The H.264 / MPEG-4 AVC Standard: Core Coding Technology and Recent Extensions

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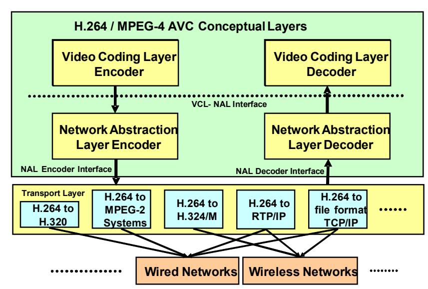
Outline

H.264 / AVC: A Brief Historical Review

- **1997**: ITU-T SG16/Q.6 (VCEG – Video Coding Experts Group) started standardization activity H.26L (“L” = long term)
- **August 1999**: 1st Test model (TML-1) chosen among 4 technical proposals from Telenor, Nokia, Strathclyde University, and HHI
- **December 2001**: Formation of the Joint Video Team (JVT) between VCEG and MPEG (Moving Pictures Experts Group) to finalize H.26L as a joint standardization project – H.264 / MPEG-4 Part 10 (**AVC: Advanced Video Coding**)
- **March 2003**: Final Draft International Standard of Version 1
- **May/July 2003**: Approval by parent bodies
- **Sept. 2004**: Finalization of Fidelity Range Extensions (“FRExt”) with a suite of 3 new “High” profiles
- **January 2005**: Scalable Video Coding (SVC) project launched

AVC: The Overall Conceptual Structure



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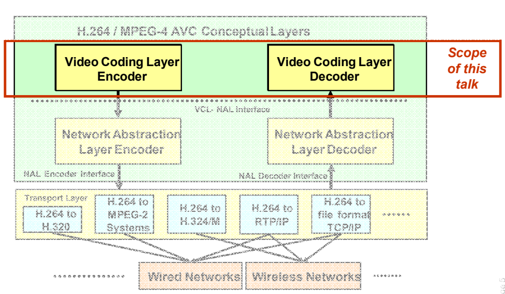
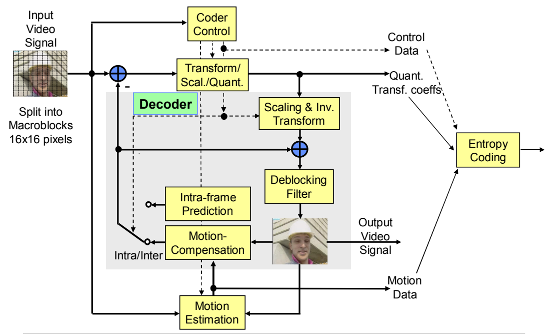


Outline

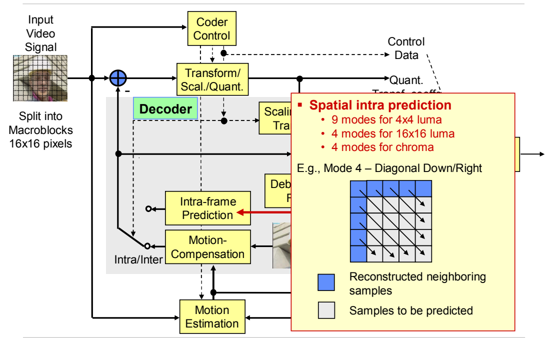
Basic Macroblock Coding Structure



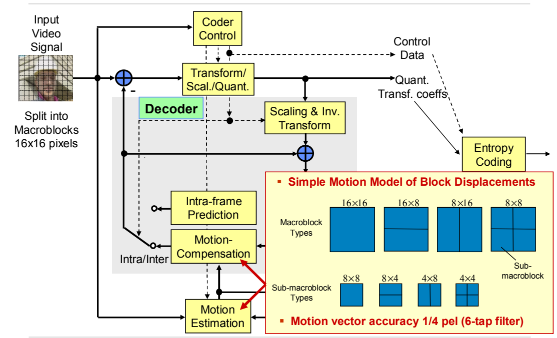
Main Innovative Features

- Video coding layer **of H.264/AVC is similar in spirit to other standards but** with important differences
- New **key features** are:
  - Enhanced motion compensation
  - Multiple reference pictures and generalized B pictures
  - Spatial intra prediction
  - Small blocks for transform coding
  - Integer block transform & adaptive transform block sizes
  - Improved deblocking filter
  - Enhanced entropy coding (CAVLC + CABAC)
- Substantial **bit rate savings (typically around 50%)** relative to any other standard for the same perceptual quality
- Network abstraction layer **takes lossy packet-switched networks into account**

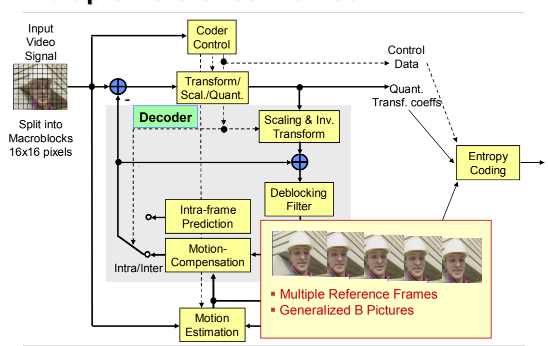
Spatial Intra Prediction



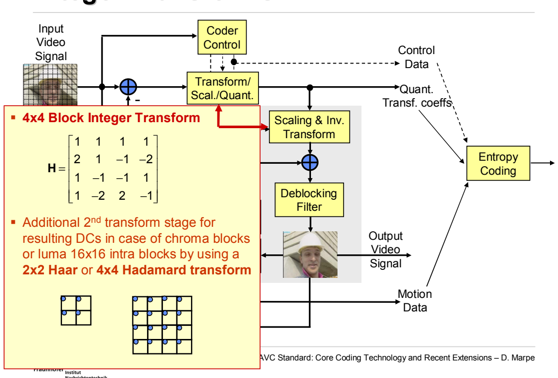
Accuracy of Motion Description



Multiple Reference Frames



Integer Transforms



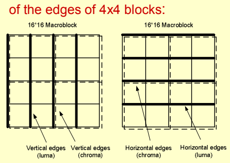
- **4x4 Block Integer Transform**

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

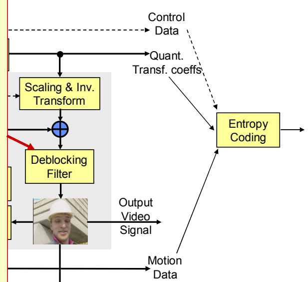
- Additional 2nd transform stage for resulting DCs in case of chroma blocks or luma 16x16 intra blocks by using a **2x2 Haar** or **4x4 Hadamard transform**

Deblocking Filter

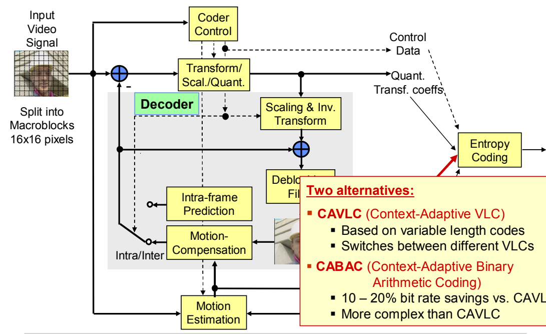
- **Deblocking within the loop** by filtering of the edges of 4x4 blocks:



- **Highly content adaptive filtering,** where filtering strength can be adjusted on three levels:
  - **On slice level** dependent on encoder (individual characteristics of the video)
  - **On edge level** dependent on inter/intra, motion, and coded residuals
  - **On sample level** with thresholds dependent on quantizer step size



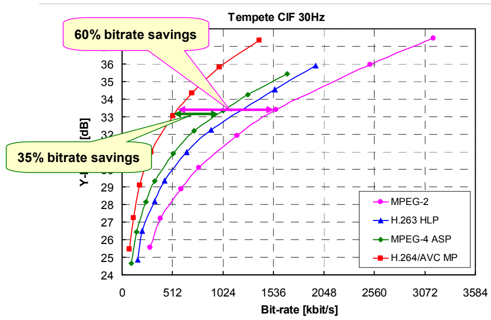
Entropy Coding



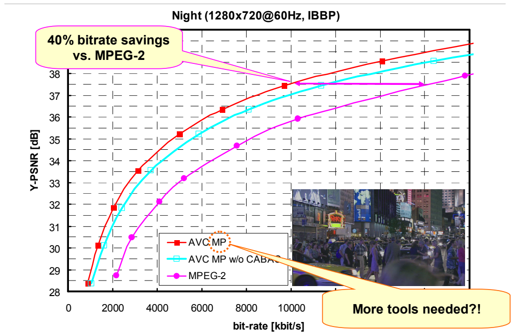
Two alternatives:

- **CAVLC** (Context-Adaptive VLC)
  - Based on variable length codes
  - Switches between different VLCs
- **CABAC** (Context-Adaptive Binary Arithmetic Coding)
  - 10 – 20% bit rate savings vs. CAVLC
  - More complex than CAVLC

Example Coding Efficiency Comparison



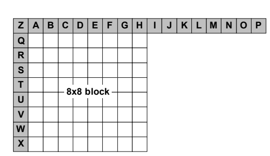
Another Example



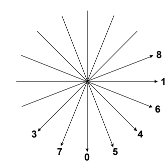
Outline

New Coding Tools in FRExt (1/2)

- 9 additional **8x8 spatial intra prediction** modes (for luma only)
- Choice of intra prediction mode and block size (4x4, 8x8, or 16x16) on macroblock (MB) level



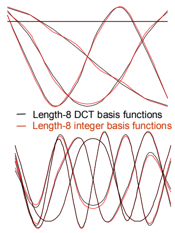
A - X, Z: Constructed samples of neighboring blocks



New Coding Tools in FRExt (2/2)

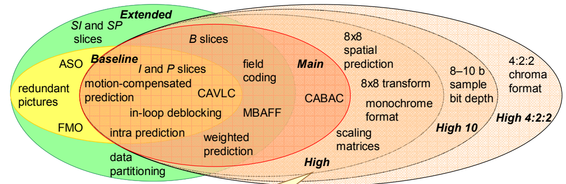
- Additional **8x8 block size integer transform** for luma
- Choice between 4x4 and 8x8 transform (on an MB level) under certain constraints imposed by the prediction block size

$$\mathbf{T}_8 = \begin{bmatrix} 8 & 8 & 8 & 8 & 8 & 8 & 8 & 8 \\ 12 & 10 & 6 & 3 & -3 & -6 & -10 & -12 \\ 8 & 4 & -4 & -8 & -8 & -4 & 4 & 8 \\ 10 & -3 & -12 & -6 & 6 & 12 & 3 & -10 \\ 8 & -8 & -8 & 8 & 8 & -8 & -8 & 8 \\ 6 & -12 & 3 & 10 & -10 & -3 & 12 & -6 \\ 4 & -8 & 8 & -4 & -4 & 8 & -8 & 4 \\ 3 & -6 & 10 & -12 & 12 & -10 & 6 & -3 \end{bmatrix}$$



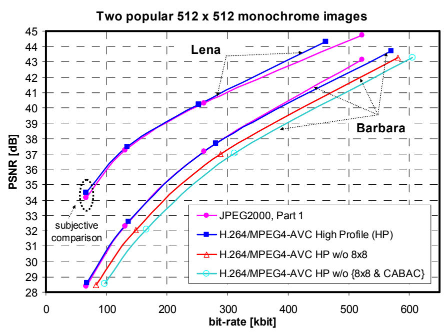
- Separable transform: $\mathbf{C}_{8x8} = \mathbf{T}_8 \cdot \mathbf{B}_{8x8} \cdot \mathbf{T}_8^T$
- Easy implementation via fast butterfly operations using shifts and adds only
- Close approximation of length-8 DCT

H.264/AVC Profiles and Related Tools



High Profile (HP) is likely to replace Main Profile (MP) in typical consumer applications!

FRExt: Intra Coding Performance



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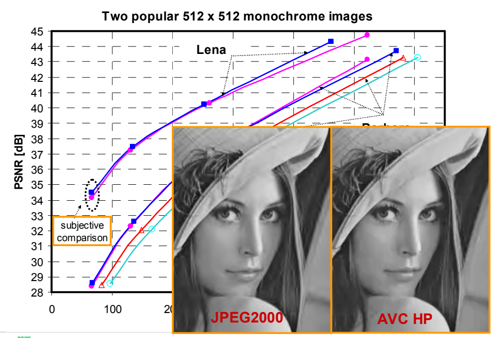
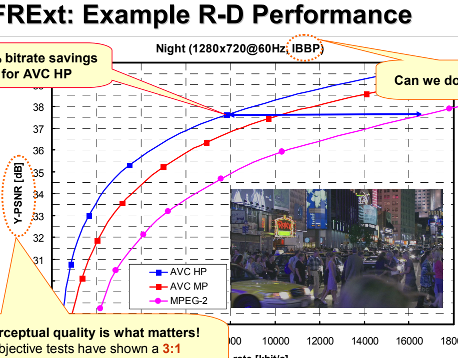


FRExt: Example R-D Performance

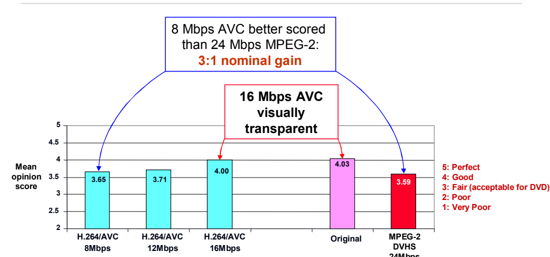
52% bitrate savings for AVC HP

Can we do better?



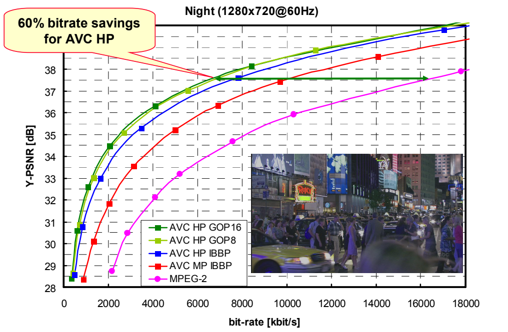
- **Perceptual quality is what matters!**
- Subjective tests have shown a **3:1 nominal gain** for AVC HP vs MPEG-2 (as shown on next slide!)

AVC HP vs MPEG-2: Subjective Results



- Test conducted in 2004 by Blu-Ray Disk Association (BDA) with studio participants
- Three movie clips at 1980x1080@24Hz (1080p)

R-D Performance using Hierarch. B Pics



New Types of Temporal Referencing

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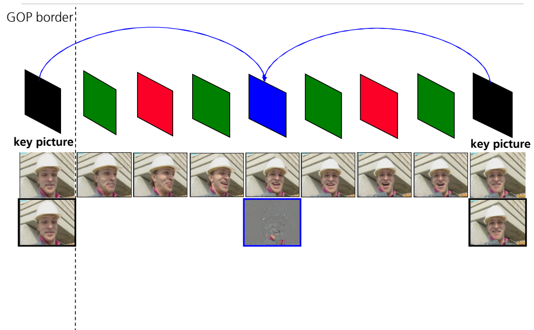

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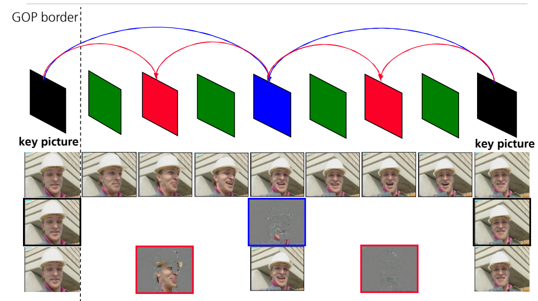

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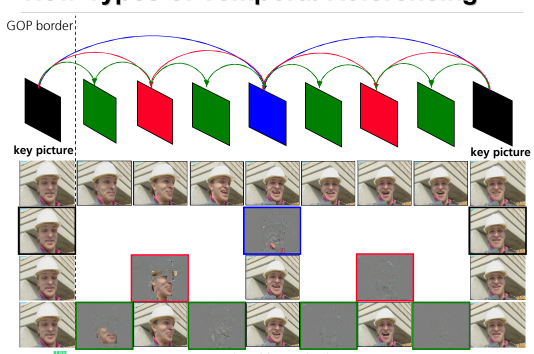
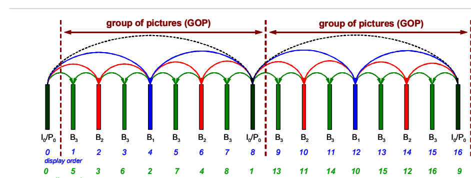


Hierarchical B Pictures



- Decoupling of display order and coding order
- Decoupling of reference ability and picture type (not possible with previous standards)
- Can provide **temporal scalability**
- Can also be used for **SNR scalability**
- Can **improve coding efficiency** by proper bit allocation

Technical Contributions of HHI

- More than 80 standard contributions to H.264/AVC since 1999
- HHI Proposals adopted as **normative parts** of H.264/AVC:
  - Context-based adaptive binary arithmetic coding (CABAC) including fast binary M coder
  - Tree-structured macroblock partition
  - Multiple-frame / multi-hypothesis prediction
  - Adaptive 8x8 transform / spatial intra prediction (together with RWTH Aachen, Germany and Broadcom Corp., USA)
- HHI Proposals adopted as **non-normative parts** of H.264/AVC:
  - Rate-Distortion (R-D) optimized coder control
  - Modified R-D optimized coder control for error-prone packet-switched networks (together with Munich TU)
  - Improved coder control for hierarchical B pictures

Administrative Support of HHI

- Co-Chair of Joint Video Team and Associate Chair of MPEG Video
  - Associate Rapporteur of VCEG: T. Wiegand
- Co-Editors of Standards
  - Co-Editor of AVC, Version 1-3: T. Wiegand
  - Co-Editor of FRExt Amendment (AVC Version 3): D. Marpe
  - Co-Editor of SVC Amendment: H. Schwarz
  - Editor of the visual part of TS 102 005 (DVB-AVC): T. Wiegand
- Maintenance of the Reference Software
  - Software Coordinator: K. Sühring
- Chairs of different JVT Ad-Hoc Groups (AHG)
  - Test Model and Ref. Software AHG: K. Sühring
  - Text and Editing AHG: T. Wiegand
  - CABAC AHG: D. Marpe

H.264 / MPEG-4 AVC Adoption Status

- **Mobile TV** (use of Baseline profile)
  - **Digital Video Broadcasting – Handheld (DVB-H)**
  - **Digital Multimedia Broadcasting (DMB)**
  - **Multimedia Broadcast/Multicast Service (MBMS)**
- **SDTV / HDTV Broadcast / IPTV** (use of High/Main profile)
  - **DVB**: revised implementation guide TS 101 154 (DVB-C/S/T)
  - **Direct-to-home broadcast satellite**, e.g.,
    - DirecTV, Dish Network (USA)
    - Sky HD, BBC HD (UK and Ireland)
    - Premiere, ProSiebenSat.1 (Germany)
  - **Terrestrial HDTV** pay-TV services in France

- **Media Storage** (High profile)
  - **HD-DVD** specification of the DVD Forum
  - **BD-ROM** specification of the Blu-Ray Disc

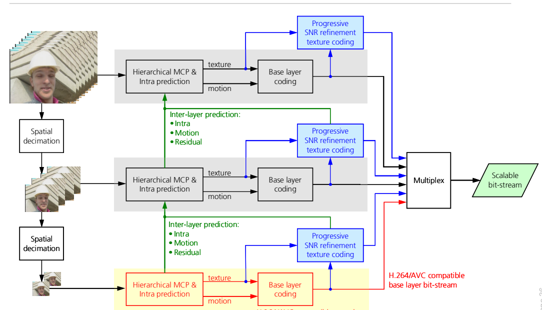
- **Gaming / Entertainment** (Baseline/Main/High profile)
  - **Sony PSP and PS 3**
  - **Apple iPod**
  - **Microsoft Xbox** (announced for 2007)

Outline

More Functionality

- More flexible source coding, i.e., **scalability is needed**
  - **Simple adaptation** to different **bit rates**, **frame rates** or **spatial resolutions** of the video content by removal of parts of a bit stream
  - However, scalability is difficult to realize and often causes severe **penalties in coding efficiency**
- ***Idea:*** **Re-use as much** of the existing H.264 / MPEG-4 AVC components such as hierarchical motion-compensated prediction together with some **new coding elements**
- **Basic architecture designed by Fraunhofer HHI** *(Schwarz, Wiegand, Marpe; started in Summer 2003)*

Architecture of AVC Scalable Extension



Spatial Scalability

- **Motion information for spatial scalable coding**
  - The trade-off between motion and residual rate highly influences the coding efficiency in hybrid video coding
  - Separate motion fields should be used for each layer in spatial scalable video coding
- **General approach for spatial scalable coding**
  - Independent coding of spatial layers with layer-specific motion parameters, but a common coding structure
  - Additional inter-layer prediction mechanisms in order to employ base layer information for efficient spatial/SNR scalable coding
- **Inter-layer prediction techniques**
  - Inter-layer intra prediction (similar to older standards)
  - Inter-layer prediction of motion information
  - Inter-layer prediction of residual information (prediction error)

Current Status of Standardization

- **HHI proposal was selected as the first Working Draft** (WD1) of prospective Scalable Video Coding (**SVC**) standard *(January 2005)*
- Most components are reused as specified in the standard
- Support of spatial, temporal and (coarse/fine-grain) SNR scalability as well as their combination
- Slightly worse coding efficiency of scalable extension (on avg.) compared to H.264/MPEG-4 AVC single layer coding
- *But*: Still work in progress ...
- Standardization work is conducted in the Joint Video Team (JVT)
- SVC will be an **Annex / Amendment to H.264 / MPEG-4 AVC**
- Official naming: **H.264 Annex F** / **MPEG-4 AVC: 2007/AMD1**
- Final draft SVC standard expected to be **ready in April 2007**

Questions & Comments ?