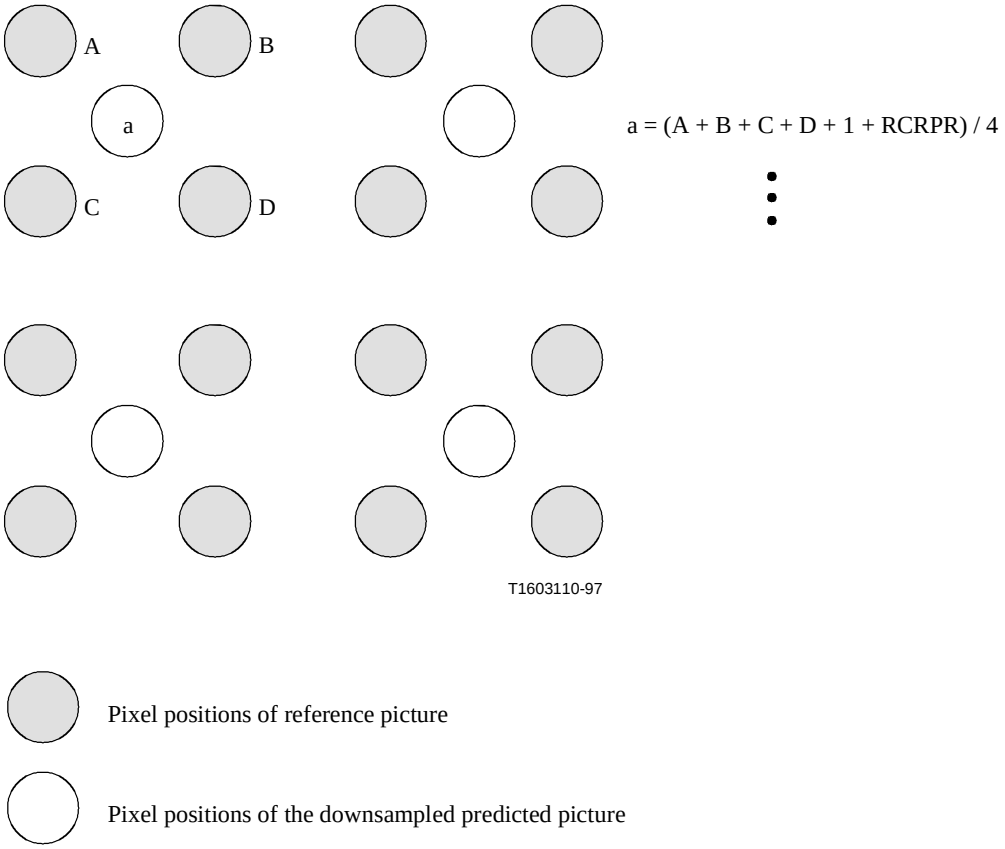


Figure P.6/H.263 – Factor-of-4 downsampling

ANNEX Q

Reduced-Resolution Update mode

Q.1 Introduction

This annex describes an optional Reduced-Resolution Update mode of this Recommendation. The capability of this mode is signaled by external means (for example, Recommendation H.245). The use of this mode is indicated in the PLUSPTYPE field of the picture header.

The Reduced-Resolution Update mode is expected to be used when encoding a highly active scene, and provides the opportunity to increase the coding picture rate while maintaining sufficient subjective quality. This mode allows the encoder to send update information for a picture that is encoded at a reduced resolution, while preserving the detail in a higher resolution reference image to create a final image at the higher resolution.

The syntax of the bitstream in this mode is identical to the syntax for coding without the mode, but the semantics, or interpretation of the bitstream is somewhat different. In this mode, the portion of the picture covered by a macroblock is twice as wide and twice as high. Thus, there is approximately one-quarter the number of macroblocks as there would be without this mode. Motion vector data also refers to blocks of twice the normal height and width, or 32 × 32 and 16 × 16 instead of the normal 16 × 16 and 8 × 8. On the other hand, the DCT or texture data should be thought of as describing 8 × 8 blocks on a reduced-resolution version of the picture. To produce the final picture, the texture data is decoded at a reduced resolution and then up-sampled to the full resolution of the picture.

After upsampling, the full resolution texture image is added to the (already full resolution) motion compensated image to create the image for display and further reference.

In this mode, a picture which has the horizontal size H and vertical size V as indicated in the picture header is created as a final image for display.

In this mode, a referenced picture used for prediction and created for further decoding has a horizontal size H_R and a vertical size V_R which are the same as in the default mode as defined in 4.1. That is, the H_R and V_R are:

$$H_R = ((H + 15) / 16) * 16$$

$$V_R = ((V + 15) / 16) * 16$$

where H and V are the horizontal size and the vertical size as indicated in the picture header and "/" is defined as division by truncation.

Then in this annex, the texture is coded at a reduced resolution with height and width of H_C and V_C where:

$$H_C = ((H_R + 31) / 32) * 32$$

$$V_C = ((V_R + 31) / 32) * 32$$

and "/" is defined as division by truncation.

If H_C and H_R, or V_C and V_R are not identical to each other, such as in the QCIF format, an extension of the referenced picture is performed , and the picture is decoded in the same manner as if the width and height are H_C and V_C. Then the resulting picture which is tiled by 32 * 32 macroblocks is cropped at the right and the bottom to the width H_R and height V_R, and this cropped picture is stored as a reference picture for further decoding.

If both H and V are the same as those of a resulting picture having the width H_C and the height V_C, this resulting picture is used for display. Otherwise, this resulting picture is further cropped to the size H * V, and the cropped picture here is used for display purpose only.

If the Temporal, SNR, and Spatial Scalability mode (Annex O) or Reference Picture Resampling mode (Annex P) is also used with this option, the source format of the current picture might be different from that of the reference picture. In this case, the resampling of the reference picture shall be performed before decoding.

NOTE – This mode can be used with the Reference Picture Selection mode (see Annex N) without modification, since the reference picture (after possible resampling by the Reference Picture Resampling mode) has the same size as indicated in the current picture header when this option is used.

Q.2 Decoding procedure

Figure Q.1 shows the block diagram of the block decoding in the Reduced-Resolution Update mode.

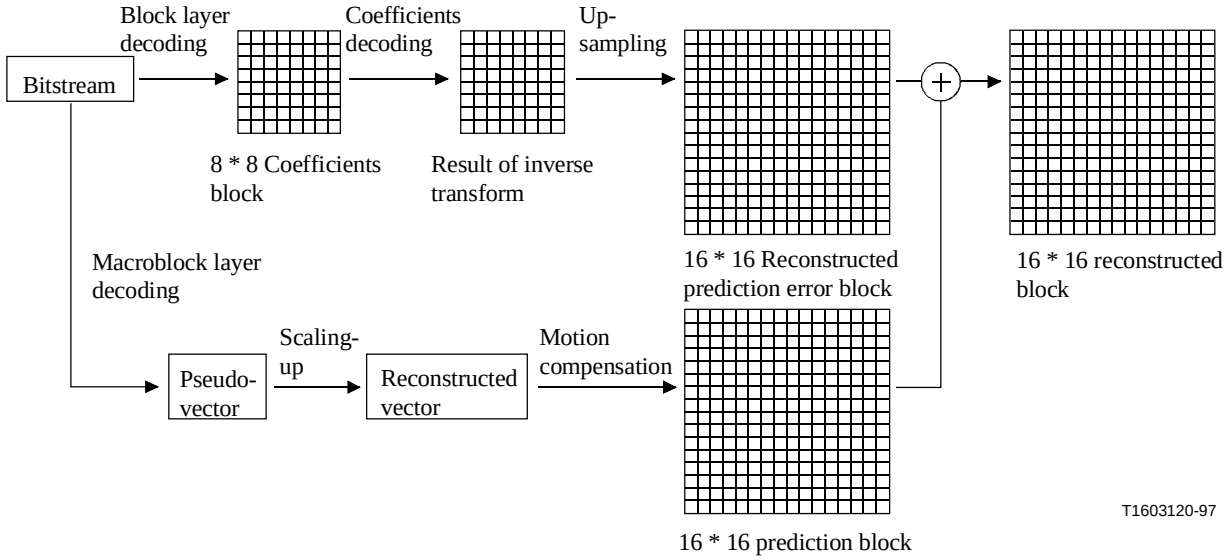


Figure Q.1/H.263 – Block diagram of block decoding in Reduced-Resolution Update mode

The decoding procedure is given in the following subclauses:

Q.2.1 Reference preparation

In some cases, the available reference picture has different size from H_C and V_C. Then, the reference picture shall be converted before decoding procedure according to Q.2.1.1 or Q.2.1.2.

Q.2.1.1 Reference Picture Resampling

If the Temporal, SNR, and Spatial Scalability mode (Annex O) or Reference Picture Resampling mode (Annex P) is also used with this option, the source format of the current picture might be different from that of the reference picture. In this case, the resampling of the reference picture according to each annex shall be performed first.

Q.2.1.2 Extension of Reference Picture

If H_R or V_R is not divisible by 32, such as with the QCIF format, the reference picture is extended. The detailed procedure for this extension is defined in Q.3.

Q.2.2 Macroblock layer decoding

Decoding can be thought of as operating on "enlarged" blocks of size 32 × 32 in luminance and 16 × 16 in chrominance. The texture and motion data for each enlarged block is decoded to create a 32 × 32 motion block and a 32 × 32 texture block, as described in Q.2.2.1 and Q.2.2.2 respectively. These motion and texture blocks are then added as described in Q.2.2.3.

Q.2.2.1 Motion compensation

First, each component of the macroblock motion vector (or four macroblock motion vectors) is formed from MVD (and possibly $MVD_{2\text{-}4}$). If in Improved PB-Frames mode, MV_F and MV_B for B-Picture is also formed from MVDB. The detailed procedure for this motion vector formation is defined in Q.4. If the current picture mode is a B-picture or EP-picture, the motion vector for forward and backward are also obtained according to Q.4.

The motion vector for the two chrominance blocks of the macroblock is obtained from the macroblock motion vector according to 6.1.1. If either the Advanced Prediction mode or the Deblocking Filter mode is in use and thus four motion vectors are defined for the macroblock, the motion vector for both chrominance blocks is obtained from the four motion vectors according to F.2. If in the Improved PB-frames mode, the creation of the chrominance vector is specified in Annex M. If a B-picture or EP-picture is used, the creation of the chrominance vector is specified in Annex O.

Then, a prediction is formed from the motion vector for an INTER macroblock. Four 16 × 16 luminance prediction blocks are obtained from the macroblock motion vector, and two 16 × 16 chrominance prediction blocks are obtained from the chrominance motion vector. For interpolation for subpixel prediction, refer to 6.1.2. If Advanced Prediction mode is also used, an enlarged overlapped motion compensation is performed to obtain four 16 × 16 luminance prediction blocks using enlarged weighting matrices, for which a detailed procedure is defined in Q.5. If the current picture mode is an Improved PB-frame, B-picture, or EP-picture, the prediction is obtained according to the other relevant annexes, except that the size of the predicted blocks is 16 × 16 instead of 8 × 8.

Q.2.2.2 Texture decoding

First, the bitstream of the block layer is decoded according to 5.4. Then, coefficients are decoded and the 8 × 8 reduced-resolution reconstructed prediction error blocks are obtained as the result of inverse transform according to 6.2.

Then the 16 × 16 reconstructed prediction error blocks are obtained by upsampling the 8 × 8 reduced-resolution reconstructed prediction error blocks. For the creation of the edge pixels in each 16 × 16 reconstructed prediction error block, only the pixels which belong to the corresponding block are used. The detailed procedure is defined in Q.6.

Q.2.2.3 Reconstruction of block

For each luminance and chrominance block, a summation of the prediction and prediction error is performed. The procedure is identical to 6.3.1, except that the size of blocks is 16 × 16 instead of 8 × 8. Then the clipping is performed according to the 6.3.2.

Then, a block boundary filter is applied to the boundary pixels of the 16 × 16 reconstructed blocks. The detailed procedure is described in Q.7.

Q.2.3 Picture store

If both H_R and V_R are divisible by 32, such as with the CIF format, the resulting picture reconstructed as described in Q.2.2 is stored as a reference picture as it is for further decoding. Otherwise, such as the QCIF format, the reconstructed picture which is just covered with 32 × 32 macroblocks is cropped at the right and the bottom to the width H_R and height V_R, and this cropped picture is stored as a reference picture for further decoding.

Q.2.4 Display

If both H and V are the same as H_C and V_C, the resulting picture in Q.2.2 is used for display purposes as it is. Otherwise, this resulting picture is further cropped to the size $H \times V$, and the cropped picture is used for display purpose only.

Q.3 Extension of referenced picture

If H_R or V_R is not divisible by 32, such as with the QCIF format, the extension of the referenced picture is performed before decoding macroblock/block layer. The width and the height of the extended reference picture for luminance are the next larger size that would be divisible by 32, and those for chrominance are the next larger size that would be divisible by 16.

NOTE – The width and height of the referenced picture in the default mode are always extended to be divisible by 16 even if the picture format has a width or height that is not divisible by 16, because the picture shall be decoded as if the width or height had the next larger size that would be divisible by 16. See 4.1.

If neither Unrestricted Motion Vector mode, Advanced Prediction mode nor Deblocking Filter mode is used with this option, the extended pixels can be arbitrary values, because the extended pixels will be never used as a reference pixels of the decoded picture to be reconstructed and displayed.

If either Unrestricted Motion Vector mode, Advanced Prediction mode or Deblocking Filter mode is also used with this option, the extension of the referenced picture is performed by duplicating the edge pixel of the referenced picture, in order to ensure the decoding when motion vectors point outside the right and bottom edge of the picture.

For example, if the Reduced-Resolution Update mode is used for a QCIF, the width of the referenced picture is 176 and the height is 144, which are not divisible by 32. In order to cover a QCIF picture with 32 × 32-sized macroblocks, the number of macroblock row should be 6, and the number of macroblock column should be 5. Therefore, the width of the extended referenced picture is 192 and the height is 160.

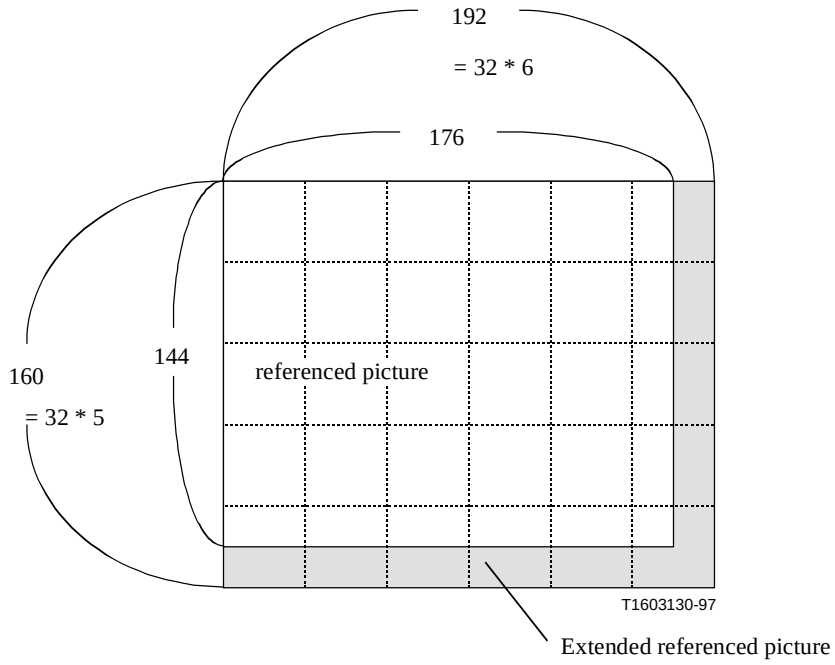


Figure Q.2/H.263 – Extension of referenced picture for QCIF picture size

The extension of the referenced picture in QCIF is illustrated in Figure Q.2. The extended referenced picture for luminance is given by the following formula:

$$R_{RRU}(x, y) = R(x', y')$$

where:

x, y	=	spatial coordinates of the extended referenced picture in the pixel domain,
x’, y	=	spatial coordinates of the referenced picture in the pixel domain,
$R_{RRU}(x, y)$	=	pixel value of the extended referenced picture at (x, y),
R(x´, y´)	=	pixel value of the referenced picture at (x´, y´),

$$x' = \begin{cases} 175 & \text{if } x > 175 \text{ and } x < 192 \\ x & \text{otherwise,} \end{cases}$$

$$y' = \begin{cases} 143 & \text{if } y > 143 \text{ and } y < 160 \\ y & \text{otherwise.} \end{cases}$$

The referenced pictures for chrominance is also extended in the same manner.

Q.4 Reconstruction of motion vectors

In Reduced-Resolution Update mode, the motion vector range is enlarged to approximately double size in both the horizontal and vertical directions. In order to realize an enlarged range using the VLC for MVD defined in Table 14, each vector component is restricted to be only half-pel or zero value. Therefore the range of each motion vector component is [–31.5, 30.5] in the default Reduced-Resolution Update mode. If the Unrestricted Motion Vector mode is used, the vector range [–limit, limit] as defined in D.2 applies to the pseudo-motion vectors and translates into [–(2 * limit–0.5), 2 * limit–1.5] for the motion vectors. For CIF this means that the pseudo-motion vector range is [–32, 31.5] and the motion vector range is [–63.5, 62.5]. If the UUI field is set to "01", the motion vectors are unlimited. However, the motion vectors (not just the pseudo-motion vectors) are always limited to point not more than 15 pixels outside the coded area as described in D.1.1. Figure Q.3 illustrates the possible positions of macroblock motion vector or four motion vector predictions around the (0, 0) vector value. The dashed lines indicate the integer coordinates.

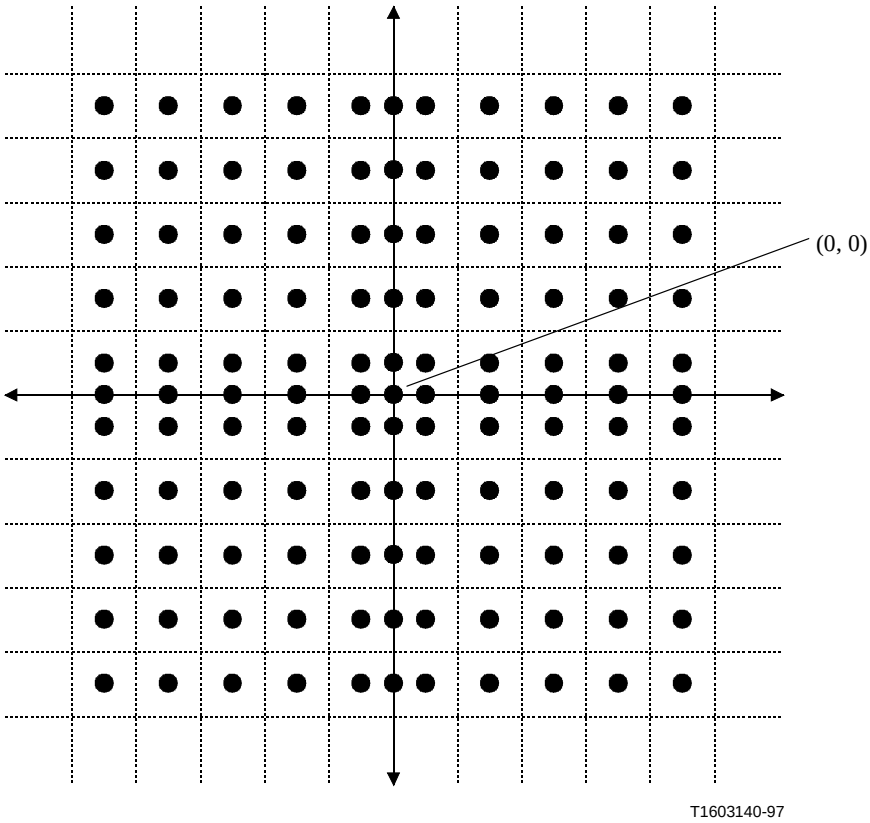


Figure Q.3/H.263 – Reconstruction of motion vector

For the macroblock using differential motion vectors in a B-picture, the motion vector for forward and backward prediction are obtained independently. In the Reduced-Resolution Update mode, the motion vector component MV_c for a luminance block is reconstructed from MVD and $MVD_{2\text{-}4}$ as follows:

1) Pseudo-prediction vector component **pseudo-P_C** is created from the prediction vector component **P_C**.

   pseudo-P_C = 0 if $P_C = 0$

   pseudo-P_C = sign(P_C) * (|P_C| + 0.5) / 2.0 if $P_C \neq 0$

   "/" indicates floating-point division (without loss of accuracy). The prediction vector component P_C is defined as the median value of the vector components MV1, MV2 and MV3 as defined in 6.1.1 and F.2.

2) Pseudo-macroblock vector component **pseudo-MV_C** is obtained by adding the motion vector differences MVD (and $MVD_{2\text{-}4}$) from Table 14 to the pseudo-P_C.

   In the default Reduced-Resolution Update mode, the value of **pseudo-MV_C** is restricted to the range [–16, 15.5]. Only one of the pair will yield a pseudo-MV_C falling within the permitted range. The procedure is performed in the similar way as defined in 6.1.1.

   If the Unrestricted Motion Vector mode is also used with the Reduced-Resolution Update mode, **pseudo-MV_C** is obtained by adding the motion vector differences MVD (and $MVD_{2\text{-}4}$) from Table D.3.

   If four motion vectors are present, the procedure is performed in the similar way as defined in F.2.

3) Motion vector component $\mathbf{MV_C}$ is obtained from pseudo-MV_C in the following formula:

$MV_C = 0$ if pseudo-$MV_C = 0$

$MV_C = \text{sign}(\text{pseudo-}MV_C) * (2.0 * |\text{pseudo-}MV_C| - 0.5)$ if pseudo-$MV_C \neq 0$

As a result, each vector component is restricted to have a half-integer or zero value, and the range of each motion vector component is enlarged to approximately twice the pseudo-motion vector range.

4) If the current picture mode is an Improved PB-frame, or when the MBTYPE indicates the direct mode in a B-picture, the motion vector components $\mathbf{MV_F}$ and/or $\mathbf{MV_B}$ for forward and backward prediction are created.

First, pseudo-motion vector components **pseudo-**$\mathbf{MV_F}$ and/or **pseudo-**$\mathbf{MV_B}$ are calculated based on the rules for the prediction modes defined in Annexes O or M.

In the case of the Bidirectional prediction in the Improved PB-frames mode (see M.2.1) or when the MBTYPE indicates the direct mode in a B-picture (see O.5.2), pseudo-MV_F and pseudo-MV_B are calculated from **pseudo-**$\mathbf{MV_D}$ and **pseudo-**$\mathbf{MV_C}$ assuming that pseudo-MV_D is zero and pseudo-MV_C is MV, as defined in Annexes G and M.

In the case of forward prediction in the Improved PB-frames mode (see M.2.2), **pseudo-**$\mathbf{MV_{DB}}$ is obtained by decoding the variable length code MVDB according to Table 13. Then, pseudo-MV_F is obtained by adding the pseudo-MV_{DB} to the **pseudo-Predictor**. In order to form the pseudo-Predictor, the predictor obtained according to the procedure defined in M.2.2 is converted to the pseudo-Predictor vector according to the formula defined in item 1) of this subclause.

In the case of backward prediction in the Improved PB-frames mode (see M.2.3), pseudo-MV_B is set to zero.

Then, the motion vectors MV_F and/or MV_B for forward and backward prediction are obtained from pseudo-MV_F and/or pseudo-MV_B according to the formula defined in item 3) of this subclause.

Q.5 Enlarged overlapped motion compensation for luminance

If Advanced Prediction mode is also used with Reduced-Resolution Update mode, enlarged matrices of weighting values are used to perform the overlapped motion compensation. Except that the size of each block and weighting matrices is 16 × 16, the procedure of the creation of each prediction block is identical to the description in F.3.

The enlarged matrices of weighting values for the 16 × 16 luminance prediction are given in Figures Q.4, Q.5, and Q.6.

4	4	5	5	5	5	5	5	5	5	5	5	5	5	4	4
4	4	5	5	5	5	5	5	5	5	5	5	5	5	4	4
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	6	6	6	6	6	6	6	6	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
4	4	5	5	5	5	5	5	5	5	5	5	5	5	4	4
4	4	5	5	5	5	5	5	5	5	5	5	5	5	4	4

Figure Q.4/H.263 – Weighting values, H_0, for prediction with motion vector of current 16 × 16 luminance block

2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
1	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Figure Q.5/H.263 – Weighting values, H_1, for prediction with motion vector of current 16 × 16 luminance blocks on top or bottom of current 16 × 16 luminance block

2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2
2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2
2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2
2	2	1	1	1	1	1	1	1	1	1	1	1	1	2	2

Figure Q.6/H.263 – Weighting values, H_2, for prediction with motion vector of 16 × 16 luminance blocks to the left or right of current 16 × 16 luminance block

Q.6 Upsampling of the reduced-resolution reconstructed prediction error

The 16 × 16 reconstructed prediction error block is obtained by upsampling the 8 × 8 reduced-resolution reconstructed prediction error block. In order to realize a simple implementation, filtering is closed within a block which enables to perform an individual upsampling on block basis. Figure Q.7 shows the positioning of samples. The upsampling procedure for the luminance and chrominance pixels which are inside the 16 × 16 reconstructed prediction error blocks is defined in Q.6.1. For the creation of the luminance and chrominance pixels which are at the boundary of 16 × 16 reconstructed prediction error block, the procedure is defined in Q.6.2. Chrominance blocks as well as luminance blocks are up-sampled. The symbol "/" in Figures Q.8 and Q.9 indicates division by truncation.

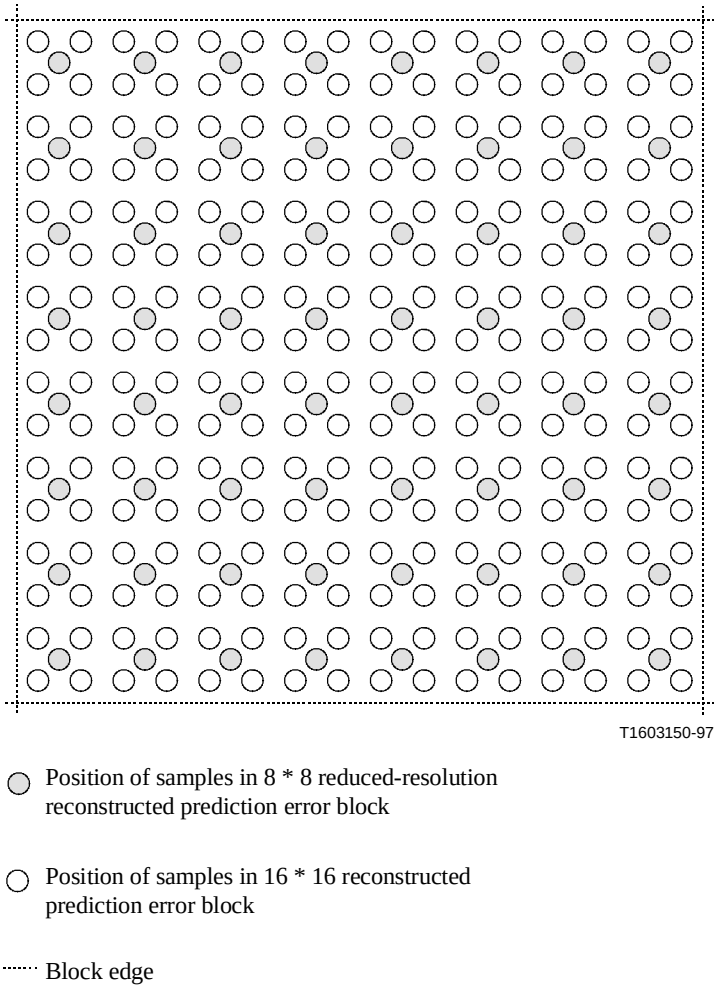


Figure Q.7/H.263 – Positioning of samples in 8 × 8 reduced-resolution reconstructed prediction error block and 16 × 16 reconstructed prediction error block

Q.6.1 Upsampling procedure for the pixels inside a 16 × 16 reconstructed prediction error block

The creation of reconstructed prediction error for pixels inside block is described in Figure Q.8. "/" indicates division by truncation.

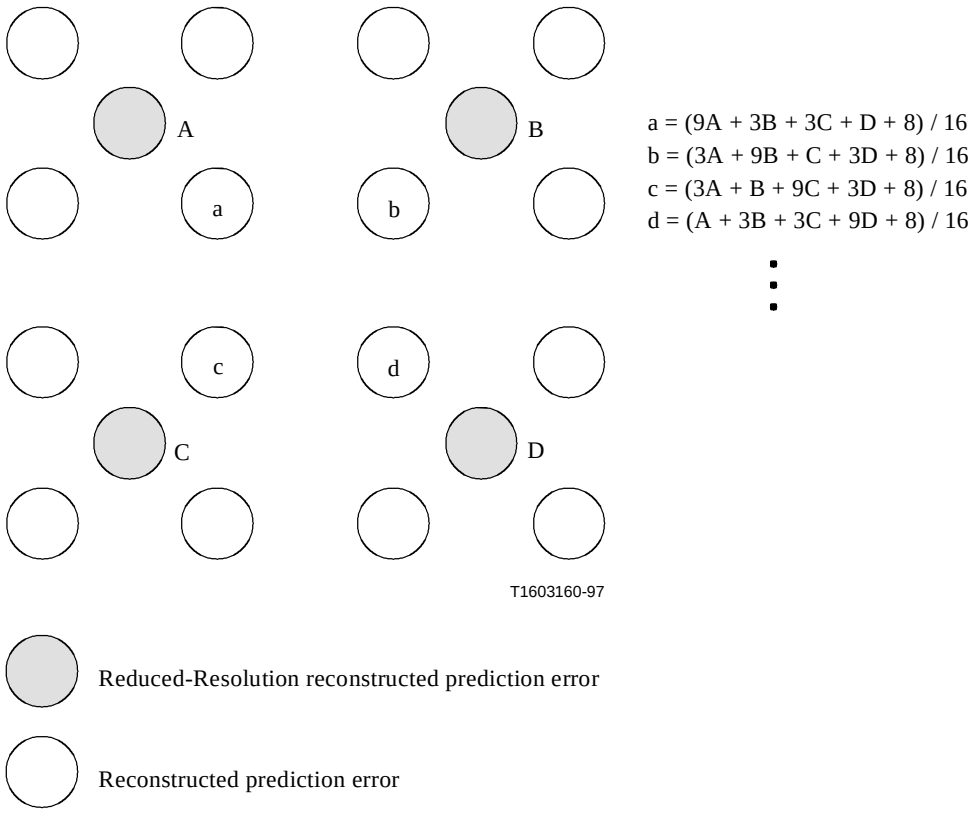


Figure Q.8/H.263 – Creation of reconstructed prediction error for pixels inside block

Q.6.2 Upsampling procdedure for the pixels at the boundary of 16 × 16 reconstructed prediction error block

The creation of reconstructed prediction error for pixels of a 16 × 16 block is shown in Figure Q.9.

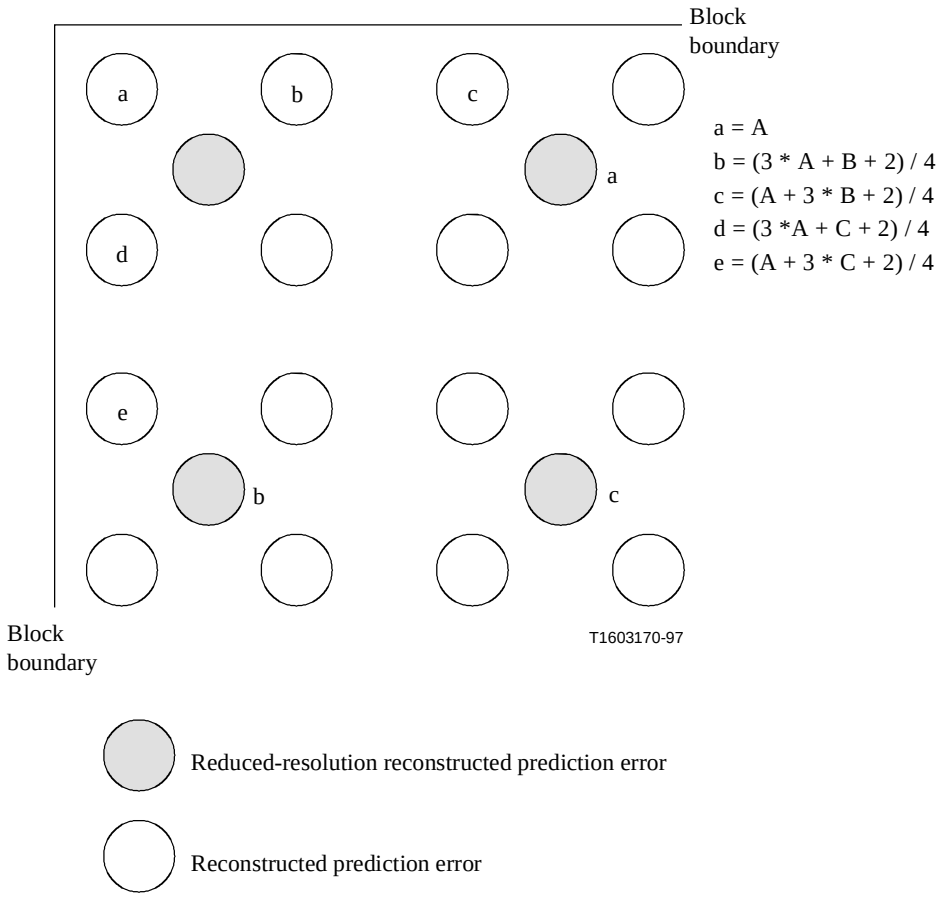


Figure Q.9/H.263 – Creation of reconstructed prediction error for pixels at the block boundary

Q.7 Block boundary filter

The filter operations are performed along the edges of the 16 × 16 reconstructed blocks at the encoder as well as on the decoder side. There are two alternative of filtering, depending on whether Deblocking Filter mode is used or not.

The default filtering in Reduced-Resolution Update mode is performed according to Q.7.1.

If Deblocking Filter mode is also used with Reduced-Resolution Update mode, the filtering is performed according to Q.7.2.

In both cases, filtering is performed on the complete reconstructed image data before storing the data in the picture store for future prediction. No filtering is performed across picture edges, slice edges in Slice Structured mode (see Annex K), or GOB boundaries having GOB headers present in Independent Segment Decoding mode (see Annex R). Chrominance as well as luminance data is filtered.

Q.7.1 Definition of the default block boundary filter

In the Reduced-Resolution Update mode, the default filtering is performed according to this subclause.

If A and B are two pixel values on a line – horizontal or vertical – of the reconstructed picture, and A belongs to one 16 × 16 block called block1 whereas B belongs to a neighboring 16 × 16 block called block2 which is to the right or below of block1. Figure Q.10 shows examples for the position of these pixels.

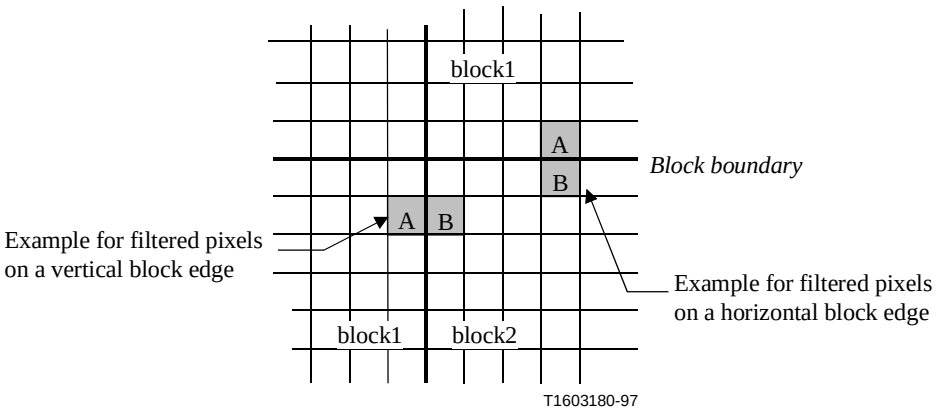


Figure Q.10/H.263 – Default block boundary filter

One of the following conditions must be fulfilled in order to turn the filter on for a particular edge:

- block1 belongs to a coded macroblock (COD==0 || MB-type == INTRA); **or**
- block2 belongs to a coded macroblock (COD==0 || MB-type == INTRA).

A shall be replaced by A1 and B shall be replaced by B1. "/" indicates division by truncation.

$$A1 = (3 * A + B + 2) / 4$$

$$B1 = (A + 3 * B + 2) / 4$$

The order of edges where filtering is performed is identical to the description provided in J.3.

Q.7.2 Definition of the block boundary filter when Deblocking Filter mode is used

If the Deblocking Filter mode (see Annex J) is used with the Reduced-Resolution Update mode, the filtering which is defined in Annex J with one modification is performed on the boundary pixels of 16×16 luminance and chrominance blocks, in place of the filtering described in Q.7.1. The one modification of the filtering in Annex J is that the parameter STRENGTH is given the value of positive infinity. This implies that the function UpDownRamp(x, STRENGTH) defined in J.3 becomes a linear function of x.

As a result, the procedure of the deblocking filter described in J.3 is redefined in the following manner:

B1 = clip(B + d1)

C1 = clip(C – d1)

A1 = A – d2

D1 = D + d2

d1 = (A–4B+4C–D) / 8

d2 = clipd1((A – D) / 4, d1/2)

ANNEX R

Independent Segment Decoding mode

R.1 Introduction

This annex describes the optional Independent Segment Decoding mode of this Recommendation, which allows a picture to be decoded without the presence of any data dependencies across slice boundaries or across GOB boundaries having non-empty GOB headers. The use of this mode is indicated in the PLUSPTYPE field of the picture header. The capability to use this optional mode is negotiated by external means (for example, Recommendation H.245).

When the use of this mode is indicated, the video picture segment boundaries (as defined by the boundaries of the slices or the upper boundaries of the GOBs for which GOB headers are sent, or the boundaries of the picture, whichever bounds a region in the smallest way) are treated as picture boundaries when decoding, including the treatment of motion vectors which cross those boundaries (which result in boundary extrapolation when the Unrestricted Motion Vector mode, the Advanced Prediction mode, the Deblocking Filter mode, or the Temporal, SNR, and Spatial Scalability mode are in use, and which are prohibited when none of those optional modes are in use).

R.2 Mode operation

A video picture segment is defined by the following.

If the Slice Structured mode (see Annex K) is not in use, then one GOB or a plural number of consecutive GOBs forms one video picture segment. The location of the top of each video picture segment is indicated by the presence of a non-empty GOB header for which the border of the video picture segment lies just above the macroblocks in the GOB for which a header is present, or the top of the picture, whichever is lower. The location of the bottom of each video picture segment is defined by the top of the next video picture segment, or the bottom of the picture, whichever is uppermost.

If the Slice Structured mode (see Annex K) is in use, then each slice forms one video picture segment.

In the Independent Segment Decoding mode, each video picture segment is decoded with complete independence from all other video picture segments, and is also independent of all data outside the same video picture segment location in the reference picture(s). This includes:

1) no use of motion vectors outside of the current video picture segment for motion vector prediction (as in 6.1.1);
2) no use of motion vectors outside of the current video picture segment as remote motion vectors for overlapped block motion compensation when the Advanced Prediction mode is in use (see F.3);
3) no deblocking filter operation across video picture segment boundaries (see J.3);
4) no use of motion vectors which reference data outside the current video picture segment unless the Unrestricted Motion Vector mode (see Annex D), the Advanced Prediction mode (see Annex F), the Deblocking Filter mode (see Annex J) or the Temporal, SNR, and Spatial Scalability mode (see Annex O) are in use; in which case the borders of the current video picture segment in the prior picture are extrapolated as described in Annex D to form predictions of the pixels which reference the out-of-bounds region;

5) no bilinear interpolation across the boundaries of the ¼-size or ½-size region corresponding to the current video picture segment for upward prediction in spatial scalability EI- and EP-pictures (as defined in Annex O);

6) when the Reduced-Resolution Update mode (see Annex Q) is in use, no block boundary filter operation across video picture segment boundaries;

7) no use of the Reference Picture Resampling mode with the Independent Segment Decoding mode.

R.3 Constraints on usage

Certain restrictions are placed on the use of other aspects of the video coding syntax when the Independent Segment Decoding mode is in use. These restrictions are made to prevent two pathological cases which otherwise would make operation of the Independent Segment Decoding mode difficult.

R.3.1 Constraint on segment shapes

In the use of the Slice Structured mode (Annex K) without the use of the Rectangular Slice submode (see K.1), there can arise cases in which the shape of a video picture segment may be non-convex (having "inside corners", or even comprising two distinct and separated regions of the picture).

Therefore, the Independent Segment Decoding mode shall not be used with the Slice Structured mode without the simultaneous use of the Rectangular Slice submode of the Slice Structured mode (see Annex K). This constraint is mandated to prevent the need for difficult special-case treatment in order to determine how and when to perform extrapolation of each video picture segment.

R.3.2 Constraint on changes of segment shapes

If the shape of the video picture segments were allowed to change in any way from picture to picture in the bitstream, there could arise cases in which the bitstream would be difficult to decode. This is because in such cases the bitstream content is not sufficient to determine the shape of each video picture segment prior to the possible appearance of motion vectors in the bitstream which require knowledge of the video picture segment shape for proper interpretation.

Therefore, when the Independent Segment Decoding mode is in use, the video picture segmentation for all pictures and frames allowing temporal prediction (i.e. all P-, B-, and EP-pictures and all Improved PB-frames) shall be the same as that used in its temporal reference picture. Also, when the Independent Segment Decoding mode is in use, the video picture segmentation for all EI-pictures shall either be the same or shall differ only by sub-dividing the video picture segmentation used in its reference picture. Also, the Independent Segment Decoding mode shall not be used in any picture or frame which uses reference pictures (all picture types except INTRA) unless the Independent Segment Decoding mode is also used in all of the reference picture(s) for the current picture. As a result of this constraint, the shape of the video picture segments in the Independent Segment Decoding mode shall never change from picture to picture except as changed in I- and EI-pictures (and the manner in which EI-pictures can change segmentation is itself also somewhat constrained).

ANNEX S

Alternative INTER VLC mode

S.1 Introduction

This annex describes an optional Alternative INTER VLC mode of this Recommendation, which improves the efficiency of inter-picture coding when significant changes are evident in the picture. This efficiency improvement is obtained by allowing some VLC codes originally designed for INTRA pictures to be used for some INTER picture coefficients and CBPY data as well. The use of this mode is indicated in the PLUSPTYPE field of the picture header. The capability to use this optional mode is negotiated by external means (for example, Recommendation H.245). The mode contains two syntax alterations, one for the encoding of INTER coefficients and another for the encoding of the INTER CBPY values.

S.2 Alternative INTER VLC for coefficients

The concept behind the design of the INTRA VLC table of Annex I is to use the same codewords as in the original INTER VLC but with a different interpretation of LEVEL and RUN. The INTRA VLC is better suited in cases where there are many and/or large-valued coefficients.

The INTRA VLC is constructed so that codewords have the same value for LAST (0 or 1) in both the INTER and INTRA tables. The INTRA table is therefore produced by "reshuffling" the meaning of the codewords with the same value of LAST. Furthermore, for events with large |LEVEL| the INTRA table uses a codeword which in the INTER table has a large RUN. In INTER blocks having a large number of large-magnitude coefficients, it can sometimes be more efficient to use the INTRA table than the INTER table, and in some such cases the choice of the VLC table can be apparent to the decoder since decoding using the INTER table would result in RUN values so large as to indicate the presence of more than 64 coefficients for a block. Under these circumstances, the INTRA table can be used to improve the efficiency of INTER coding.

S.2.1 Encoder action

The encoder may use the INTRA VLC table for coding an INTER block whenever the decoder can detect its use – in other words, whenever decoding using the INTER VLC table would cause coefficients outside the 64 coefficients of a block to be addressed.

The encoder would normally choose to use the INTRA VLC table for coding an INTER block only when the above condition is satisfied and also when the INTRA VLC usage results in fewer bits than the INTER VLC for the same coefficient values. This will often be the case when there are many large coefficients, due to the way the INTRA VLC was produced (since the ordinary INTER VLC table contains long run-lengths for the same codewords in which the INTRA VLC table contains large coefficient amplitudes).

S.2.2 Decoder action

The decoding process is as follows:

1) The decoder first receives all coefficient codes of a block.
2) The codewords are then interpreted assuming that INTER VLC is used. If the addressing of coefficients stays inside the 64 coefficients of a block, the VLC decoding is finished.
3) If coefficients outside the block are addressed, the codewords shall be interpreted according to the INTRA VLC.

S.3 Alternative INTER VLC for CBPY

The INTER CBPY codewords (Table 13) are designed with the assumption that there are more Y blocks with all zero coefficients than there are with at least one non-zero coefficient. When both C_B and C_R blocks have at least one non-zero coefficient, i.e. $CBPC_5 = CBPC_6 = 1$, this assumption no longer holds. For this reason, when the Alternative INTER VLC mode is in use, the CBPY codewords as defined in Table 13 for INTRA macroblocks shall also be used for INTER macroblocks whenever $CBPC_5 = CBPC_6 = 1$.

ANNEX T

Modified Quantization mode

T.1 Introduction

This annex describes an optional Modified Quantization mode of this Recommendation, which modifies quantizer operation. The use of this mode is indicated in the PLUSPTYPE field of the picture header. The capability to use this optional mode is negotiated by external means (for example, Recommendation H.245).

This mode includes four key features:

1) The bit-rate control ability for encoding is improved by altering the syntax for the DQUANT field.
2) Chrominance fidelity is improved by specifying a smaller step size for chrominance than that for luminance data.
3) The range of representable coefficient values is extended to allow the representation of any possible true coefficient value to within the accuracy allowed by the quantization step size.
4) The range of quantized coefficient levels is restricted to those which can reasonably occur, to improve the detectability of errors and minimize decoding complexity.

T.2 Modified DQUANT Update

This mode modifies the semantics of the DQUANT field. With this mode, it is possible to use DQUANT either to modify QUANT by plus or minus a small amount, or to signal any specific new value for QUANT. The size of the small amount of modification depends on the current value of QUANT. By use of this mode, more flexible control of the quantizer step size can be specified in the DQUANT field.

The codeword for DQUANT in this mode is no longer a two-bit fixed length field. It is a variable length field which can either be two bits or six bits in length. Whether it is two or six bits depends on the first bit of the code. The description below is therefore split into two sections, depending on the first bit.

T.2.1 Small-step QUANT alteration

When the first bit of the DQUANT field is 1, only one additional bit is sent in DQUANT. The single additional bit is used to modify QUANT by a differential value. The change in the value of QUANT is dependent on the second bit of DQUANT and on the prior value of QUANT, as shown in Table T.1.

Example: If the previous value of QUANT is 29 and DQUANT is signalled with the codeword "11", then the differential value is +2, and thus the resulting new QUANT value is 31.

Table T.1/H.263 – Semantics of small-step QUANT alteration

	Change of QUANT	
Prior QUANT	**DQUANT = 10**	**DQUANT = 11**
1	+2	+1
2-10	–1	+1
11-20	–2	+2
21-28	–3	+3
29	–3	+2
30	–3	+1
31	–3	–5

T.2.2 Arbitrary QUANT selection

When the first bit of the DQUANT field is 0, five additional bits are sent in DQUANT. The following five bits represent a new QUANT as defined in 5.1.19.

Example: Regardless of the current value of QUANT, if DQUANT is signalled with the code word ’001111’, then the new value of QUANT is 15.

T.3 Altered quantization step size for chrominance coefficients

When the modified quantization mode is in use, the quantization parameter of the chrominance coefficients is different from the quantization parameter of the luminance. The luminance quantization parameter is signaled in the bitstream. It is called QUANT. When this mode is in use, a different quantization parameter termed QUANT_C is used for the inverse quantization of chrominance coefficients. The relation between QUANT and QUANT_C is given in Table T.2. If the Deblocking Filter mode (see Annex J) is in use, QUANT_C shall also be used for the application of the deblocking filter to the chrominance data. Whenever QUANT is discussed herein in any other context, it shall mean the quantization step size of the luminance.

Table T.2/H.263 – Relationship between QUANT and QUANT_C

Range of QUANT	Value of QUANT_C
1-6	QUANT_C = QUANT
7-9	QUANT_C = QUANT – 1
10-11	9
12-13	10
14-15	11
16-18	12
19-21	13
22-26	14
27-31	15

T.4 Modified coefficient range

When the Modified Quantization mode is in use, quantized DCT coefficients having quantization level magnitudes greater than 127 can be represented in the bitstream. This has two advantages:

1) Encoder performance is improved by allowing the true full range of possible coefficient values to be represented.

2) Encoder complexity is reduced by eliminating the need to increase the quantization step size upon encountering certain large coefficient values which would otherwise be unrepresentable.

It is possible that the correct value of a DCT coefficient prior to quantization in the encoder will have a magnitude as high as 2040. Thus, a range of –127 to +127 for LEVEL is insufficient to cover the entire range of possible coefficient values whenever the quantization parameter QUANT or QUANT_C is less than 8. The expanded coefficient range broadens the range of LEVEL to allow any true coefficient value to be more properly encoded.

When the Modified Quantization mode is in use, the meaning of the LEVEL field following an ESCAPE code (0000 011, as per 5.4.2) is altered. In this mode, rather than being forbidden, the bit sequence 1000 0000 is used to represent an EXTENDED-ESCAPE code. An AC coefficient of magnitude greater than 127 is represented by sending an EXTENDED-ESCAPE code, immediately followed by a fixed-length EXTENDED-LEVEL field of 11 bits. An extended coefficient value is encoded into the EXTENDED-LEVEL field by taking the least significant 11 bits of the two's-complement binary representation of LEVEL and cyclically rotating them to the right by 5-bit positions. This rotation is necessary to prevent start code emulation. The cyclic rotation is illustrated in Figure T.1.

Bits of LEVEL field

b11	b10	b9	b8	b7	b6	b5	b4	b3	b2	b1

Bits of EXTENDED-LEVEL field

b5	b4	b3	b2	b1	b11	b10	b9	b8	b7	b6

Figure T.1/H.263 – Cyclic rotation of coefficient representation

T.5 Usage restrictions

When the Modified Quantization mode is in use, certain restrictions are placed on the encoded coefficient values. This has several benefits:

1) The detectability of bit errors is improved by prohibiting certain unreasonable coefficient values, thus allowing these values to be recognized as bit errors by the decoder; and

2) Decoder complexity is reduced by reducing the wordlength necessary for inverse quantization prior to clipping.

3) Start-code emulation is prevented for coefficients encoded using the EXTENDED-ESCAPE mechanism described in T.4.

These restrictions are as follows. When the Modified Quantization mode is in use:

1) For any coefficient, the reconstruction level magnitude |REC| produced by the inverse quantization process described in 6.2.1 using the current value of QUANT or QUANT_C as appropriate, and the encoded value of LEVEL, shall be less than 4096. This additional restriction applies to all coefficients, regardless of whether the coefficient is sent using the EXTENDED-ESCAPE mechanism or not.

2) The bitstream shall not use either the normal ESCAPE code or the EXTENDED-ESCAPE code to encode a combination of LAST, RUN, and LEVEL for which there exists a codeword entry in the applicable VLC table, which is either Table 16 (see 5.4.2) or Table I.2 (see I.3).

3) The EXTENDED-ESCAPE code shall be used only when the quantization parameter for the coefficient (QUANT or QUANT_C) is less than eight (8).

4) The EXTENDED-ESCAPE code shall be used only when it is followed by an EXTENDED-LEVEL field representing a value of LEVEL which is outside of the range −127 to +127.

APPENDIX I

Error tracking

I.1 Introduction

This appendix describes a method to recover efficiently after transmission errors if erroneous MBs are reported via a feedback channel to the encoder. The capability of sending and processing feedback information is signalled via external means (for example, by Recommendation H.245). Furthermore, format and content of the feedback message are defined externally (for example, by Recommendation H.245).

I.2 Error tracking

Because INTRA coding stops temporal error propagation, it should be used for macroblocks which are severely affected by transmission errors. This requires that the location and extent of image artefacts can be made available to the encoder. The following algorithm provides an estimated error distribution based on feedback information received by the encoder. It considers spatial error propagation caused by motion-compensated prediction as well as the delay until the reception of the feedback message. The algorithm illustrates one possible approach to evaluate feedback messages for spatio-temporal error tracking. Other algorithms are possible.

Assume N macroblocks within each frame enumerated mb = 1...N from top-left to bottom-right. Let $\{n_{err}, mb_{first}, mb_{last}\}$ be the feedback message to the encoder, where $mb_{first} \leq mb \leq mb_{last}$ indicates a set of erroneous macroblocks in frame n_{err}.

To evaluate the feedback message, the encoder must continuously record information during the encoding of each frame. First, the initial error $E_0(mb, n)$ that would be introduced by the loss of macroblock mb in frame n needs to be stored. Assuming a simple error concealment where erroneous macroblocks are treated as not coded, $E_0(mb, n)$ is computed as the Summed Absolute Difference (SAD) of macroblock mb in frame n and n – 1. Second, the number of pixels transferred from macroblock mb_{source} in frame n – 1 to macroblock mb_{dest} in frame n is stored in dependencies $d(mb_{source}, mb_{dest}, n)$. These dependencies are derived from the motion vectors.

Assume that a feedback message arrives before frame n_{next} is encoded, such that $n_{next} > n_{err}$. Then, the estimated error E(mb, n_{err}) in macroblock mb and frame n_{err} is initialized as:

$$E(mb, n_{err}) = \begin{cases} E_0\,(mb, n_{err}) & \text{for } mb_{first} \le mb \le mb_{last} \\ 0 & \text{else} \end{cases}$$

For subsequent frames n, with $n_{err} < n < n_{next}$, the error may be estimated as:

$$E(mb, n) = \sum_{i=1}^{N} E(i,\ n-1)\ \frac{d(i,\ mb,\ n)}{256}$$

where a uniformly distributed error in each macroblock is assumed after each iteration.

The estimated error E(mb, $n_{next} - 1$) is incorporated into the mode decision of the next frame. For example, macroblock mb is coded in INTRA mode, if E(mb, $n_{next} - 1$) exceeds a threshold.

In practice, error tracking information will only be stored for the latest M frames. Then, if $n_{err} < n_{next} - M$, no error-tracking information is available and the encoder must take special action. For example, the next frame may be coded in INTRA mode. However, other procedures are possible and may be more effective.

APPENDIX II

Recommended Optional Enhancement

II.1 Introduction

With the variety of optional modes available in this Recommendation (H.263 Version 2), it is crucial that several preferred mode combinations for operation be defined, so that option-enhanced terminals will have a high probability of connecting to each other using some syntax better than the "baseline." This appendix contains a list of preferred mode combinations, structured into three "levels" of support. Each level includes support for the levels below it, creating an "onion peel" structure of capabilities. The primary objective of this appendix is to describe the order in which modes should be supported in decoders, rather than to enforce a particular small set of mode combinations upon encoders.

In determining which modes would be placed into this level structure, the primary criteria used were performance-related: improvement in subjective quality, impact on delay, and impact on complexity (this includes computational burden, data dependencies, and ease of implementation). However, because this appendix seeks to address a wide variety of applications and transport layers, features addressing error resilience and ease of packetization were also incorporated into the same level structure. In keeping with these objectives, the levels of support described in this appendix are intended to be *universal*, so that the means of transport will not be an issue and the need for application-specific "profiles" will be minimized. This universality is seen as a key to promoting good interoperability across different types of terminals and networks. To maintain universality, several optional features have not been included in the level structure described herein. The absence of these features is not meant to be a condemnation of their usage; instead, their absence reflects only a collective opinion about the likelihood of widespread adoption of these features across a full spectrum of terminals, networks, and applications.

II.2 Levels of preferred mode support

Each optional mode described in this appendix has been categorized into one of three levels of support. While the ratio of performance improvement to computational complexity was a major criterion used in this categorization, utility for packetization and error resilience were also considered. Decoder support for a given level implies support for all lower levels. Furthermore, decoder support for a given level implies support for all subset combinations of the constituent modes of that level and all lower levels. This last requirement exists so that the limitations placed upon an encoder's choice of mode combinations is minimized. This is in keeping with the primary objective of this appendix, which is to describe the order in which modes should be supported at the decoder, rather than to enforce a particular small set of mode combinations upon the encoder.

Backward compatibility is also an important issue to consider. For this reason, a preferred mode combination including only the Advanced Prediction mode (Annex F) is also recommended (although this Recommendation falls outside the level structure defined below), since Advanced Prediction is regarded as the most beneficial of the optional modes in the original edition (Version 1) of this Recommendation.

II.2.1 Level 1 preferred modes

The first level of support is composed of the following modes:

1) **Advanced INTRA Coding (Annex I)** – Use of this mode improves the coding efficiency for INTRA macroblocks (whether within INTRA pictures or predictively-coded pictures). The additional computational requirements of this mode are minimal at both the encoder and decoder (as low as a maximum of 8 additions/subtractions per 8 × 8 block in the decoding process plus the use of a different but very similar VLC table in order to obtain a significant improvement in coding efficiency). For these reasons, Advanced INTRA Coding is included at this lowest level of support.

2) **Deblocking Filter (Annex J)** – Because of the significant subjective quality improvement that may be realized with a deblocking filter, these filters are already widely in use as a method of post-processing in video communication terminals. Annex J represents the preferred mode of operation for a deblocking filter because it places the filter within the coding loop. This placement eases the implementation of the filter (by reducing the memory requirement) and somewhat improves the coding performance over a post-procesing implementation. As with the Advanced Prediction mode, this mode also includes the four-motion-vector-per-macroblock feature and picture boundary extrapolation for motion compensation, both of which can further improve coding efficiency. The computational requirements of the deblocking filter are several hundred operatons per coded macroblock, but memory accesses and computational dependencies are uncomplicated. This last point is what makes the Deblocking Filter preferable to Advanced Prediction. Also, the benefits of Advanced Prediction are not as substantial when the Deblocking Filter is used as well. Thus, the Deblocking Filter is included at this lowest level of support while Advanced Prediction is deferred to Level 3.

3) **Supplemental Enhancement Information (Full-Frame Freeze Only) (Annex L, see L.4)** – The full-frame freeze is very simple to implement, requiring only that the decoder be able to stop the transfer of data from its output buffer to the video display. This sub-mode is useful for preventing the display of low-fidelity pictures while the encoder is building up a higher fidelity picture.

4) **Modified Quantization (Annex T)** – This mode includes an extended DCT coefficient range, modified DQUANT syntax, and a modified step size for chrominance. The first two features allow for more flexibility at the encoder and may actually decrease the encoder's computational load (by eliminating the need re-encode macroblocks when coefficient level saturation occurs). The third feature noticeably improves chrominance fidelity, typically with little added bit-rate cost and with virtually no increase in computation. At the decoder, the only significant computational burden is the ability to parse several new bitstream symbols.

II.2.2 Level 2 preferred modes

The second level of support is composed of the following modes:

1) **Unrestricted Motion Vectors (With UUI = "1" Sufficient) (Annex D)** – Annex D has two primary features:

   a) picture boundary extrapolation; and

   b) longer motion vector support.

   The first is already supported by the inclusion of Annex J in the first level of support. The longer motion vector support can provide a significant improvement in coding efficiency, especially for large picture sizes, rapid motion, camera movement, and low picture rates. When used with PLUSPTYPE present, this mode also allows for longer motion vector differences, which can significantly simplify encoder operation. The longer motion vectors do present a potential problem for the decoder in terms of memory access, but frame-size-dependent limits on the maximum motion vector size prevent this problem from becoming an appreciable obstacle to implementation.

2) **Slice Structured Mode (Annex K)** – For compatibility with packet-based transport layers, the Slice Structured mode is included here. All submodes of Annex K are to be supported, including the Rectangular Slice submode and the Arbitrary Slice Ordering submode. The additional computational burden imposed by the Slice Structured mode is minimal, limited primarily to bitstream generation and parsing.

3) **Reference Picture Resampling (Implicit Factor-of-4 Mode Only) (Annex P)** – The implicit factor-of-4 mode of Reference Picture Resampling allows for automatic reference picture resampling only when the size of the new frame is changed, as indicated in the picture header. No bitstream overhead is required for this mode of operation. Predictive dynamic resolution changes allow an encoder to make intelligent trade-offs between temporal and spatial resolution. Furthermore, this simplest mode of operation for Annex P (factor of 4 upsampling or downsampling only) adds only a modest amount of computational complexity to both the encoder or decoder, since the factor of 4 case uses a simple fixed FIR filter (requiring roughly 4 operations per pixel, at most).

II.2.3 Level 3 preferred modes

The third and final level of support is composed of the following modes:

1) **Advanced Prediction (Annex F)** – From a coding efficiency standpoint, this mode is the most important of the modes available in the prior version (Version 1) of this Recommendation. It includes overlapped block motion compensation, the four-motion-vector-per-macroblock feature, and it allows for motion vectors to point outside of the picture boundaries. The use of Advanced Prediction results in significant improvements in both subjective and objective performance. It does, however, require an appreciable increase in computation. More importantly, the data dependencies introduced by Advanced Prediction result in a complicated order of processing at the decoder. Coupled with the fact

that the quality improvements are not as obvious when the Deblocking Filter is also in use, these complexity considerations are the reason this mode is part of the third support level, rather than the first. However, since implementations of Recommendation H.263 that were designed prior to the adoption of the other modes in this list might have implemented Advanced Prediction by itself, Advanced Prediction-only operation is also recommended for maximal backward compatibility.

2) **Improved PB-frames (Annex M)** – The Improved PB-frames mode represents a substantial improvement over the basic PB-frames mode (Annex G) and has been demonstrated to significantly improve the coding efficiency for video sequences with a low degree of motion. While the basic version of PB-frames had problems in handling scene cuts and irregular motion, the Improved PB-frames mode may be used effectively at all times. In terms of computational burden, this mode is roughly neutral (especially for macroblock-pipelined architectures). However, because the Improved PB-frames mode can have a negative impact on delay and because it requires an additional frame store to implement (at both the encoder and decoder), it is placed in a higher layer.

3) **Independent Segment Decoding (Annex R) –** While the Independent Segment Decoding mode does introduce a significant amount of complexity (in terms of ease of implementation), it also significantly improves the error robustness of a video decoder, particularly in the presence of packet losses. For this reason, it is likely that many applications in which data can be lost in transmission (whether through packet loss or channel interference) will make use of the Independent Segment Decoding mode, especially in combination with the Slice Structured mode.

4) **Alternate INTER VLC (Annex S)** – This mode has been demonstrated to improve coding efficiency especially for pictures with heavy motion which are coded with high fidelity. This mode uses the same VLC table as the Advanced INTRA Coding mode and is also simple from a computational standpoint (for each block, it requires at most one additional pass over the parsed symbols to decode them into DCT coefficients). However, it is possible that this mode could lead to some difficulty in implementation (especially on highly pipelined architectures), which is why it is not included at the lower levels of support.

II.3 Picture formats and picture clock frequencies

To ensure a high quality level of interoperability, encoders and decoders supporting a large standard picture format (QCIF, CIF, 4CIF, 16CIF) should support all smaller standard picture formats. (As specified elsewhere in this Recommendation, decoders shall support sub-QCIF and QCIF, and encoders shall support sub-QCIF or QCIF.) Decoders should be capable of operation with a smaller picture format at maximum frame rates no lower than the maximum frame rate for which it is capable of operation with a larger standard picture format. For example, a decoder capable of decoding 4CIF pictures at 15 pictures per second [actually 15*(1000/1001) pictures per second] should also be able to decode CIF, QCIF and SQCIF pictures at least at 15 pictures per second.

Encoders and decoders supporting custom picture formats and/or custom picture clock frequencies are recommended to follow the guidelines below:

1) An encoder or decoder which supports a custom picture format should support all standard picture formats equal or smaller in both height and width than those of any supported custom picture format. For example, an encoder supporting a custom picture format of 256 × 256 should support QCIF and SQCIF picture encoding.

2) An encoder or decoder which supports a custom picture clock frequency for a standard picture format should support a higher or equal frame rate (in pictures per second) at the standard picture clock frequency of 30 Hz [actually 30*(1000/1001) Hz] for the same picture format. For example, if a decoder supports QCIF pictures at 12.5 pictures per second with a 25 Hz picture clock, it should at least be able to decode QCIF pictures at 15 pictures per second at 30 Hz. If a custom picture format is used, all supported smaller or equal standard picture formats should be capable of operating at frame rates for the standard picture clock frequency no lower than the maximum frame rate of the custom picture format.

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