The H.264/AVC Video Coding Standard

(ITU-T Rec. H.264 | ISO/IEC 14496-10)

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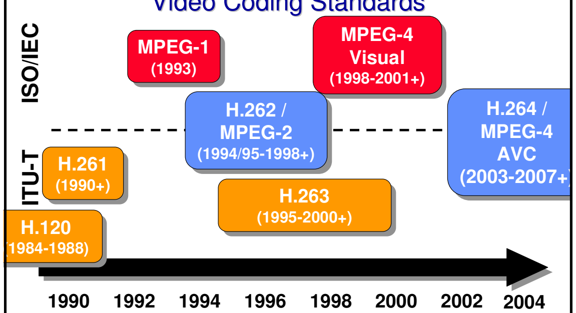
Video Coding Standardization Organizations

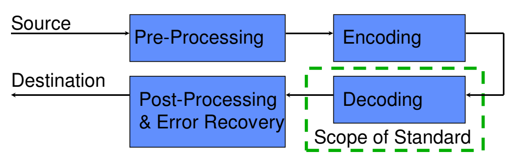
- Two organizations have historically dominated general-purpose video compression standardization:
  - ITU-T Video Coding Experts Group (VCEG)
    International Telecommunications Union – Telecommunications Standardization Sector (ITU-T, a United Nations Organization, formerly CCITT), Study Group 16, Question 6
  - ISO/IEC Moving Picture Experts Group (MPEG)
    International Standardization Organization and International Electrotechnical Commission, Joint Technical Committee Number 1, Subcommittee 29, Working Group 11
- Recently, the Society for Motion Picture and Television Engineers (SMPTE) has also entered with "VC-1", based on Microsoft's WMV 9 *but this talk covers only the ITU and ISO/IEC work.*

Chronology of International Video Coding Standards



The *Scope* of Picture and Video Coding Standardization

- Only the *Syntax* and *Decoder* are standardized:
  - Permits optimization beyond the obvious
  - Permits complexity reduction for implementability
  - Provides *no* guarantees of Quality



The Advanced Video Coding Project AVC / ITU-T H.264 / MPEG-4 part 10

- History: ITU-T Q.6/SG16 (**VCEG - Video Coding Experts Group**) "H.26L" standardization activity (where the "L" stood for "long-term")
- **Aug 1999**: 1st test model (TML-1)
- **July 2001:** MPEG open call for technology: H.26L demo'ed
- **Dec 2001**: Formation of the **Joint Video Team (JVT)** between VCEG and MPEG to finalize H.26L as a new joint project (similar to MPEG-2/H.262)
- **July 2002**: Final Committee Draft status in MPEG
- **Dec '02** Technical freeze, FCD ballot approved
- **May '03** Completed in both orgs
- **July '04** Fidelity Range Extensions (FRExt) completed
- **Jan '07** Professional Profiles completed

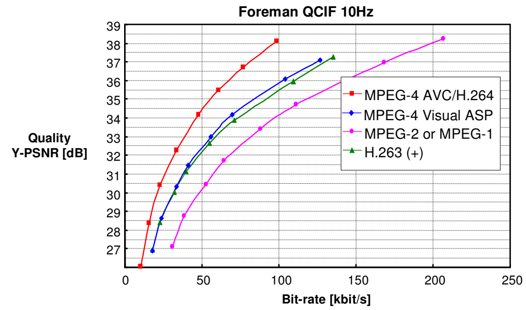
H.264/AVC Objectives

- **Primary technical objectives:**
  - Significant improvement in coding efficiency
  - High loss/error robustness
  - "Network Friendliness" (carry it well on MPEG-2 or RTP or H.32x or in MPEG-4 file format or MPEG-4 systems or …)
  - Low latency capability (better quality for higher latency)
  - Exact match decoding
- **Initial extension objectives (in FRExt and Prof Profiles):**
  - Professional applications (more than 8 bits per sample, 4:4:4 color sampling, etc.)
  - Higher-quality high-resolution video
  - Alpha plane support (a degree of "object" functionality)
  - Extended color gamut support

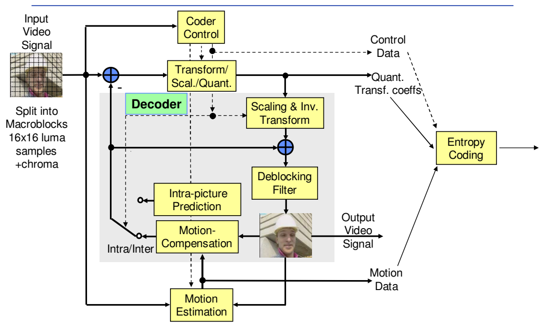
A Comparison of Performance

- Test of different standards (ICIP 2002 study)
- Using same rate-distortion optimization techniques for all codecs
- Streaming test: High-latency (included B frames)
  - Four QCIF sequences coded at 10 Hz and 15 Hz (Foreman, Container, News, Tempete) and
  - Four CIF sequences coded at 15 Hz and 30 Hz (Bus, Flower Garden, Mobile and Calendar, and Tempete)
- Real-time conversation test: No B frames
  - Four QCIF sequences encoded at 10Hz and 15Hz (Akiyo, Foreman, Mother and Daughter, and Silent Voice)
  - Four CIF sequences encoded at 15Hz and 30Hz (Carphone, Foreman, Paris, and Sean)
- Compare four codecs using PSNR measure:
  - **MPEG-2** (in high-latency/streaming test only)
  - **H.263** (high-latency profile, conversational high-compression profile, baseline profile)
  - **MPEG-4 Visual** (simple and advanced simple profiles with & without B pictures)
  - **H.264/AVC version 1** (with & without B pictures)
- Note: These test results are from a private study and are not an endorsed report of the JVT, VCEG or MPEG organizations.

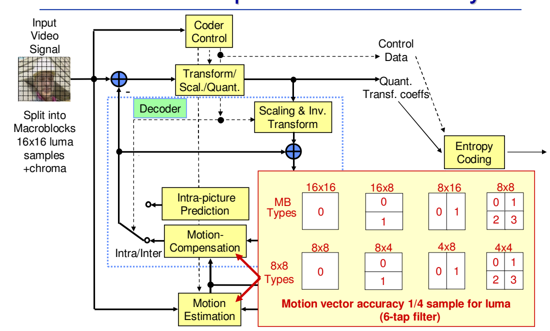
Comparison to MPEG-2, H.263, MPEG-4p2



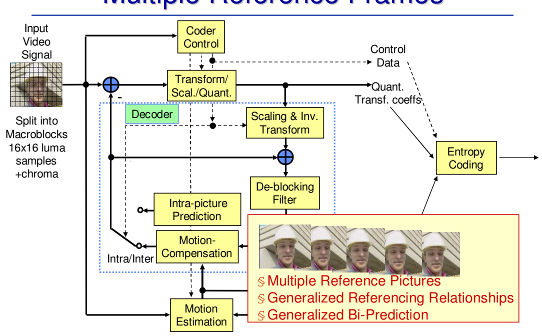
MPEG-4 AVC/H.264 Structure



Motion Compensation Accuracy

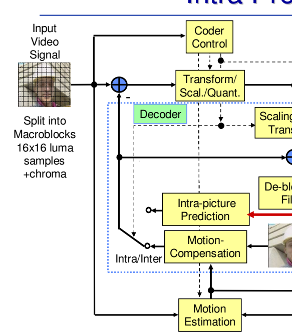


Multiple Reference Frames



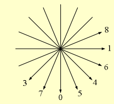
- Multiple Reference Pictures
- Generalized Referencing Relationships
- Generalized Bi-Prediction

Intra Prediction



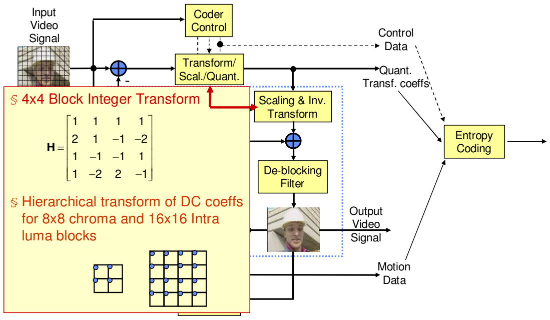
- Directional spatial prediction (9 types for 4x4 luma pred, 4 types for 16x16 luma pred, 4 types for 8x8 chroma pred)

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



e.g., Mode 4:
diagonal down/right prediction
a, f, k, p are predicted by
(A + 2M + I + 2) >> 2

DCT-Like Transform Coding

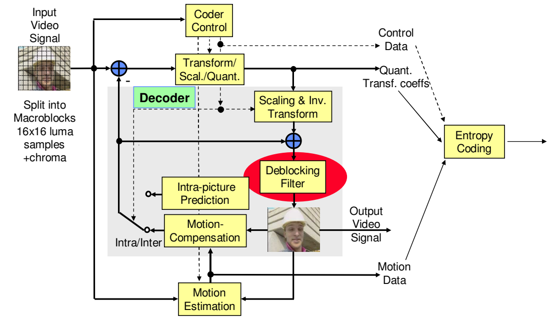


§ 4x4 Block Integer Transform

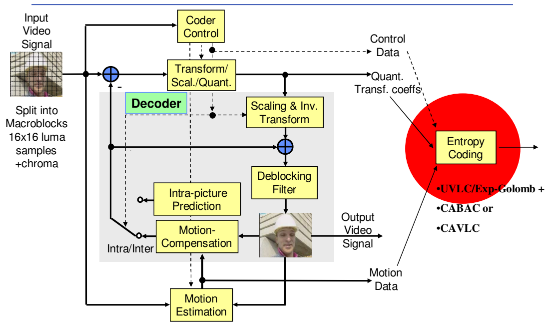
$$\mathbf{H} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 1 & -2 & 2 & -1 \end{bmatrix}$$

§ Hierarchical transform of DC coeffs for 8x8 chroma and 16x16 Intra luma blocks

Deblocking Filter



Entropy Coding



H.264/AVC Version 1 Profiles

- **Three profiles in version 1: Baseline, Main, and Extended**
- **Baseline (esp. Videoconferencing & Wireless)**
  - I and P progressive-scan picture coding (not B)
  - In-loop deblocking filter
  - 1/4-sample motion compensation
  - Tree-structured motion segmentation down to 4x4 block size
  - VLC-based entropy coding
  - Some enhanced error resilience features
    - Flexible macroblock ordering/arbitrary slice ordering
    - Redundant slices

Non-Baseline H.264/AVC Version 1 Profiles

- **Main Profile (esp. Broadcast)**
  - All Baseline features **except** enhanced error resilience features
  - Interlaced video handling
  - Generalized B pictures
  - Adaptive weighting for B and P picture prediction
  - ***CABAC (arithmetic entropy coding)***
- **Extended Profile (esp. Streaming)**
  - All Baseline features
  - Interlaced video handling
  - Generalized B pictures
  - Adaptive weighting for B and P picture prediction
  - ***More error resilience: Data partitioning***
  - ***SP/SI switching pictures***

Fidelity-Range and Professional Extensions

- AVC standard finished May 2003, published as “twin text”
  - ITU-T Recommendation H.264
  - ISO/IEC 14496-10 MPEG-4 AVC
- Fidelity-Range Extensions (FRExt)
  - Work item initiated in July 2003
  - More than 8 bits, color other than 4:2:0
  - Alpha coding
  - More coding efficiency capability
  - Also new supplemental information
- Professional Profiles
  - Work item initiated in October 2005
  - Focus initially on 4:4:4 (replacing prior FRExt 4:4:4 profile)
  - Later work on all-intra and new supplemental information

FRExt Technical Features – Part 1

- Larger transforms
  - 8x8 transform (as was in older standards)
  - Drop 4x8, 8x4, or larger, 16-point…
- Filtered intra prediction modes for 8x8 block size
- Quantization matrix
  - 4x4, 8x8, intra, inter trans. coefficients weighted differently
  - Old idea, dating to JPEG and before (circa 1986?)
  - Full capabilities not yet explored (visual weighting)
- Coding in various color spaces
  - 4:2:2, 4:2:0, Monochrome, with/without Alpha
  - New integer color transform (a VUI-message item)

FRExt Technical Features – Part 2

- Efficient lossless interframe coding
- Film grain characterization for analysis/synthesis representation
- Stereo-view video support
- Deblocking filter display preference

8x8 16-Bit (Bossen) Transform

$$\begin{bmatrix} 8 & 8 & 8 & 8 & 8 & 8 & 8 & 8 \\ 12 & 10 & 6 & 3 & -3 & -6 & -10 & -12 \\ 8 & 4 & -4 & -8 & -8 & -4 & 4 & 8 \\ 10 & -3 & -12 & -6 & 6 & 12 & 3 & -10 \\ 8 & -8 & -8 & 8 & 8 & -8 & -8 & 8 \\ 6 & -12 & 3 & 10 & -10 & -3 & 12 & -6 \\ 4 & -8 & 8 & -4 & -4 & 8 & -8 & 4 \\ 3 & -6 & 10 & -12 & 12 & -10 & 6 & -3 \end{bmatrix}$$

8x8 Transform Advantage (JVT-K028, IBBP coding, prog. scan)

Sequence	% BD bit-rate reduction
Movie 1	11.59
Movie 2	12.71
Movie 3	12.01
Movie 4	11.06
Movie 5	13.46
Crawford	10.93
Riverbed	15.65
Average	**12.48**

Quantization Matrix

- Similar concept to MPEG-2 design
- Vary step size based on frequency
- Adapted to modified transform structure
- More efficient representation of weights
- Eight downloadable matrices (at least 4:2:0)
  - Intra 4x4 Y, Cb, Cr
  - Intra 8x8 Y
  - Inter 4x4 Y, Cb, Cr
  - Inter 8x8 Y

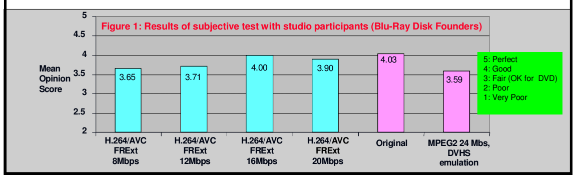
New Profiles Created by FRExt

- 4:2:0, 8-bit: "High" (HP)
- 4:2:0, 10-bit: "High 10" (Hi10)
- 4:2:2, 10-bit: "High 4:2:2" (Hi422)

- Effectively the same tools, but acting on different input data
- The High Profile has been a major force in recent industry developments (HD DVD, Blu-ray Disc, DBS, Terrestrial Broadcast, IPTV, etc.)
- The others are emerging in professional applications (e.g., content acquisition, editing, studios, recording)

A Performance Test for High Profile (from JVT-L033 - Panasonic)

- Subjective tests by Blu-Ray Disk Founders of FRExt HP
  - 4:2:0/8 (HP) 1920x1080x24p (1080p), 3 clips.
  - Nominal 3:1 advantage to MPEG-2
    - 8 Mbps HP scored better than 24 Mbps MPEG-2
  - Apparent **transparency** at 16 Mbps

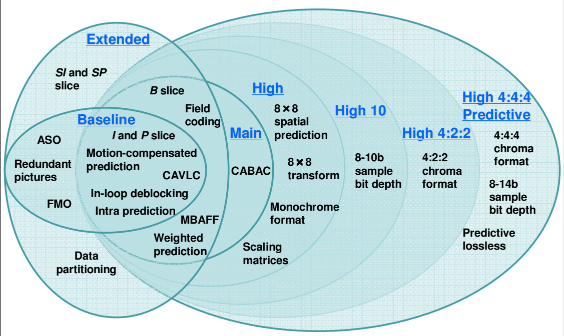


Some Notes on Quality Testing

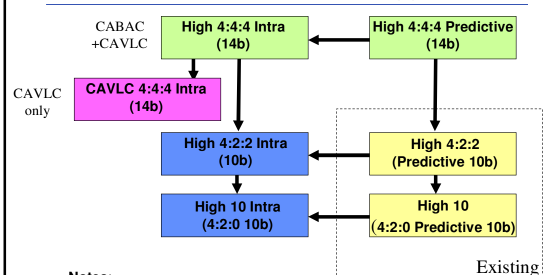
- Use recent reference software (if using ref software)
- Use rate-distortion optimization in encoder
- Use large-range good-quality motion search
- Use appropriate "High" profile (incl. adaptive transform)
- If testing for PSNR, use "flat" quant matrices
- Otherwise, use "non-flat" quant matrices
- Use CABAC entropy coding
- Use more than 1 or 2 reference pictures
- Use hierarchical B reference frames coding structure
- Use bi-predictive search optimization (see JVT-N014)
- If testing high-quality PSNR, use adaptive thresholding*

* = See G. Sullivan & S. Sun, "On Dead-Zone…", VCIP 2005/JVT-N011

AVC Profile Overview

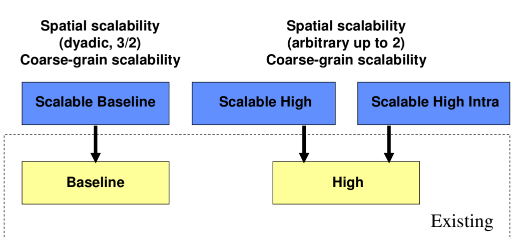


New Profiles for Professional Apps (2007)



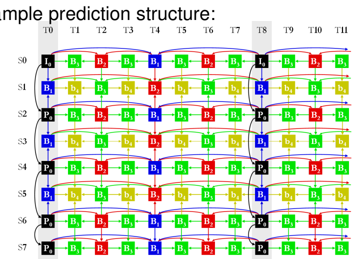
Notes:
Arrows denote capability subset hierarchy.
Four profiles not shown: **Baseline**, **Extended**, **Main**, **High**.

New Scalable Video Coding Profiles



Work-in-progress: Multi-view Video Coding

- N camera views, synchronized in time
- Example prediction structure:



For Further Information

- JVT, MPEG, and VCEG management team members:
  - Gary J. Sullivan (garysull@microsoft.com)
  - Jens-Rainer Ohm (ohm@ient.rwth-aachen.de)
  - Ajay Luthra (aluthra@motorola.com)
  - Thomas Wiegand (wiegand@hhi.de)

- H.264/AVC literature references:
  - *IEEE Transactions on Circuits and Systems for Video Technology* Special Issue on H.264/AVC (July 2003) [Includes several highly-referenced papers] (Luthra, Sullivan, Wiegand, *Eds.*)
  - Paper in *Proceedings of IEEE* Jan 2005 (Sullivan & Wiegand)
  - Overview incl. FRExt: SPIE Aug 2004 (Sullivan, Topiwala, & Luthra)
  - Paper at SPIE VCIP 2005: Meta-overview and deployment (Sullivan)
  - Paper in *IEEE Communications Magazine*, Aug 2006 (Marpe, Wiegand, Sullivan)
  - Paper on Professional Extensions, *IEEE ICIP,* Sept 2007 (Sullivan *et al.*)
  - Wikipedia H.264/MPEG-4 AVC page
  - *IEEE Transactions on Circuits and Systems for Video Technology* Special Issue on Scalable Video Coding – Standardization and Beyond (Sept 2007) (Wiegand, Sullivan, Ohm, Luthra, *Eds.*)