Overview of International Video Coding Standards (preceding H.264/AVC)

Gary J. Sullivan, Ph.D.

ITU-T VCEG Rapporteur | Chair
ISO/IEC MPEG Video Rapporteur | Co-Chair
ITU/ISO/IEC JVT Rapporteur | Co-Chair

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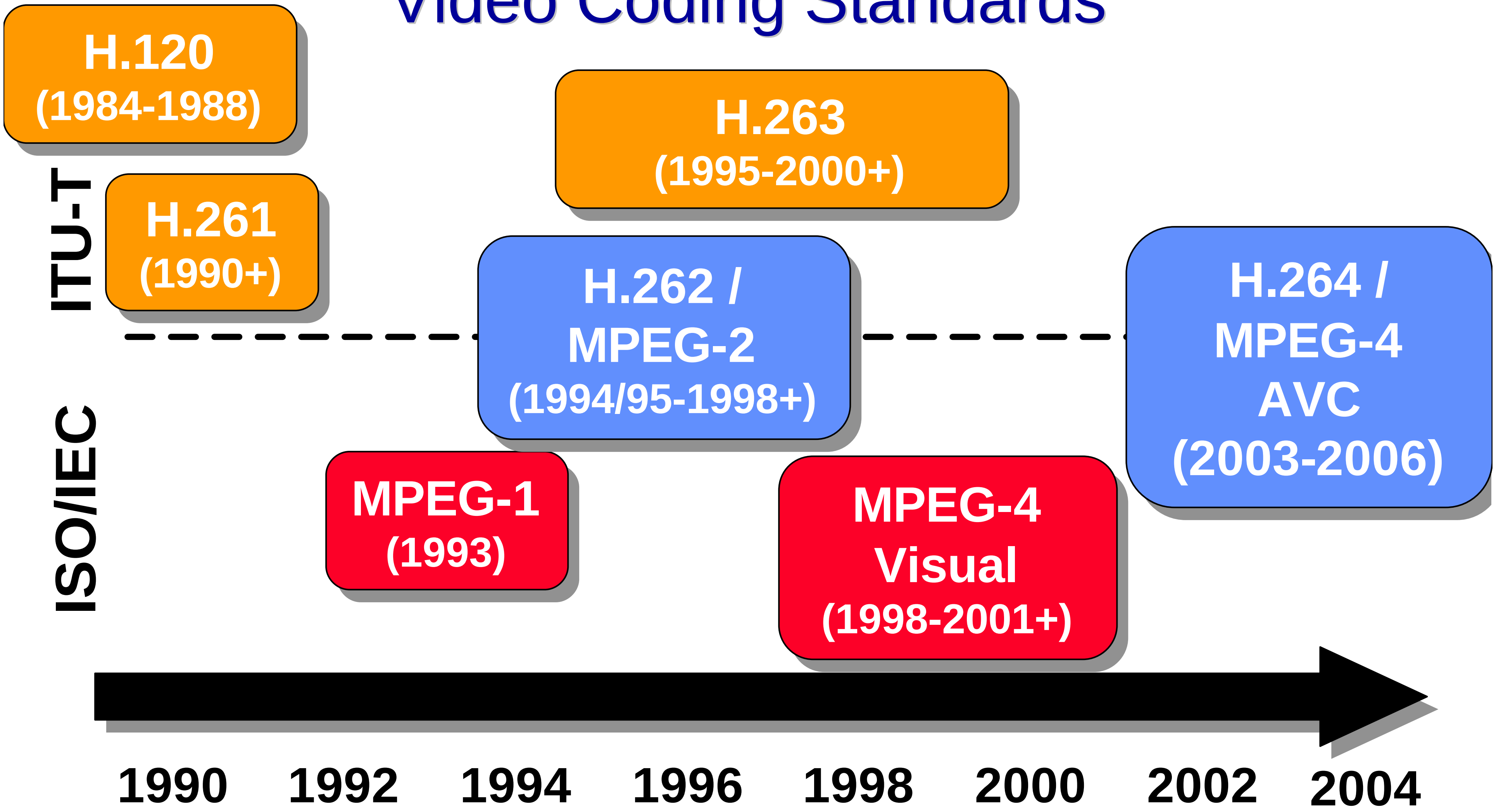
Video Coding Standardization Organizations

- Two organizations have dominated 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)

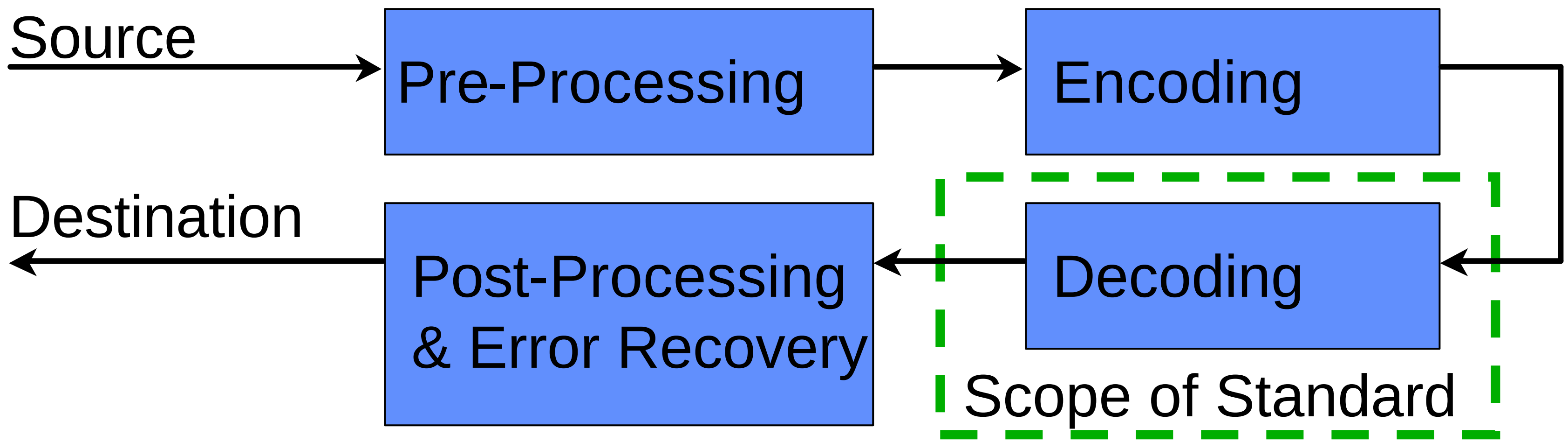
    International Standardization Organization and International Electrotechnical Commission, Joint Technical Committee Number 1, Subcommittee 29, Working Group 11

Chronology of International Video Coding Standards



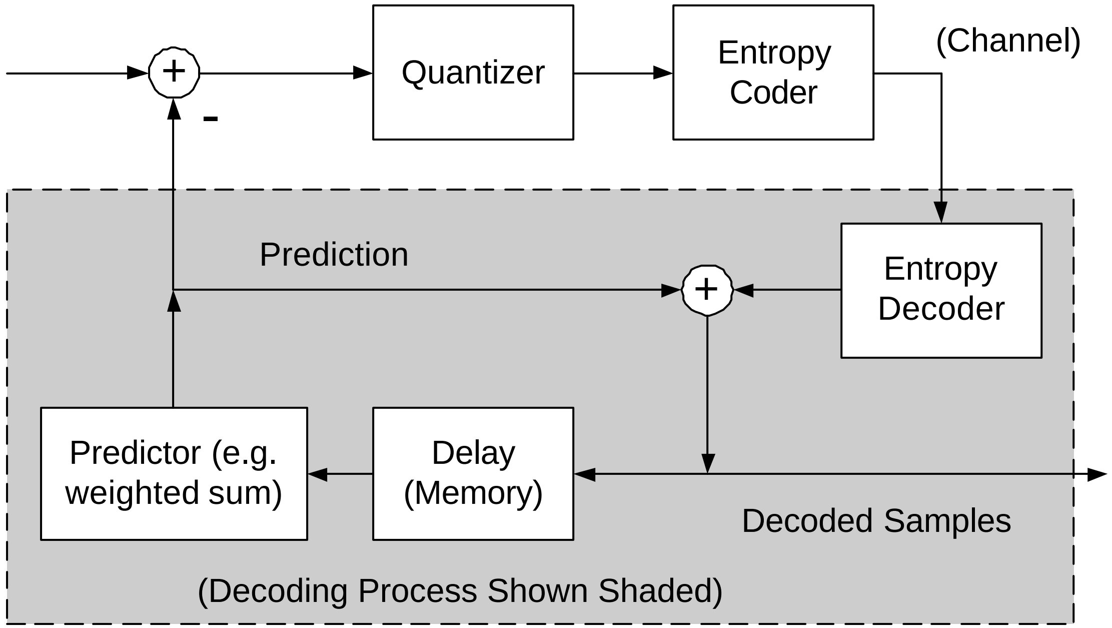
The *Scope* of Picture and Video Coding Standardization

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



Predictive Coding and DPCM

- Separate quantization of each sample is known as pulse-code modulation (PCM)
- *Predictive Coding or Differential PCM:* Generate an estimate for the value of the input data, and encode only the remaining difference.



H.120 : The First Digital Video Coding Standard

- ITU-T (ex-CCITT) Rec. H.120: The first digital video coding standard (1984)
  - v1 (1984) had conditional replenishment, DPCM, scalar quantization, variable-length coding, switch for quincunx sampling
  - v2 (1988) added motion compensation and background prediction
  - Operated at 1544 (NTSC) and 2048 (PAL) kbps
  - Few units made, essentially not in use today

"Intra" Picture Coding by DCT

Basic "intra" image representation: Discrete Cosine Transform (DCT) (early '70s, ITU+ISO JPEG approved '92):

- Analyze 8x8 blocks of image according to DCT frequency content (images tend to be smooth)
- Find magnitude of each discrete frequency within the block
- Round off ("quantize") the amounts to scaled integer values ('50s, '60s, ...)
- Send integer approximations to decoder using "Huffman" variable-length codes (VLC, early '50s)

The Discrete Cosine Transform

- The DCT (unitary type II DCT):

$$F_{m,n}(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \left(c_u \sqrt{\frac{2}{M}} \right) \left(c_v \sqrt{\frac{2}{N}} \right) f(mM + x, nN + y) \cdot \cos\left[\frac{(2x+1)up}{2M} \right] \cdot \cos\left[\frac{(2y+1)vp}{2N} \right]$$

- The Inverse DCT (unitary type III DCT):

$$\hat{f}(mM + x, nN + y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} \left(c_u \sqrt{\frac{2}{M}} \right) \left(c_v \sqrt{\frac{2}{N}} \right) \hat{F}_{m,n}(u,v) \cdot \cos\left[\frac{(2x+1)up}{2M} \right] \cdot \cos\left[\frac{(2y+1)vp}{2N} \right]$$

- Definition of Constants

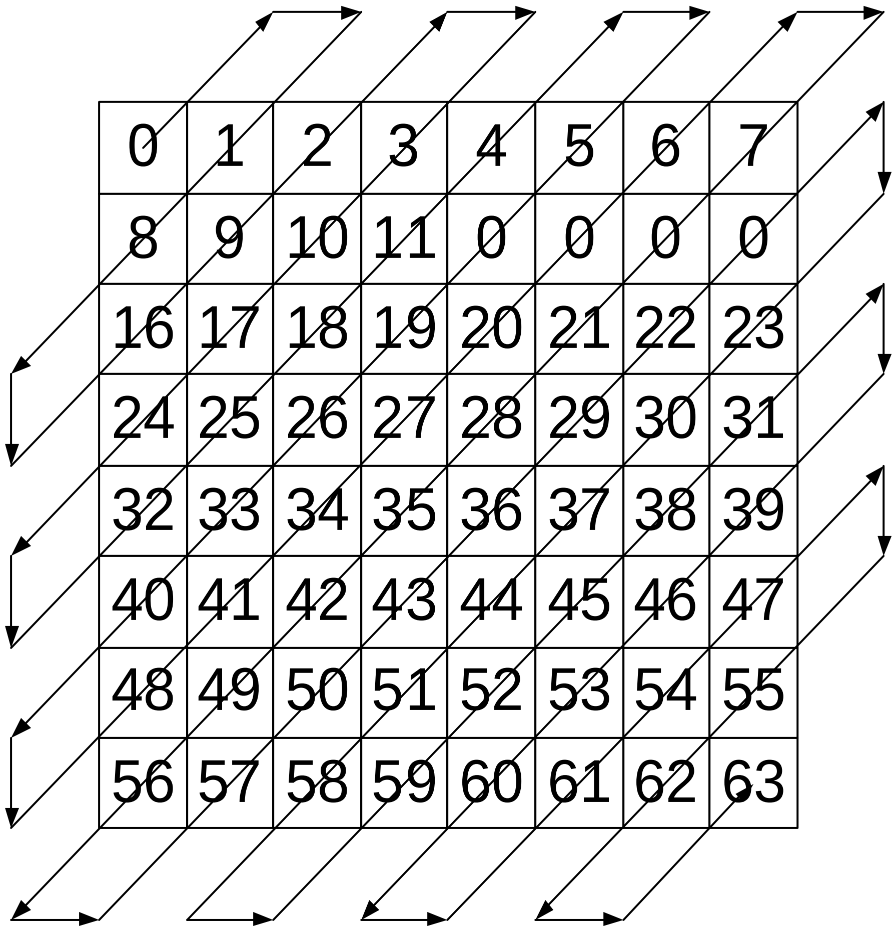
$c_u = 1/\sqrt{2}$ for $u = 0$, otherwise 1.

$c_v = 1/\sqrt{2}$ for $v = 0$, otherwise 1.

$M = 8$ in current visual standards

$N = 8$ in current visual standards

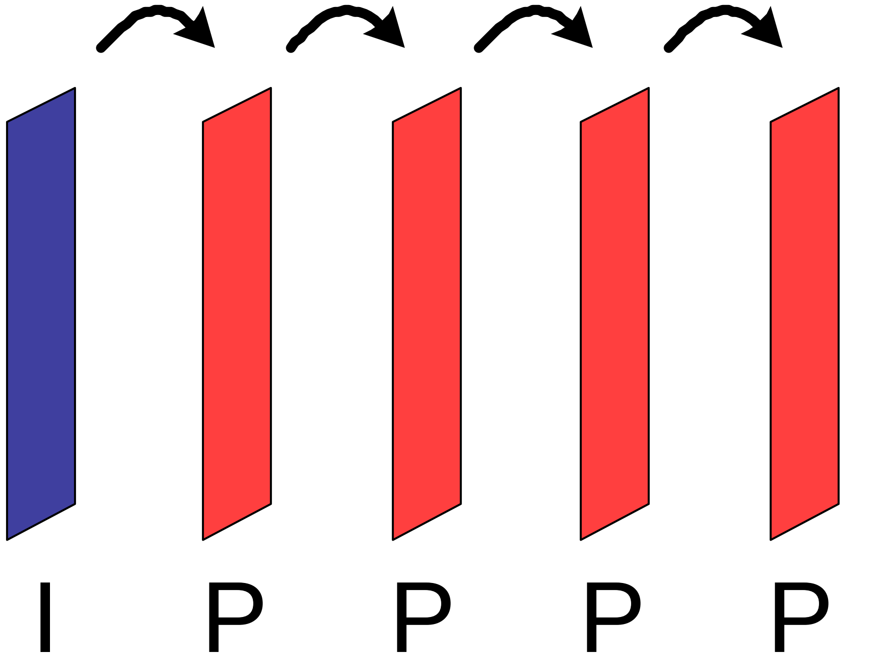
Coefficient Scan Order: The Zig-Zag Scan



Interframe Motion Prediction

- Large areas of images stay the same from frame to frame, changing mostly due to motion
- *Conditional Replenishment:* Can signal to leave a block area of the image unchanged, or replace it with new data
- *Interframe Difference Coding:* Could encode a refinement to the value of an area
- *Displaced Frame Difference Coding:* Can predict an image area by copying some nearby part of the previous image (motion compensation) and optionally adding some refinement

P-Picture Predictive Coding

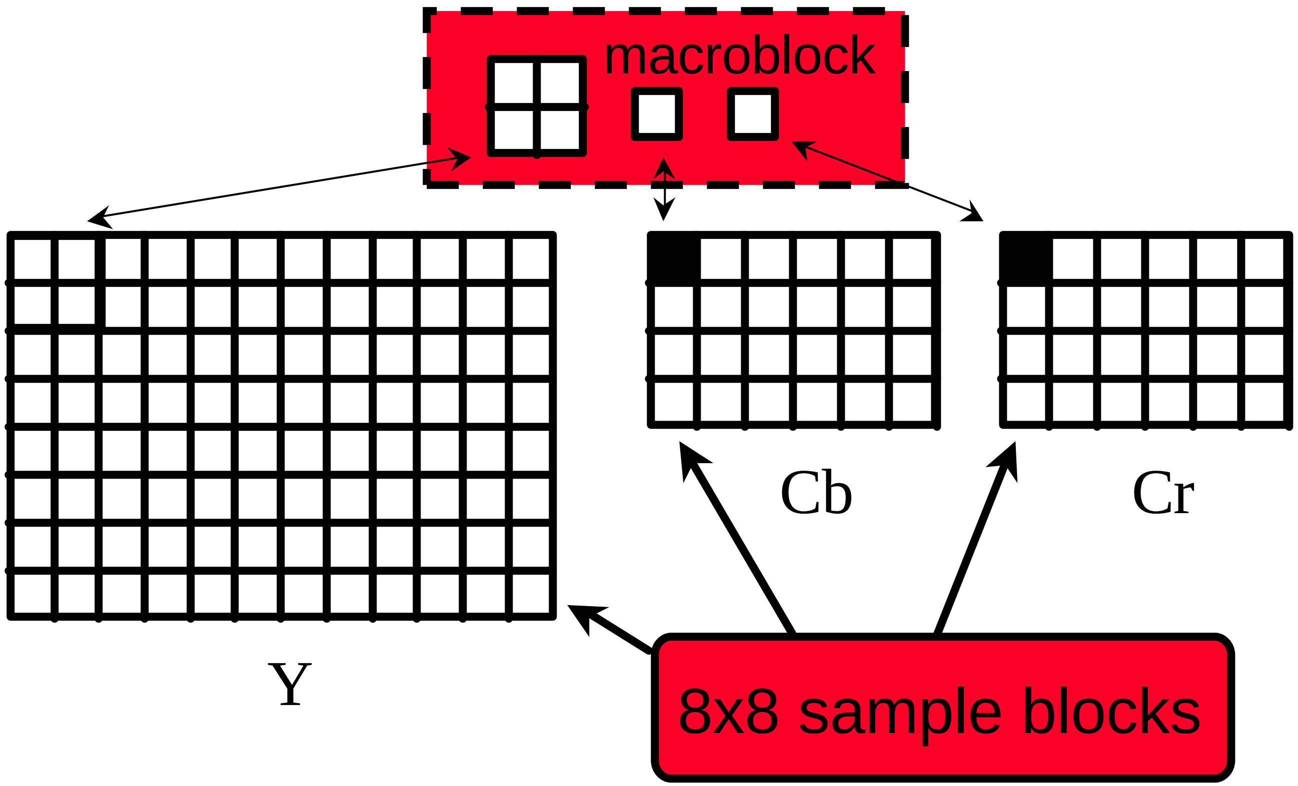


H.261: The Basis of Modern Video Compression

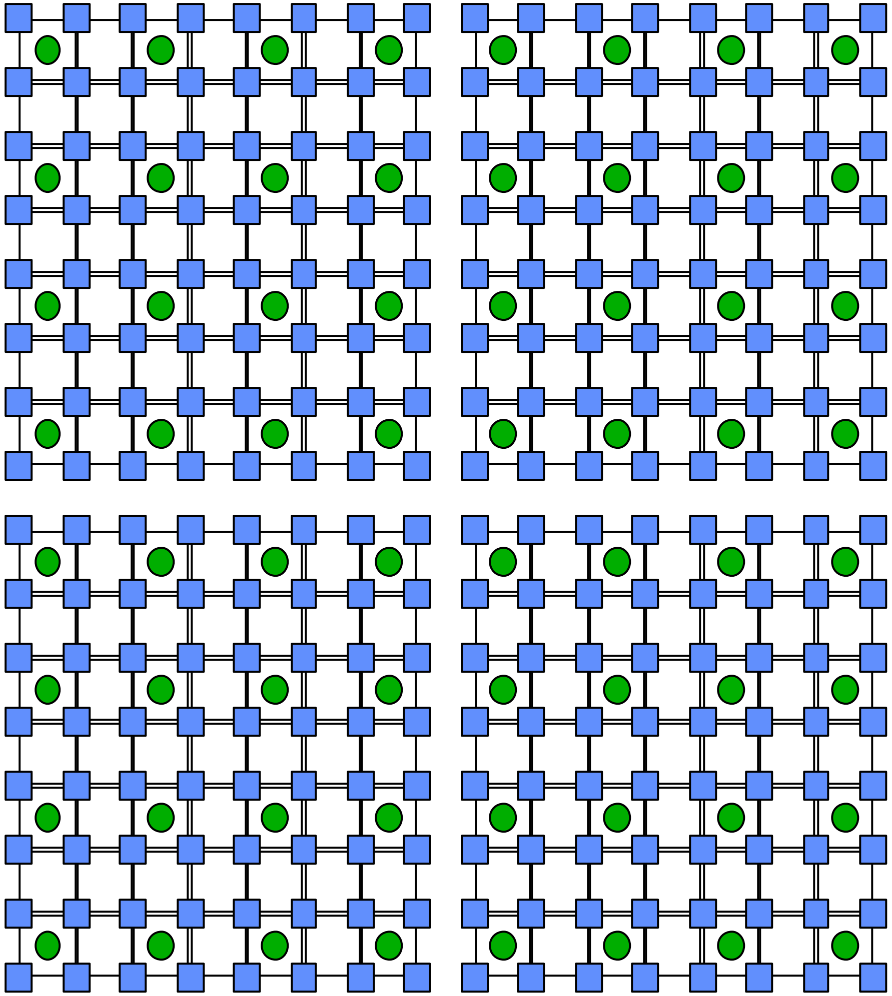
- ITU-T (ex-CCITT) Rec. H.261: The first widespread practical success
  - First design (late ‘90) embodying typical structure dominating today:
    - **16x16 macroblock motion compensation,**
    - **8x8 DCT,**
    - **scalar quantization,**
    - **zig-zag scan, and**
    - **run-length**
    - **variable-length coding**
  - Key aspects later dropped by other standards: loop filter, integer motion comp., 2-D VLC, header overhead
  - v2 (early ‘93) added a backward-compatible high-resolution graphics trick mode
  - Operated at 64-2048 kbps
  - Still in use, although mostly as a backward-compatibility feature – overtaken by H.263

Blocks and Macroblocks

The luma and chroma planes are divided into blocks. Luma blocks are associated with Cb and Cr blocks to create a macroblock.



H.261&3 Macroblock Structure



= luma pixel

= chroma pixel

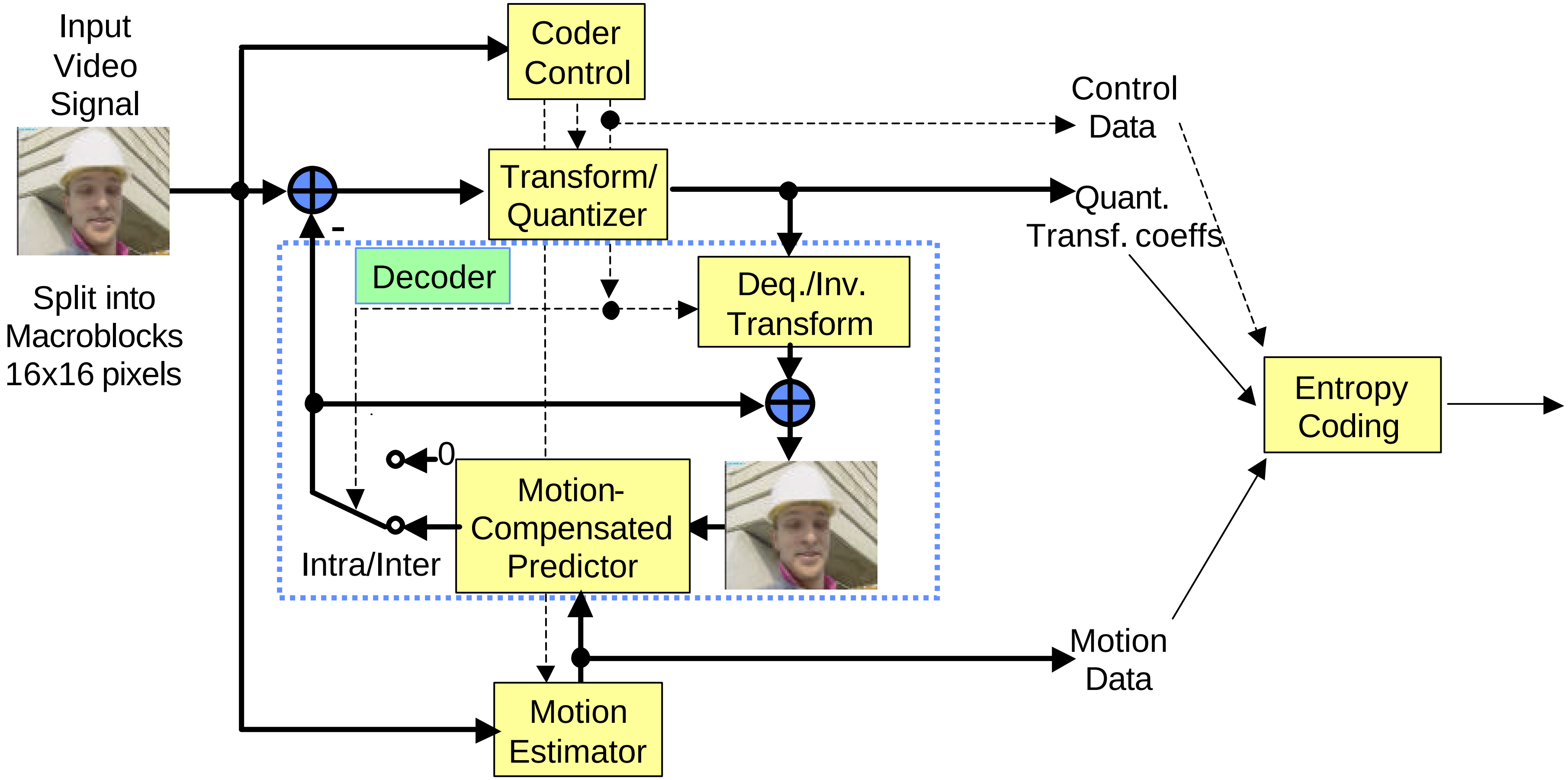
(two chroma fields)

Intra/Inter Decisions:
16x16 macroblock
DCT of 8x8 blocks

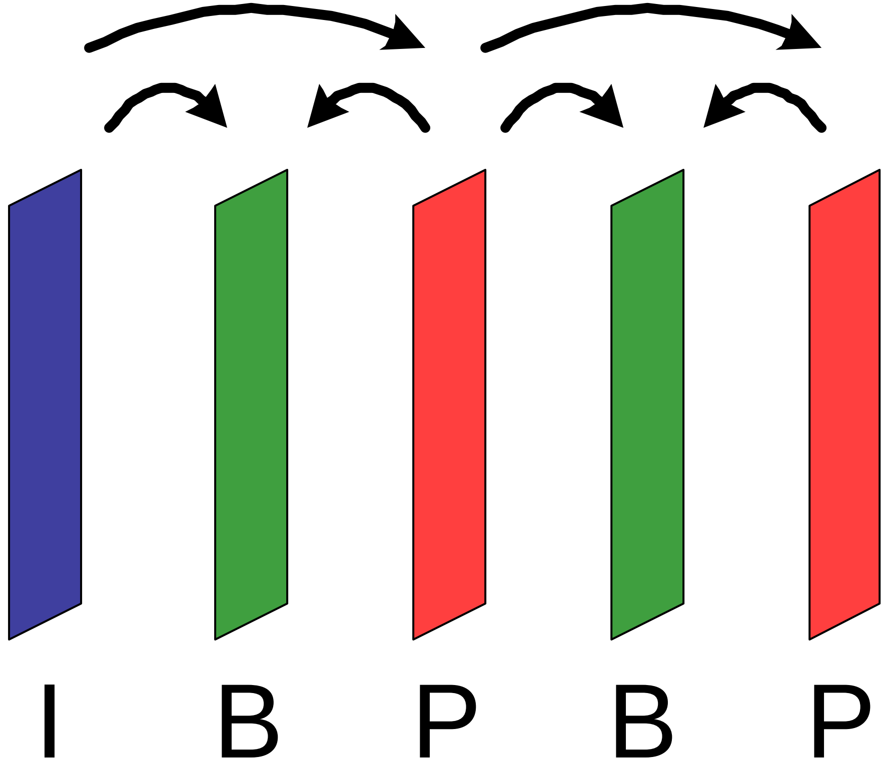
H.261:
16x16 1-pel motion

H.263:
16x16 1/2-pel motion
or (AP mode)
8x8 1/2-pel motion
with overlapping

Basic Hybrid Structure of H.261, etc. (late '90)



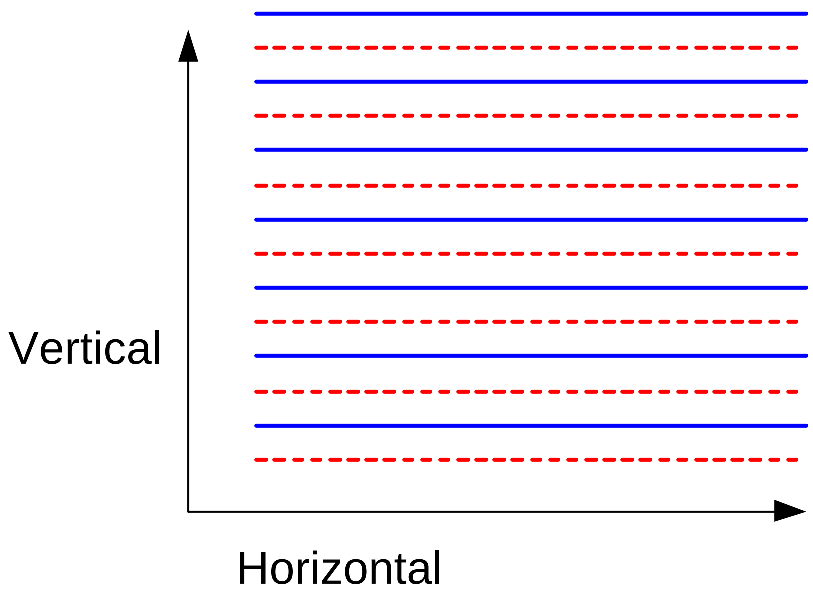
Predictive Coding with B Pictures

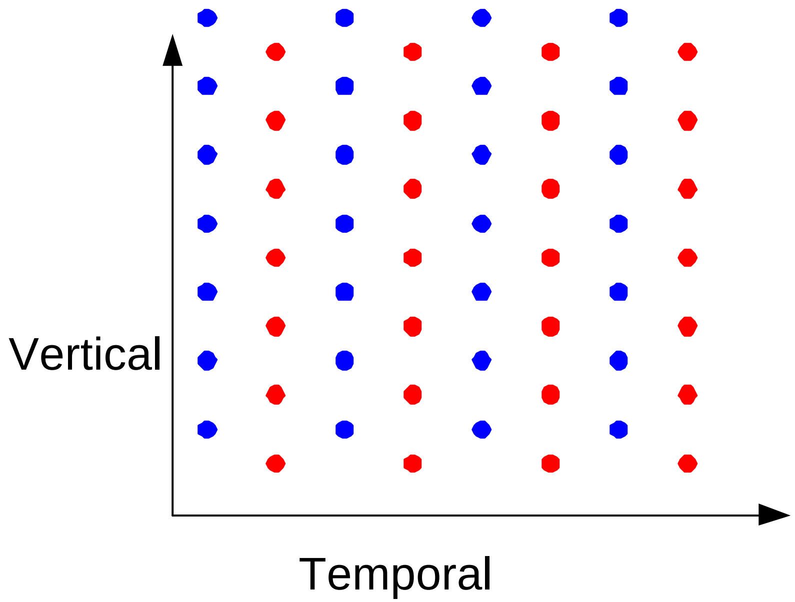


MPEG-1:
Practical Video at Higher Rates than H.261

- Formally ISO/IEC 11172-2 (‘93), developed by ISO/IEC JTC1 SC29 WG11 (MPEG) – use is fairly widespread (esp. Video CD in Asia), but mostly overtaken by MPEG-2
  - Superior quality to H.261 when operated a higher bit rates (≥ 1 Mbps for CIF 352x288 resolution)
  - Can provide approximately VHS quality between 1-2 Mbps using SIF 352x240/288 resolution
  - Technical features inherited from H.261
    - **16x16 macroblocks**
    - **16x16 motion compensation,**
    - **8x8 DCT,**
    - **scalar quantization,**
    - **zig-zag scan, and**
    - **run-length**
    - **variable-length coding**
  - Technical features added:
    - **Bi-directional motion prediction**
    - **Half-pixel motion**
    - **Slice-structured coding**
    - **DC-only “D” pictures**
    - **Quantization weighting matrices**

Interlaced Video
(Welcome to the 1940 Analog World)





MPEG-2/H.262: Even Higher Bit Rates and Interlace

- Formally ISO/IEC 13818-2 & ITU-T H.262, developed ('94) jointly by ITU-T and ISO/IEC SC29 WG11 (MPEG) – Now in very wide use for DVD and standard and high-definition DTV (the most commonly used video coding standard)
  - Primary new technical features:
    - **Support for interlaced-scan pictures**
    - **Increased DC quantization precision**
  - Also
    - **Various forms of scalability (SNR, Spatial, breakpoint)**
    - **I-picture concealment motion vectors**
  - Essentially the same as MPEG-1 for progressive-scan pictures, and MPEG-1 forward compatibility required
  - Not especially useful below 2-3 Mbps (range of use normally 2-5 Mbps SDTV broadcast, 6-8 DVD, 20 HDTV)
  - Essentially fixed frame rate

H.263: The Next Generation

- ITU-T Rec. H.263 (v1: 1995): The next generation of video coding performance, developed by ITU-T – the current premier ITU-T video standard (has overtaken H.261 as dominant videoconferencing codec)
  - **Superior quality to prior standards at all bit rates (except perhaps for interlaced video)**
  - **Better by a factor of two at very low rates**
  - **Versions 2 (late 1997/early 1998) & v3 (2000) later developed with a large number of new features**
  - **Profiles defined early 2001**
  - A somewhat tangled relationship with MPEG-4

What Was in H.263 Version 1?

- "Baseline" Algorithm Features beat H.261
  - Half-pel motion compensation (also in MPEG-1)
  - 3-D variable length coding of DCT coefficients
  - Median motion vector prediction
  - More efficient coding pattern signaling (?)
  - Deletable GOB header overhead (also in MPEG-1, but not 2?)
- Optional Enhanced Modes
  - Increased motion vector range with picture extrapolation
  - Variable-size, overlapped motion with picture extrapolation
  - PB-frames (bi-directional prediction)
  - Arithmetic entropy coding
  - Continuous-presence multipoint / video mux

H.263+ Feature Categories

- Error resilience
- Improved compression efficiency (e.g., 15-25% overall improvement over H.263v1)
- Custom and Flexible Video Formats
- Scalability for resilience and multipoint
- Supplemental enhancement information

H.263++ Version 3 Features

- **Annex U**: Fidelity enhancement by macroblock and block-level reference picture selection – a significant improvement in picture quality
- **Annex V**: Packet Loss & Error Resilience using data partitioning with reversible VLCs (roughly similar to MPEG-4 data partitioning, but improved by using reversible coding of motion vectors rather than coefficients)
- **Annex W**:Additional Supplemental Enhancement Information
  - IDCT Mismatch Elimination (specific fixed-point fast IDCT)
  - Arbitrary binary user data
  - Text messages (arbitrary, copyright, caption, video description, and URI)
  - Error Resilience:
    - Picture header repetition (current, previous, next+TR, next-TR)
    - Spare reference pictures for error concealment
  - Interlaced field indications (top & bottom)

MPEG-4 “**Visual**”: Baseline H.263 and Many Creative Extras

- MPEG-4 **part 2** (v1: early 1999), formally ISO/IEC 14496-2
- Contains the H.263 baseline design
  - **coding efficiency enhancements (esp. at low rates)**
- Adds many creative new extras:
  - **more coding efficiency enhancements**
  - **error resilience / packet loss enhancements**
  - **segmented coding of shapes**
  - **zero-tree wavelet coding of still textures**
  - **coding of synthetic and semi-synthetic content,**
  - **10 & 12-bit sampling,**
  - **more**
  - **v2 (early 2000) & v3 (early 2001) later added**

MPEG-4 **Visual** Focus: Simple Profile

- The most basic video coding profile of MPEG-4
- No shape coding
- Progressive-scan video only
- Most popular in low cost / low rate / low resolution apps (e.g., mobile) – top bit rate & resolution limited
- Basic contents
  - H.263 baseline
  - Motion vectors over picture boundaries
  - Variable block-size motion compensation
  - Intra DCT coefficient prediction
  - Handling of four streams in most levels
  - Error / packet-loss features – data partitioning, RVLC

MPEG-4 **Visual** Focus: Advanced Simple Profile

- Target goal: General rectangular video with improved coding efficiency
- Progressive-scan and interlaced video support
- Up to SDTV resolution
- Basic contents
  - All of Simple profile
  - B pictures
  - Global motion compensation
  - Quarter-sample motion compensation
  - Interlace handling

MPEG-4 **Visual** Focus: Studio Profile

- Target goal: studio & professional use
- Progressive-scan and interlaced video support
- Up to very high resolution and bit rate
- Basic contents
  - Enhanced-accuracy IDCT
  - B pictures
  - 10 & 12 bit sample accuracy
  - 4:2:2 & 4:4:4 chroma sampling structures

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")
- **August 1999**: 1st test model (TML-1)
- **July 2001:** MPEG open call for technology: H.26L demo'ed
- **December 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
- January '05 Scalable Video Coding launched

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
- **Additional version 2 objectives (in FRExt):**
  - 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)

AVC Structure