The Dreaded 'C' Word!

Presented by

Neil Garner

Knowledge for TV Professionals

in association with

CONFERENCE 2020
FIAT/IFTA-IASA

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C is for….

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Training for TV

- Training for TV is a UK based training company delivering operational, technical and production training to the TV industry across the world.
- We have trained in more than 40 different countries worldwide.
- Training partners include:
- ….and a few of our training customers:

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Neil Garner

- 1981-84. Studied music and sound engineering (Tonmeister) at University.
- 1985. Trained as a teacher.
- 1987 Joined BBC as a Recording Operator (VTR and Telecine operations). Worked on live studio programs, editing, quality assessment and control, transmission operations.
- Worked for the BBC Academy for 17 years, developing many of their commercial courses. Customers included, Sky, ITV and many international broadcasters.
- Setup Training for TV in 2006.

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The Plan

- Part 1 - The problem and the solution.
- Part 2 - How does that work?
- Part 3 - So what does it look like?

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The Problem…

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Digital

- Digital is best… or so they would have you believe… but Digital is only the 'bit the in the middle'… all signals start analogue and end analogue, because our eyes and ears are analogue!
- Digital is very good at maintaining quality while the signal is being transported, stored, manipulated…. but it can only ever be 'the bit in the middle'.
- In the best systems media is converted to digits soon after capture and back to analogue shortly before playback.

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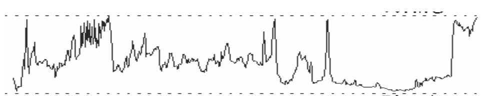
What is Analogue

- An infinitely detailed electronic representation of a real world property shown with relation to an infinitely detailed timescale.



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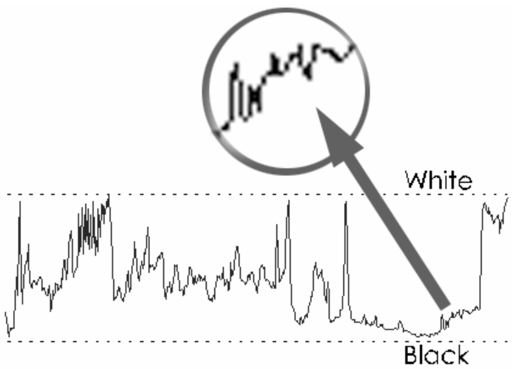
What is Digital

- A finitely detailed electronic representation of a real world property shown with relation to a finitely detailed timescale.

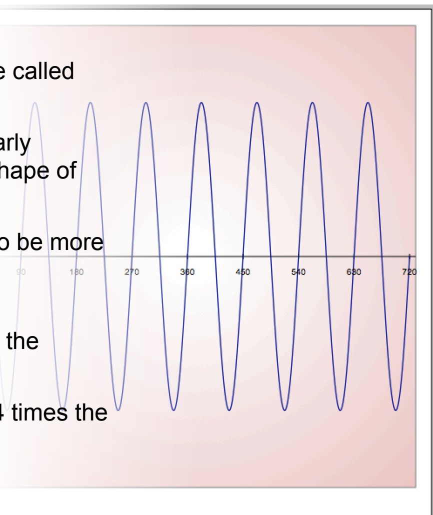
Analogue and Digital

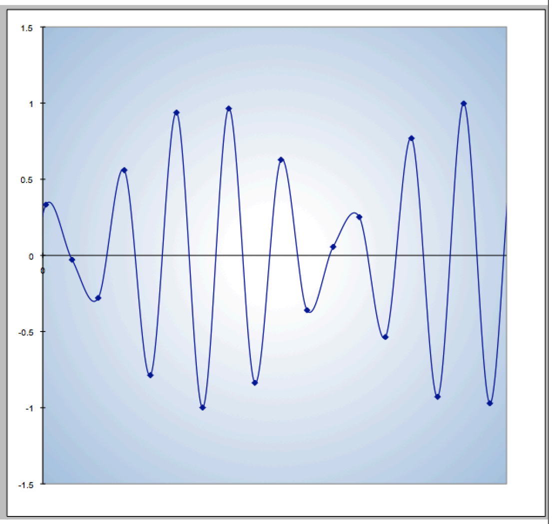
- Analogue is infinitely detailed, but in Digital we chose to use a certain number of discrete 'steps' in order to match the original as closely as is needed.



Measuring in Digital

- The measurements we make are called SAMPLES.
- Samples have to be taken regularly enough to accurately chart the shape of the waveform.
- In practice the sample rate has to be more than twice the highest analogue frequency.
- In Digital video we use 2.3 times the highest frequency.
- In Digital audio we use 2.2 or 2.4 times the highest frequency.





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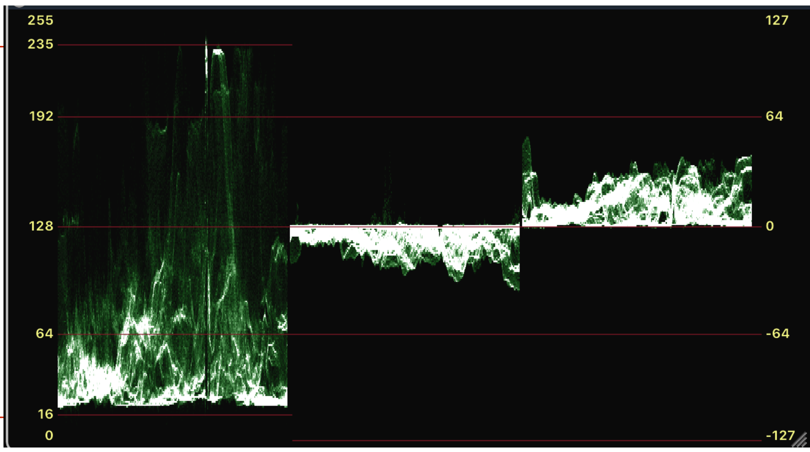
Measuring in Digital

- Voltage is turned into numerical steps called QUANTISING LEVELS.
- Below is 8-bit video, which we use for many systems including almost all delivery.



white = 235 or 11101011

black = 16 or 00010000

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Binary

Use the table to convert binary into decimal numbers.

Each 1 or 0 is worth double the previous one.

Add the numbers in the second row if a 1 is present in the bottom row.

8 bit

bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	LSB
128	64	32	16	8	4	2	1
0	**1**	**1**	**1**	**0**	**0**	**0**	**0**

0111000 = 64+32+16 = 112 out of 256 possibilities - nearly mid grey.

12 bit

bit 12	bit 11	bit 10	bit 9	bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	LSB
2048	1024	512	256	128	64	32	16	8	4	2	1
0	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**

001100000101 = 512+256+4+1 = 773 out of 4098 possibilities. - quite a dark grey

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Bits, Bytes and Big Numbers

- A Binary Digit or Bit (b) is the basic unit of digital
- Kilo Bit is a Thousand Bits - (actually 1,024)
- Mega Bits is a Million Bits - (actually 1,024,000)
- Giga Bits is a Thousand Million Bits - (1,024,000,000)
- Tera Bits is a Million Million Bits - (1,024,000,000,000)
- Peta Bits is a Thousand Million Million bits - (1,024,000,000,000,000)

- A Byte (B) is a series of 8 Bits
- 8Kb = 1KB.

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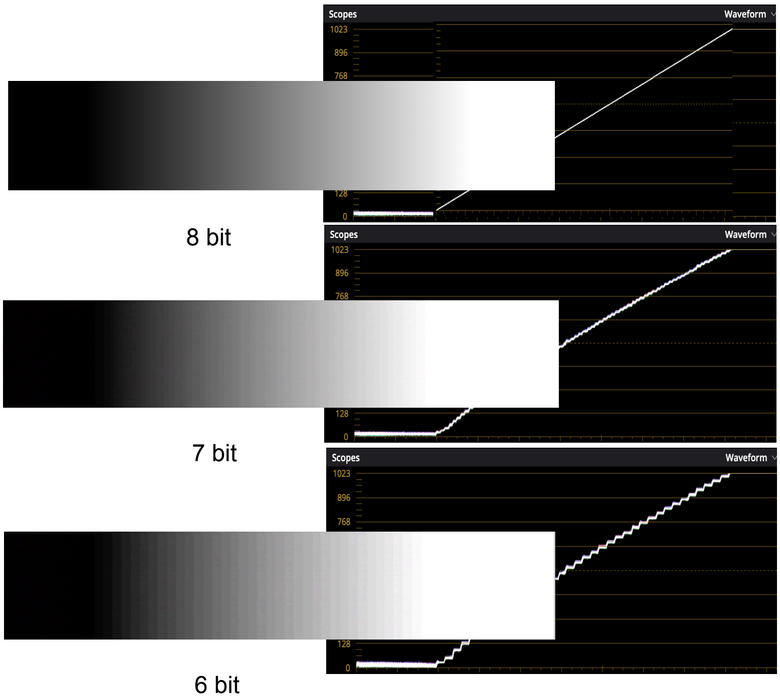
Quantisation

- Each sample will be 'quantised' into a range of specific levels.
- The number of levels are defined by the numbers of binary 'bits' used.
- Different Systems use different values.
    - Production Mixers can use up to 24 bits for audio… over 17 million levels.
    - AES digital audio uses 20 bit samples... over 1 million levels.
    - CD's and broadcast digital audio uses 16 bits with 65,536 levels.
    - Early CD and digital TV sound used 14 bits or 16,384 levels.
    - Long play DV recordings use 12 bits or 4096 levels
    - UHD TV…. 10 or 12 - maybe more?
    - SDI Digital video uses 10 bits with 1024 levels
    - Telephones use 8 bits with 256 levels.
    - Transmission video and standard quality TV production use 8 bits with 256 levels



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The SD Video World Standard

- The sampling frequency was chosen to be 13.5 MHz - in other words, the amount of signal is measured 13.5 Million times a second.
    - 13.5 MHz = 864 x 625 x 25 - Europe, Africa and most of Asia…
      = 858 x 525 x 29.97 - N America and Pacific Rim
- The signals shall be component - i.e. Y, Cb, Cr
- The sampling of the component signals shall be in the ratio 4:2:2
- For 10 Bit resolution this gives rise to a data rate of:
    - Y = 13.5 MHz * 10 bits = 135 Mbits }
    - Cb= 6.75 MHz * 10 bits = 67.5 Mbits } = 270 Mbits/sec
    - Cr = 6.75 MHz * 10 bits = 67.5 Mbits }

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HD Video World Standard

- The sampling frequency was chosen to be 74.25 MHz - in other words, the amount of signal is measured 74.25 Million times a second.
    - e.g. 2640 (inc 720 blank samples) x 1125 (inc blanking) x 25
- The signals shall be component - i.e. Y, Cb, Cr
- The sampling of the component signals shall be in the ratio 4:2:2
- For 10 Bit resolution this gives rise to a data rate of:
- Y = 74.25 MHz * 10 bits = 742.5 Mbits }
- Cb = 37.125 MHz * 10 bits = 371.25 Mbits } = 1.485 Gbits/sec
- Cr = 37.125 MHz * 10 bits = 371.25 Mbits }
- If the signal is progressive at 50 frames (1080p 50) it will be 2.97Gbits/sec

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How Many ?

- 1500 Mbits per second -
- That's enough to fill a 600 GB computer hard disk in less than one hour.

A standard DVD would manage:

- 130 seconds for 270Mb SD
- 24 seconds for 1.5 Gb 1080i 25
- 12 seconds for 3 Gb 1080p 50
- 3 seconds for 12Gb UHD…

  …that's about 2,600 disk changes for a 130 minute movie assuming the machine could receive data that fast!

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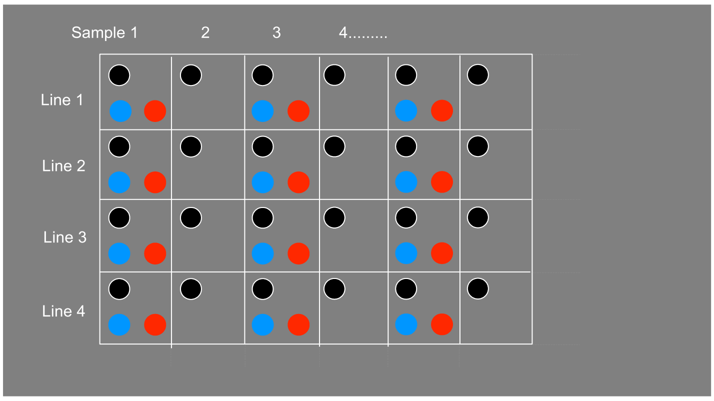
Sampling Patterns – 4:2:2

- The diagram shows the 4:2:2 sampling pattern.
- Every pixel has a luminance sample (Black)
- The R-Y and B-Y samples are only taken every other pixel.
- It has full vertical resolution, but only half horizontal resolution.



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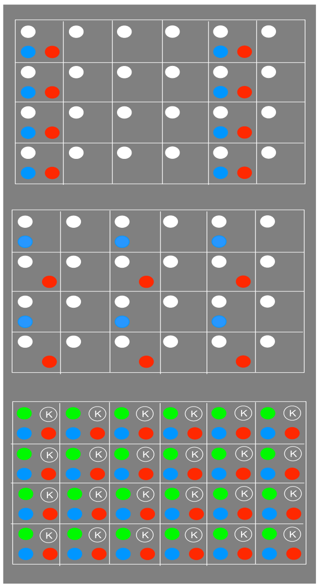
Sampling Patterns

- 4:1:1.
  - Every pixel has a luminance sample, but only every fourth has a colour one.
    - Full vertical and quarter horizontal colour resolution
    - Used with DVCPro and NTSC DVCam/Mini DV.
- 4:2:0
  - Every pixel has a luminance sample, every other has one colour with them alternated between lines.
    - Half vertical and horizontal colour resolution.
    - Used for DVB and PAL DV Cam/Mini DV.
- 4:4:4:4
  - Red, Green Blue and Key on every pixel.
    - Full resolution... up to 540Mb per second for SD.
    - For high end operations and graphics.



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Sampling reduction in action…

- **As good as it gets….!**
- **4:4:4**
- This is RGB and has to include every sample for every colour in order to maintain resolution.
- It is as it would be coming of the chips in the camera… or in the graphics generation system.

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Sampling reduction in action…

- **Can you see a difference….?**
- **4:2:2**
- This is RGB and has to include every sample for every colour in order to maintain resolution.
- It is as it would be coming of the chips in the camera… or in the graphics generation system.

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Sampling reduction in action…

- **No you can't… but a keyed might at this point!**
- **4:2:0**
- This is RGB and has to include every sample for every colour in order to maintain resolution.
- It is as it would be coming of the chips in the camera… or in the graphics generation system.

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Sampling reduction in action…

- **Still can't see it… your not alone!**
- **4:1:1**
- This is RGB and has to include every sample for every colour in order to maintain resolution.
- It is as it would be coming of the chips in the camera… or in the graphics generation system.

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Sampling reduction in action…

- **Look at David Beckham ear….**
- 1/8 Horizontal Colour Resolution…
- This is not really something we use…. only an example to help you understand!

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Sampling reduction in action…

- **The orange shadow on the wall..**
- 1/16 Horizontal Colour Resolution…
- This is not really something we use…. only an example to help you understand!

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Sampling reduction in action…

- **Posh is now looking very blue… is she still alive?**
- 1/32 Horizontal Colour Resolution…
- This is not really something we use…. only an example to help you understand!
- **This is still somewhat better than VHS colour… it has about 1/50th of the original bandwidth.**

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…and just to compare!

- When you compare the pictures the difference is obvious, but without a comparison, it is much harder and your brain will largely enhance the image back to what you want to see….
- It is why the VHS was able to dominate our viewing for 30 years!

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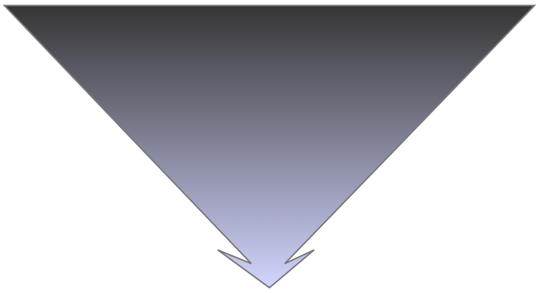
So what do we watch…?

1500 Mb/s? (HD)



Err….No.

Something closer to 8Mbits

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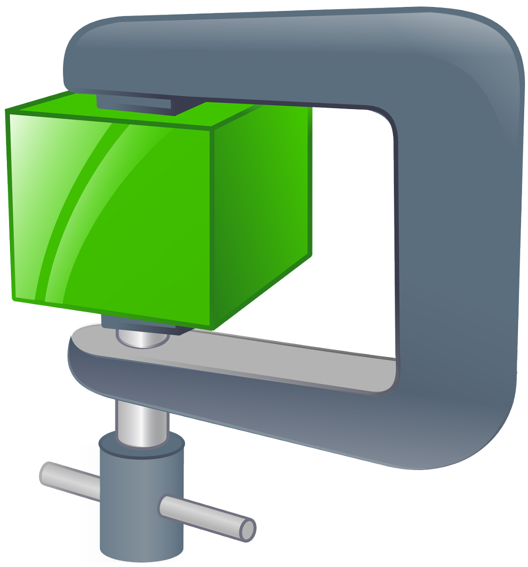
What is Compression?

- Is the technique we use to reduce the amount of data that we need to describe an image or sound.
- A fairer name to use might be data reduction….
  - Unfortunately there are many compression systems that we may use and each has it’s own advantages and disadvantages. Some are old, some are more efficient, some are free, some are….
  - As with all processes where we use less information to describe a complicated scenario, errors can occur, and generally speaking the more we try to reduce the information, the more errors can occur.



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What is the cost?

- Like all good things, compression has its disadvantages too:
  - It may degrade the quality of the signal, especially if applied to excess. i.e. 2:1 compression will probably be barely perceptible 100:1 compression may be obvious.
  - Different compression systems can interfere with one another, and two subtle compressions each using a different system may become very obvious.
  - Cascading the output of one system into another is called concatenation, and may give rise to undesirable artefacts.
  - Systems which work well in most circumstances, may have problems in others. It is difficult to quote examples, because the signals which cause systems to fail are difficult to predict….

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Why do we do it?

- The use of compression in the digital system can lead to a number of advantages.
  - It may allow more signals to be sent down one pathway, allowing more phone calls, TV channels, radio stations to be delivered to the user.
  - It may allow high quality signals to use low quality systems. e.g. Spotify/Apple Music, etc. CD quality stereo audio over telephone line which normally sounds dreadful!
  - It allows signals which would have too much data for a simple system to handle. e.g. non-linear editors. (Computer based edit systems which store pictures on a hard disk).
  - MONEY….!

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Where do we use it?

- Compression is at the heart of the digital revolution and the sharing world we now live in…
- Without compression, we would not all have:
  - Phone and cheap calls.
  - Video and audio streaming.
  - Easy file sharing
  - Digital TV services
  - Digital Radio Services.
  - Satellite communications.
  - Rich media on the internet.
  - Digital cameras and picture sharing.
  - Data files and office documents…

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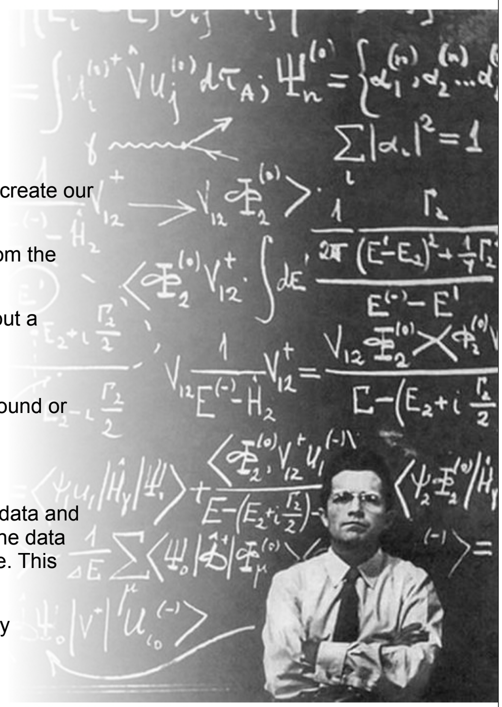
How does it work?



- There are 2 fundamental ways in which compression is used.
  - Lossless compression
    - This use mathematics to find better ways of encoding the numbers we use to create our digital blueprints.
    - It has developed from a crude system to one which now uses mathematics from the cutting edge of university research… or **Rocket Science**.
    - Techniques in currently in use often involve entropy mathematics which is about a measure of the unpredictability or information content in data. It is about the management of unpredictabiity…
    - It can be used on any data…. from a spreadsheet or document to a picture, sound or entire program.
  - Lossy compression
    - This is generally only used with audio or video data. It does not record all the data and will produce errors and artefacts. It is based on using techniques which take the data from parts of the signal which are less obvious…. and hence not so noticeable. This also takes makes to an extreme level.
    - The techniques and types of compression used for lossy compression will vary according to the media.

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BMP

- This is a black and white 8-bit .bmp file.
- It uses one byte for each pixel.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file 443KB… including some metadata and packing.
- It is uncompressed.

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image

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JPEG

- Same picture…. but JPEG.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file is 303KB… including some metadata and packing.
- It uses a different method to encode the image.
- It has 100% quality factor, so is still uncompressed.

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image

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JPEG

- Same picture…. but a different JPEG.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file is now 71KB… including some metadata and packing.
- It uses a different method to encode the image.
- It has 70% quality factor, so is is now a compressed image….
- … but you probably cannot tell!

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image

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JPEG

- Same picture…. but lower quality factor.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file is now 43KB… including some metadata and packing.
- It uses a different method to encode the image.
- It has 30% quality factor, so is is now a heavily compressed image….
- … you can now tell very easily!

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image

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JPEG

- Same picture…. but JPEG.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file is 303KB… including some metadata and packing.
- It uses a different method to encode the image.
- It has 100% quality factor, so is still uncompressed.

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image

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Another BMP

- This is still black and white 8-bit .bmp file.
- It uses one byte for each pixel.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file is still 443KB… including some metadata and packing.
- It is uncompressed.

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image

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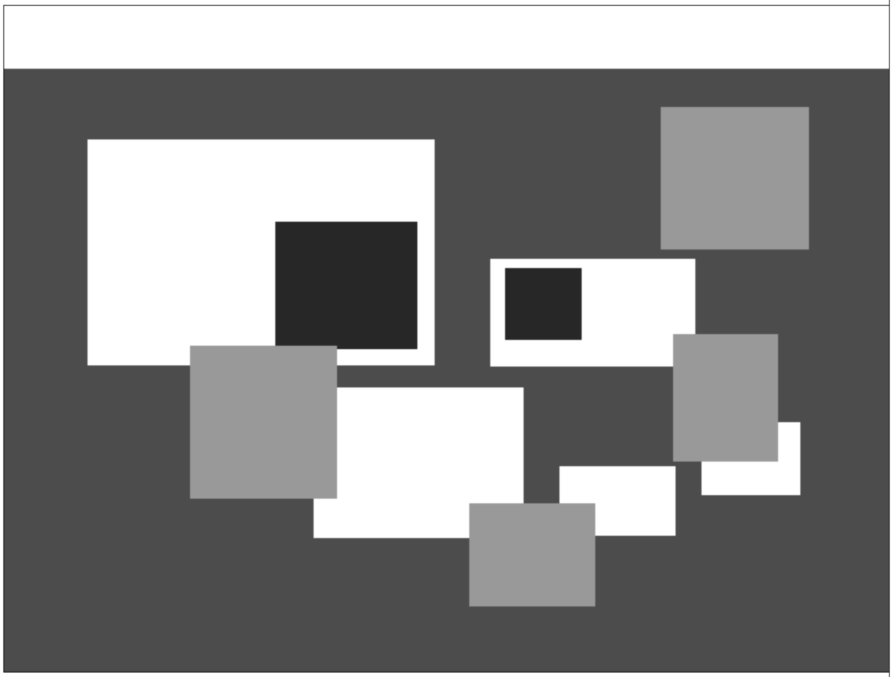
Another JPEG

- This is now a black and white 8-bit .jpg file.
- This SD picture has a 768 x 576 pixels. A total of 442K pixels.
- The file is only 20KB… including the metadata and packing.
- **…but has 100% quality, so it is uncompressed!**
- Using the different encoding system to pack the data, the simple nature of the image means big savings are made…

1.jpg	303 KB	JPEG image
2.jpg	71 KB	JPEG image
3.jpg	43 KB	JPEG image
original.bmp	443 KB	Windo...P image
Simple.bmp	416 KB	Windo...P image
Simple.jpg	20 KB	JPEG image



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End of Part 1

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Part 2 - How does it work?

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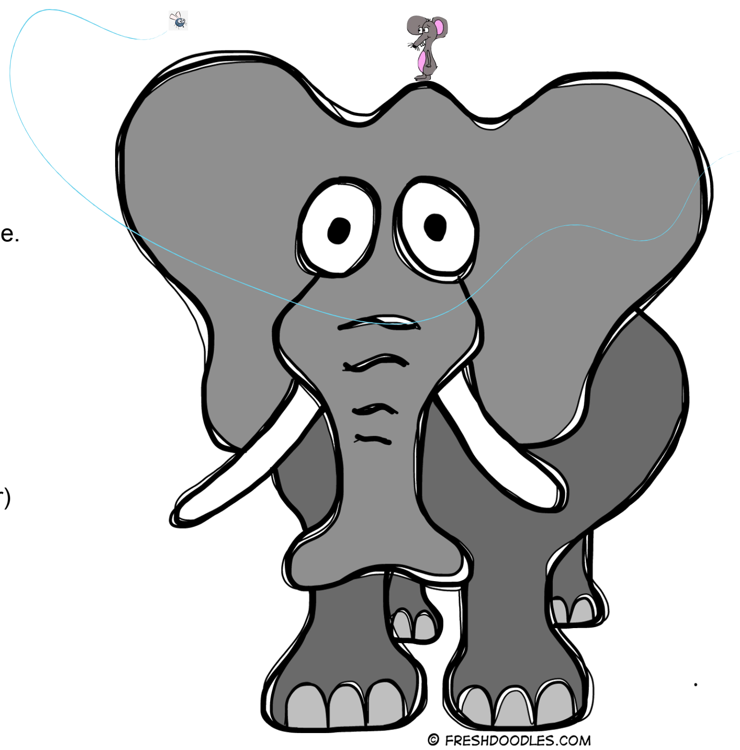
Video Compression



- Compared to metadata or audio, video is very large.
- Metadata a few Kb.
- 20bit Audio 1.9Mbs^{-1}
- SD video 270Mbs^{-1} (140x bigger)
- 1080i video 1.485Gbs^{-1}(780x bigger)
- 1080p video 2.97Gbs^{-1} (1,560x bigger)
- UHD video starts at 12Gbs^{-1} (at least 6300x bigger)

- **THE REQUIREMENT FOR VIDEO COMPRESSION IS OBVIOUS!**

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Video Compression

- Two basic types of compression are used:
- Individual Frame… (Intra Frame).
  - Will work on individual images, trying to find and remove repeated information within that image.
  - E.g. large parts of the sky may be exactly the same colour and brightness.
  - This is ideal for pre production work…..
- Multiple Frames… (Inter-frame).
  - This system additionally, will take a group of frames and try to find common material in all of them.
  - E.g. for static images, most parts of the subsequent frames will be almost identical to the first.
  - This type of compression is always used for transmission or distribution.

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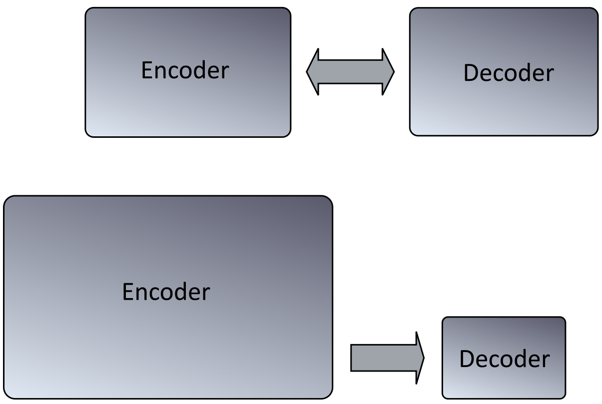
Compression Basics

- Compression can be:
  - Symmetric – Two way - equal complexity at both ends
    - Video conferencing
    - Contribution links
  - Asymmetric – One way, one to many - low complexity at the receiver
    - Terrestrial/satellite broadcasting



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Video Compression Principles

- Use a coding scheme that allocates short codes to the most frequently occurring source values
- Pictures contain Spatial Redundancy
- Television and film pictures also have temporal redundancy
- Identify and Remove redundant information. It can be replaced later with no loss of quality.
- Throw away the content which is least obvious or to which the eye is least sensitive.

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Intra-Frame Compression

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Intra frame Compression

- Only deals with frame at a time.
  - Less compression before looses are noticeable.
  - Less processing.
  - Easier to work with in post.
- Examples could include:
  - AVC Intra
  - DNxHD
  - Apple Pro Res
  - JPEG
  - JPEG2000
  - DV

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DCT and Wavelet Transforms

- Similar idea... different maths.
- DCT is particularly efficient with smoother textures.
  - Much easier to work with because the content is broken down.
  - Good compression efficiency, but less kind on the eye when losses occur.
- Wavelets are more efficient at dealing with transients.
  - Tends to be used on much larger blocks or whole pictures.
  - Needs lots more processing power.
  - produces much softer and gently applied artefacts.

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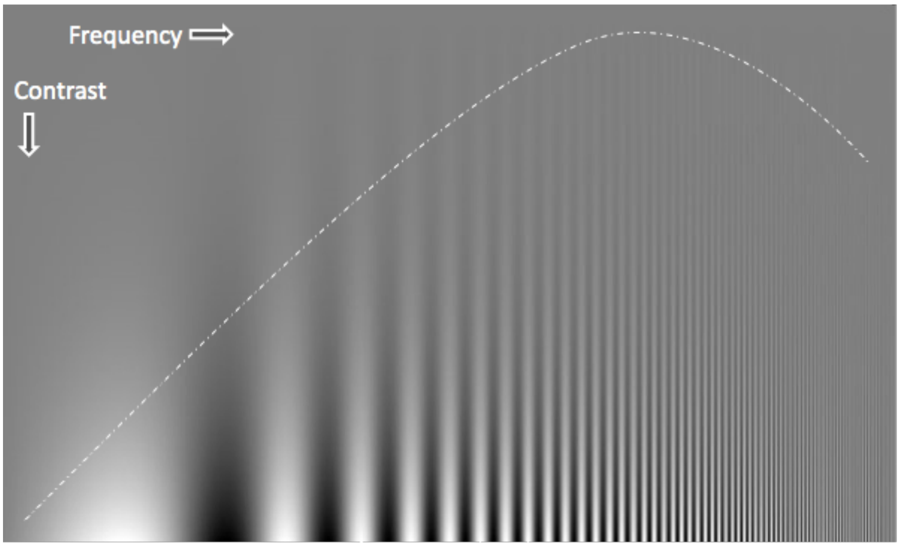
What can we see best?



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DCT

- Discrete Cosine Transforms (DCT) are used widely in video codecs.
- It is a set of mathematical transformations which analyse content in horizontal, vertical space.
- It is a branch of Fourier transforms which are used in a similar way to analyse waveforms and provide spectral analysis.
- DCT can only be applied to small areas of a picture as it very quickly becomes too complex if the areas get too large.
- In most codecs the pictures are split into blocks of between 16 and 64 pixels.

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DCT

- More Rocket Science!

$$\begin{aligned} X_{k_1,k_2} &= \sum_{n_1=0}^{N_1-1} \left(\sum_{n_2=0}^{N_2-1} x_{n_1,n_2} \cos\left[\frac{\pi}{N_2}\left(n_2+\frac{1}{2}\right)k_2\right]\right) \cos\left[\frac{\pi}{N_1}\left(n_1+\frac{1}{2}\right)k_1\right] \\ &= \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} x_{n_1,n_2} \cos\left[\frac{\pi}{N_1}\left(n_1+\frac{1}{2}\right)k_1\right] \cos\left[\frac{\pi}{N_2}\left(n_2+\frac{1}{2}\right)k_2\right]. \end{aligned}$$

The inverse of a multi-dimensional DCT is just a separable product of the inverses of the corresponding one-dimensional DCTs (see above), e.g. the one-dimensional inverses applied along one dimension at a time in a row-column algorithm.

The *3-D DCT-II* is only the extension of *2-D DCT-II* in three dimensional space and mathematically can be calculated by the formula

$$X_{k_1,k_2,k_3} = \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} \sum_{n_3=0}^{N_3-1} x_{n_1,n_2,n_3} \cos\left[\frac{\pi}{N_1}\left(n_1+\frac{1}{2}\right)k_1\right] \cos\left[\frac{\pi}{N_2}\left(n_2+\frac{1}{2}\right)k_2\right] \cos\left[\frac{\pi}{N_3}\left(n_3+\frac{1}{2}\right)k_3\right], \quad \forall k_i = 0,1,2,\ldots,N_i-1.$$

The inverse of **3-D DCT-II** is **3-D DCT-III** and can be computed from the formula given by

$$x_{n_1,n_2,n_3} = \sum_{k_1=0}^{N_1-1} \sum_{k_2=0}^{N_2-1} \sum_{k_3=0}^{N_3-1} X_{k_1,k_2,k_3} \cos\left[\frac{\pi}{N_1}\left(n_1+\frac{1}{2}\right)k_1\right] \cos\left[\frac{\pi}{N_2}\left(n_2+\frac{1}{2}\right)k_2\right] \cos\left[\frac{\pi}{N_3}\left(n_3+\frac{1}{2}\right)k_3\right], \quad \forall n_i = 0,1,2,\ldots,N_i-1.$$

- Go much information!

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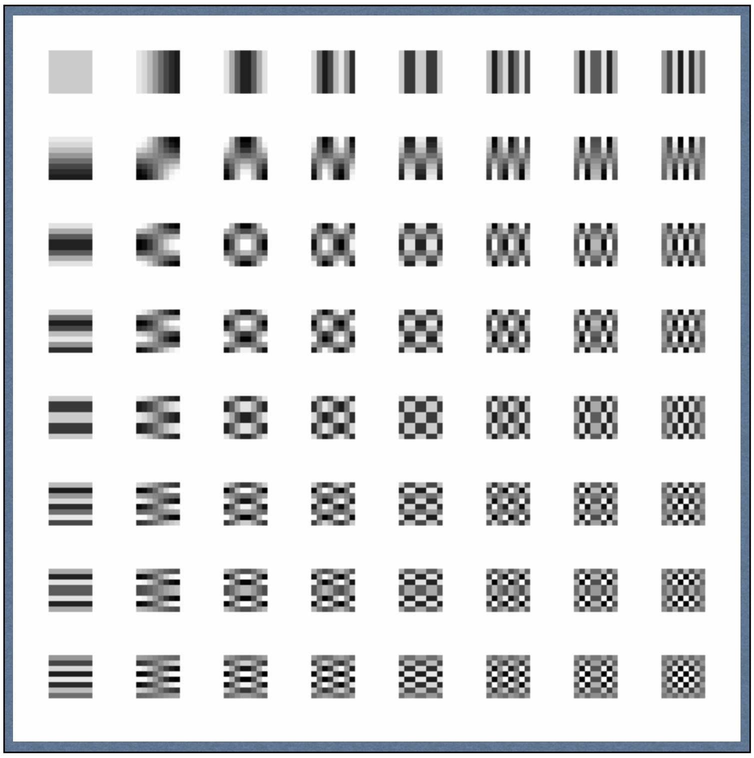
DCT Terms

- Discrete Cosine Transform (DCT) is about looking for pattern within each block.
- For 8x8 blocks, 64 different patterns are used, which are all made from Cosine curves.
- This is the same number of patterns as there are pixels, so if all are used, the result uses the same amount of data as normal.
- It is when you look at the data collected the genius of the system becomes apparent.



Knowledge for TV Professionals

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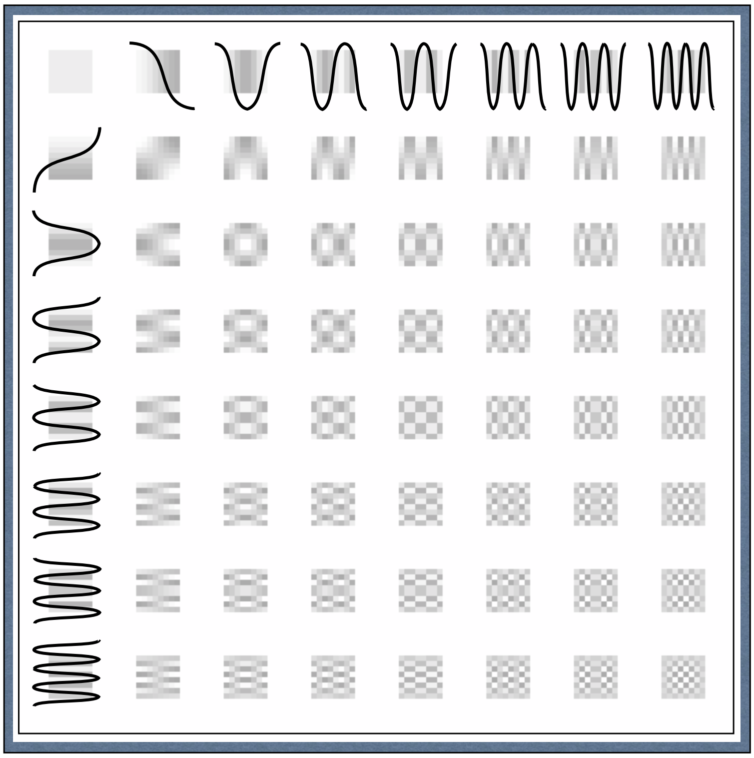

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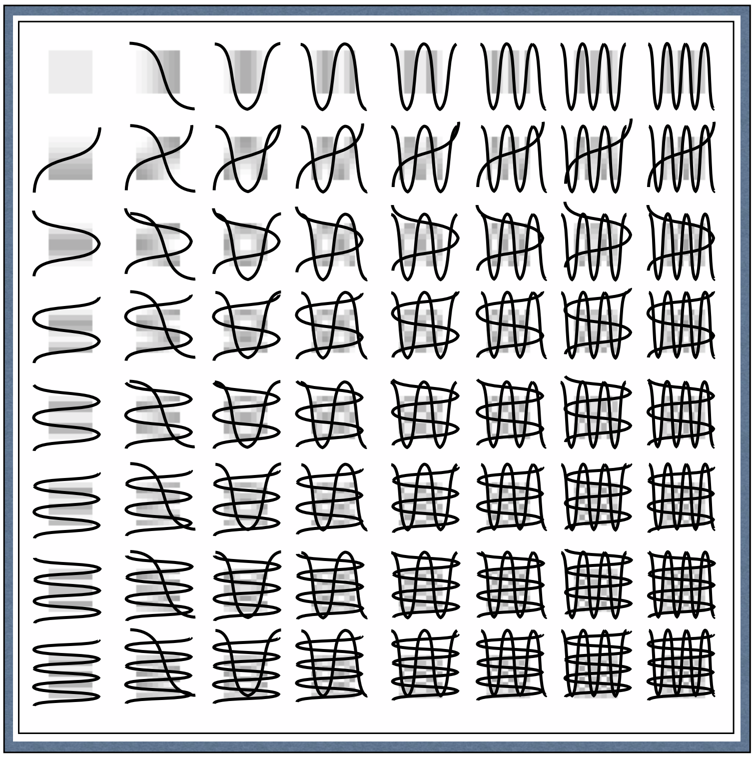

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Original

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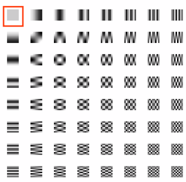
DC Term Only



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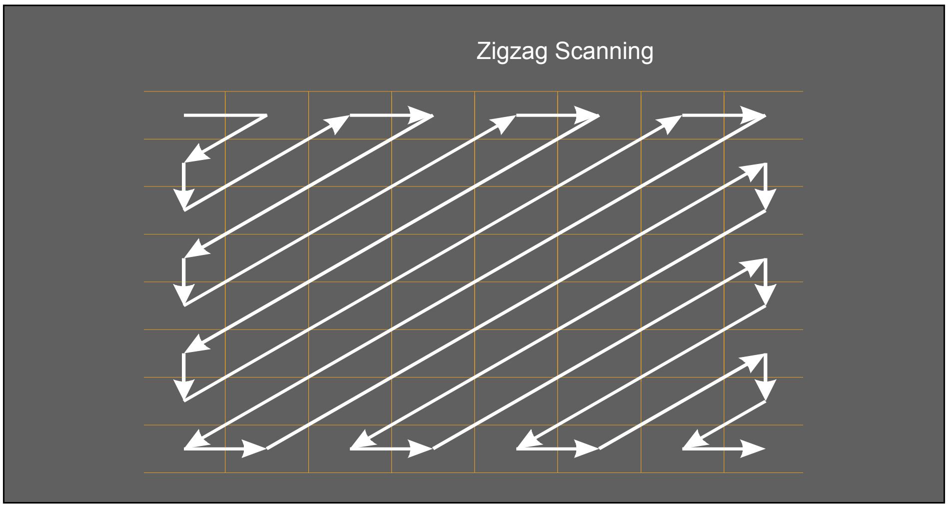
DCT and Compression



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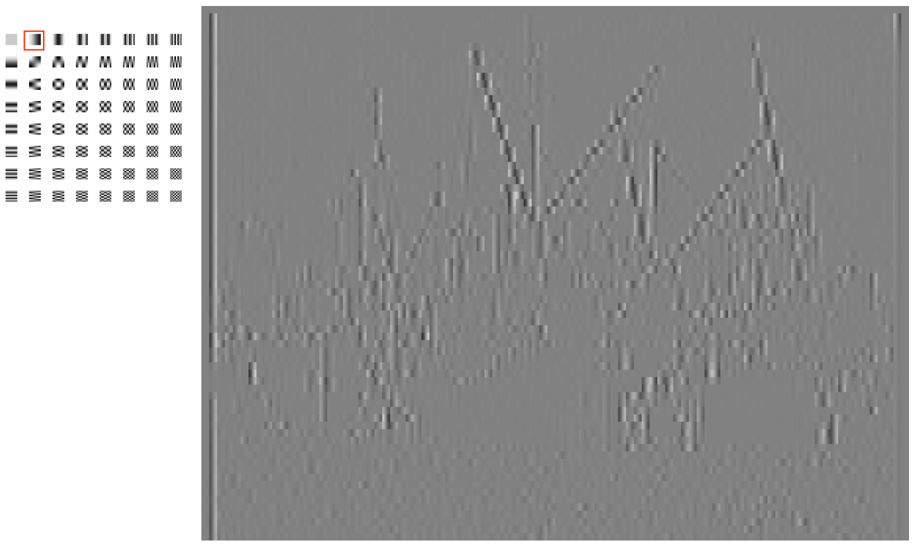
1st Horizontal Term



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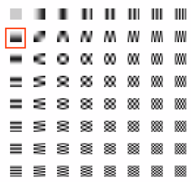
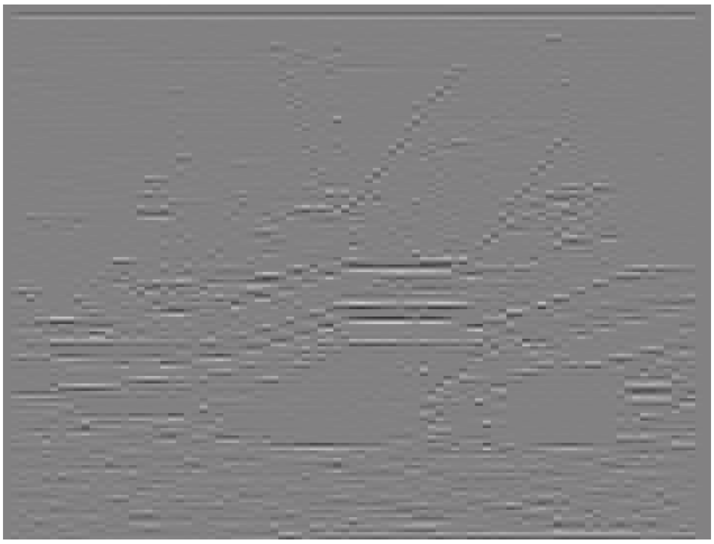
1st Vertical Term





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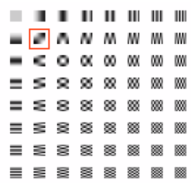
1st Diagonal Term



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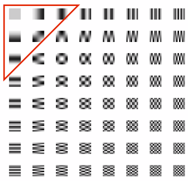
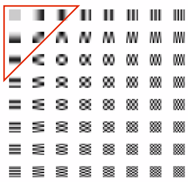
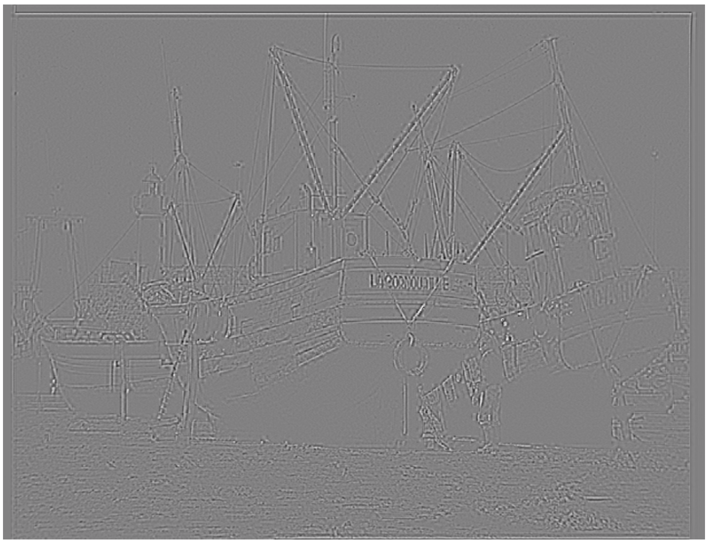
Top 6 Terms



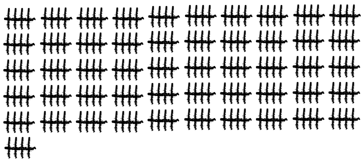
Original - Top 6 Terms Difference

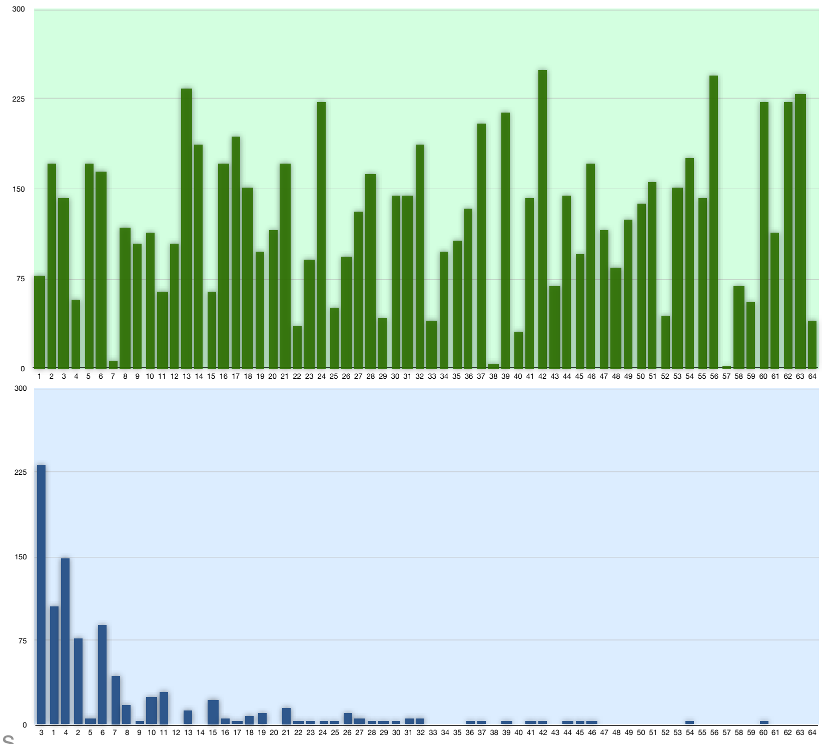




Data Distribution

- In a bit map, all the data is equally distributed… the chance of having a white pixel is just as likely as a grey or black pixel… so all measurements must be equal.
- In DCT… the distribution changes as the patterns change.
- Both carry the same information… it is just written a different way!
- We do just the same with counting…
  - 11111111 in binary is
    - 255 in decimal
    - FF in Hex.
  - But is also…





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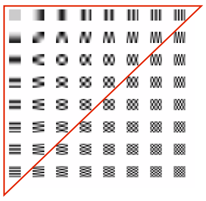
Top 36 Terms



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The Quality Factor - Quantiser Tables

- Each No. represents the amount we divide by
  - i.e.. its the inverse of significance
  - If you divide a 10 figure binary number by 1, you still have a 10 figure number, however, divide by 2 and you reduce it to 9 digits and 8 when you divide by 4….. 64 will be down to a 2 figure number!
  - As a result it makes the measurements less accurate and smaller things start to disappear due to rounding….

1	1	2	4	8	16	32	64
1	2	4	8	16	32	64	64
2	4	8	16	32	64	64	64
4	8	16	32	64	64	64	64
8	16	32	64	64	64	64	64
16	32	64	64	64	64	64	64
32	64	64	64	64	64	64	64
64	64	64	64	64	64	64	64

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All 64 Terms Using Re Quantisation

This uses the same amount of data as 36 terms with no quantiser table

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5 X The Error Of 36 Terms Difference

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5 X The Error With Re Quantisation Difference

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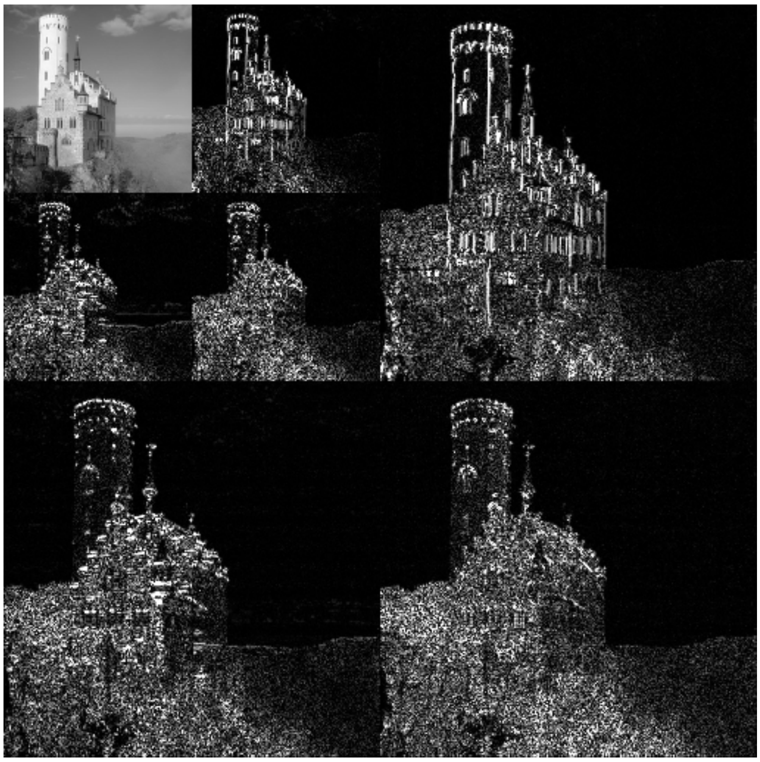
Wavelets



- Wavelets use different Maths to DCT.
- You start with a low resolution image and then add in detail to increase the resolution.
- This process can be repeated several times to gradually upscale the image.
- As a result the entire picture is compressed in one go.... no blocks!

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Wavelets

- Not as common as DCT compression because it is much harder to do.
- The maths are much bigger because the entire picture is compressed in one go.
- With the advent of multiple core processors, wavelets are now easier to handle.
- Wavelets have the advantage of their artefacts being less obtrusive.
- Simpler systems can always disgard the most detailed information and still have a workable result, albeit at lower resolution.

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Wavelet Compression

- JPEG2000.... .jpx file.
- MJPEG2000.... .j2p file.
  - Better efficiency than DCT based JPEG.
- DIRAC
  - produced by BBC Research.
- Tico

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Tico

- The **Ti**ny **Co**dec….
- A Mezzanine Compression system used in 4K production.
  - Visually Lossless up to 4:1.
  - Persistent and Robust: Indistinguishable image loss over multiple generations
  - Latency: Few Microseconds – very few line of pixels (selectable from 1 to x)
  - Small complexity and ultra-compact codec: easy to implement in low-cost FPGA or ASIC. It uses little internal memory and no external memory.
  - Powerful , Real-time or faster than real-time in CPU
  - Compatible with different resolutions, from mobile to 4K/8K UHDTV, via multiple usual transport schemes.
  - Designed to be a standard for the industry-wide support: TICO compression technology is available on multiple software and hardware technologies. Code, hardware IP-cores and software libraries are licensable from intoPIX.

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Inter Frame Compression

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Inter Frame Compression

- works with moving images
  - based on a kit of tools
    - efficient coding (like JPEG)
    - spatial redundancy (like JPEG)
    - temporal redundancy
    - Throwing away the least needed (like JPEG)
- Examples include
    - Beta SX
    - MPEG2
    - HDV
    - H264/MPEG4
    - Sony XD Cam & XD Cam EX

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Inter-frame compression

- Produces much higher efficiency than Intra frame codecs.
- Takes a lot more effort to encode.
- Takes a lot more effort to decode.

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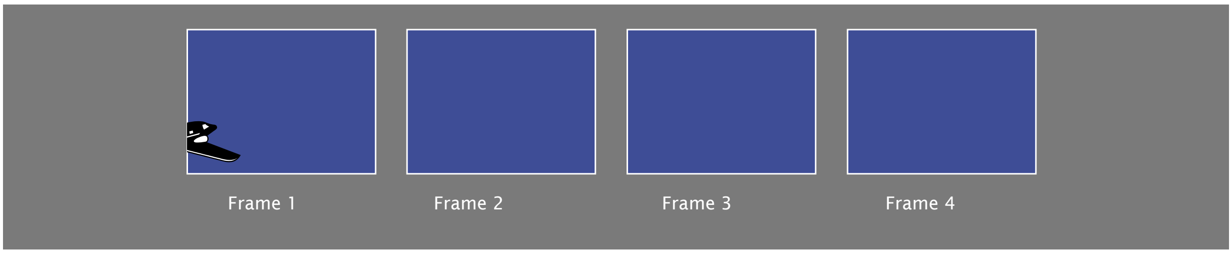
MPEG Motion



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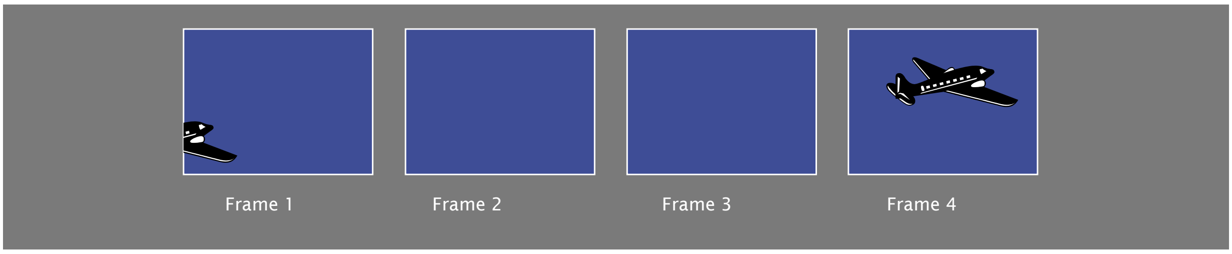
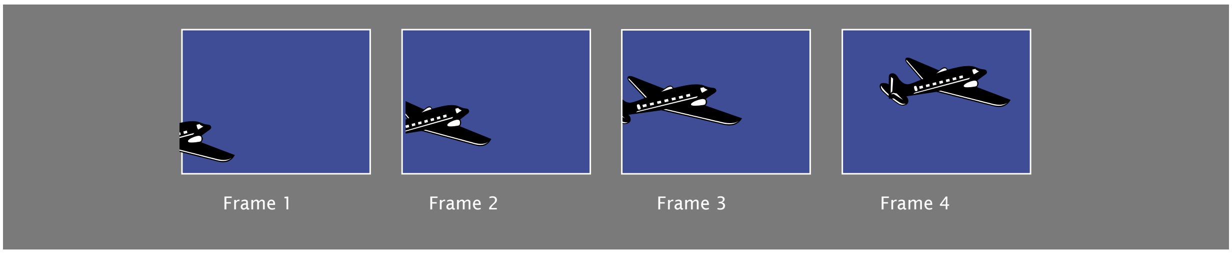
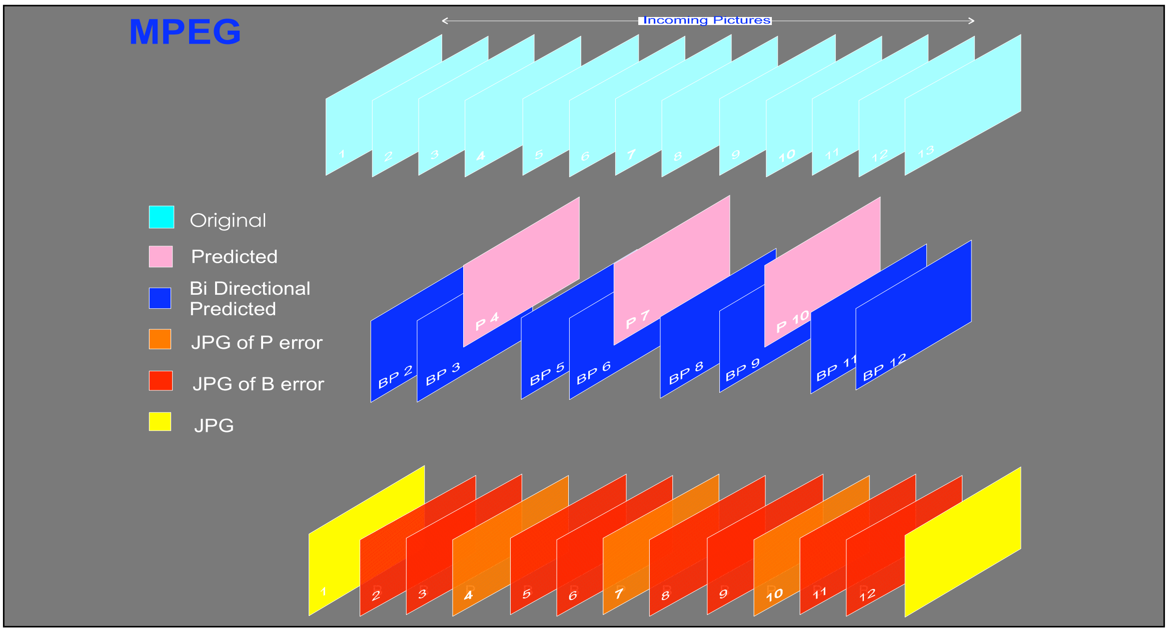
MPEG Motion



MPEG Motion



Long GOP MPEG



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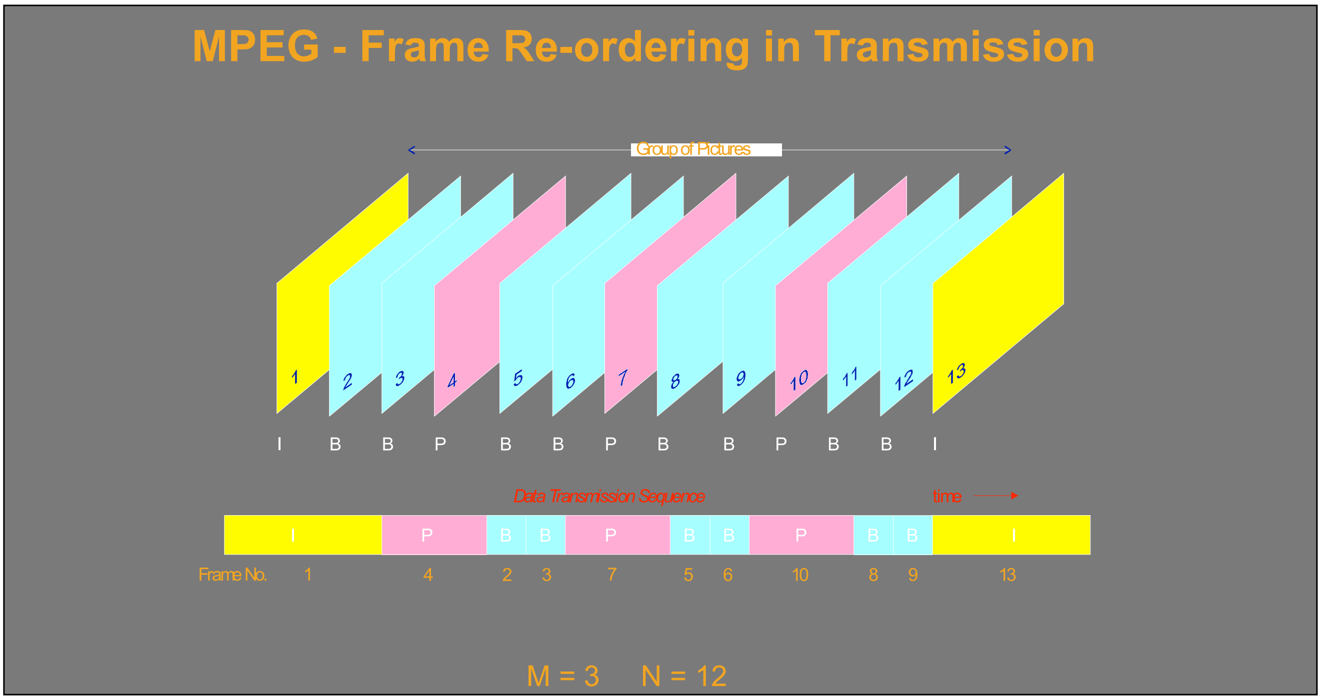

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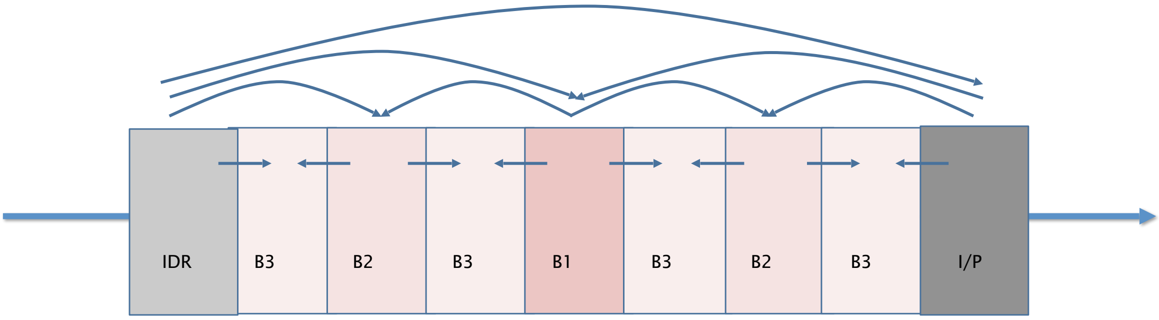
Hierarchical GOPs

- In MPEG-2, a GOP consists of one I frame and multiple P and B frames, each B frame uses the nearest past I or P frames both past and future for prediction. B frames are not used for prediction.
- Advanced codecs remove this major restriction, providing the encoder the flexibility to choose whether to use B frames as references for prediction.



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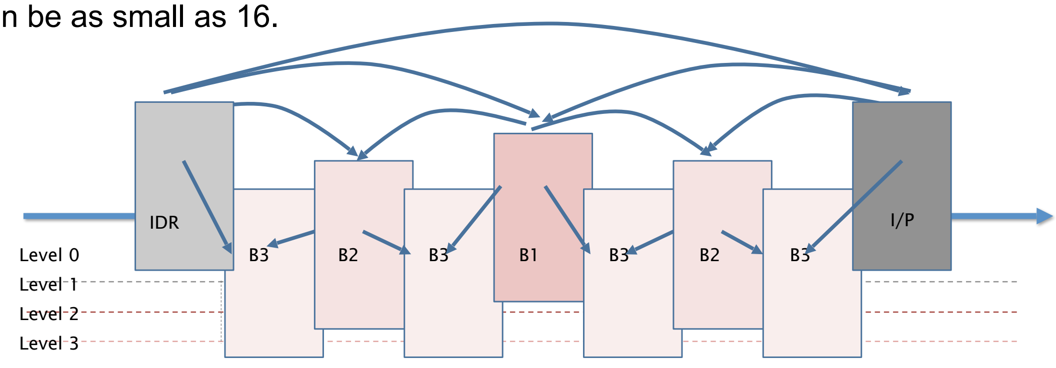
Hierarchical GOPs

- The B frame of the Level 1 (B1) uses only the surrounding I/P references for prediction. Others can use any higher level picture
- No real limit on the GOP length; however, the maximum number of stored frames can be as small as 16.



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Motion Estimation

- Global motion compensation- this is where the whole picture moves…
  - **Pan.** Horizontal movement, left and right.
  - **Tilt.** Vertical movement of the camera angle, i.e. pointing the camera up and down
  - **Zoom.** The picture is magnified by the lens, so that the image grows larger or smaller, but the relative positions of foreground and background objects remain constant.
- Non – global compensation
  - **Crab.** Movement which stays a constant distance from the action, especially side-to-side movement. Foreground content will move through the sot, while distant content stays almost stationary.
  - **Crane.** Moving the camera position vertically with respect to the subject, so that foreground and background relationships change.
  - **Track.** The camera moves closer or further from the subject, so that the relationship between foreground and background objects changes.

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Motion Vectors

- When you are finding the redundant temporal content, it is necessary to work out how things are moving, because it is likely that it will not be a single pixel which moves… whole blocks will move together.
- The system creates a map of the motion vectors, which in turn can be used to predict not only the adjacent content of the current frame, but to then predict the movement and content in subsequent frames. This is called Intra and inter frame prediction.

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End of Part 2

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Part 3 - What does it look like?

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Interframe Codecs

Training for TV

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MPEG2

- Developed in the early 1990's. It provided kit of tools which can be used by manufacturers in their products, so each model of codec will provide different results.
- Has continued to develop over the years because as processors continue to develop the way in which the tools can be used and applied also continues to develop.
- The mainstay of DVB-T DVB-S and DVB-C at SD resolution.
- Complete set tools including video, audio and transport.
- Reasonable quality from 10 Mbits for SD.
- Reasonable quality from 35 Mbits for HD???
- The mainstay of HDV and Sony XDCamHD 420 (18-35 Mbits)
- Sony XDCamHD 422 (50 Mbits)

MPEG2

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H.264 MPEG4 part 10

- The mainstay of many domestic systems such as phones, cameras and video games.
- Block based (DCT).
- Lots of advanced prediction algorithms and features.
- Very efficient.
- Used for all HD transmission systems, such as DVB C2, T2 and S2.
- Very heavy code and decode load.

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High Efficiency Video Coding (HEVC)

- New video compression and successor to H.264/ MPEG-4 AVC
- Under joint development by the ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG)
- HEVC is said to:
  - Improve video quality
  - Double the data compression ratio compared to H.264
  - Support resolutions up to 8K UHD (7680 × 4320)

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The Aim

- The aim of HEVC was to at least halve the data rate required to deliver a signal of similar quality.
- This would be at the cost of up to 4x the coding effort.

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High Efficiency Video Coding (HEVC)

- Differences
  - Primarily for progressive scan video
  - Adaptable DCT transform sizes
  - Parallel processing tools
  - Higher bit depth
  - Intra prediction – 33 directional modes (compared to 8 for H.264)
  - Loop filters – improved de-blocking and new Sample Adaptive Offset (SAO)

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HECV H265

- The latest high tech codec gained ITU approval and was published in 2013.
- 2nd Edition followed in July 2014 and was published in Jan 2015.
  - It included extensions for multi views, different range extensions and scalability extensions.
- 4th Edition came in Dec 2017

H.265
HEVC

HEVC and its' uses

- HEVC at first glance appears to be straightforward replacement for H264 and therefore aimed at the content delivery market and therefore the domestic consumer.
- It allows high resolution content to be delivered to the home at very low bit rates.
- However, there are also other profiles for other uses
  - An Intra frame only and can cope with bit depths up to 16 bits. These will be used as the next generation of acquisition and post production codecs in the same way that AVC Intra has been used.
  - A Graphics based profile to produce state of the art coding for portable graphics functions, still pictures and images.
  - Monochrome profiles for security applications such as infrared imaging.
  - High end, high throughput profiles which might be used for movie production.

HEVC Levels

Level	Max luma sample rate (samples/s)	Max luma picture size (samples)	Max bit rate for Main profile (kbit/s)		Example picture resolution @ highest frame rate	Min Compression ratio	Max number of slices per picture	Max number of tiles	
			Main tier	High tier				rows	columns
1	552,960	36,864	128	-	128×96@33.7 (6) 176×144@15.0 (6)	2	16	1	1
2	3,686,400	122,880	1,500	-	176×144@15.0 (16) 352×288@30.0 (6)	2	16	1	1
2.1	7,372,800	245,760	3,000	-	352×288@60.0 (12) 640×360@30.0 (6)	2	20	1	1
3	16,588,800	552,960	6,000	-	640×360@67.5 (12) 720×480@42.1 (8) 720×576@37.5 (8) 960×544@30.0 (6)	2	30	2	2
3.1	33,177,600	983,040	10,000	-	960×544@60.0 (9) 1280×720@33.7 (6)	2	40	3	3
4	66,846,720	2,228,224	12,000	30,000	1,280×720@68.0 (12) 1,920×1,080@32.0 (6) 2,048×1,080@30.0 (6)	4	75	5	5
4.1	133,693,440		20,000	50,000	1,280×720@136.0 (12) 1,920×1,080@64.0 (6) 2,048×1,080@60.0 (6)	4			
5	267,386,880	8,912,896	25,000	100,000	1,920×1,080@128.0 (16) 3,840×2,160@32.0 (6) 4,096×2,160@30.0 (6)	6	200	11	10
5.1	534,773,760		40,000	160,000	1,920×1,080@256.0 (16) 3,840×2,160@64.0 (6) 4,096×2,160@60.0 (6)	8			
5.2	1,069,547,520		60,000	240,000	1,920×1,080@300.0 (16) 3,840×2,160@128.0 (6) 4,096×2,160@120.0 (6)	8			
6	1,069,547,520	########	60,000	240,000	3,840×2,160@128.0 (16) 4,096×2,160@120.0 (12) 7,680×4,320@32.0 (6)	8	600	22	20
6.1	2,005,401,600		120,000	480,000	3,840×2,160@240.0 (16) 4,096×2,160@225.0 (12) 7,680×4,320@60.0 (6)	8			
6.2	4,010,803,200		240,000	800,000	3,840×2,160@300.0 (16) 4,096×2,160@300.0 (12) 7,680×4,320@120.0 (6)	6			

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Features and Profiles

Feature	Version 1		Version 2						
	Main	Main 10	Main 12	Main 4:2:2 10	Main 4:2:2 12	Main 4:4:4	Main 4:4:4 10	Main 4:4:4 12	Main 4:4:4 16 Intra
Bit depth	8	8 to 10	8 to 12	8 to 10	8 to 12	8	8 to 10	8 to 12	8 to 16
Chroma sampling formats	4:2:0	4:2:0	4:2:0	4:2:0/4:2:2	4:2:0/4:2:2	4:2:0/4:2:2/4:4:4	4:2:0/4:2:2/4:4:4	4:2:0/4:2:2/4:4:4	4:2:0/4:2:2/4:4:4
4:0:0 (Monochrome)	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
High precision weighted prediction	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Chroma QP offset list	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cross-component prediction	No	No	No	No	No	Yes	Yes	Yes	Yes
Intra smoothing disabling	No	No	No	No	No	Yes	Yes	Yes	Yes
Persistent Rice adaptation	No	No	No	No	No	Yes	Yes	Yes	Yes
RDPCM implicit/explicit	No	No	No	No	No	Yes	Yes	Yes	Yes
Transform skip block sizes larger than 4x4	No	No	No	No	No	Yes	Yes	Yes	Yes
Transform skip context/rotation	No	No	No	No	No	Yes	Yes	Yes	Yes
Extended precision processing	No	No	No	No	No	No	No	No	Yes

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VP9 & AV1

- VP9 and AV1 are codecs developed by Google for web based activities.
- They are open source codecs, so are available for anyone to use or develop, but not to patent or own.
- They are competitors with HEVC H265.
- VP9 has been around for about 5 years and will be superseded by the Alliance for Open Media's AV1 which is still under development.
- VP9 is the principle codec for Youtube.
- AV1 is intended to be at least 25% more efficient than H265, but is not yet there…
- It uses a much greater complexity of maths and prediction so takes up to 10x more effort to encode.

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Examples

- Showing compression artefacts and issues is going to be difficult when using a heavily compressed link over and beyond anything created by the codec…
- By compressing the file in advance and then viewing individual frames, hopefully, we will still be able to show some specific issues!

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Impairments Caused By Video Compression

- What happens when we go too far?
  - Blocking - Appearance of the block structure
  - Mosquito noise - Noise around sharp edges
  - Dirty window - Stationary artefacts in areas of motion – or “sticking”
  - Wavy noise - Seen during slow pans and similar to Mosquito noise
  - Loss of resolution & saturation
  - Ghost Images

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Ghost Images

- At 2Mb/s the compression cannot cope…
- Loss of fine detail….
- The gravel is a random material and therefore cannot be predicted… it looses all definition.

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Disolves

- At 2Mb/s the compression cannot cope…
- It is much harder to predict things when one picture is fading away and another is appearing…..
- The data runs out and quality factors drop.
- Blockiness results!

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Ghost Images

- At 2Mb/s the compression cannot cope…
- Note the bass drums….
- Look…. No hands (or sticks)!

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Tracking Shot - Car Following Camera

- In this picture all the content is moving the around the edge of the picture into the centre as the woods rush past.
- Predicting the picture is difficult, because everything is getting smaller as it recedes into the distance!

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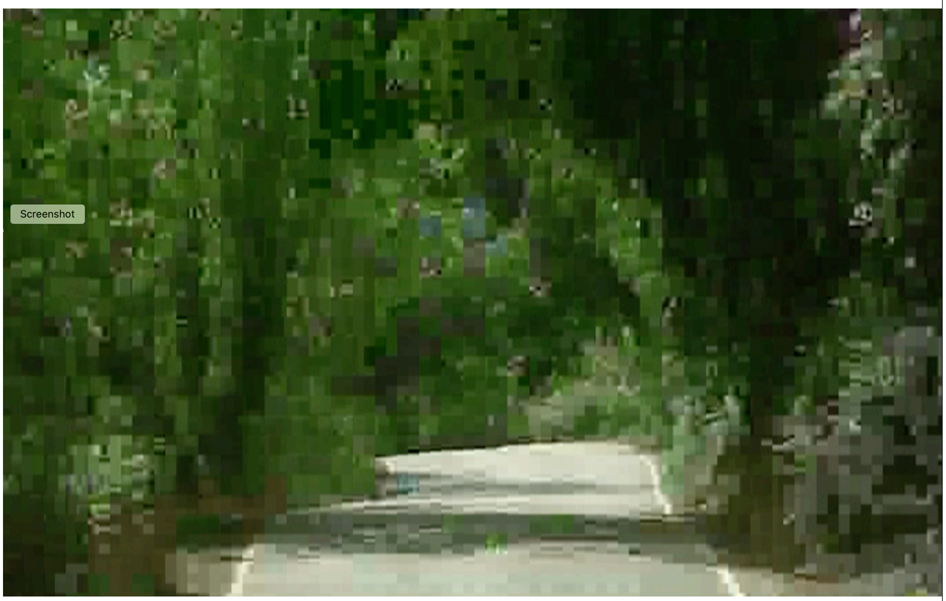
Frame 1 after a cut….

- You cannot predict something when it is new….
- This is the first frame of the next shot… Any prediction is by making the picture from content in the previous completely different shot!



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Frame 2 after a cut….

- The shot gets markedly better at this point.
- There is more data to make this picture…. probably a ‘P’ frame

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Frame 5 after a cut….

- The shot gets even better….
- There is more data to make this picture…. probably a new ‘I’ frame.

Knowledge for TV Professionals

Oh Dear!

- This is as hard as it gets….
- Each piece of gras has it's own trajectory and an auto focus is trying to keep the picture sharp…
- The movement is almost impossible to track and the focus auto focus is constantly hunting.
- Nothing is predictable and there is so much happening….
- Yet at the same time, there isn't!

Knowledge for TV Professionals

Intra Frame Codecs

- Intraframe codecs are brilliant for editing and places where robustness is key.
- If a reasonable data rate is used, they will cope well with multiple encodes and decodes.
- This picture has been encoded and decoded into ProRes 120 five times, but without doing anything to the pictures….

Knowledge for TV Professionals

Inter Frame Codecs

- Interframe codecs deliver remarkable quality when used properly.
- However, if you use them in a production scenario, you will end up encoding and decoding over and over….
- …. then it will all go wrong!
- This picture has been encoded and decoded into XDCam 50 five times, but without doing anything to the pictures….

Knowledge for TV Professionals

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Ultra low bit rates….

- H264 and H265 are capable of running with very low bit rates.
- This clip has been chosen because it is very complicated and difficult. It throws everything at the codec all at once!
- At 2Mb/s the picture is far from perfect, but is actually remarkably good.
- Remember this is 750:1 compression!

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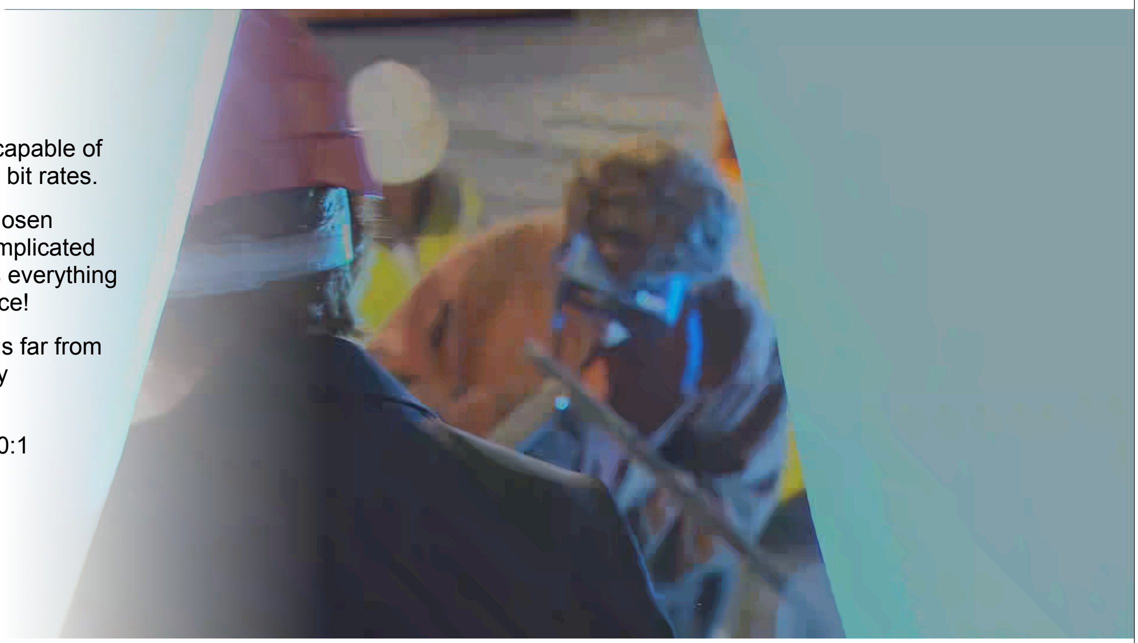
Ultra low bit rates….



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Thank you for listening

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