On Audio-Visual File Formats

Reto Kromer • AV Preservation by reto.ch

On the Materiality of Audio-Visual Heritage
Elías Querejeta Zine Eskola
Donostia (San Sebastián), Spain
17–20 October 2023

1

Summary

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

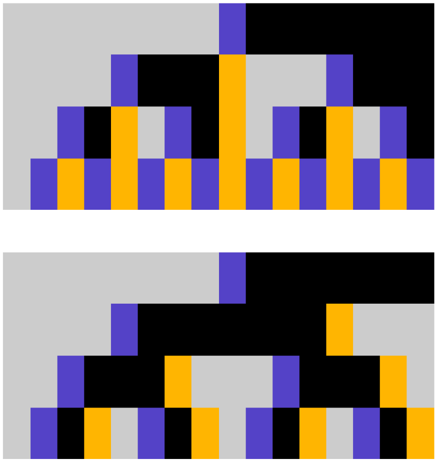
2

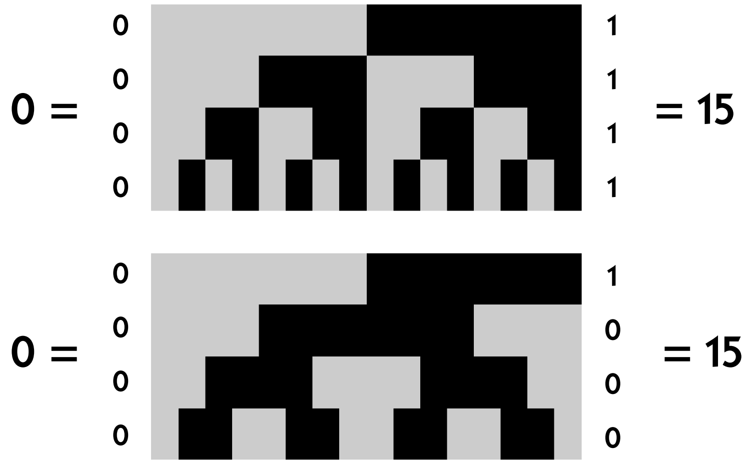
Digital Audio

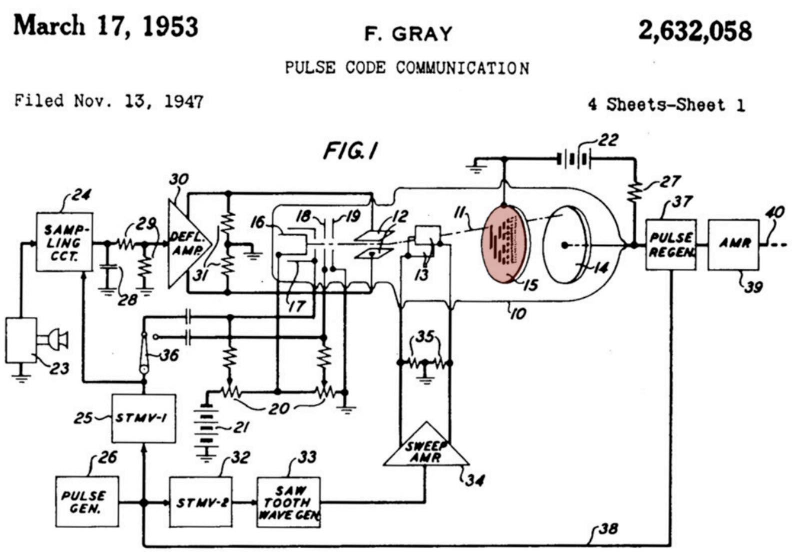
3

Frank Gray (1887–1969)

4

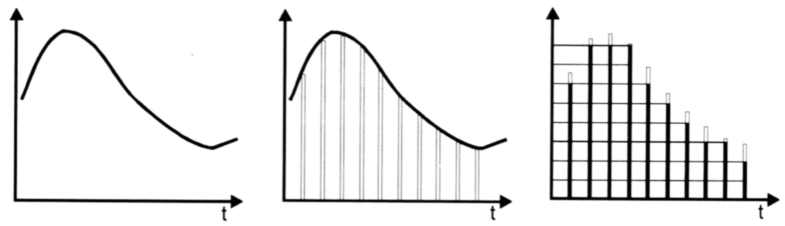






Digital Audio

- sampling
- quantisation
- compression



digitisation = sampling + quantisation

Sampling

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

Quantisation

- 16 bit (2^{16} = 65 536)
- 24 bit (2^{24} = 16 777 216)
- 32 bit (2^{32} = 4 294 967 296)

Digital Video

Digital Video

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

13

Resolution

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

14

Bit Depth

- 8 bit (2^{8} = 256)
- 10 bit (2^{10} = 1 024)
- 12 bit (2^{12} = 4 096)
- 16 bit (2^{16} = 65 536)
- 24 bit (2^{24} = 16 777 216)

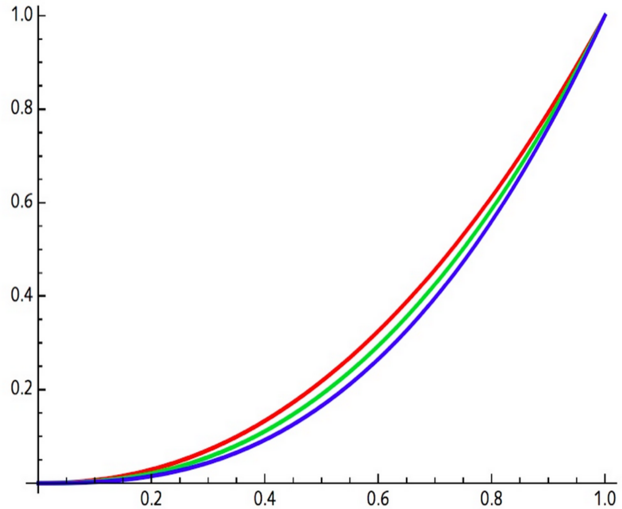
15

Linear, Power, Logarithmic

"medium grey"

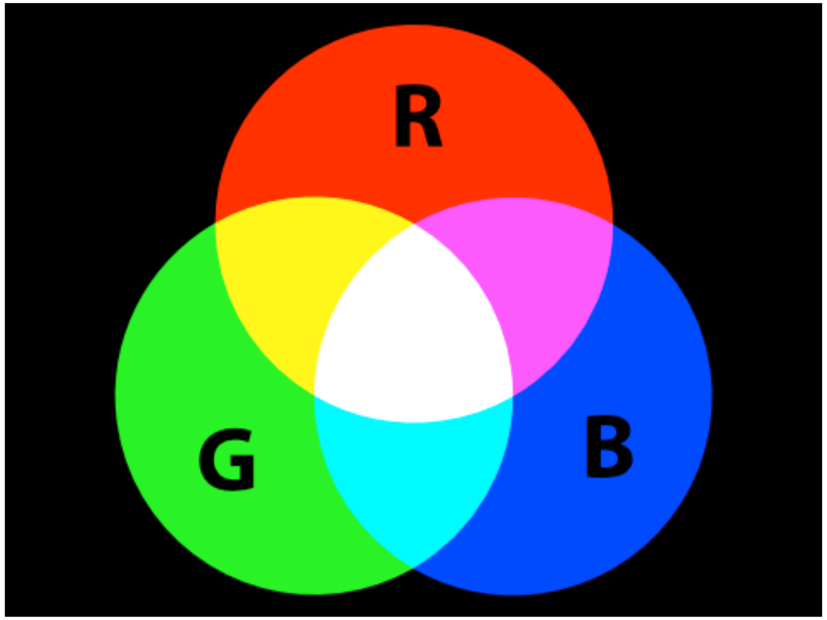
- linear scale: 18 %
- power function: 50 %
- logarithmic scale: 50 %

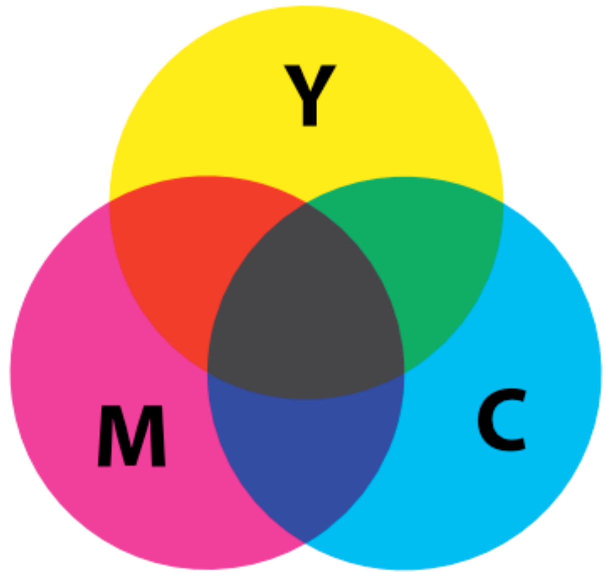
16



Colour Model

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





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

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

21

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

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

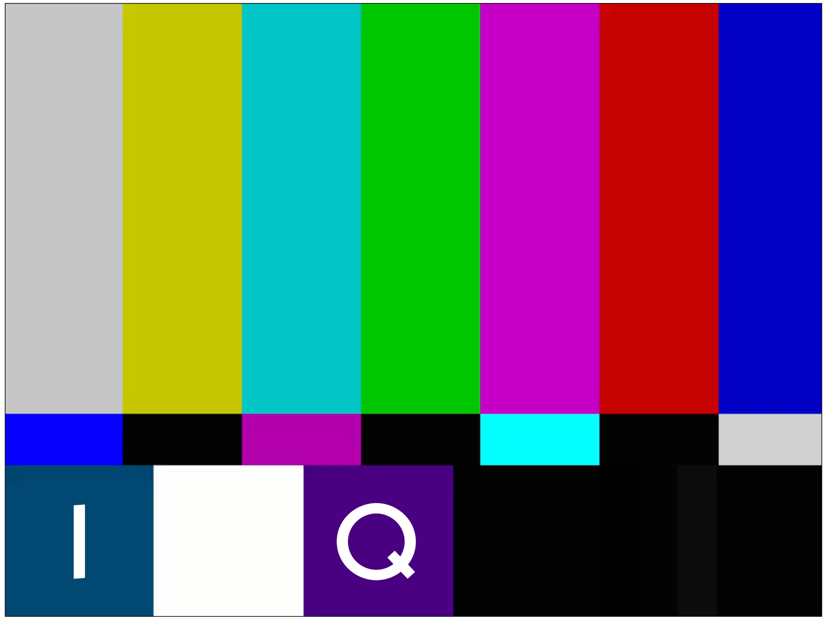
22

23

RGB24

00000000 00000000 00000000	11111111 00000000 00000000	00000000 11111111 00000000	00000000 00000000 11111111
00000000 11111111 11111111	11111111 00000000 11111111	11111111 11111111 00000000	11111111 11111111 11111111

24



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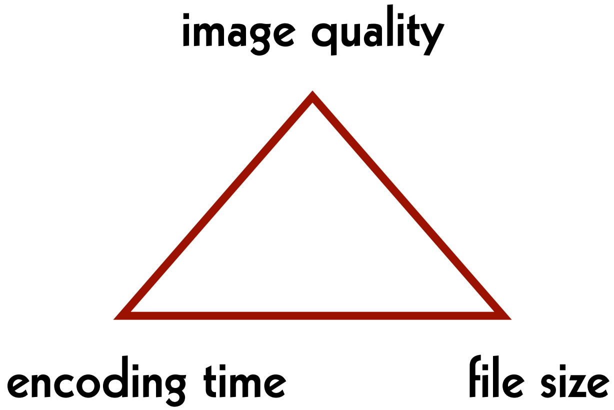


26

Compression

- uncompressed
- lossless compression
- lossy compression
- chroma subsampling
- born compressed

27

Uncompressed

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

Examples: TIFF, DPX, DNG, OpenEXR

28

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

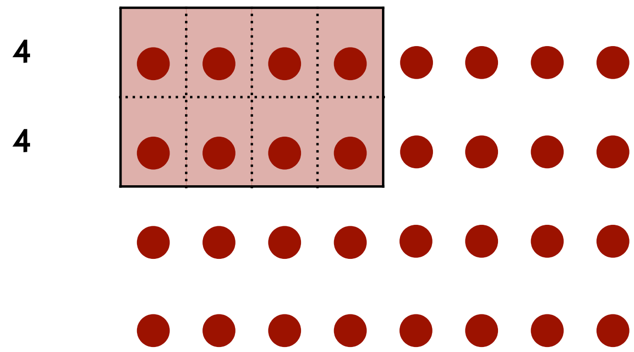
Examples (mezzanine): ProRes 422, ProRes 4444; DNxHD, DNxHR

Examples (access): H.264 (AVC), H.265 (HEVC), H.266 (VVC); AV1

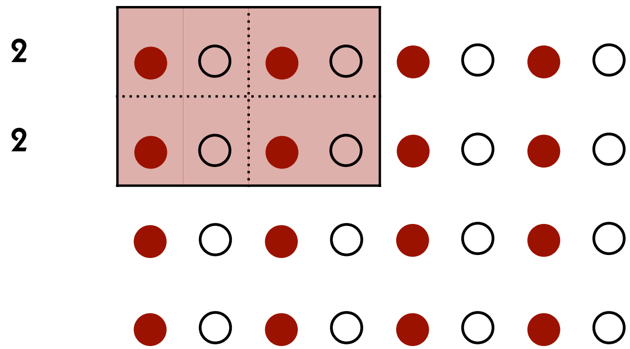
Chroma Subsampling

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

4:4:4



4:2:2



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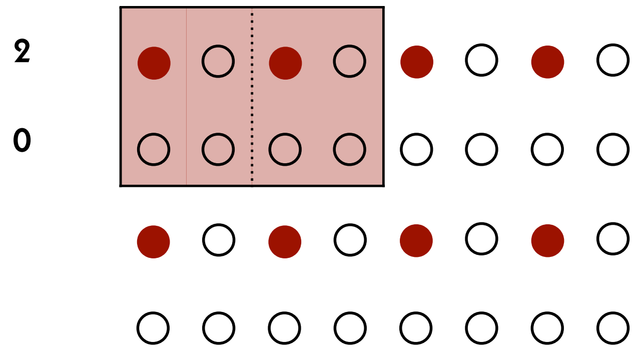

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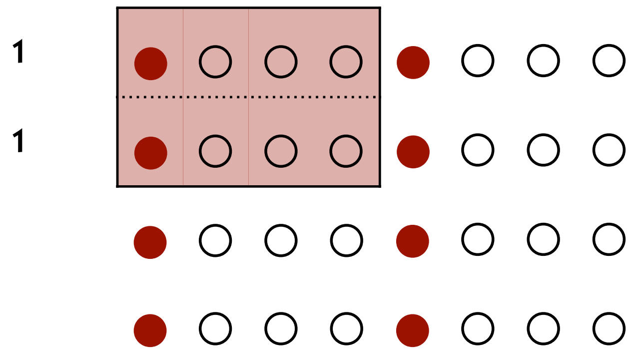


Born Compressed

- optimised for both image acquisition and postproduction

Examples: CineForm RAW, ProRes RAW, Blackmagic RAW

Uncomfortable Truths

- sensors are colour blind
- Bayer sensors do not generate full RGB

Bryce E. Bayer (1929–2012)

United States Patent [19] — **Bayer**

[11] **3,971,065**
[45] **July 20, 1976**

[54] **COLOR IMAGING ARRAY**

[75] Inventor: **Bryce E. Bayer,** Rochester, N.Y.

[73] Assignee: **Eastman Kodak Company,** Rochester, N.Y.

[22] Filed: **Mar. 5, 1975**

[21] Appl. No.: **555,477**

[52] **U.S. Cl.** .... **358/41;** 350/162 SF; 350/317; 358/44

[51] **Int. Cl.²**... **H04N 9/24**

[58] **Field of Search** .... 358/44, 45, 46, 47, 358/48; 350/317, 162 SF; 315/169 TV

[56] **References Cited**

UNITED STATES PATENTS

2,446,791	8/1948	Schroeder	358/44
2,508,267	5/1950	Kasperowicz	358/44
2,884,483	4/1959	Ehrenhaft et al.	358/44
3,725,572	4/1973	Kurokawa et al.	358/46

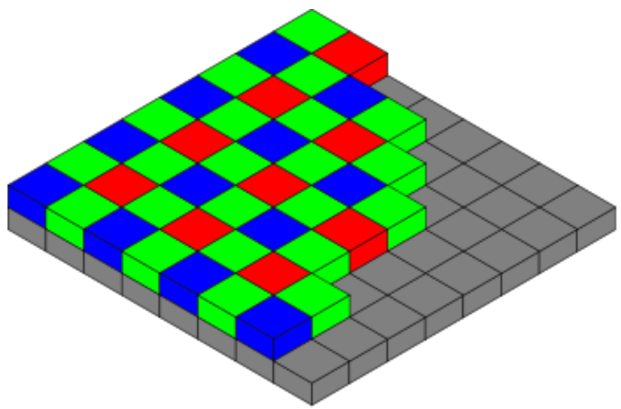
Primary Examiner—George H. Libman
Attorney, Agent, or Firm—George E. Grosser

[57] **ABSTRACT**

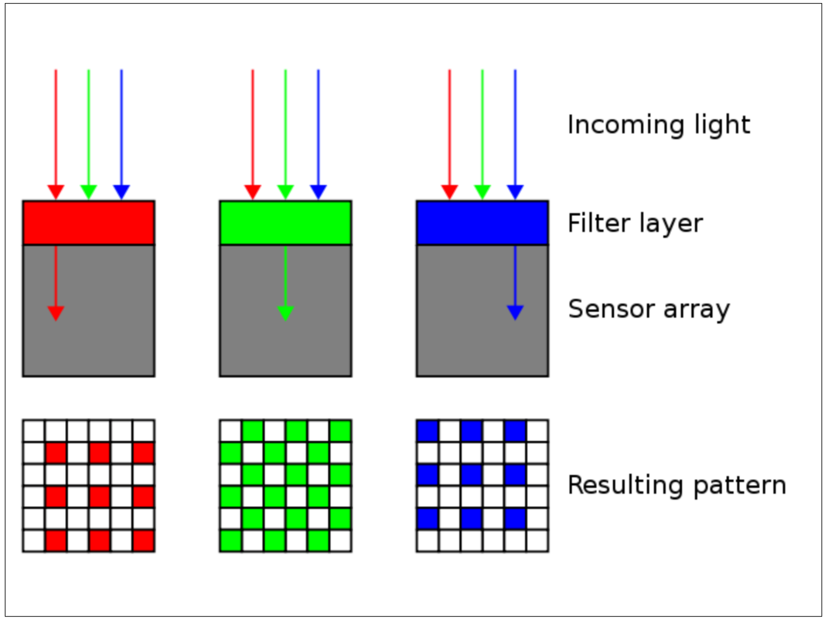
A sensing array for color imaging includes individual luminance- and chrominance-sensitive elements that are so intermixed that each type of element (i.e., according to sensitivity characteristics) occurs in a repeated pattern with luminance elements dominating the array. Preferably, luminance elements occur at every other element position to provide a relatively high frequency sampling pattern which is uniform in two perpendicular directions (e.g., horizontal and vertical). The chrominance patterns are interlaid therewith and fill the remaining element positions to provide relatively lower frequencies of sampling.

In a presently preferred implementation, a mosaic of selectively transmissive filters is superposed in registration with a solid state imaging array having a broad range of light sensitivity, the distribution of filter types in the mosaic being in accordance with the above-described patterns.

11 Claims, 10 Drawing Figures



source: wikipedia.org



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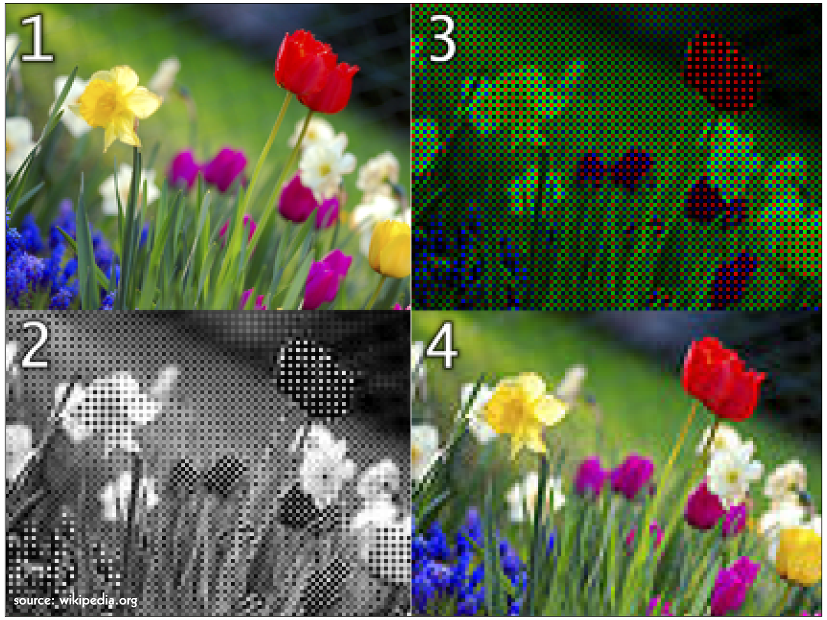

42

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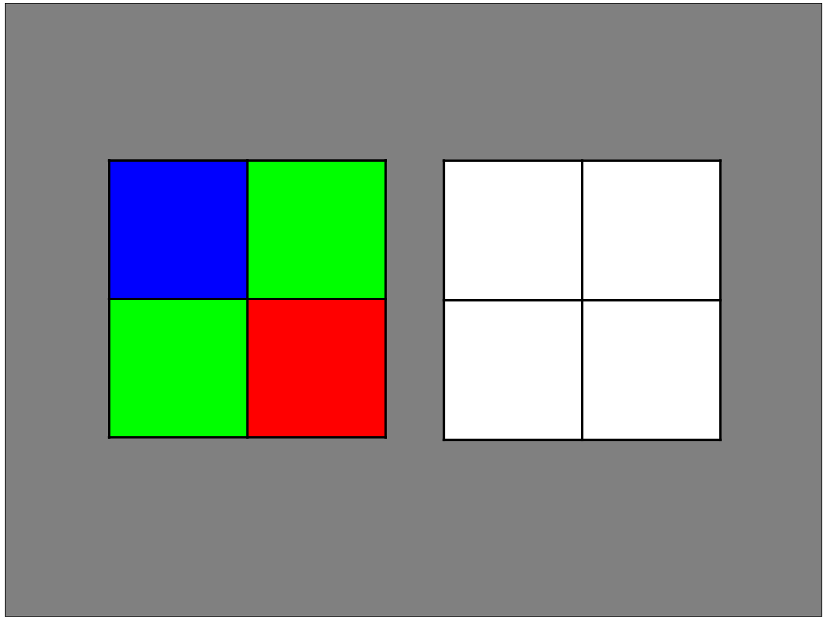

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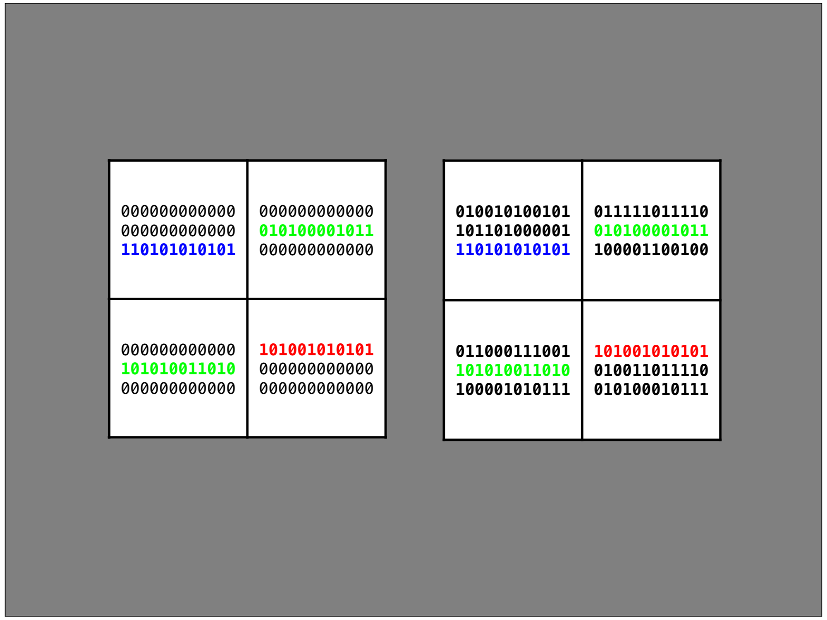
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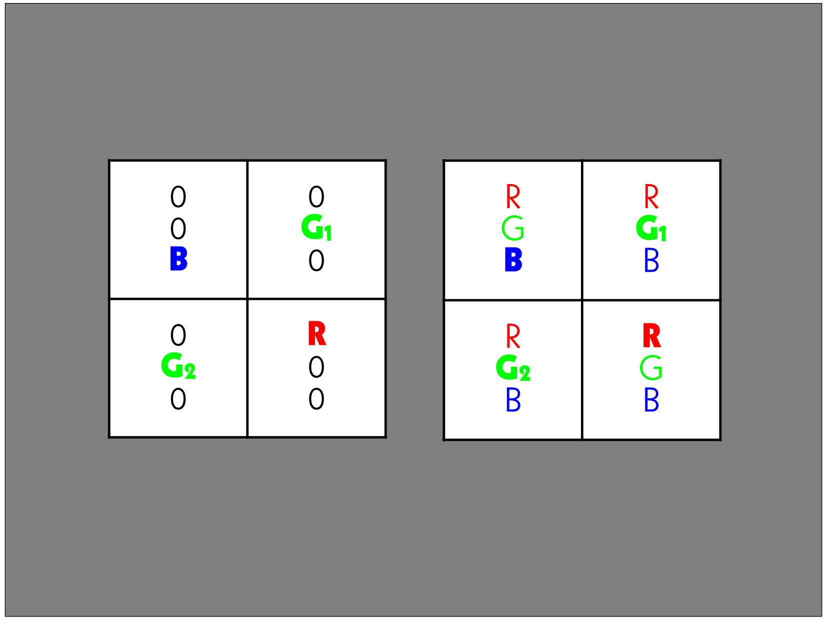
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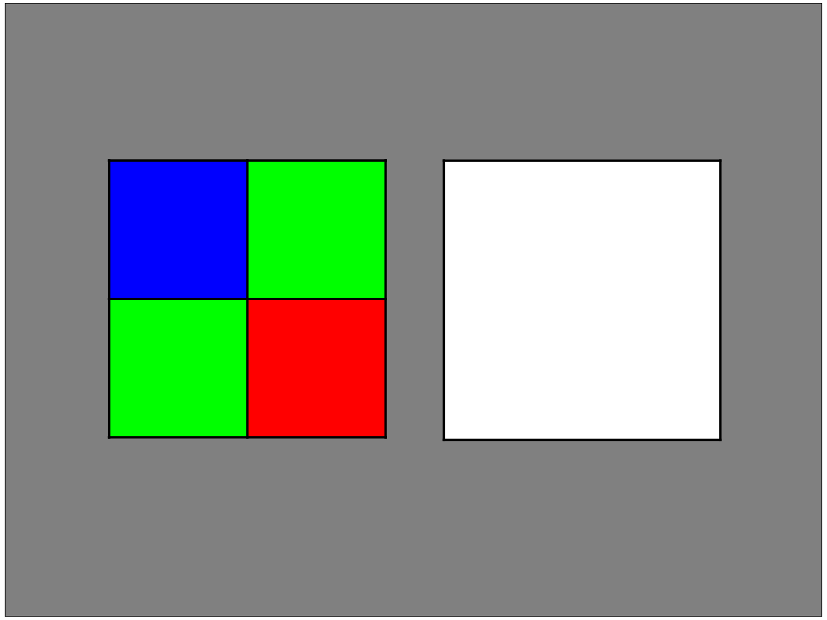

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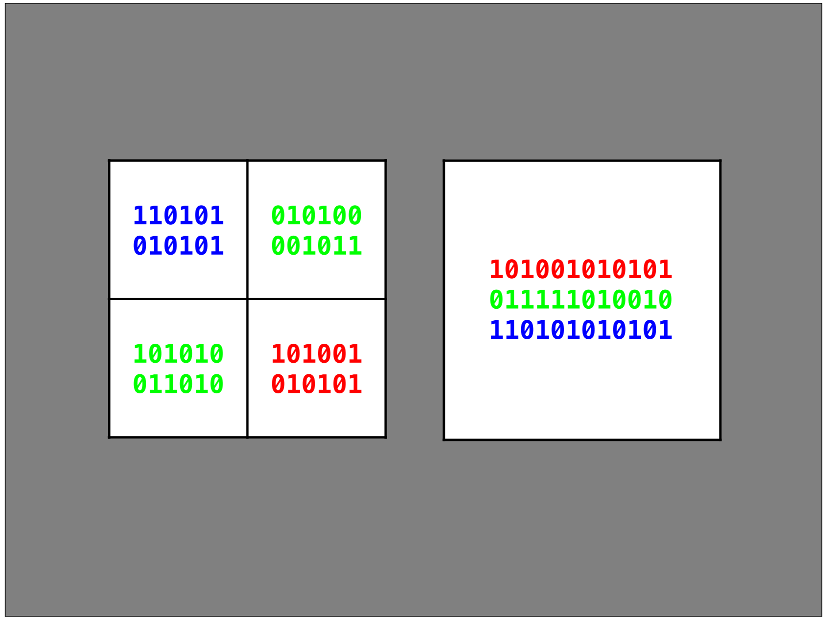
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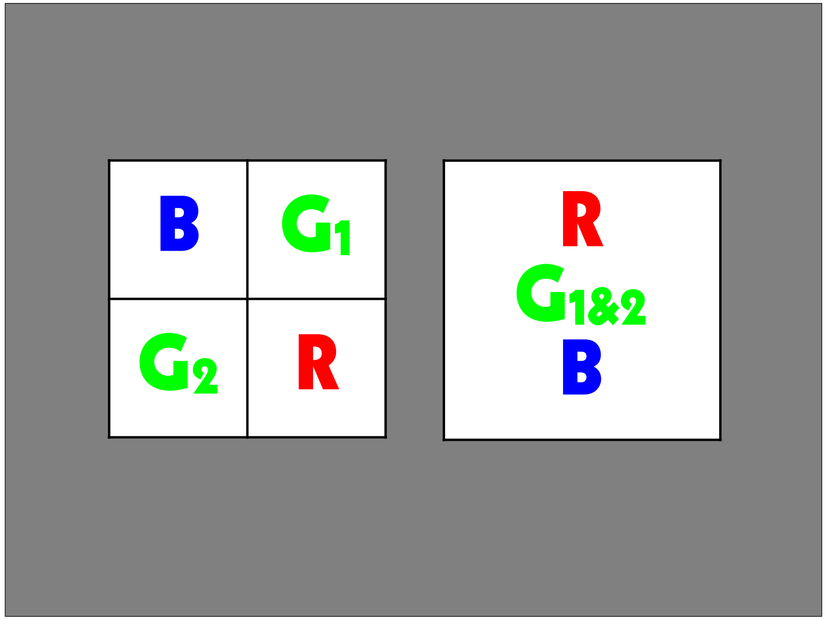


49

Ways to use Bayer-type data

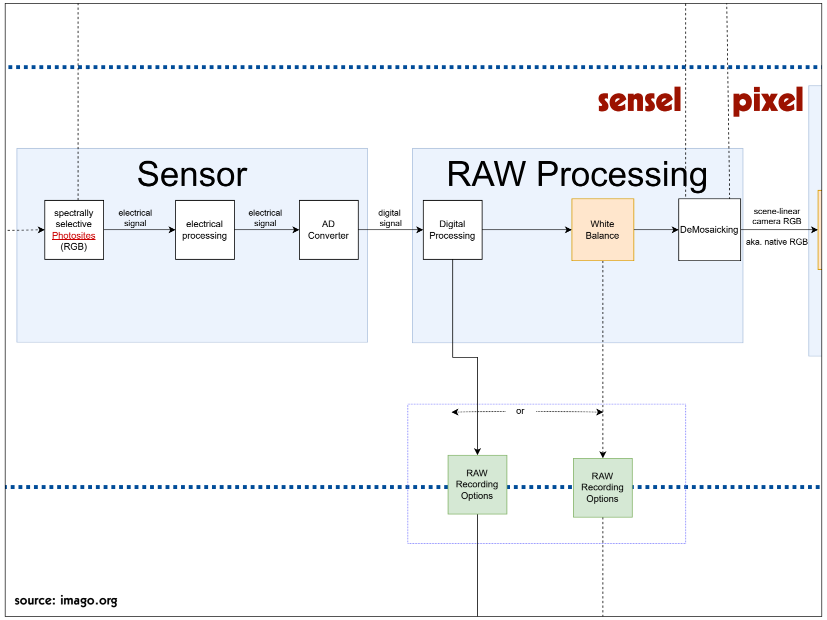
digital blow-up to RGB

- 3 times the amount of the generated data
- the file has the full sensor resolution
- only ⅓ of the data are real

digital reduction to RGB

- ¾ the amount of the generated data
- the file has ½ of the sensor resolution
- all data are real

50



51

Ways to store Bayer-type data

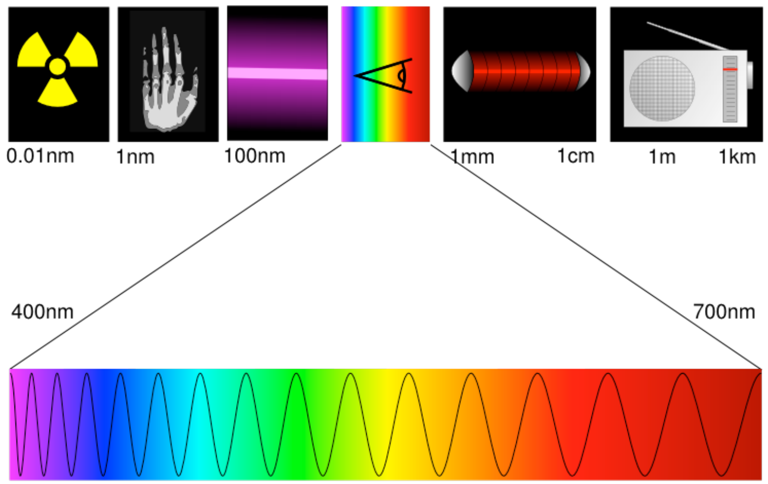
- pixel values generated by one de-mosaicking algorithm (digital blow-up)
- pixel values generated by mixing two green sensel values into one (digital reduction)
- raw sensel values

52

Standard Illuminant

- D50
- D55
- D65
- D75

53



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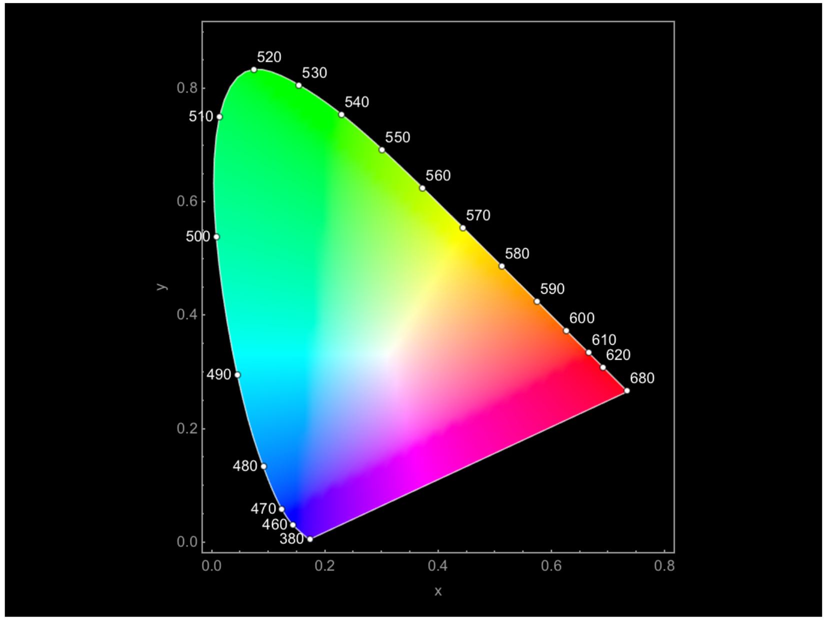

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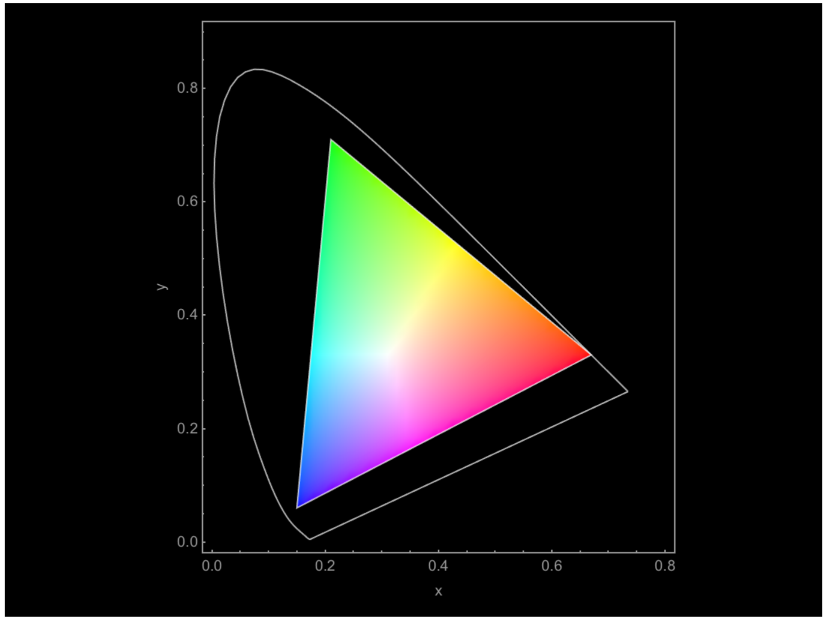

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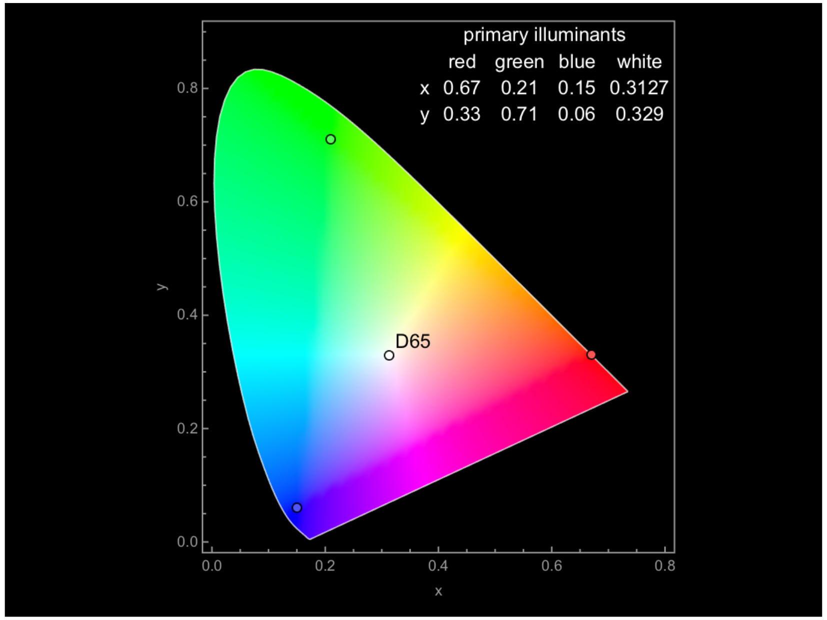
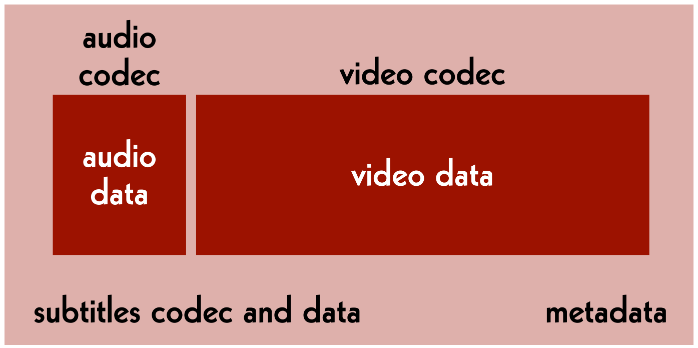


File Structure

File Structure

audio-visual container (wrapper)



Audio-Visual Container

- MP4
- QuickTime (.mov)
- AVI
- MXF
- Matroska (.mkv)
- Flash

Single Images

- folder
- TAR
- ZIP

- MXF
- Matroska (.mkv)

- CinemaDNG
- Motion JPEG

61

Audio Codec

- WAVE
- BWF

- AAC
- MP3

- FLAC

62

Video Codec (Master)

images

- TIFF
- DPX
- JPEG 2000
- OpenEXR
- DNG

streams

- $Y'C_BC_R$ 8 bit
- $Y'C_BC_R$ 10 bit
- HuffYUV
- FFV1

63

Video Codec (Mezzanine)

- ProRes 422, ProRes 4444
- DNxHD, DNxHR

- CineForm RAW
- ProRes RAW
- Blackmagic RAW

64

Video Codec (Access)

- H.264 (AVC)
- H.265 (HEVC)
- H.266 (VVC)

- AV1

RAW data are cooked.

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, 16 bit
- MXF, DPX, 2K, R′G′B′, 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

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

Archive Master and Mezzanine

film
- Matroska, FFV1, 2K, RGB, 16 bit
- Matroska, FFV1, 2K, R′G′B′, 12 bit

video
- Matroska, FFV1, “HD”, Y′CBCR 4:2:2, 10 bit
- Matroska, FFV1, “HD”, Y′CBCR 4:4:4, 12 bit

audio
- Matroska, FLAC, 96 kHz, 24 bit
- Matroska, FLAC, 192 kHz, 24 bit

Access

MP4

video
- H.265, «HD», Y′CBCR 4:2:0, 8 bit, lossy
- H.266, «HD», Y′CBCR 4:2:0, 8 bit, lossy
- AV1, «HD», Y′CBCR 4:2:0, 8 bit, lossy

audio
- AAC, 96 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

→ retokromer.ch/publications/JFP_96.html

Pros & Cons

container:

- folder
- TAR
- ZIP
- MXF
- Matroska
- AXF

video codec:

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

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

The Missing Piece of Software

RAWcooked (CLI)

→ mediaarea.net/RAWcooked

RAWcooked

- encoding into Matroska (.mkv) using FFV1 video codec and FLAC audio codec
- all metadata preserved
- decoding with bit-by-bit reversibility
- possibility to embed sidecar files (e.g. MD5, LUT, XML)
- compatibility with media players

MXF Container (.mxf)

video codec

- DPX
- JPEG 2000
- DNxHD, DNxHR
- ProRes 422, ProRes 4444

85

SMPTE RDD 48:2018

SMPTE REGISTERED DISCLOSURE DOCUMENT

MXF Archive and Preservation Format Registered Disclosure Document

Page 1 of 113

The attached document is a Registered Disclosure Document prepared by the sponsor identified below. It has been examined by the appropriate SMPTE Technology Committee and is believed to contain adequate information to satisfy the objectives defined in the Scope, and to be technically consistent.

This document is NOT a Standard, Recommended Practice or Engineering Guideline, and does NOT imply a finding or representation of the Society.

Every attempt has been made to ensure that the information contained in this document is accurate. Errors in this document should be reported to the proponent identified below, with a copy to eng@smpte.org.

All other inquiries in respect of this document, including inquiries as to intellectual property requirements that may be attached to use of the disclosed technology, should be addressed to the proponent identified below.

Proponent Contact Information:
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Washington, DC 20540-1300

Email: kmur@loc.gov

86

MXF / DPX

MXF

→ SMPTE RDD 48:2018

DPX

→ SMPTE ST 268M:2015

87

MXF / JPEG 2000

MXF

→ SMPTE RDD 48:2018

JPEG 2000

→ ISO/IEC 15444-1:2019

→ etc.

88

MXF / DNx

MXF
→ SMPTE RDD 48:2018

DNxHD, DNxHR
→ not disclosed

MXF / ProRes

MXF
→ SMPTE RDD 48:2018

ProRes 422, ProRes 4444
→ SMPTE RDD 36:2015

SMPTE RDD 36:2015

SMPTE REGISTERED DISCLOSURE DOCUMENT

Apple ProRes Bitstream Syntax and Decoding Process

Page 1 of 39 pages

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All other inquiries in respect of this document, including inquiries as to intellectual property requirements that may be attached to use of the disclosed technology, should be addressed to the proponent identified below.

Proponent contact information:

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1 Infinite Loop, MS: 77-2YAK
Cupertino, CA 95014
USA

Email: ProRes@apple.com

Matroska Container (.mkv)

video codec

- FFV1
- ProRes 422, ProRes 4444

Matroska / FFV1

Matroska (.mkv)
→ IETF Internet Draft

FFV1
→ IETF RFC 9043

93

Stream: Internet Engineering Task Force (IETF)
RFC: 9043
Category: Informational
Published: August 2021
ISSN: 2070-1721
Authors: M. Niedermayer D. Rice J. Martinez

RFC 9043
FFV1 Video Coding Format Versions 0, 1, and 3

Abstract

This document defines FFV1, a lossless, intra-frame video encoding format. FFV1 is designed to efficiently compress video data in a variety of pixel formats. Compared to uncompressed video, FFV1 offers storage compression, frame fixity, and self-description, which makes FFV1 useful as a preservation or intermediate video format.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for informational purposes.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are candidates for any level of Internet Standard; see Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc9043.

94

Matroska / ProRes

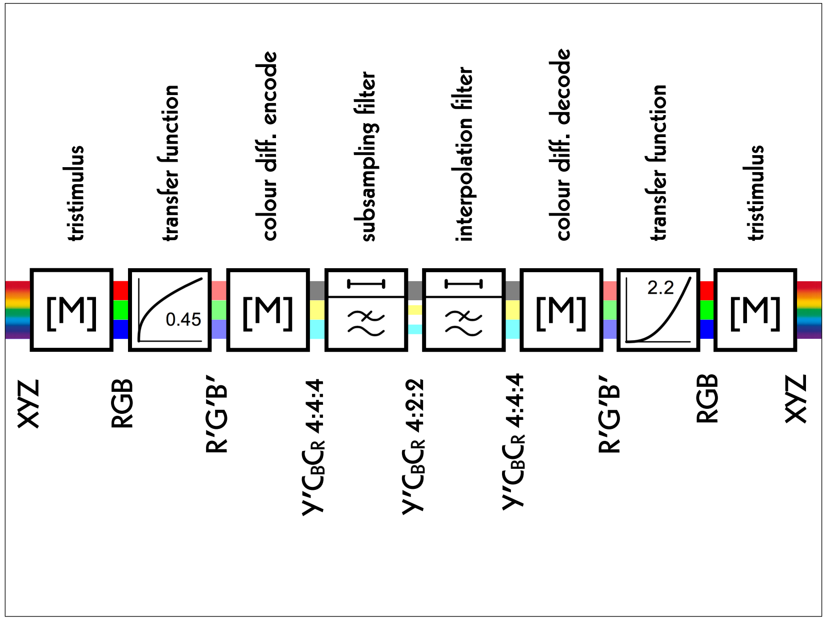
Matroska (.mkv)
→ IETF Internet Draft

ProRes 422, ProRes 4444
→ SMPTE RDD 36:2015

95

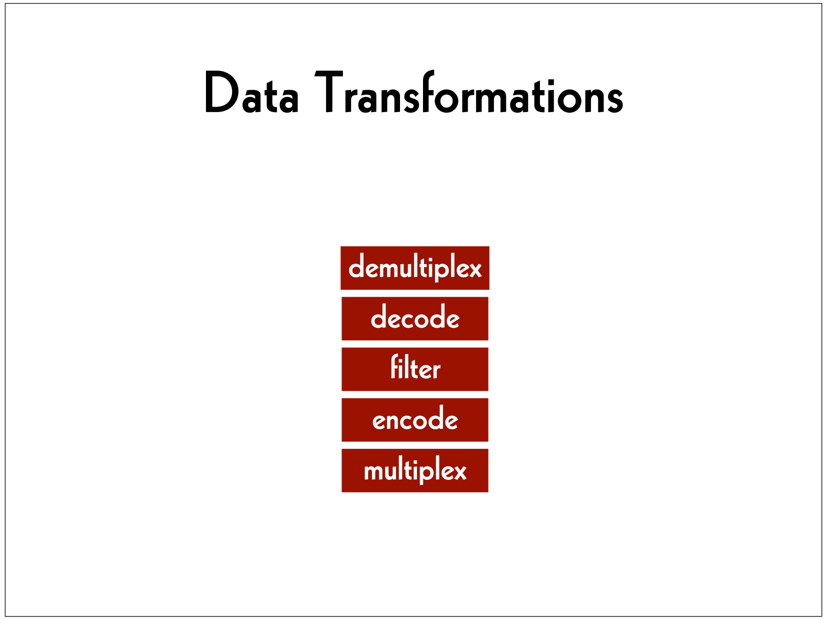
Transformations

96



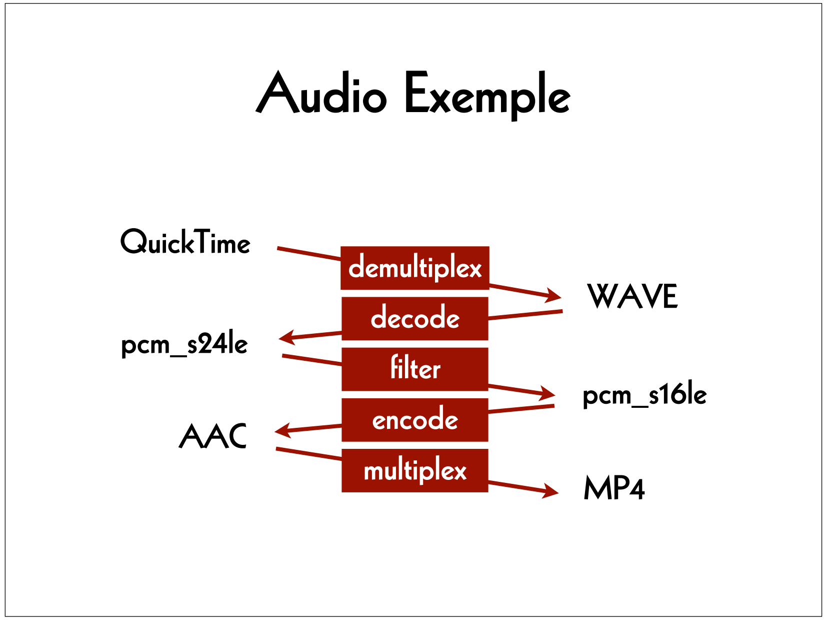
tristimulus
transfer function
colour diff. encode
subsampling filter
interpolation filter
colour diff. decode
transfer function
tristimulus
[M]
0.45
[M]
[M]
2.2
[M]
XYZ
RGB
R′G′B′
Y′CBCR 4:4:4
Y′CBCR 4:2:2
Y′CBCR 4:4:4
R′G′B′
RGB
XYZ

97



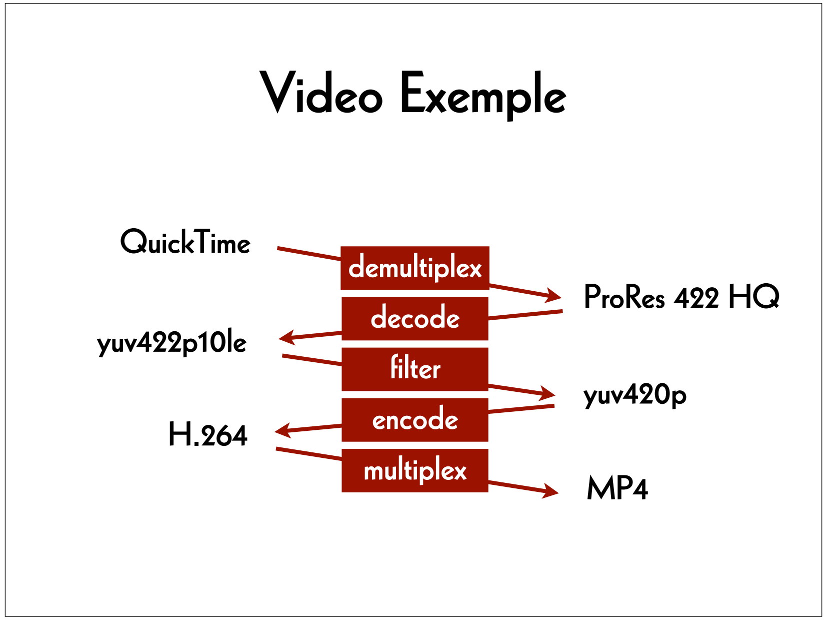
Data Transformations
demultiplex
decode
filter
encode
multiplex

98



Audio Exemple
QuickTime
demultiplex
WAVE
decode
pcm_s24le
filter
pcm_s16le
encode
AAC
multiplex
MP4

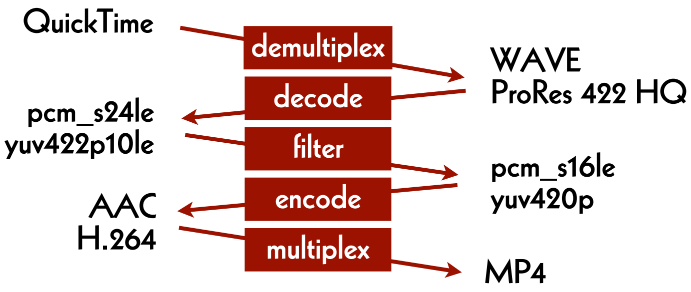
99



Video Exemple
QuickTime
demultiplex
ProRes 422 HQ
decode
yuv422p10le
filter
yuv420p
encode
H.264
multiplex
MP4

100

Audio-Visual Exemple



Data Maintenance

Plan the Next Migration

- file naming
- barcodes
- checksums
- write the full index onto the cartridge
- technical metadata
- code to retrieve the files

File Naming (Example)

- title_codec.container
- title_codec_container_algorithm.txt

- film_H264.mp4
- film_H264_mp4_md5.txt

Checksums

cryptographic

- MD5
- SHA-1
- SHA-256
- SHA-512

non-cryptographic

- CRC-32
- xxHash 32
- xxHash 64
- xxHash 128

Longterm

- storage of the cartridges
- three copies …
- … in geographically distant locations
- data integrity check
- data migration
- availability of LTO desks

Reading

Reto Kromer: **On the Bright Side of Data Migrations**, in «IASA Journal», n. 49 (December 2018), IASA, p. 18–22

→ retokromer.ch/publications/IASA_49.html

read | script | write

script to modify

- container
- codec
- both container and codec
- metadata
- filename

#1: ProRes-born Content

from:

- ProRes stored in a QuickTime (.mov) container

to:

- ProRes stored in a Matroska (.mkv) container

Update the Container

→ read file from source LTO
→ demultiplex file

- ProRes 422, 10 bit [yuv422p10le]
- ProRes 4444, 10 bit [yuv444p10le or yuva444p10le] or 12 bit [yuv444p12le]

→ multiplex file
→ write file to destination LTO

#2: Video

from:

- AVI / 8-bit and 10-bit uncompressed
- MOV / 8-bit and 10-bit uncompressed
- MP4 / 8-bit and 10-bit uncompressed

to:

- Matroska / FFV1

Container and Codec

→ read file from source LTO
→ demultiplex file
→ decode file

- $Y'C_BC_R$, 4:2:2, 8 bit, uyvy422

→ encode file
→ multiplex file
→ write file to destination LTO

Container and Codec

- ➔ read file from source LTO
- ➔ demultiplex file
- ➔ decode file
  - $Y'C_BC_R$, 4:2:2, 10 bit, yuv422p10le
- ➔ encode file
- ➔ multiplex file
- ➔ write file to destination LTO

#3: Filename

from:

- Title_YUV422.mkv

to:

- Title_YCbCr422_9d5084b5b0a08d5022b39e0e75241d12.mkv

Always remember:

To do nothing is **never** an option!

Coda

Live in the real world!

There is only one efficient way:

- keep the analogue source elements as long as possible
- more prevention:
  → better insulation
  → more efficient air conditioning
- less handling of the source elements
- make digital masters and access copies

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