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Metropolitan Police Video Training

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Video Measurement - Principals (4 days)

Course Aim

The aim of the course is to provide grounding in video fundamentals, compression and picture quality analysis for staff who work with video processing, detection and vision systems.

Course Structure

- Day 1 - TV Fundamentals; *Scanning and Sampling, Colour Systems, Analogue Composite Coding*
- Day 2 - TV Fundamentals; *Digital Component Coding, Conversion of Film to Television, High Definition*
- **Day 3 - Compression; *DCT principles, Intra-Frame vs Inter-Frame Encoding, blocks and macroblocks etc.***
- Video Tape Recording; *Magnetic recording principles, rotary recording, Simple VT maintenance.*
- Day 4 - Television Measurements; *Analogue, Digital*
- Picture Quality Analysis; *Analogue picture impairments, digital picture impairments, compression*
- TV Displays; *CRT, LCD and Plasma displays. Problems with LCD and Plasma, Projection systems.*

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Compression - Uncompressed video and codecs

- The data rate of uncompressed standard def video is 270Mbits^{-1}
- High def comes in at 1.48Gbits^{-1} and 3Gbits^{-1}
- These data rates are far too high to record on videotape or send over a network
- Using mathematical techniques the digital data that represents pixels – colour and luminance values – are transformed into a description that allows the pixels to be re-constituted and hence occupies much less space
- Depending on the application video can be compressed to 10% or less of its original size.
- The particular mathematical function used to achieve this is called a codec
- Different codecs have pros and cons depending on application (shoot, edit, TX etc)

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Early computer-based graphics and video formats

With the exception of MPEG most computer video formats tend to;

- Have square pixels (because computer monitors do)
- Use RGB for their colour representation
- Use varying framerates (from 12fps up)

None of these lend those early computer video systems to television!

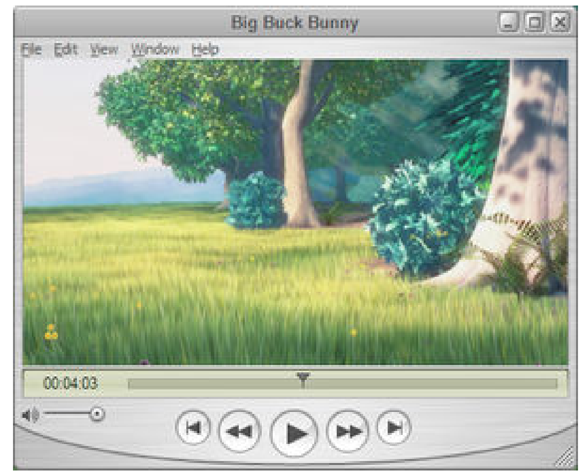

image: Wikipedia

The same can be said of computer still image formats – TIFF, Targa, BMP, etc – also;

- They may use CMYK colour space
- Graphics software may work in DPI rather than absolute resolutions
- Varying degrees and quality of anti-aliasing

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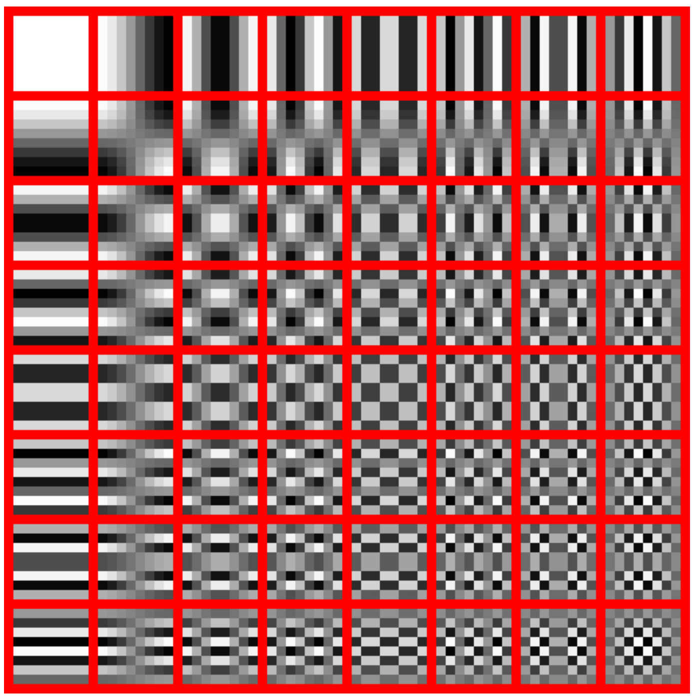
Video compression – how does that work?

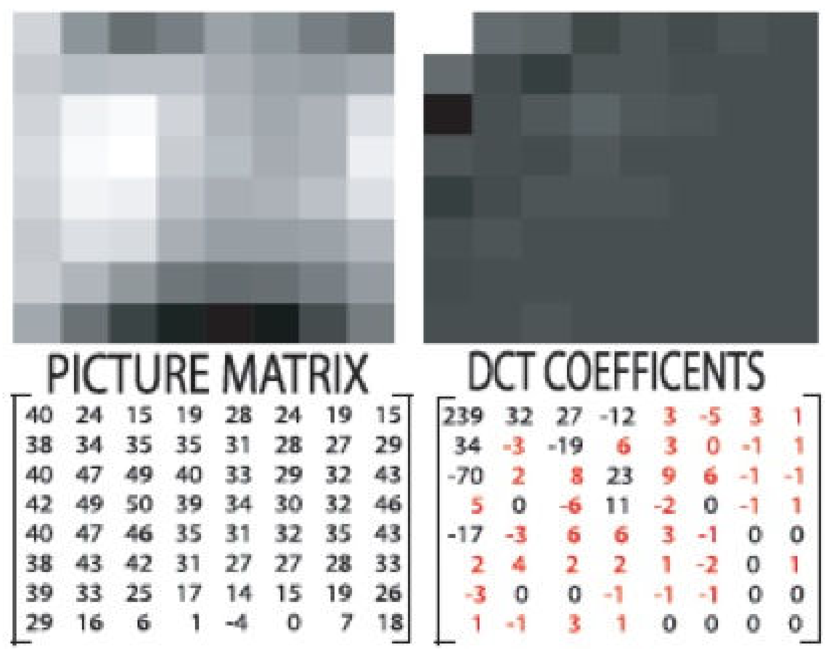
There are two aspects of video that we can exploit to reduce the data load;

- Large areas of similarity within each video frame; ***Intra*** *frame encoding*
- Large areas of similarity between video frames; ***Inter*** *frame encoding*

DCT principles

The Discrete Cosine Transformation is an example of a Fourier Transform (but using only real numbers). When applied to pixels (still and moving images) the picture information is transformed from pixel values into frequency values.





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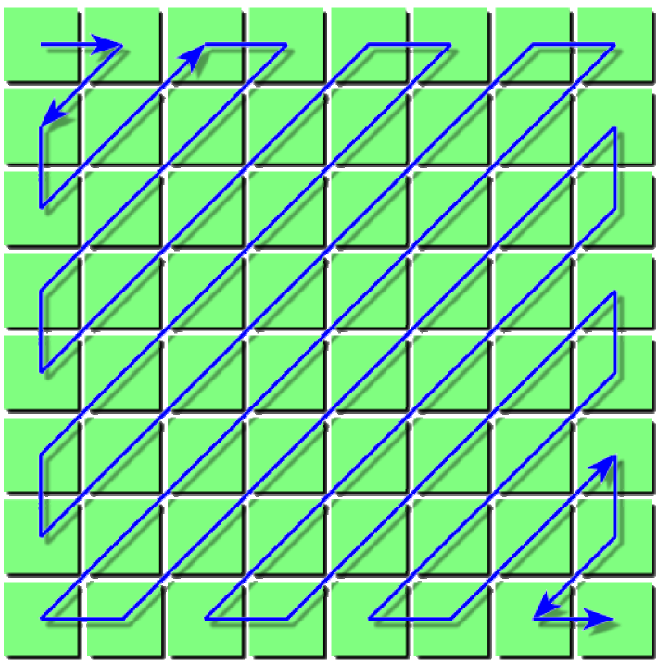
DCT principles

The Discrete Cosine Transformation doesn't actually reduce the data load – there are still 64 bytes of data required for an 8x8 macroblock, but looking at the DCT data shows that by 'zig-zagging' across the matrix allows us to use run-length encoding.



It's the run-length encoding that allows us to reduce the data rate. By the time the encoder gets to the bottom right of the matrix of the block there are long runs of similar values and these can be recorded as a value and a number of repetitions.

- If the block was all of one colour the 64-bytes might be reduced to two bytes.
- Even if this part of the picture is very complicated (lots of detail) quite high compression is possible.
- At some point though throwing away too much of the data results in pictures that don't come back nicely!

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3, 15, 25, 50, 150:1

Compression ratios

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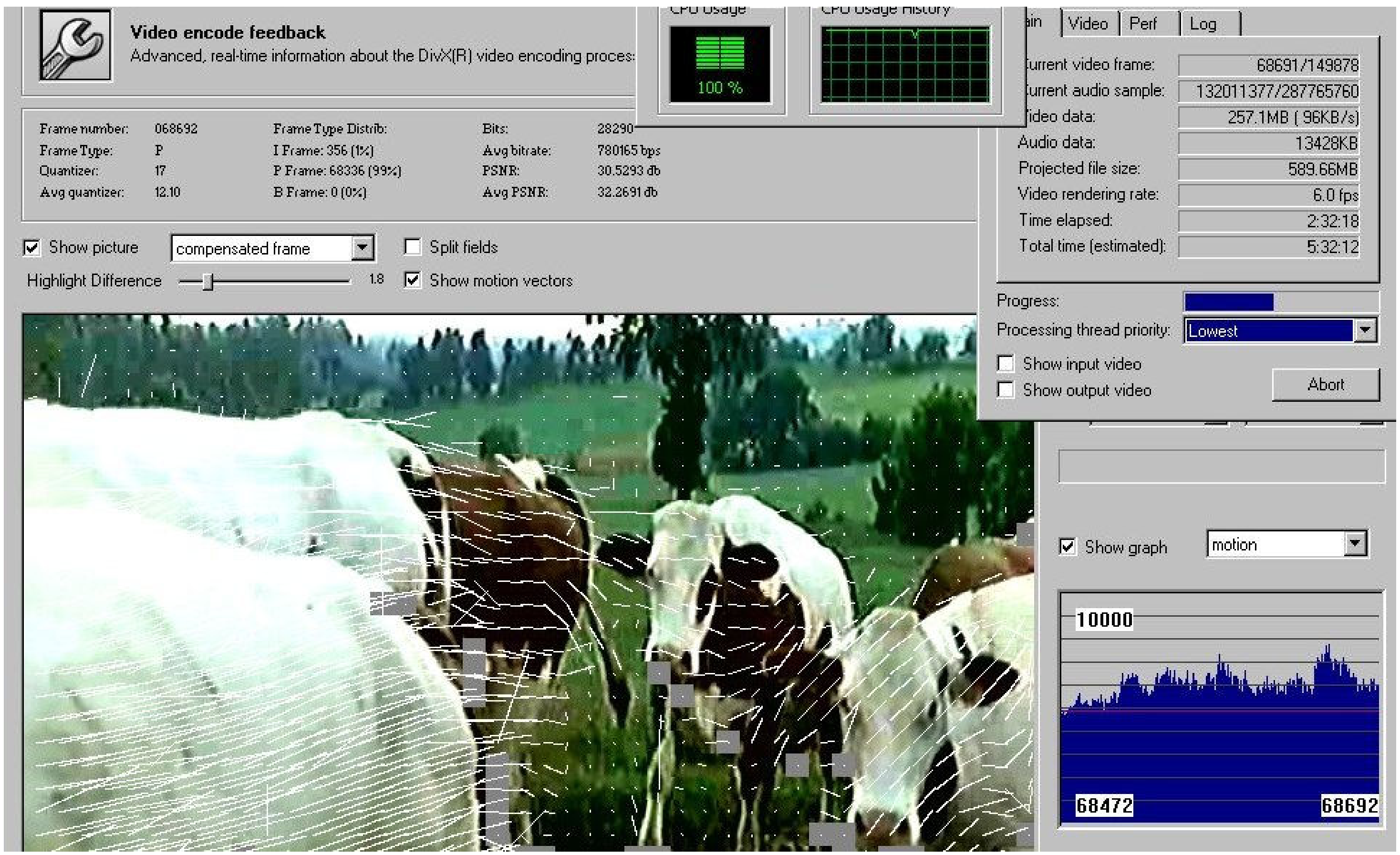
Inter-frame compression

- Applied to a sequence of video frames, rather than a single image.
- In general, relatively little changes from one video frame to the next.
- Inter-frame compression exploits the similarities between successive frames, known as temporal redundancy, to reduce the volume of data required to describe the sequence.

There are several inter-frame compression techniques, of various degrees of complexity, most of which attempt to more efficiently describe the sequence by reusing parts of frames the receiver already has, in order to construct new frames.

- The location of the similar or matching block in the past frame might be different from the location of the target block in the current frame.
- The relative difference in locations is known as the motion vector.
- If the target block and matching block are found at the same location in their respective frames then the motion vector that describes their difference is known as a zero vector.

Inter-frame compression



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Inter-frame compression

When coding each block of the predicted frame;

- The motion vector detailing the position (in the past frame) of the target block's match is encoded in place of the target block itself
- Because fewer bits are required to code a motion vector than to code actual blocks, compression is achieved.

During decompression;

- The decoder uses the motion vectors to find the matching blocks in the past frame (which it has already received)
- It copies the matching blocks from the past frame into the appropriate positions in the approximation of the current frame, thus reconstructing the image.
- In general a perfect replica is not possible with block based motion compensation and thus the technique is lossy.

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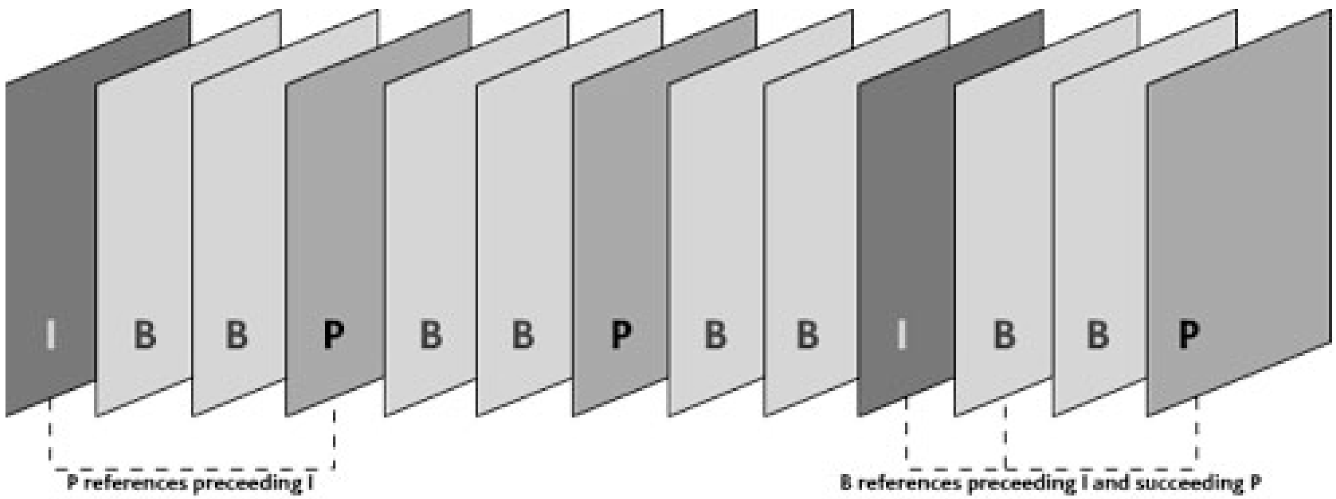
MPEG – Motion Picture Expert Group

- **MPEG-1**, 1993 – The basis for CDi and VideoCD (early DVD predecessors) – only 1.5Mbit/s and a quarter-screen resolution of 350x288 pixels. No interlaced video, 4x3 and stereo audio only. Long GOP
- **MPEG-2**, 1995 – Full standard def video, basis of DVD and DVB-T, C & S. Variable data rate and full 601 resolution using Y, Cr, Cb colour sampling. 16x9 or 4x3 video, up to 5.1 audio via AC3. 23.976, 25, and 29.97 FPS. Long GOP or i-frame (TX vs editing).
- **MPEG-4**, 1998 –The basis of most modern video encoding for acquisition, post and delivery. Multi-resolution, multi-framerate, multi-audio standards, editing or TX variants.

Domestic delivery -> TX -> Editing

Editing vs Transmission codecs

MPEG2 and all MPEG4 variants are based on a mathematical model of video called the **Discrete Cosine Transform** (DCT). Once applied to the video data this function then allows the codec to reduce the data rate of the video stream – you can transmit it and store more of it on disk.



Once the data in the video frames has had the DCT function applied the codec can also define different types of video frames that go to make up the **Group of Pictures** (GOP).

Editing vs Transmission codecs cont.

- **I-frame:** An intra-frame, or I-frame, is a video frame which has been encoded without any reference to any other frame. A video file will always start with an I-frame and will have subsequent I-frames added at regular intervals. I-frames are also known as key-frames and are important for random access of video files such as rewind, fast-forward and seek operations. The downside to an I-frame is that they are the largest in terms of size as the whole video frame is encoded every time.
- **P-frame:** A predictive inter-frame, or P-frame uses previous I or P-frames as a reference when encoding. This means a P-frame will analyze a previous I or P-frame for any static elements which do not change between frames. Any areas which do not change are not encoded therefore a P-frame only stores video which registers movement making them much smaller than I-frames. The downside to P-frames is that they are sensitive to transmission errors because of their dependency on earlier frames.
- **B-frame:** A bi-predictive inter frame, or B-frame makes reference to both a preceding reference frame as well as a future reference frame. Using B-frames improves the prediction and ultimately the quality of decoded video but it also increases the processing requirements and latency.

Editing vs Transmission codecs cont.

The requirements of editing and transmission differ somewhat;

- Editing requires immediate access to each video frame and should not have to build a complete frame by looking at the frames that surround it, so an **I-Frame** only (or 'short-GOP' codec) is used.
- Transmission would rather leverage the additional image quality available to a long-GOP system and so a 12-frame (typical) GOP is used.

Rule of five;

- Uncompressed standard definition video ~ 250Mbits/sec
- I-Frame editing codec, MPEG2 ~ 50Mbits/sec
- Long GOP transmission codec, MPEG2 ~ 10Mbits/sec
- Statistical Multiplexed DVB stream to the home ~ 2Mbits/sec

Contemporary standards – HD and MPEG4

HD video makes things considerably easier – the Rec 709 standard defines;

- 1920x1080 resolution at 16x9 now has square pixels!
- Wider variety of frame rates (including 24 PsF)

MPEG4 is the basis for most acquisition, editing and transmission codecs currently.

- MPEG4 improves the performance of MPEG2 by allowing macroblocks to the referenced across I-Frame boundaries.
- MPEG4-part 10 (aka 'H.264' or AVC) further improves performance by using variable sized macroblocks and blocks that can 'look around' for similarity.
- It's hard to see how much further DCT-based codecs can go!

Complexity of H.264; two examples

- Intra-prediction - In the other video standards, in an ‘Intra’ frame, all the 16x16 Macroblocks are self-contained: they are not generated based upon Macroblocks in preceding or following frames, nor from other Macro-blocks in the same frame. However, H.264/AVC takes advantage of the fact that within a frame, Macroblocks which are located close to each other often have similar data – so that even within an ‘Intra’ frame it is possible to use prediction techniques where the value of one Macroblock is derived from the values of the video data in one of the surrounding Macroblocks.

- Smaller blocks for enhanced efficiency - H.264/AVC allows the 16x16 Macroblocks to be sub-divided down to blocks as small as 4x4, to enhance the compression efficiency. In MPEG-2 and MPEG-4, there is just one type of 'Intra' Macroblock, containing compressed video which does not refer to any other Macroblock.

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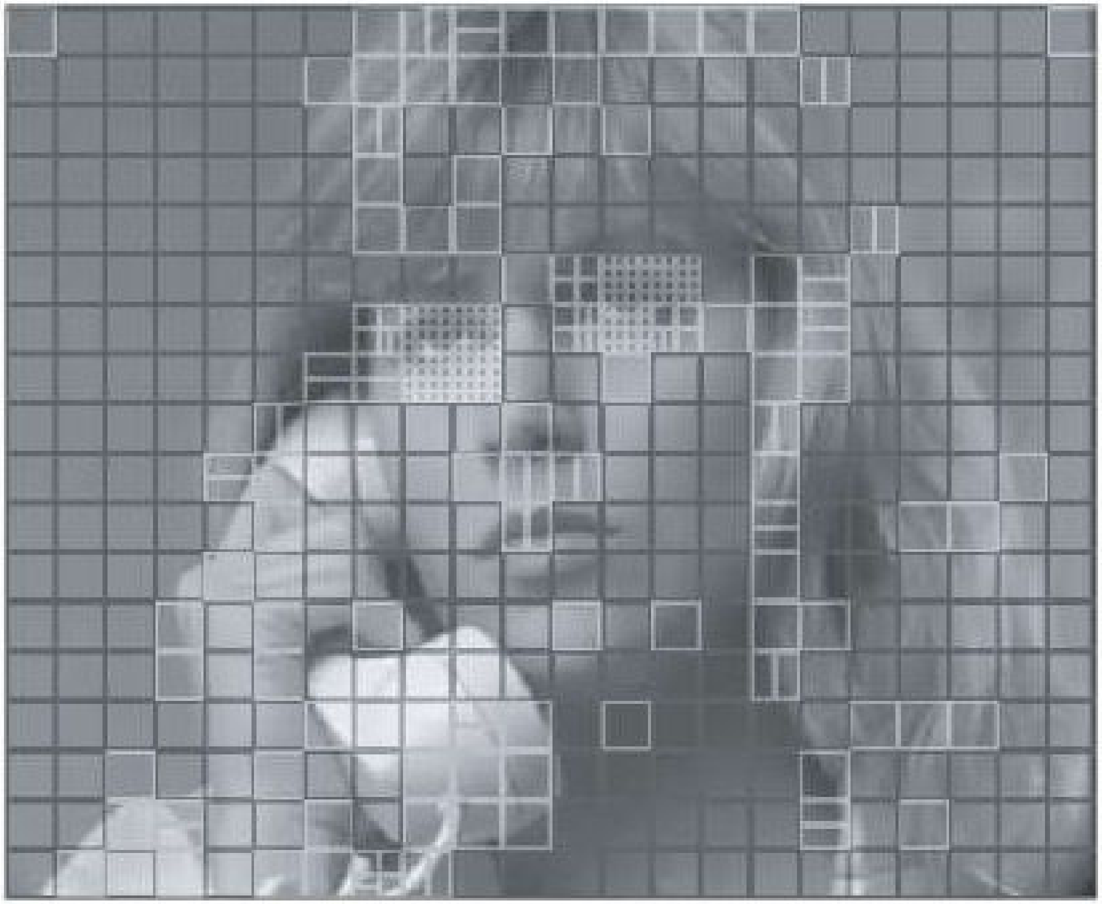
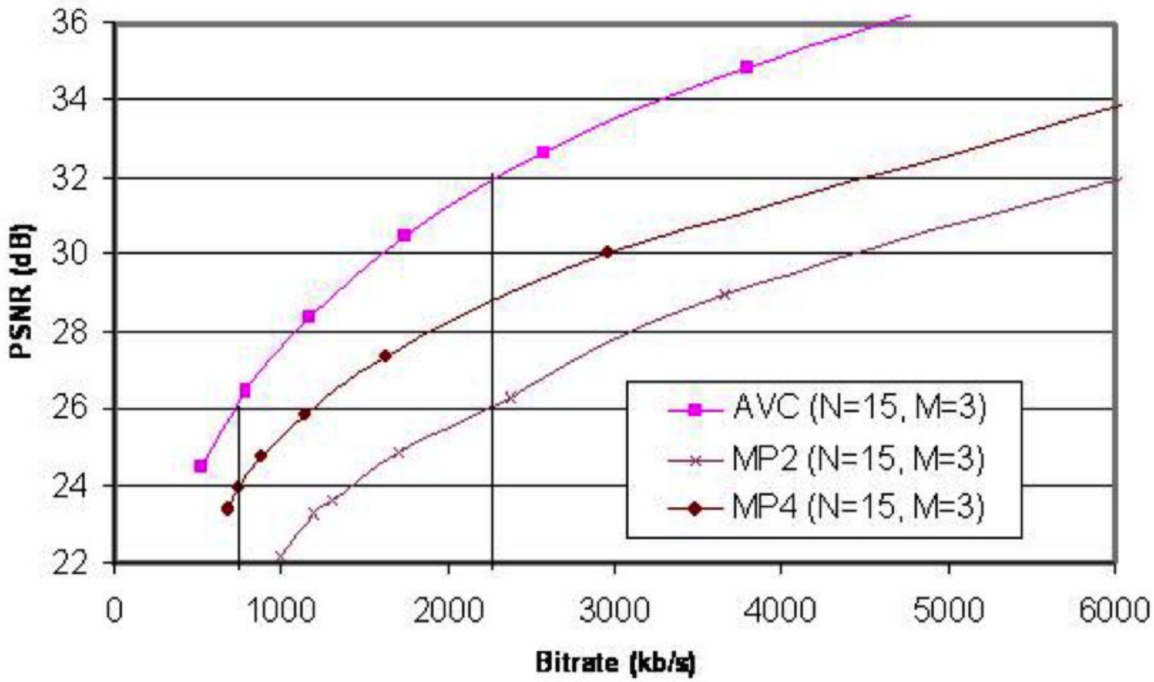
However, with the complexities above (and others), in H.264/AVC there are 26 types of Intra Macroblock. There are many other complex elements in H.264/AVC, such as the 'CABAC' Entropy coding, where bits are shared such that fractions of 1 bit effectively represent a specific syntax element.



Qualitative comparison of MPEG2, MPEG4 & H.264
Video reams at the same resolution, encoded three times.



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Contemporary editing & acquisition formats

- Avid DNX HD – I-frame only (i.e. editing) **codec**.
- Quicktime – Apple's wrapper format, especially **ProRes codec**.
- MXF –a 'universal' wrapper format that can encapsulate different codecs
- MPEG2 – the **codec** used in HDV, XDCam
- DV – I-Frame only **codec**, initially domestic cameras but extends up to HD (100Mbits^{-1})

You have to distinguish between ***codecs*** (that mathematical function that changes raw pixels into a file-description of how to re-create the pixels; compression) and ***container*** formats (AKA wrapper).

Picture faults

We've already seen this – too much intra-frame compression is applied and the macroblocks are visible.

This effect is seen if pictures become too detailed for the available data rate.

One solution is Variable Bitrate Encoding (VBR) or even Statistical Multiplexing (StatMux)

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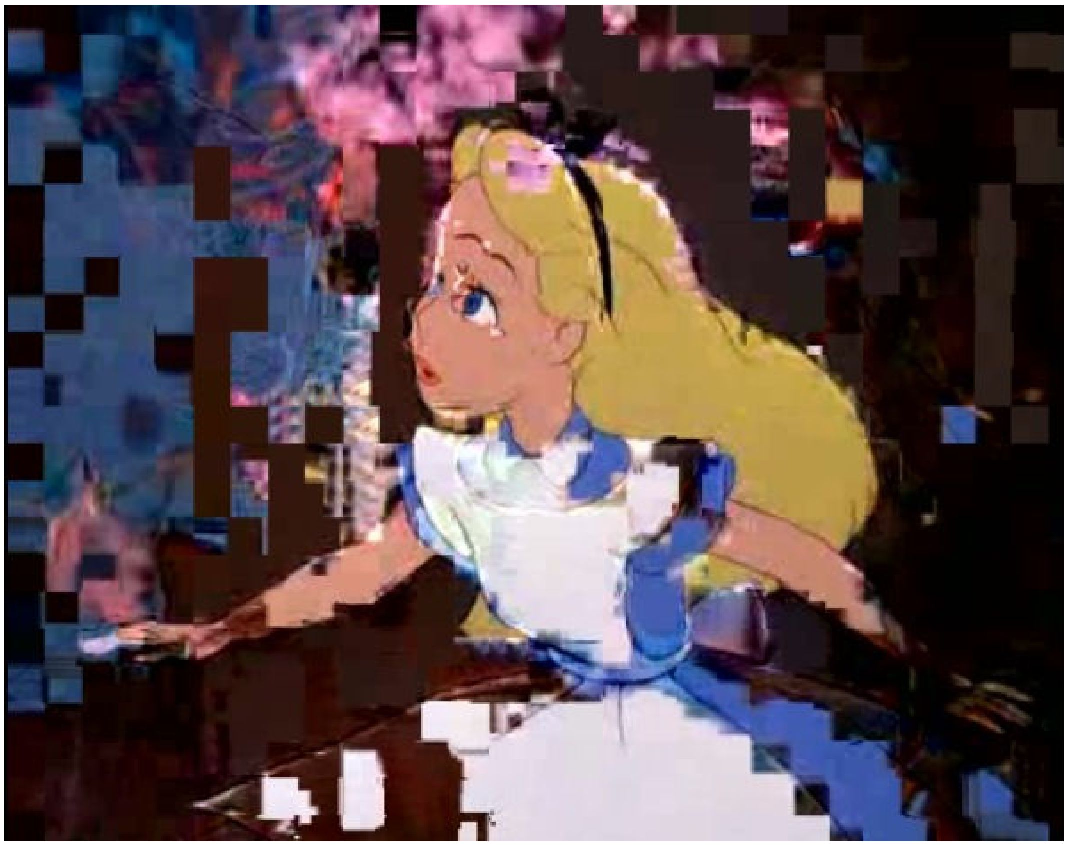
Picture faults



In this frame the previous I-Frame has been corrupted and the decoder is unable to make a complete picture, only those elements that have arrived in new B & P-frames.

This problem is worse in MPEG4 as blocks may refer back to pictures from many seconds ago, unlike MPEG2 where there is always a new GOP started every 12-frames (15-frames in NTSC).

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