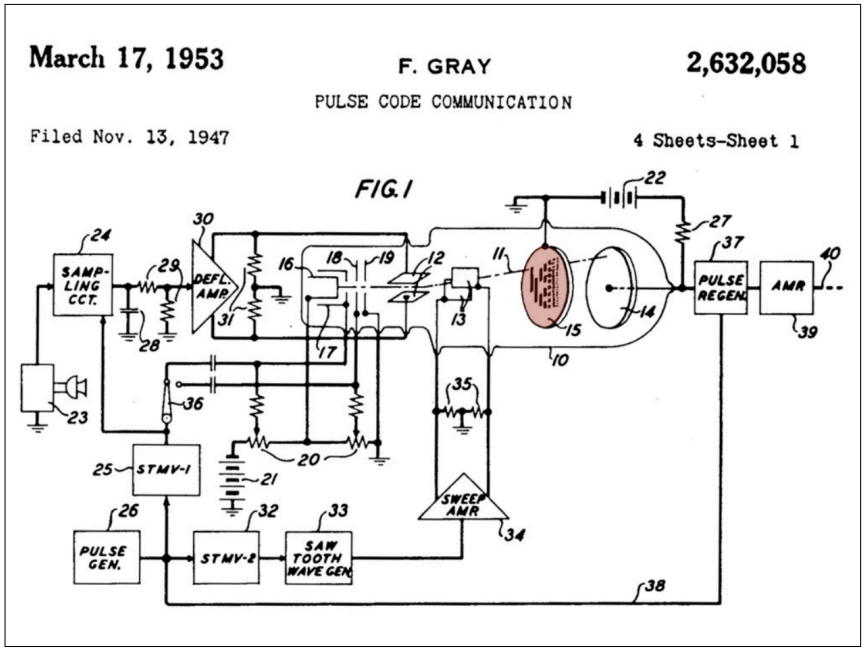

March 17, 1953 F. GRAY 2,632,058

PULSE CODE COMMUNICATION

Filed Nov. 13, 1947 4 Sheets-Sheet 1

FIG. 1

On Audio-Visual File Formats

Reto Kromer • AV Preservation by reto.ch

Open-Source Tools and Resources for Digital Film Preservation
Tate, London, United Kingdom
30–31 October 2019

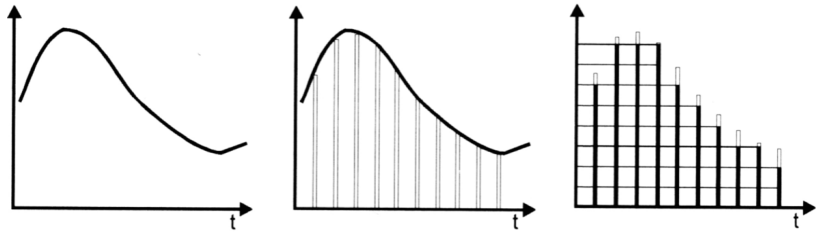
Summary

- digital audio and digital video
- container, codec, raw data
- different formats for different purposes
- audio-visual data transformations

Digital Audio

Digital Audio

- sampling
- quantisation



digitisation = sampling + quantisation

Sampling

- 44.1 kHz
- 48 kHz
- 96 kHz
- 192 kHz

Quantisation

- 16 bit
- 24 bit
- 32 bit

Digital Video

Digital Video

- resolution
- bit depth
- linear, power, logarithmic
- colour model
- chroma subsampling
- illuminant

Resolution

- SD 480i / SD 576i
- HD 720p / HD 1080i
- 2K / HD 1080p
- 4K / UHD-1
- 8K / UHD-2

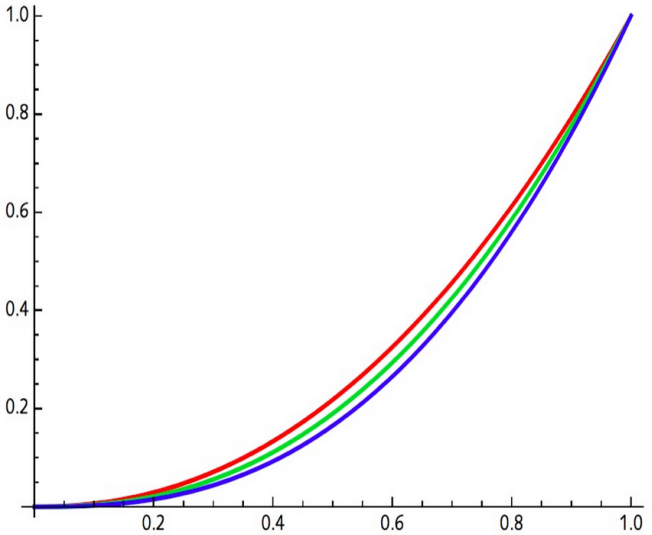
Bit Depth

- 8 bit
- 10 bit
- 12 bit
- 16 bit
- 24 bit

Linear, Power, Logarithmic

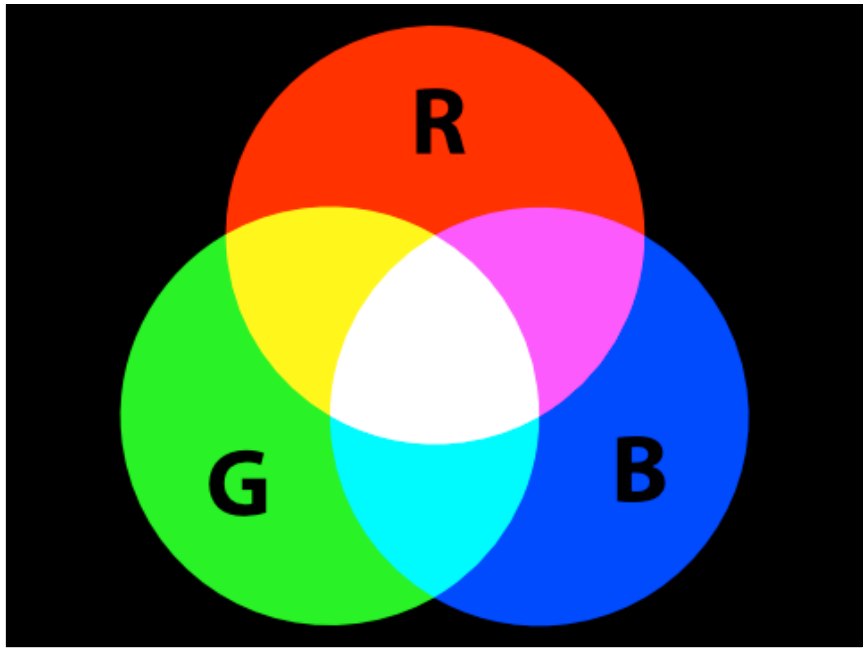
«medium grey»

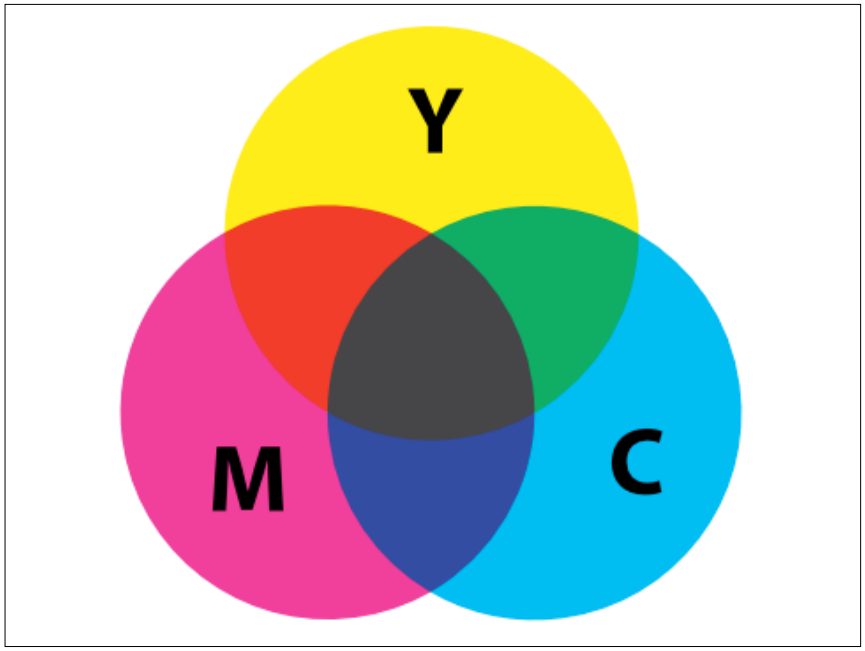
- linear: 18%
- power: 50%
- logarithmic: 50%



Colour Model

- XYZ, L*a*b*
- RGB / R′G′B′ / CMY / C′M′Y′
- Y′IQ / Y′UV / Y′D_BD_R
- Y′C_BC_R / Y′C_OC_G
- Y′P_BP_R





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$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1.396523 \\ 1 & -0.342793 & -0.711348 \\ 1 & 1.765078 & 0 \end{pmatrix} \begin{pmatrix} Y' \\ C_B \\ C_R \end{pmatrix}$$

$$\begin{pmatrix} Y' \\ C_B \\ C_R \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.168074 & -0.329965 & 0.498039 \\ 0.498039 & -0.417947 & -0.080992 \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$$

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$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1 & 1 & -1 \\ 1 & 0 & 1 \\ 1 & -1 & -1 \end{pmatrix} \begin{pmatrix} Y' \\ C_O \\ C_G \end{pmatrix}$$

$$\begin{pmatrix} Y' \\ C_O \\ C_G \end{pmatrix} = \begin{pmatrix} \frac{1}{4} & \frac{1}{2} & \frac{1}{4} \\ \frac{1}{2} & 0 & -\frac{1}{2} \\ -\frac{1}{4} & \frac{1}{2} & -\frac{1}{4} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$$

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20

RGB24

Compression

- uncompressed
- lossless compression
- lossy compression
- born compressed

Uncompressed

+ data simpler to process
+ software runs faster
− bigger files
− slower writing, transmission and reading

Examples: TIFF, DPX, DNG, OpenEXR

Lossless Compression

+ smaller files
+ faster writing, transmission and reading
− data processing complexer
− software runs slower

Examples: JPEG 2000, FFV1

Lossy Compression

- optimised for image acquisition and/or postproduction
- optimised for access

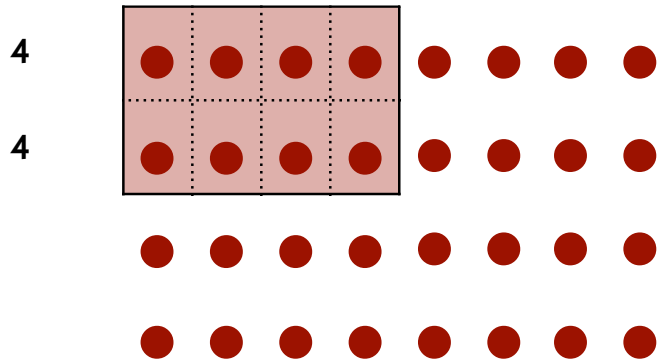
Examples (mezzanine): ProRes 422, ProRes 4444, DNxHD, DNxHR

Examples (access): H.264 (AVC), H.265 (HEVC), AV1

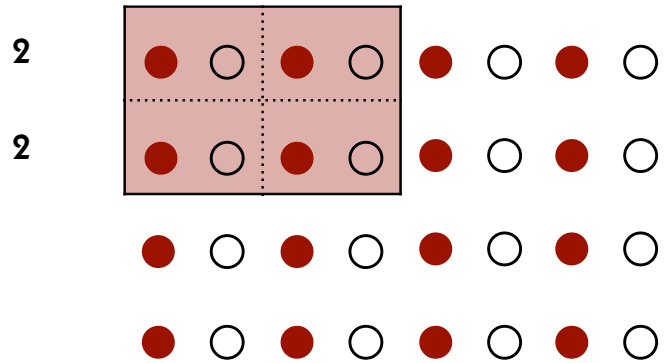
Chroma Subsampling

- 4:4:4
- 4:2:2
- 4:2:0 / 4:1:1

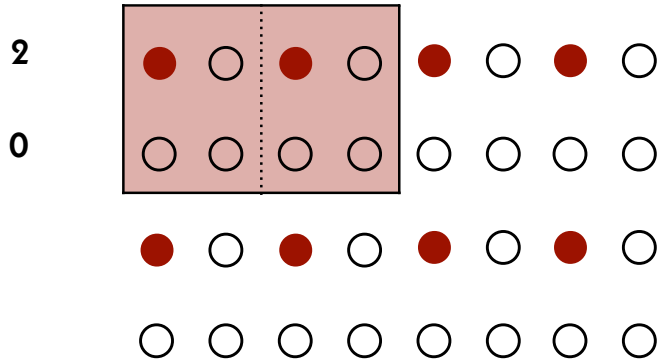
4:4:4



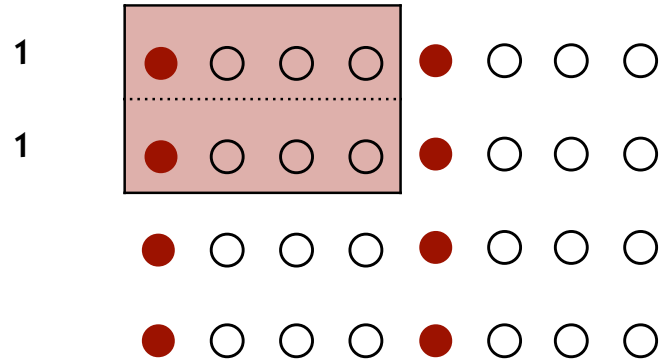
4:2:2



4:2:0



4:1:1

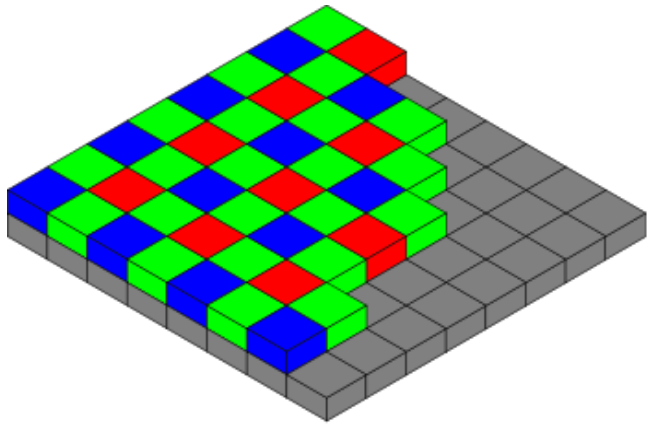


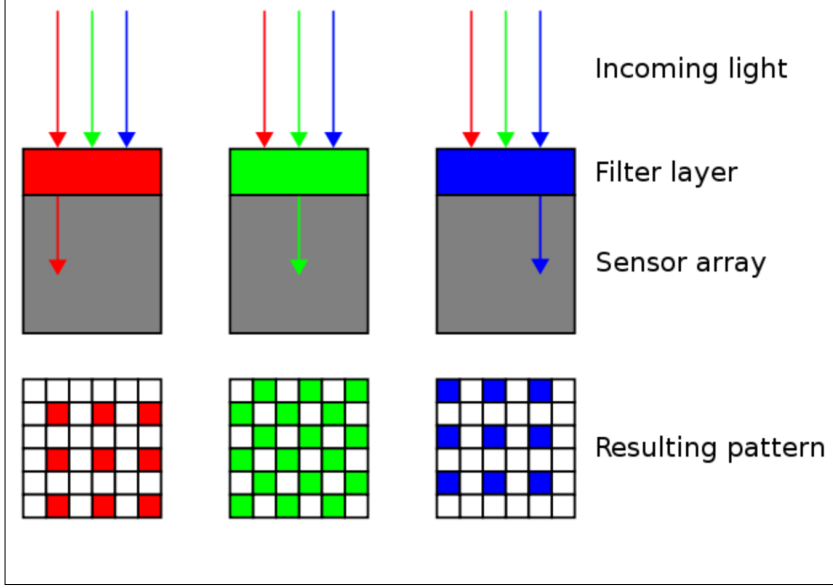
Born Compressed

- optimised for both image acquisition and postproduction

Examples: CineForm RAW, ProRes RAW

Bayer





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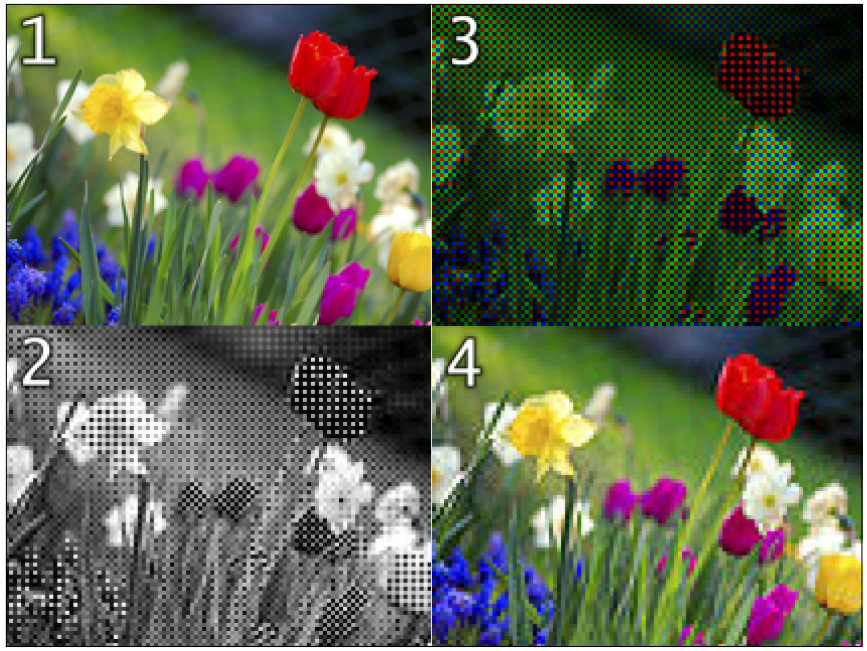

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Illuminant

- D50
- D55
- D65
- D75

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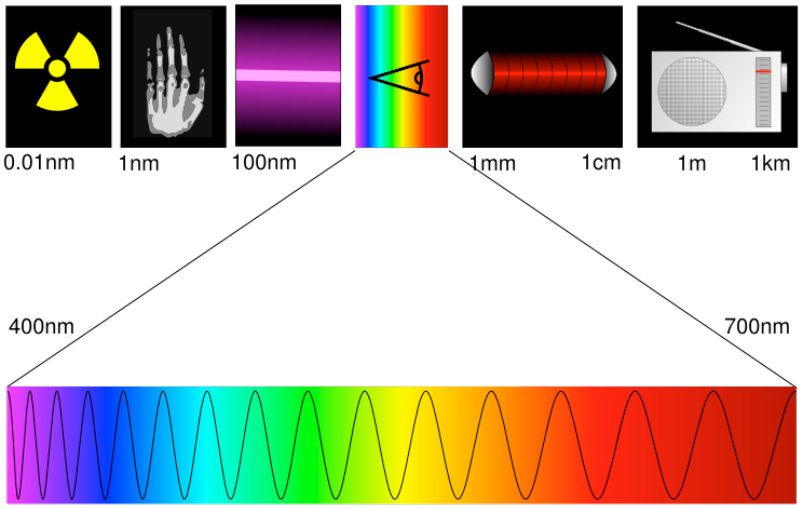

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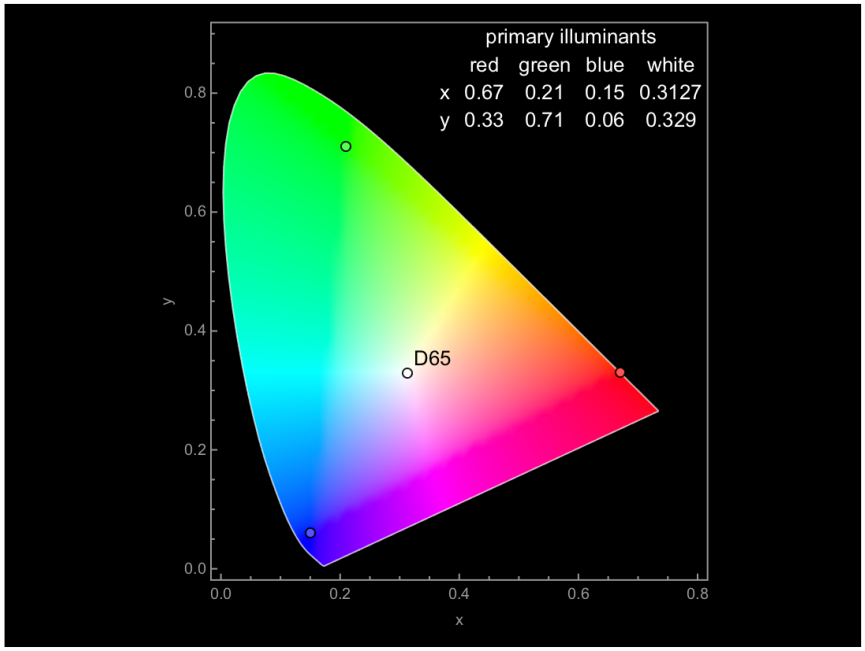

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File Structure

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01110101001010101000101101010111100
01001101010101010101000010111010100
01110101001010101000101101010111100
00011101010101010101000010111010100
01101010100101010100010110101011110
00101010101010101000010111010100000
01110101001010101000101101010111100
01010101010101010000101110101001100
10010111010100101010100010110101010
11100101010101010100001011101010100
01110101001010101000101101010111100
01010101010101010011010101000000010
00101000101010101010010101010101010
```

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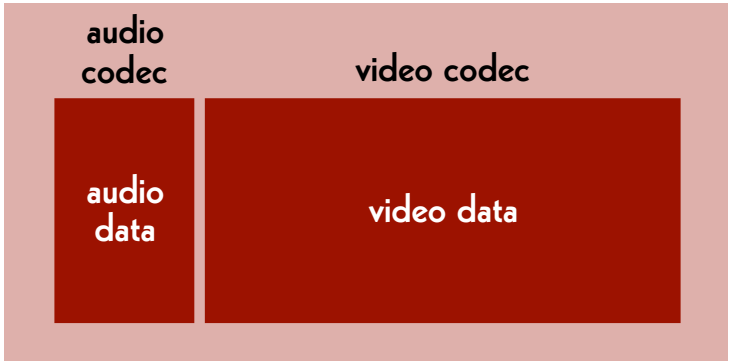
File Structure

audio-visual container (wrapper)



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Audio-Visual Container

- MP4
- MOV
- AVI
- MXF
- Matroska (.mkv)
- Flash

Audio-Visual Container

- MP4
- MOV
- AVI
- MXF
- Matroska (.mkv)
- Flash

Single Images

- folder
- TAR
- ZIP
- MXF
- Matroska (.mkv)
- CinemaDNG

Audio Codec

- WAVE
- BWF
- FLAC
- AAC
- MP3

Video Codec (Master)

images

- TIFF
- DPX
- JPEG 2000
- OpenEXR
- DNG

streams

- 8 bit raw
- 10 bit raw
- HuffYUV
- FFV1

Video Codec (Mezzanine)

- ProRes 422, ProRes 4444, ProRes RAW
- DNxHD, DNxHR
- CineForm RAW

Video Codec (Access)

- H.264, H.265 (HEVC), AV1

Data is anything
but «raw».

Audio Data

- pcm_s16le
- pcm_s24le
- pcm_s32le

Video Data

- rgb48le
- rgb24
- rgb72le
- bayer_bggr16le
- bayer_bggr24le
- yuv444p16le
- yuv422p10le
- uyvy422
- yuv420p
- yuv444p24le

What is inside my DPX?

- log neg encoding
- log RGB encoding or quasi-log encoding
- gamma encoding or power function encoding
- scene-linear encoding

File Formats

Principles

- The archive must be able to handle the file formats it holds.

- open source
- simple to use and well documented
- widely used by the community

Different Purposes

archive master format:
➔ for preservation

mezzanine format:
➔ for professional use in post-production

dissemination formats:
➔ for widely spreading and easy access

Elena Rossi-Snook:

Archiving without access isn't preservation, it's hoarding.

Archive Master (Today)

film
- folder, TIFF, 2K, RGB, 4:4:4, 16 bit
- MXF, DPX, 2K, R'G'B', 4:4:4, 10 bit

video
- AVI, «raw», HD, $Y'C_BC_R$, 4:2:2, 10 bit
- Matroska, FFV1, HD, $Y'C_BC_R$, 4:2:2, 10 bit

audio
- BWF, 96 kHz, 24 bit
- FLAC, 96 kHz, 24 bit

Mezzanine (Today)

video
- ProRes 4444, 2K
- DNxHR, 2K
- ProRes 422 HQ, HD
- DNxHD 175x, HD

audio
- BWF, 48 kHz, 24 bit
- WAVE, 48 kHz, 24 bit

Dissemination (Today)

MP4

Video
- H.264, SD, yuv420p, «lossy»
- H.264, HD, yuv420p, «lossy»

Sound
- AAC, 44.1 kHz, 16 bit
- AAC, 48 kHz, 16 bit

Archive Master and Mezzanine

film
- Matroska, FFV1, 2K, «RGB», 4:4:4, 16 bit

video
- Matroska, FFV1, HD, $Y'C_BC_R$, 4:2:2, 10 bit

audio
- Matroska, FLAC, 96 kHz, 24 bit

Access

WebM (a subset of Matroska)

Video
- «H.265», HD, yuv420p

Sound
- «FLAC», 48 kHz, 16 bit

Reading

Reto Kromer: **Matroska and FFV1: One File Format for Film and Video Archiving?**, in «Journal of Film Preservation», n. 96 (April 2017), FIAF, Brussels, Belgium, p. 41–45

➔ https://retokromer.ch/publications/JFP_96.html

Pros & Cons

container:

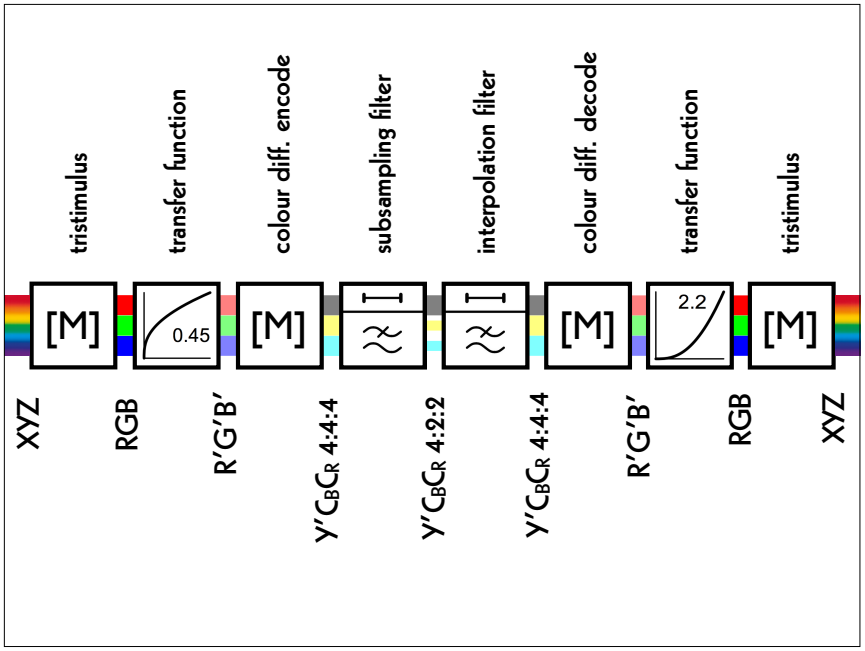
- folder
- TAR
- ZIP
- MXF
- Matroska

codec:

- TIFF
- DPX
- JPEG 2000
- FFV1
- OpenEXR
- CineForm RAW
- ProRes RAW

	avantages	disavantages
TIFF DPX OpenEXR	data easier to process	bigger files
JPEG 2000 FFV1	smaller files	data complexer to process

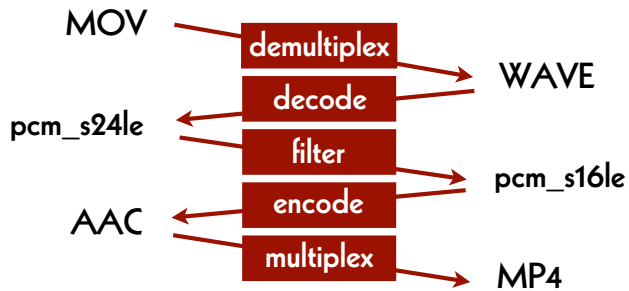
Transformations



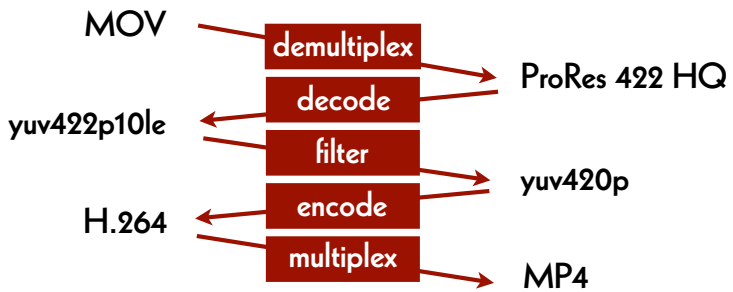
Data Transformations

demultiplex
decode
filter
encode
multiplex

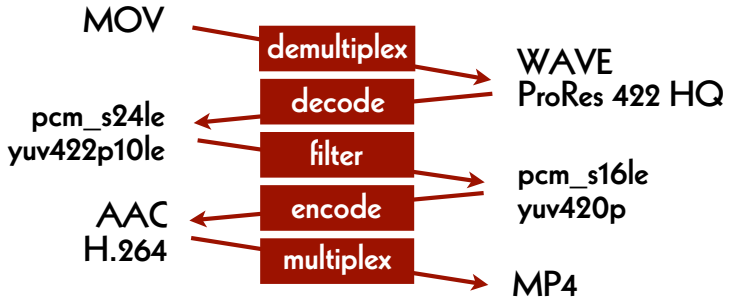
Audio Exemple



Video Exemple



Audio-Visual Exemple



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