On Audio-Visual File Formats

Reto Kromer • AV Preservation by reto.ch

On the Materiality of Audio-Visual Heritage
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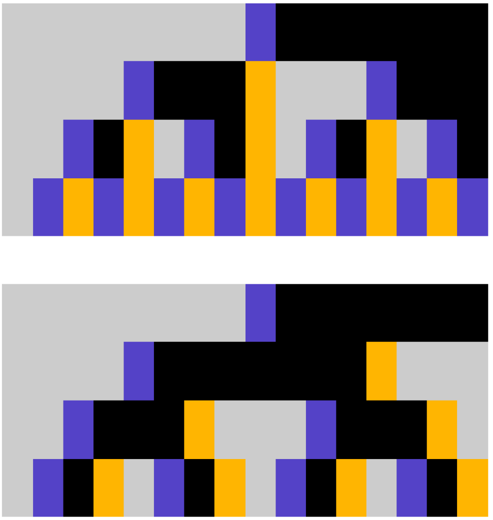
Donostia (San Sebastián), Spain
28 September – 1 October 2021

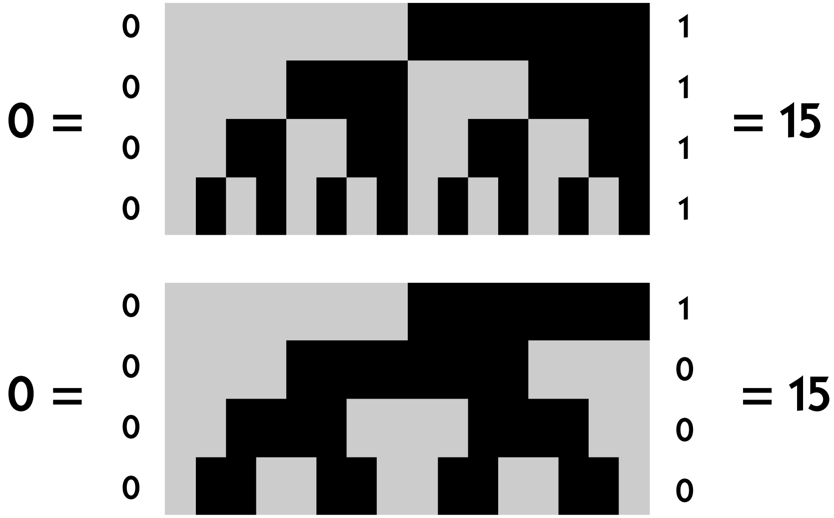
Summary

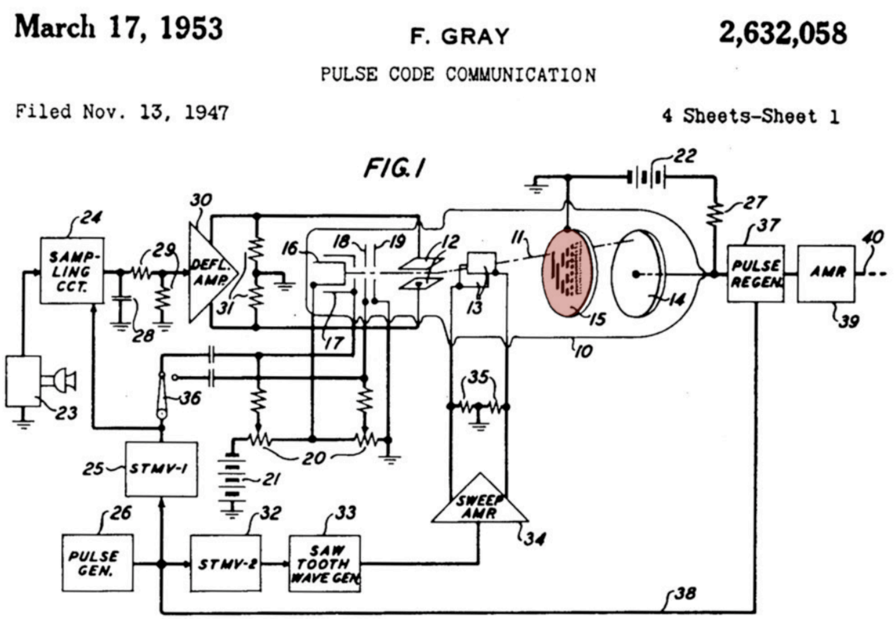
- digital audio and digital video
- container, codec, raw data
- different formats for different purposes
- audio-visual data transformations
- data maintenance

Digital Audio

Frank Gray

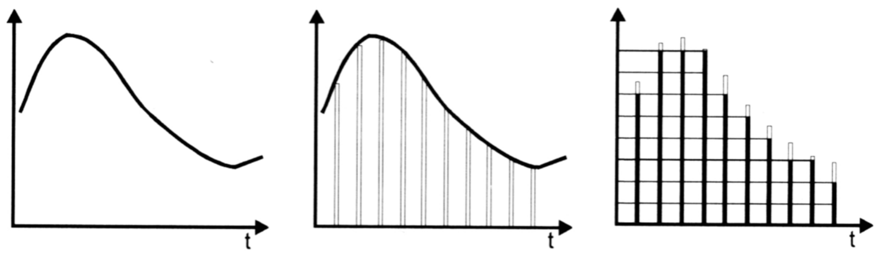






Digital Audio

- 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

Resolution

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

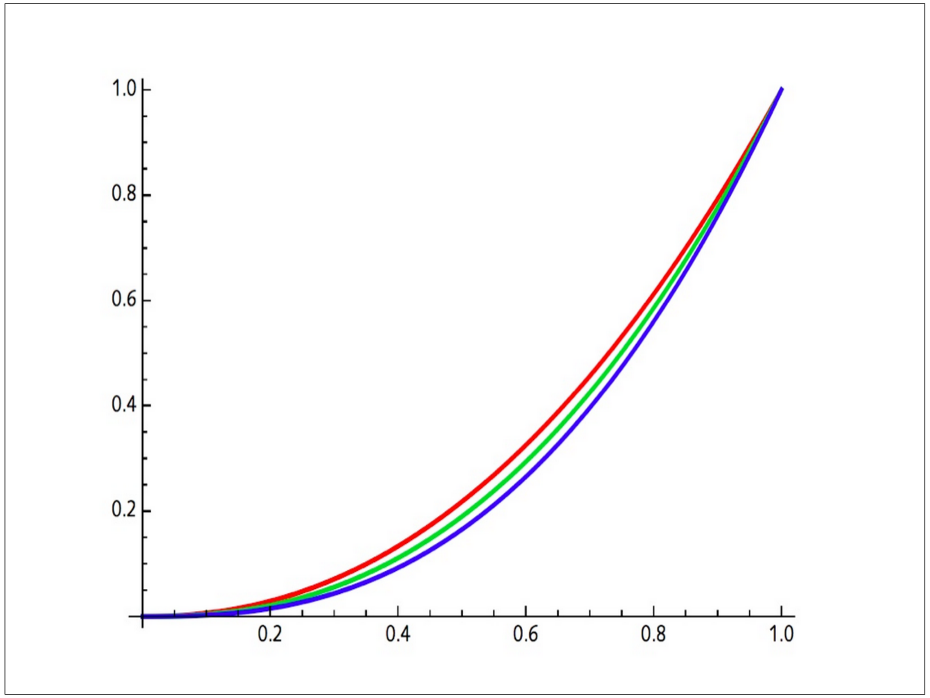
Bit Depth

- 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)

Linear, Power, Logarithmic

"medium grey"

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

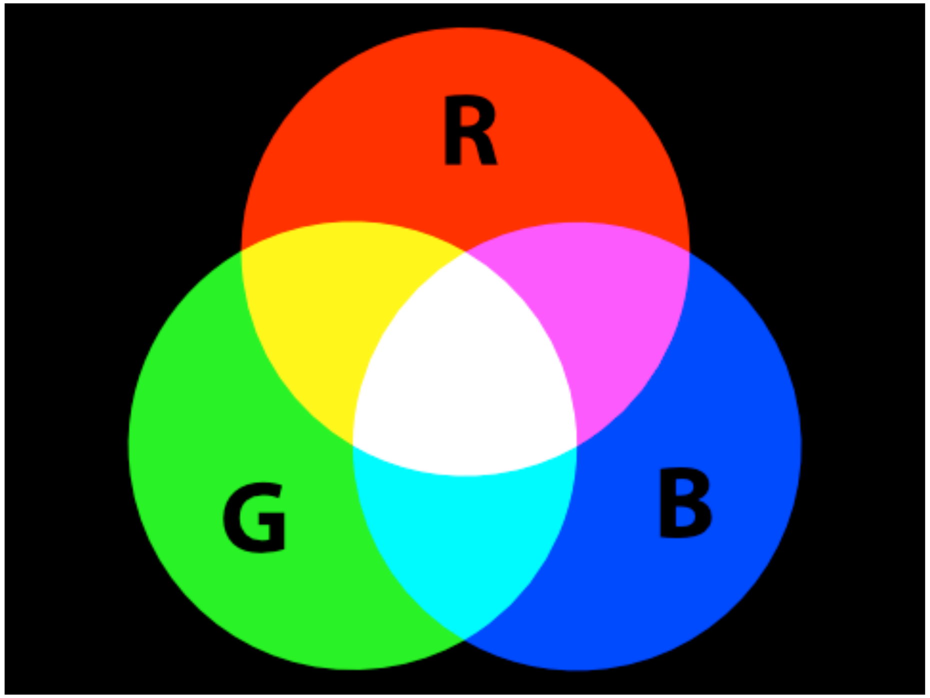


17

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

18



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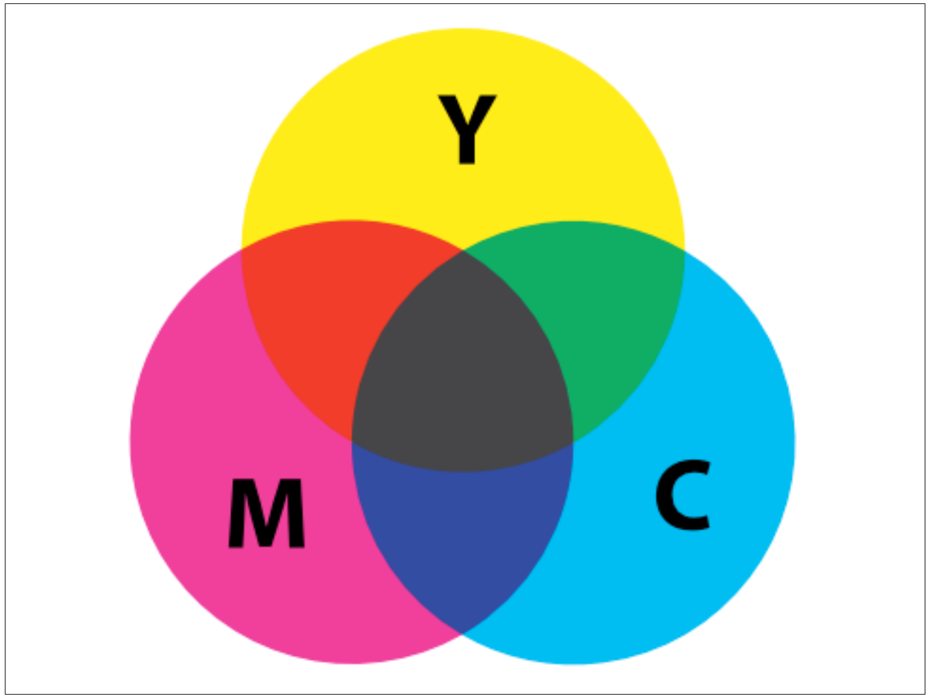


20

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

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

21

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

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

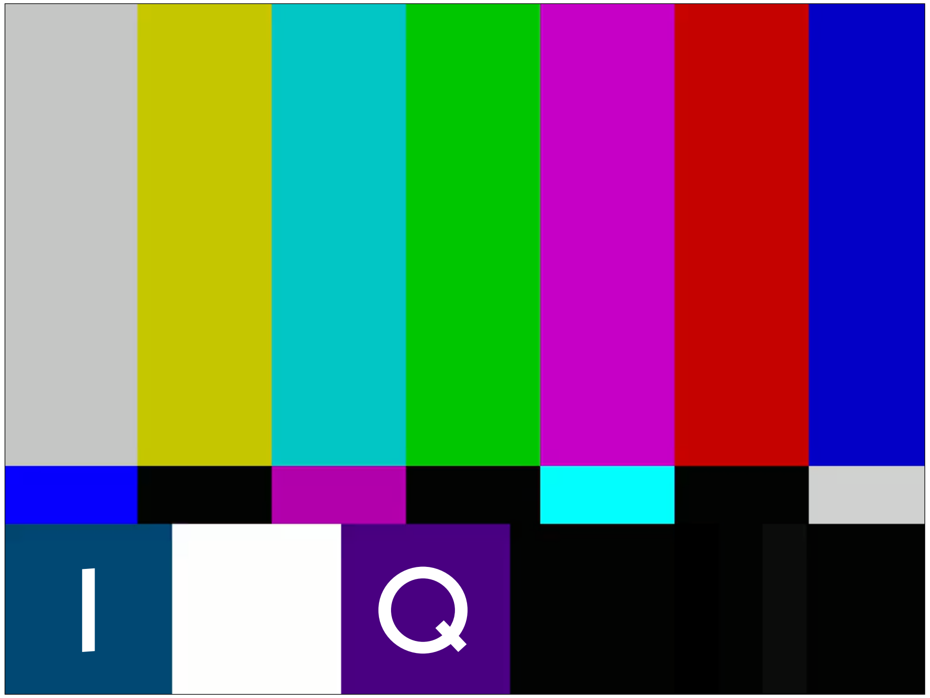
22

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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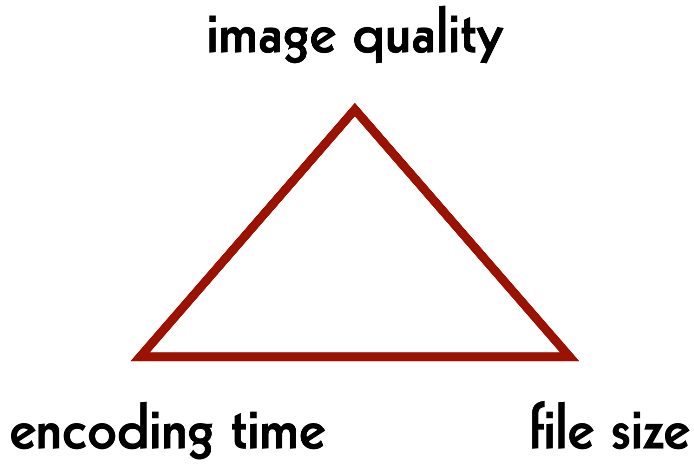


26

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

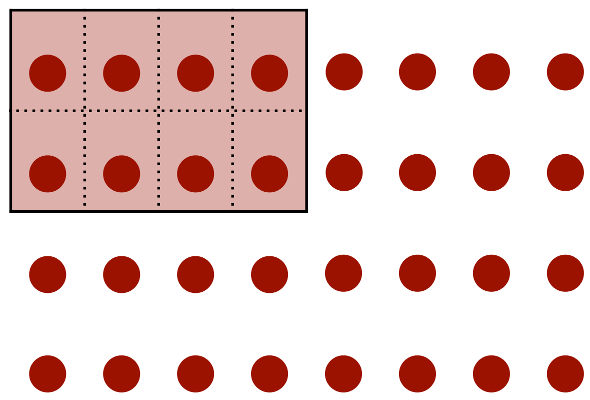
Chroma Subsampling

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

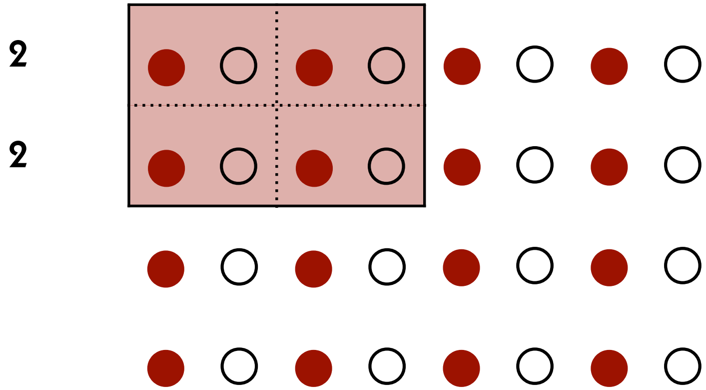
4:4:4

4

4

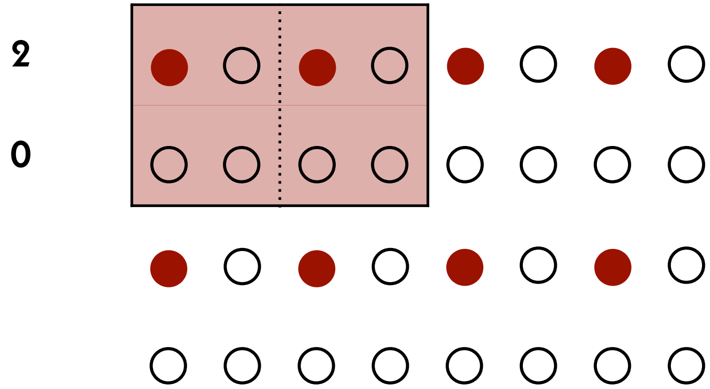


4:2:2



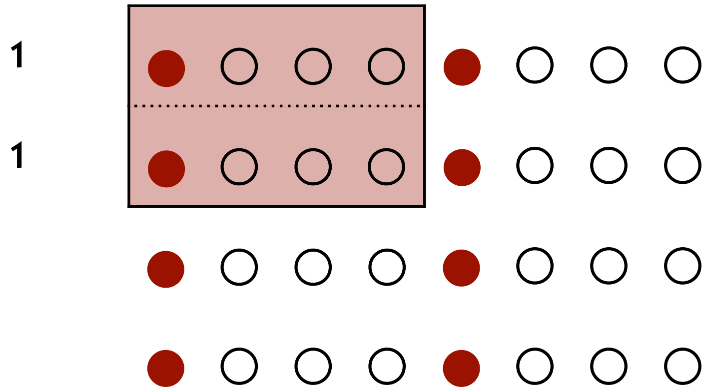
33

4:2:0



34

4:1:1



35

Born Compressed

- optimised for both image acquisition and postproduction

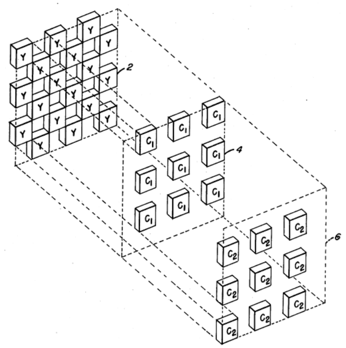
Examples: CineForm RAW, ProRes RAW, Blackmagic RAW

36

Uncomfortable Truths

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

Bryce E. Bayer



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

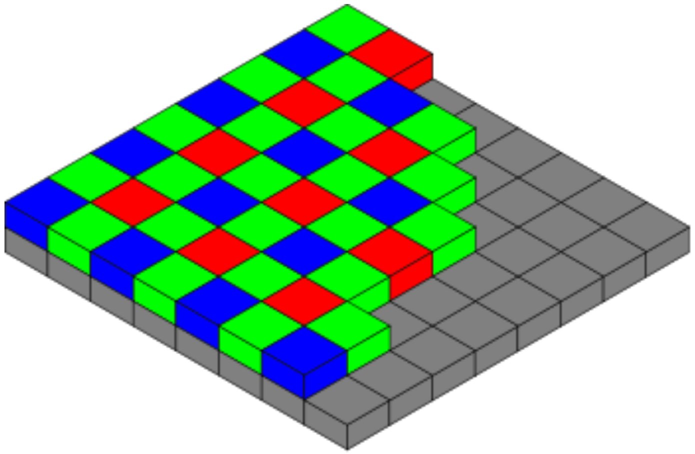
[57] **ABSTRACT**

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

Bayer



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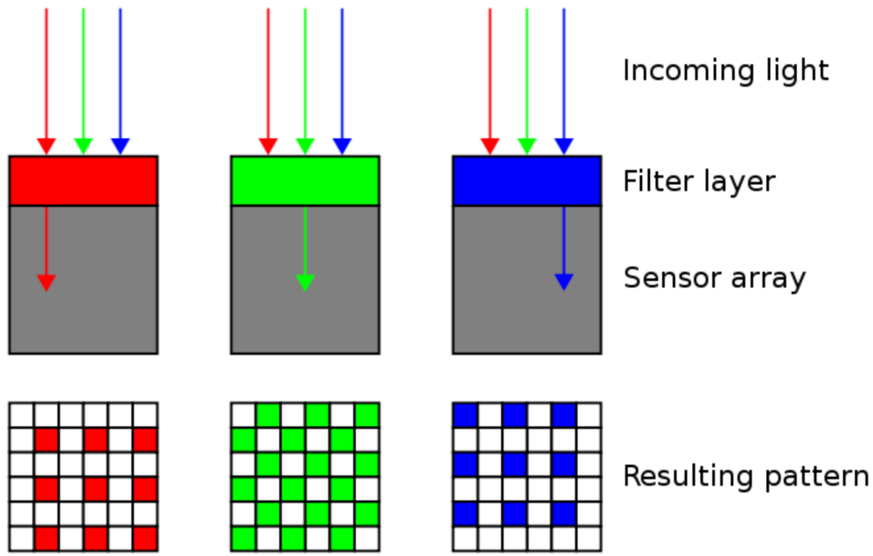

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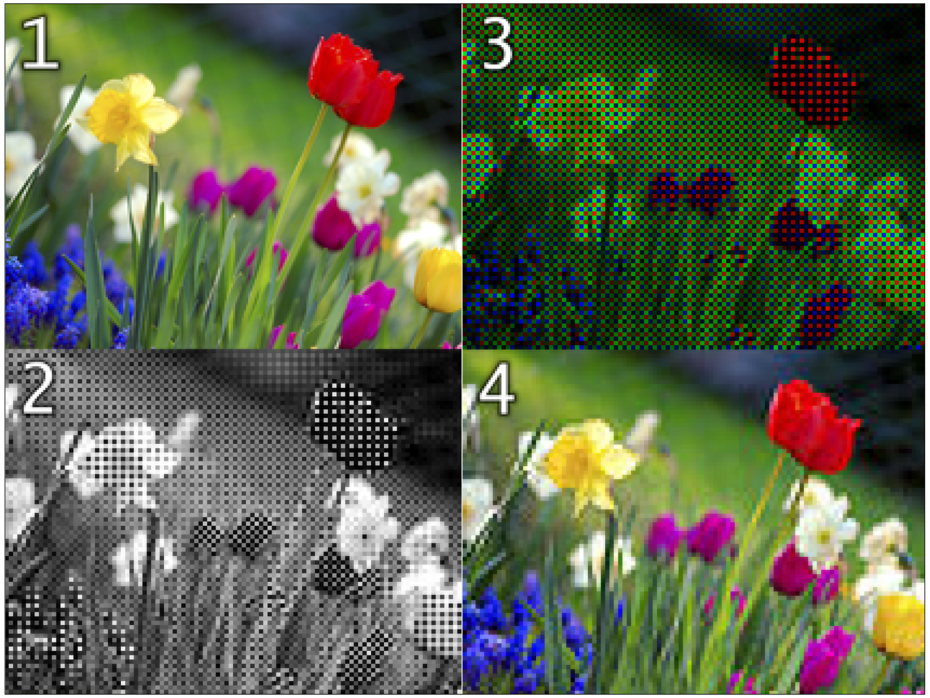

43

0111010100101010100010110101011110
0100110101010101010100001011101010
0111010100101010100010110101011110
0001**110101010101****010100001011101010**
011010**101001010101**0001011010101111
0010101010101010000101110101010000
0111010100101010100010110101011110
0101010101010101000010111010100110
1001011101010010101010001011010101
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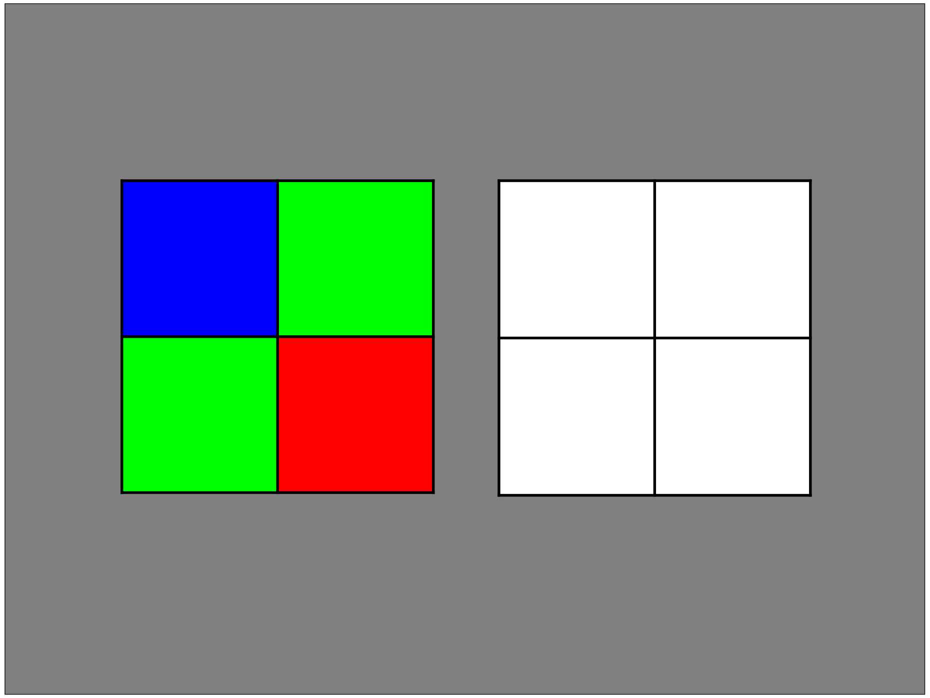
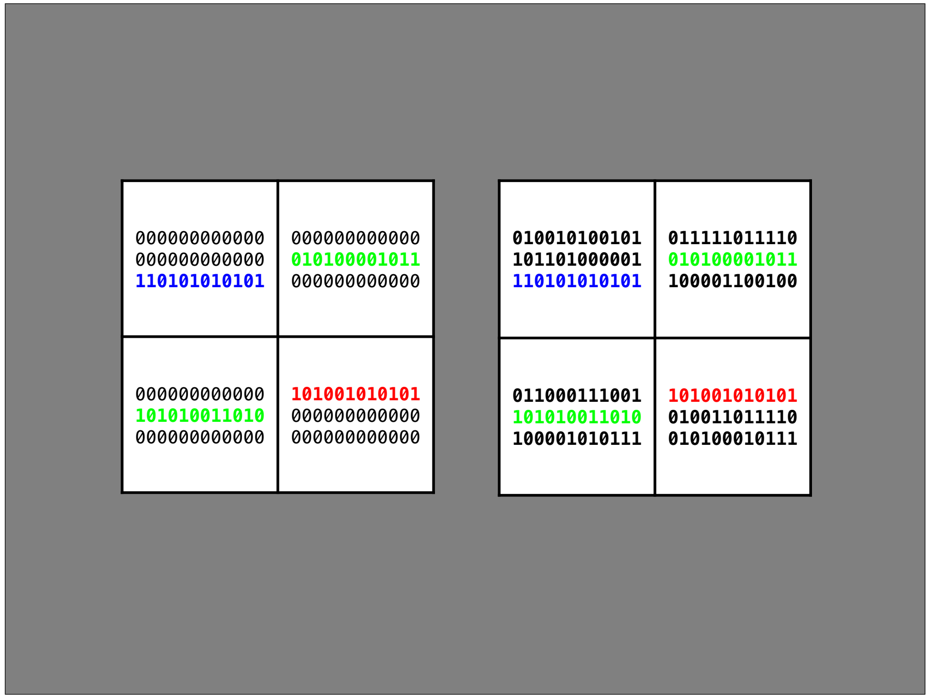
0101010101010101001101010100000001
0010100010101010101001010101010101

44



45


000000000000
000000000000
110101010101
000000000000
010100001011
000000000000
000000000000
101010011010
000000000000
101001010101
000000000000
000000000000
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101101000001
110101010101
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100001100100
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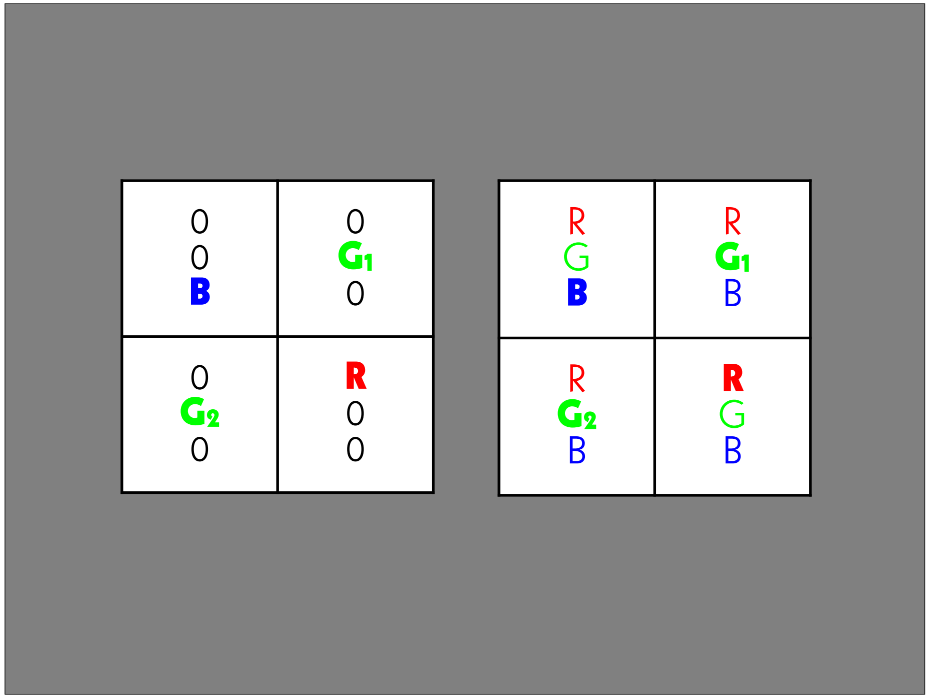
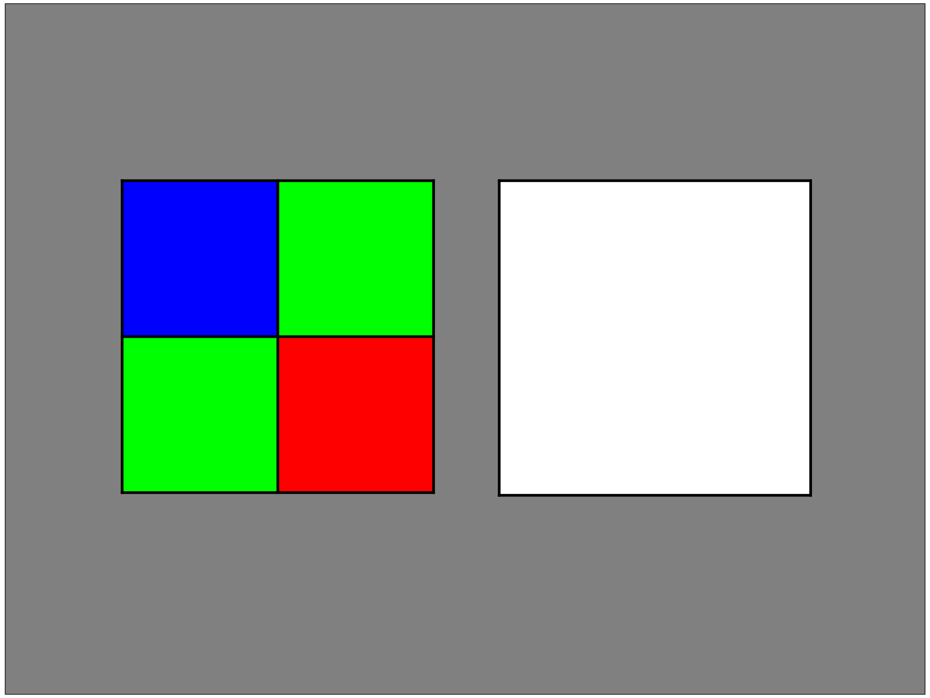
010011011110
010100010111

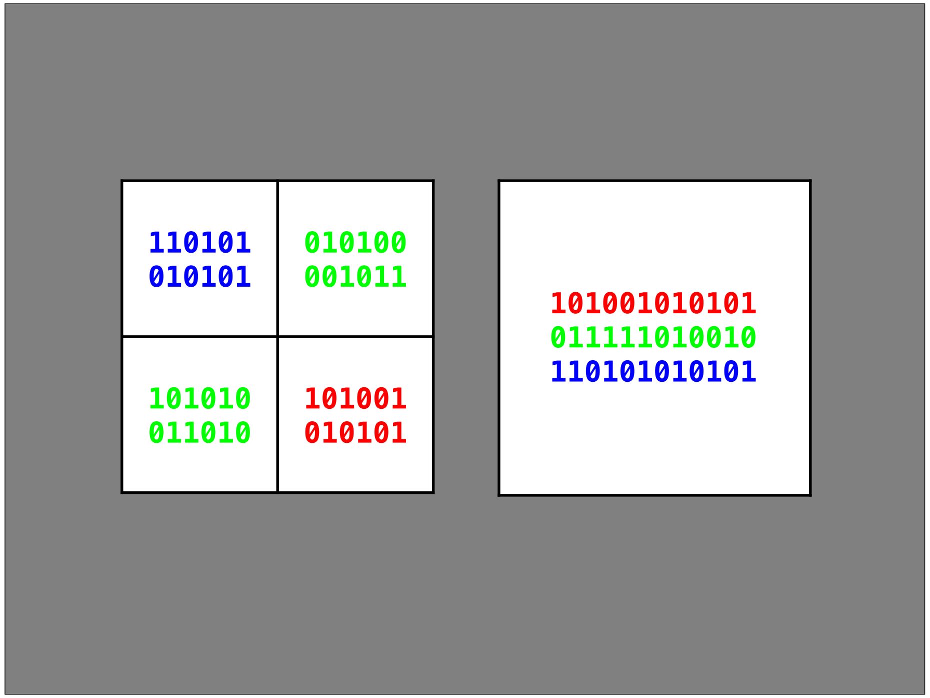
46

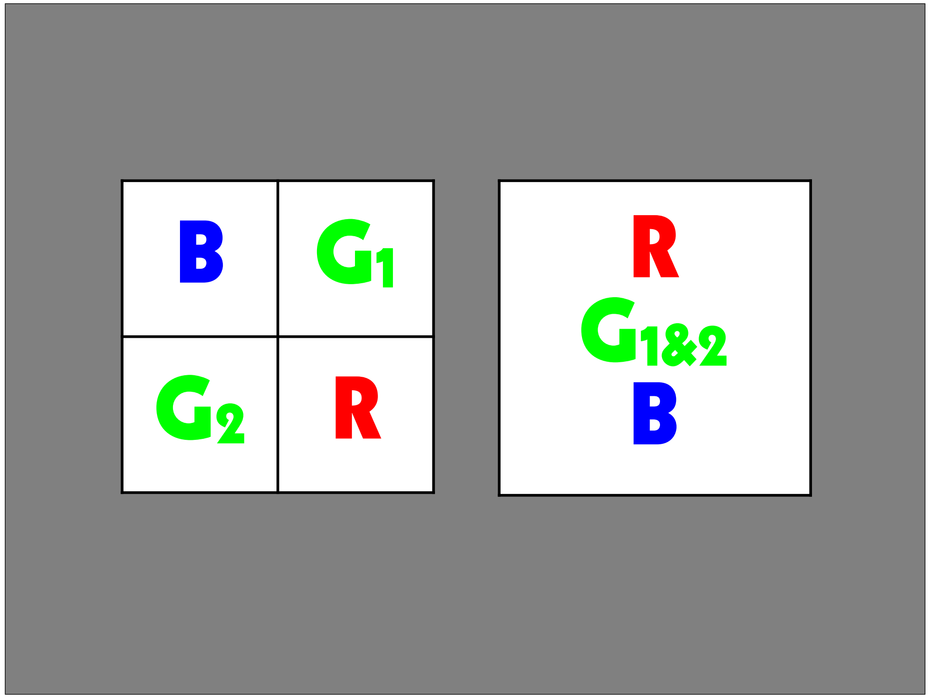

0
0
B
0
G1
0
0
G2
0
R
0
0
R
G
B
R
G1
B
R
G2
B
R
G
B

47



48





Two ways to use Bayer data

digital blow-up to RGB

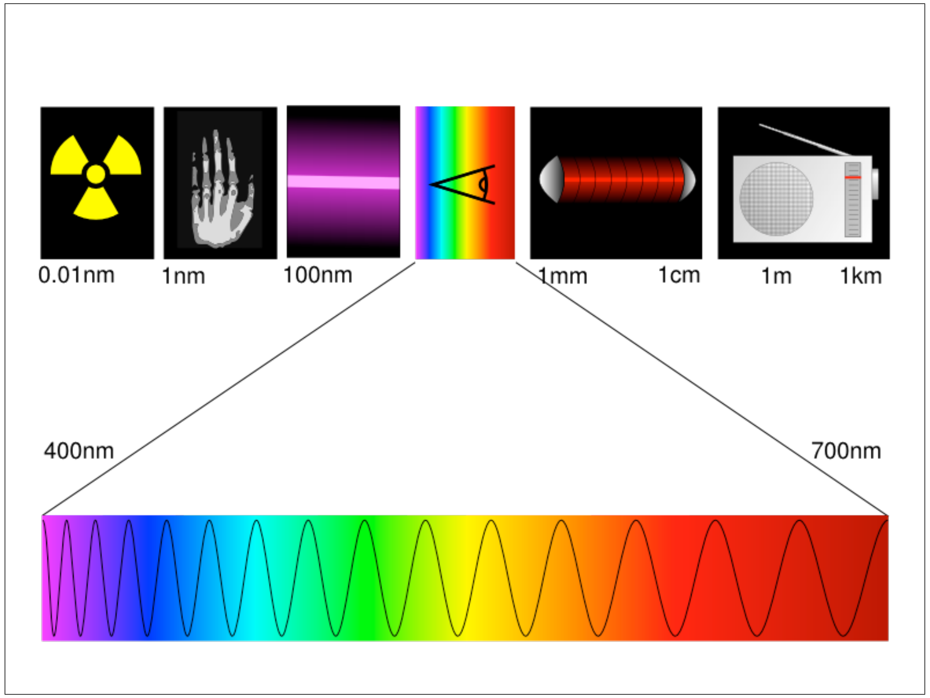
- 3 times the amount of the generated data
- the file has the full sensor resolution
- only ⅓ of the data are real

digital reduction to RGB

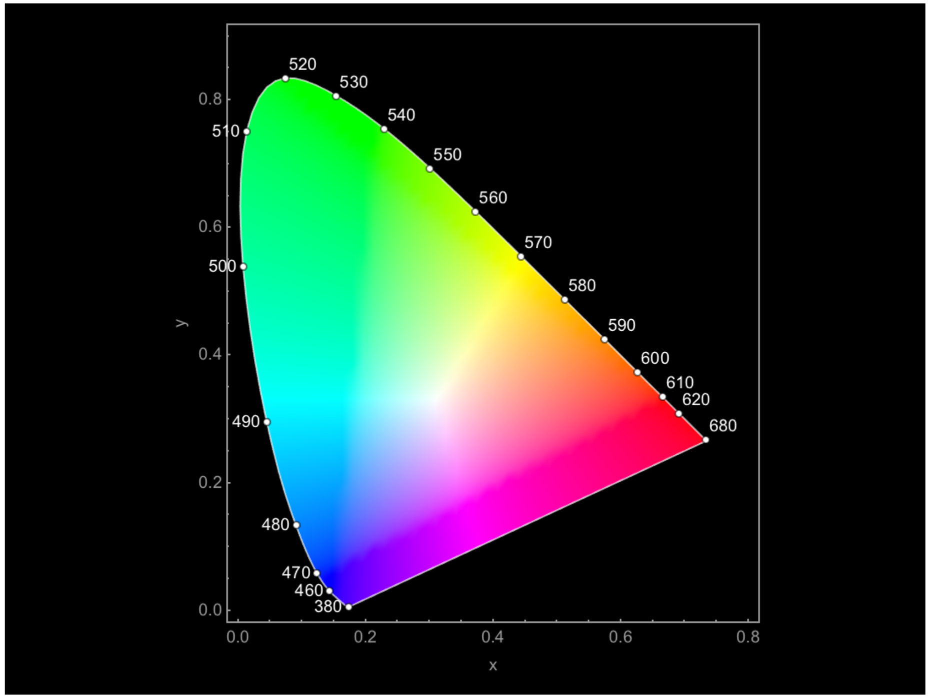
- ¾ the amount of the generated data
- the file has ½ of the sensor resolution
- all data are real

Illuminant

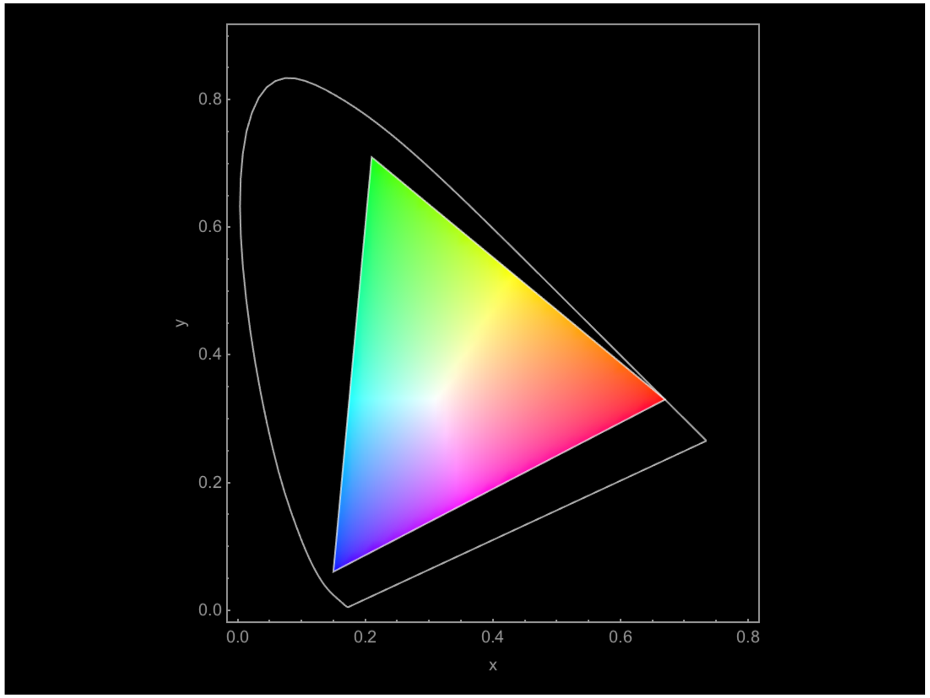
- D50
- D55
- D65
- D75


0.01nm
1nm
100nm
1mm
1cm
1m
1km
400nm
700nm

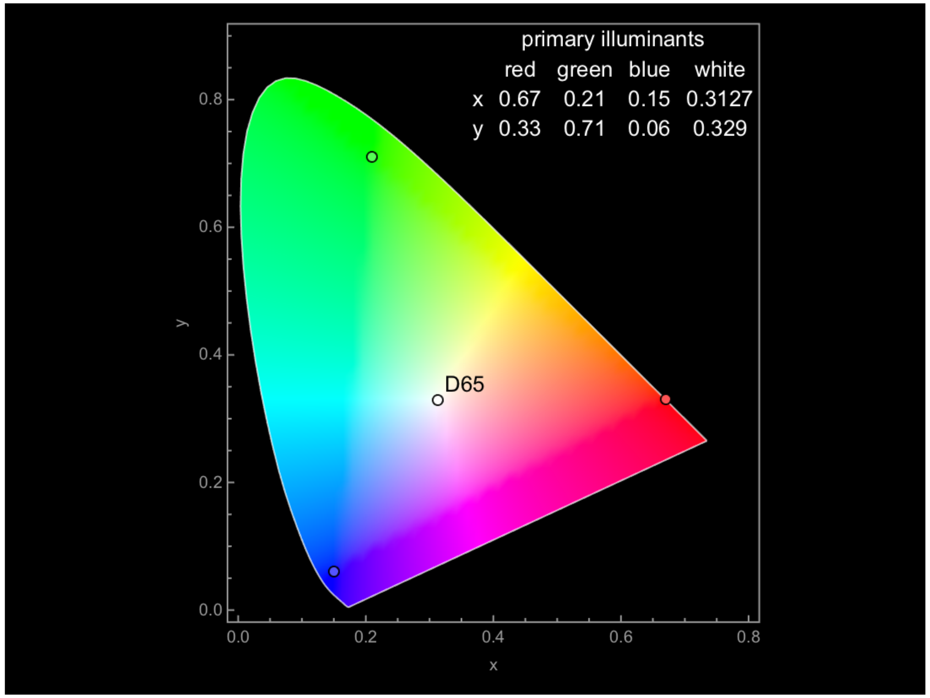
53


520
530
540
550
560
570
580
590
600
610
620
680
510
500
490
480
470
460
380
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
x
y

54


0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
x
y

55


primary illuminants
red green blue white
x 0.67 0.21 0.15 0.3127
y 0.33 0.71 0.06 0.329
D65
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
x
y

56

File Structure


```
0111010100101010100010110101011110
0100110101010101010100001011101010
0111010100101010100010110101011110
0001110101010101010100001011101010
0110101010010101010001011010101111
0010101010101010000101110101010000
0111010100101010100010110101011110
0101010101010101000010111010100110
1001011101010010101010001011010101
1110010101010101010100001011101010
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0101010101010101001101010100000001
0010100010101010101001010101010101
```
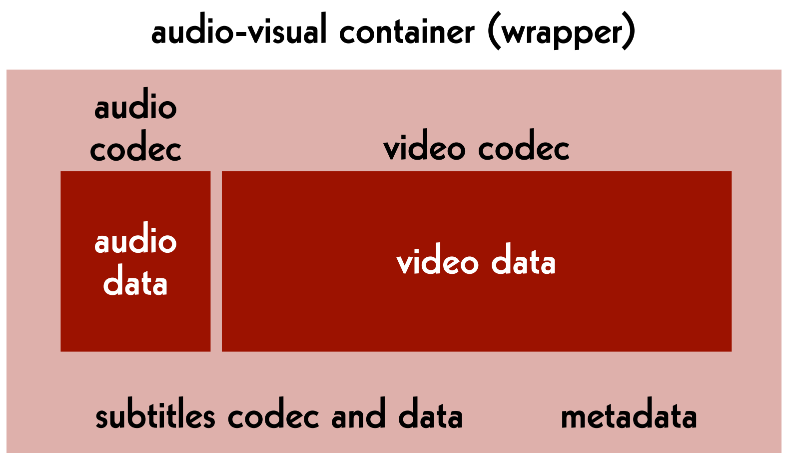


File Structure



Audio-Visual Container

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

Single Images

- folder
- TAR
- ZIP

- MXF
- Matroska (.mkv)

- CinemaDNG
- Motion JPEG

Audio Codec

- WAVE
- BWF

- AAC
- MP3

- FLAC

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
- Blackmagic RAW

Video Codec (Access)

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

- AV1

65

Data is anything but «raw».

66

Audio Data

- pcm_s16le
- pcm_s24le
- pcm_s32le

67

Video Data

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

68

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.

73

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

74

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

75

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

76

Archive Master and Mezzanine

film

- Matroska, FFV1, 2K, R′G′B′ 4:4:4, 16 bit

video

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

audio

- Matroska, FLAC, 96 kHz, 24 bit

Access

video

- H.265, “HD”, yuv420p
- H.266, “HD”, yuv420p
- AV1, “HD”, yuv420p

audio

- 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

➔ retokromer.ch/publications/JFP_96.html

Pros & Cons

container:

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

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

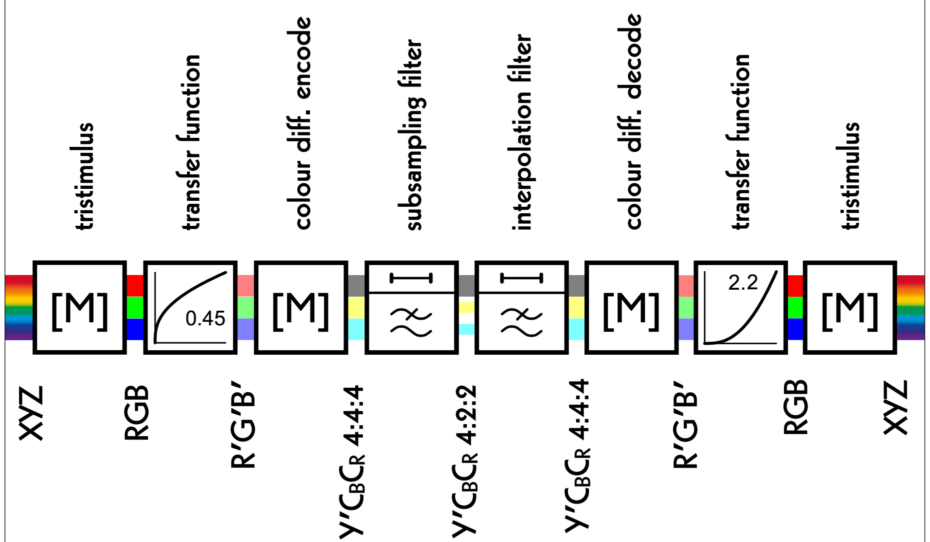
RAWcooked

- 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

Transformations

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.140251 \\ 1 & -0.393931 & -0.580809 \\ 1 & 2.028398 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y'_{601} \\ U \\ V \end{bmatrix}$$

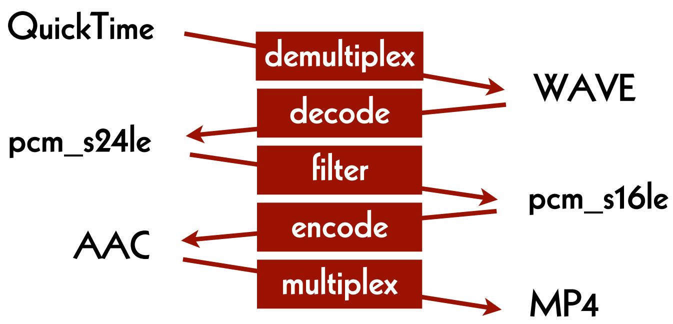
$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0.956295 & 0.621025 \\ 1 & -0.272558 & -0.646709 \\ 1 & -1.104744 & 1.701157 \end{bmatrix} \cdot \begin{bmatrix} Y'_{601} \\ I \\ Q \end{bmatrix}$$



Data Transformations

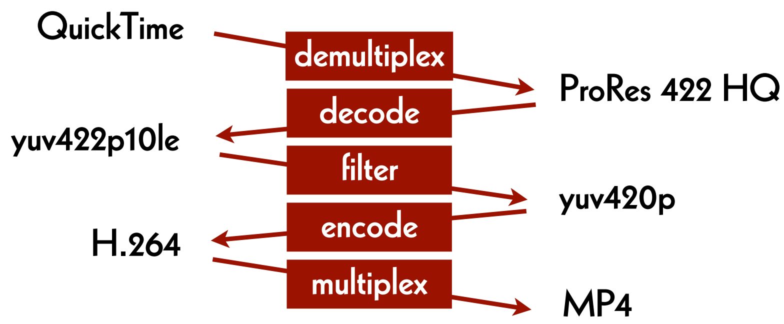
- demultiplex
- decode
- filter
- encode
- multiplex

Audio Exemple



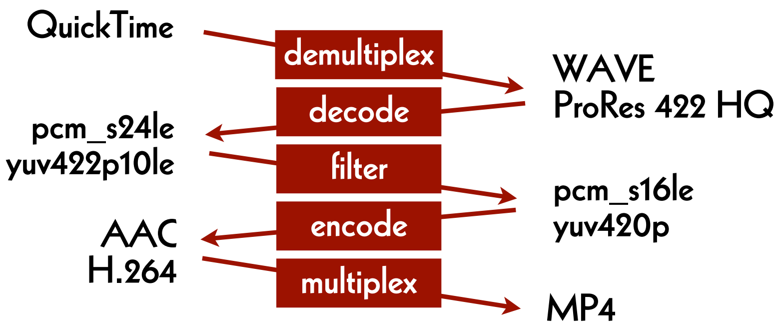
89

Video Exemple



90

Audio-Visual Exemple



91

Data Maintenance

92

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

Data Migrations

2014

- our internal archive from LTO-4 to LTO-6 (5.7 PB)

2014–2021

- two dozen migrations for clients

2021

- our internal archive from LTO-6 to LTO-8 (25.2 PB)

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

101

SMPTE RDD 36:2015

SMPTE REGISTERED DISCLOSURE DOCUMENT

Apple ProRes Bitstream Syntax and Decoding Process

Page 1 of 39 pages

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.

102

#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

103

Container and Codec

→ read file from source LTO
→ demultiplex file
→ decode file
- $Y'C_BC_R$, 4:2:2, 8 bit, «raw» [uyvy422]

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

104

Container and Codec

- ➔ read file from source LTO
- ➔ demultiplex file
- ➔ decode file
  - Y'CBCR, 4:2:2, 10 bit, «raw» [yuv422p10le]
- ➔ encode file
- ➔ multiplex file
- ➔ write file to destination LTO

#3: Filename

from:

- Title_YUV422.mkv

to:

- Title_YCbCr422_9d5084b5b0a08d5022b3 9e0e75241d12.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

Acknowledgements (1)

- Swiss Federal Institute of Technology
- Massachusetts Institute of Technology
- Kinemathek Lichtspiel, Bern

- Charles Poynton
- Dave Rice & Misty De Meo
- Agathe Jarczyk & David Pfluger

Acknowledgements (2)

- Tommy Aschenbach

- Claudio Weidmann
- Jim Lindner
- Carl Eugen Hoyos
- Peter Bubestinger-Steindl
- Jérôme Martinez
- Michael Niedermayer

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