Introduction

Video CODEC[1] technology is mainly used in two situations:

1) The bitstream can be stored and downloaded to the player decoder on a physical medium such as a Blu-Ray DVD, storage dongle, or a hard drive.

2) The bitstream can be delivered linearly via broadcast distribution or over an IP network from a source location A and received at a destination location B. The packetized data stream can be encapsulated as a series of MPEG-2 Transport packets for broadcast or in an IP packet for streaming. Added restrictions that can limit the number of bits transmitted are available bandwidth and real-time processing demands. This approach can stream encoded camera capture content or pre-encoded VOD files.

The data rate for uncompressed UHD Video content can be prohibitive, especially for visually high-intensity (Sports) content requiring higher framerates.

As an example: Video data rate = [Pixels/Frame] x [Frames/sec] x [Bits/Pixel]
For 4Kp60: [3840x2160]x[60]x[24] = ~12 Gbits/sec.

This data rate is beyond the capability of most consumer-available networks and, thus, not commercially viable.

At current bandwidth capacity, storage limits are at the TB level, with consumer network bandwidth capacities typically at 10-20 Mbps. Lossless Data Compression, looking at individual pixels discretely, only gives a 2 or 3x compression efficiency. However, what is needed for current technologies requires an order of ~100x compression efficiencies. Further efficiencies can be attained by looking across groups of pixels and several frames. This intraframe processing takes advantage of the spatial and temporal redundancies, and using tools such as motion prediction and compensation, intra-prediction, and spatial transforms further reduce the data rate requirement.

In addition, video CODEC technologies achieve additional efficiency by incorporating lossy compression techniques (e.g., quantization, motion vector prediction) combined with knowledge of perceptual modeling based on the human visual system (HVS). These efficiencies are achieved by removing less perceptual information (e.g., removing higher spatial frequencies through frequency-weighted quantization). With continued advancements in compression technology, video CODECs such as HEVC and VVC now offer two orders of magnitude bit rate reduction compared to uncompressed source videos.

UHD CODECS

A video CODEC processes pixels of the image information to compress the data with minimal perceptual visual impact to reduce bandwidth or video file size. The originating master content is extracted as a sampled video signal, organized as sets of video frames intended to be played at the specified resolution and framerates. The video content is encoded into a packetized set of bits known as a bitstream, which, when received by the decoder, can be rendered out a set of pixels at the specified resolution and frame rate that now represents the video content.

[1] CODEC is an abbreviation for enCOder/DECoder

Video CODECs reflect the growth in processing power, storage capacity, and bandwidth availability in each generation. This evolution enables the development of practical commercial and consumer product delivery of Ultra HD programs. Some dates and parameters of recent CODEC-developments are:

Table 1. MPEG Video Codec Comparisons (2023)

Video CODEC[1]	Organization	Date	Typical Distribution Rates[2] (4kp60)
Advanced Video Coding (AVC/H.264)	ISO/IEC & ITU (MPEG)	2004	28-36 Mbps
Higher Efficiency Video Coding (HEVC/H.265)	ISO/IEC & ITU (MPEG)	2013	14-18 Mbps
Versatile Video Coding (VVC/H.266)	ISO/IEC & ITU (MPEG)	2019	7-9 Mbps

Notes: 1. There are established non-MPEG CODECs described in the Guidelines Yellow Book in section 7.4.1. Examples of non-MPEG CODECs are AV1 in 2018 from the Alliance of Open Media (AOM) and AVS, a family of codecs (IEEE 1857.4)

2. These bitrates illustrate the relative coding efficiency rates between each generation of MPEG CODECs. Services may sometimes use higher bitrates to preserve higher visual qualities for more complex content. The bitrate required to achieve a particular quality can vary between encoder brands and generally decreases over time.

The development of Ultra High Definition (UHD) Content and workflows occurred around 2015 and was factored into the HEVC requirements and included in later CODEC efforts. Earlier CODEC efforts can handle UltraHD content (e.g., AVC/H.264). While the specifications have been updated to include carriage of UltraHD formats, existing deployment of this older CODEC technology makes it difficult to update or redeploy in support of UltraHD.

Features of CODECS

As part of the encoding functionality, the CODEC must provide random access for playback functionalities in the bitstream, such as Seek, FFWD, or RWD. The bitstream also carries video signaling information through the carriage of video parameters so that the decoding device can identify and present the bitstream while decoding it. Random access to the bitstream can be structured by constructing points in the bitstream (frames) with no temporal dependencies on other frames typically referenced as I, IDR, or keyframes. These can also be aligned with the segmentation requirements needed for OTT delivery.

Video Parameters can be identified using "profiles" or the actual carriage of a determined video parameter. Profiles restrict the CODEC's toolset and the type of video signal to allow for cost-effective decoders. Specific encoding parameters are carried via Higher-Level Syntax constructs in the bitstream.

Additional information to correctly process the bitstream (beyond decoding) is carried in separate data packets in the bitstream called SEI (Supplemental Enhancement Information). For UltraHD, this may include dynamic metadata information for HDR10+, SL-HDR1, or Dolby Vision.

Video CODECS in UltraHD Bitstreams (Distribution)

In addition to supporting a range of resolutions, the CODEC must support specific dynamic range levels that require Chroma Format information and bit depth. SD or HD signals typically use 4:2:0 color sampling with 8-bit depth for pixel values to handle the dynamic range of an SDR signal. In contrast, UltraHD signals require 4:2:0,10 bit depth for pixel values to accommodate the dynamic range of an HDR signal. CODEC profiles need to specify which types of signals are supported, while video parameters identify which specific format is in the bitstream.

The characteristics describing UltraHD are primarily contained in high-level Syntax elements of the bitstream, either in the Video Usability Information (VUI) parameters or optimized in Supplemental Enhancement Information (SEI) parameters or directly in a NAL unit. VUI Information includes Color Space and Color Gamut (e.g., BT.2020), Transfer or Gamma Curves (e.g., PQ or HLG), Color Representation (e.g., YCC, RGB, ICtCp), Full/Narrow Video Range, Chroma Location. SEI Information relevant to UltraHD includes Mastering Display Colour Volume (MDCV), Content Light Level Information (CLLI), Alternative Transfer Characteristics, Content Color Volume (CCV), and Rec. ITU-T T.35 generic structures.

Dynamic Metadata (DM) can assist with displaying UltraHD content by providing data to a display that may have limited color space capabilities that optimize or convert the content signal to match the characteristics of the display. Some examples of DM in Ultra HD are HDR10+, Dolby Vision, and SL-HDR1. This information can be carried in a NAL Unit carrying a SEI T.35 construct or possibly directly in a NAL Unit type.

Guidelines Information

Video CODEC features are described as a foundational Ultra HD technology in the Guidelines Rainbow books. Sections of relevance to CODEC utilization include:

Orange Book - Foundational Technologies for Ultra HD, Section 7 Foundational Technologies for Ultra HD – Sub-Sections 7.1/7.2/7.3

Yellow Book – Beyond Foundational Technologies- Section 7.1 HDR w/Dynamic Metadata, Section 7.4. Encoding, Section 10.1 Dynamic Resolution Encoding, Section 10.1.5 Syntax Requirements

Green Book-Ultra HD Distribution, Section 8.1 Video, Section 8.4 Broadcast Center Processing and Primary Distribution, Section 8.5 Final Distribution Processing from MVPD/OTT/DTT Providers

NB: Copies of the Guideline Books can be found at: https://ultrahdforum.org/guidelines/

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