

Audiovisuelle Dateiformate

Reto Kromer • AV Preservation by reto.ch

FFmpeg-Workshop
Hochschule der Künste Bern
25. Mai 2023

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Inhalt

- digitaler Ton und digitales Bild
- Container, Codec, Rohdaten
- verschiedene Formate für unterschiedliche Zwecke
- audiovisuelle Dateiumwandlungen
- Datensicherung und Migration

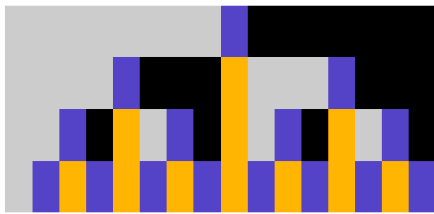
2

Digitaler Ton

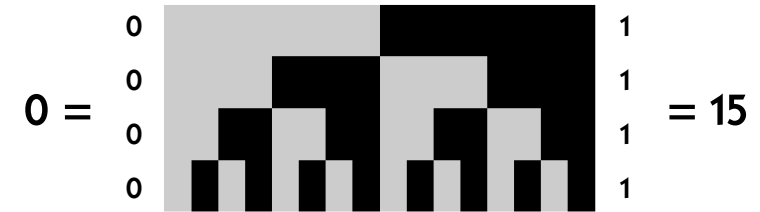
3

Frank Gray
(1887–1969)

4



5



6

March 17, 1953

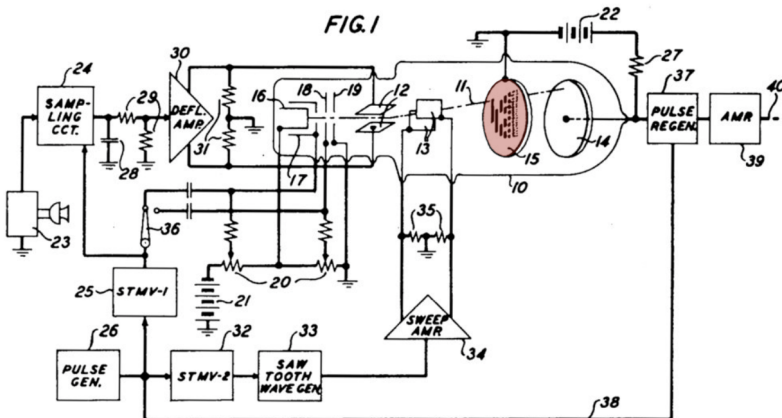
F. GRAY

2,632,058

PULSE CODE COMMUNICATION

Filed Nov. 13, 1947

4 Sheets-Sheet 1

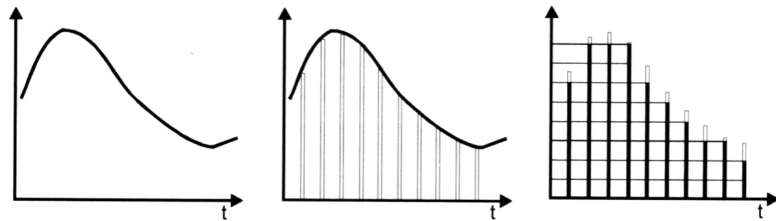


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Digitaler Ton

- Abtastung
- Quantisierung
- Kompression

8



Digitalisierung = Abtastung + Quantisierung

9

Abtastung

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

10

Quantisierung

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

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Digitales Bild

12

Digitales Bild

- Auflösung
- Quantisierungsauflösung
- linear, Potenzfunktion, logarithmisch
- Farbraum
- Kompression und Farbunterabtastung
- Normlicht

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Auflösung

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

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Quantisierungsauflösung

- 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 ($2^{24} = 16\,777\,216$)

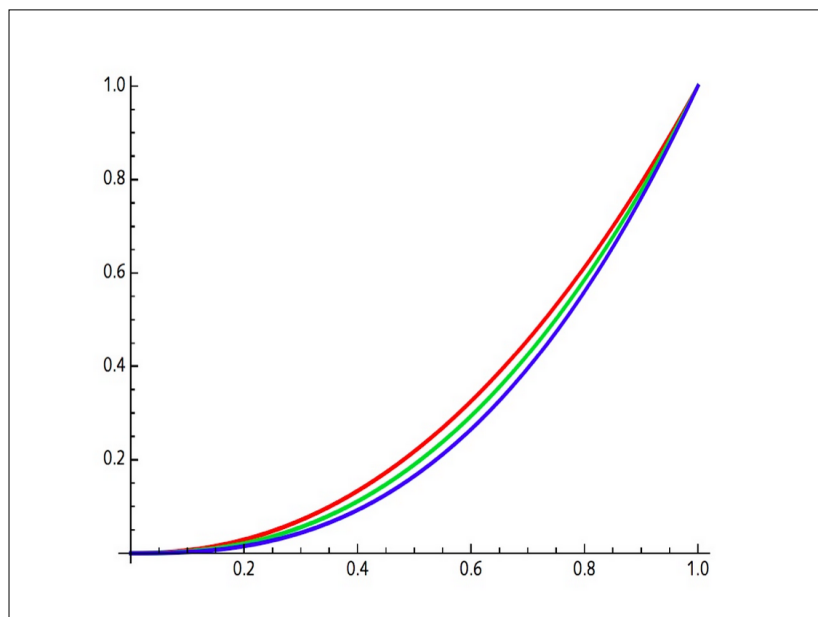
15

Linear, Potenz, Logarithmus

«Mittelgrau»

- lineare Funktion: etwa 18 %
- Potenzfunktion: 50 %
- Logarithmusfunktion: 50 %

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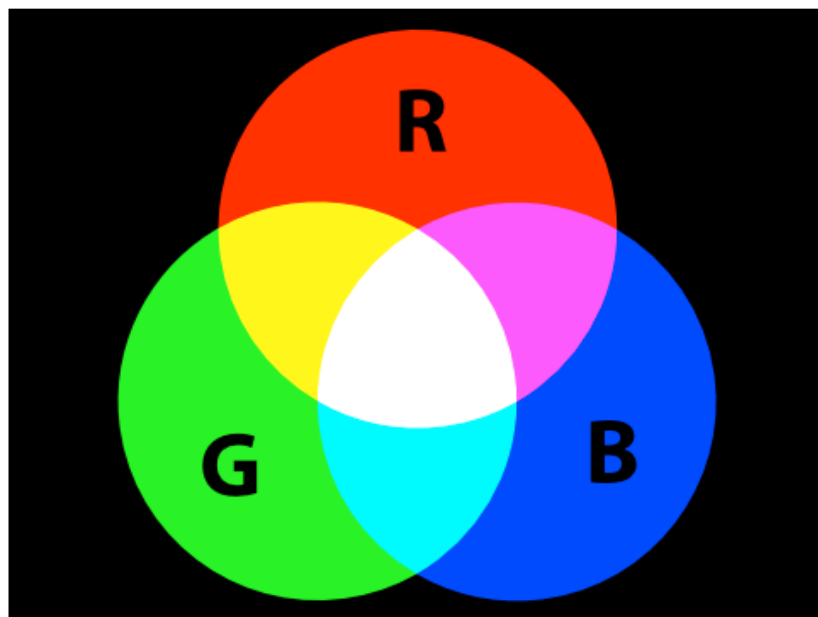


17

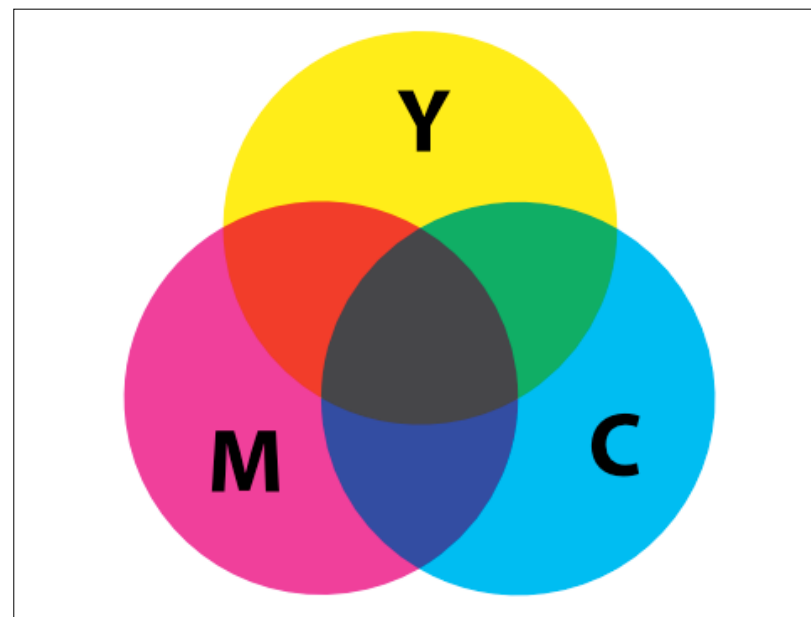
Farbraum

- 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



19



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

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

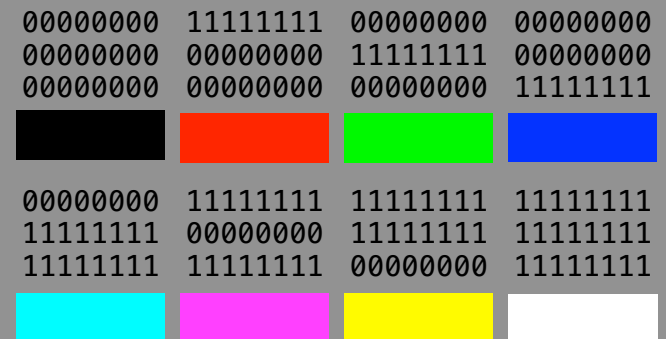
$$\begin{pmatrix} Y' \\ C_O \\ C_G \end{pmatrix} = \begin{pmatrix} \frac{1}{4} & \frac{1}{2} & \frac{1}{4} \\ \frac{1}{2} & 0 & -\frac{1}{2} \\ -\frac{1}{4} & \frac{1}{2} & -\frac{1}{4} \end{pmatrix} \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$$

22



23

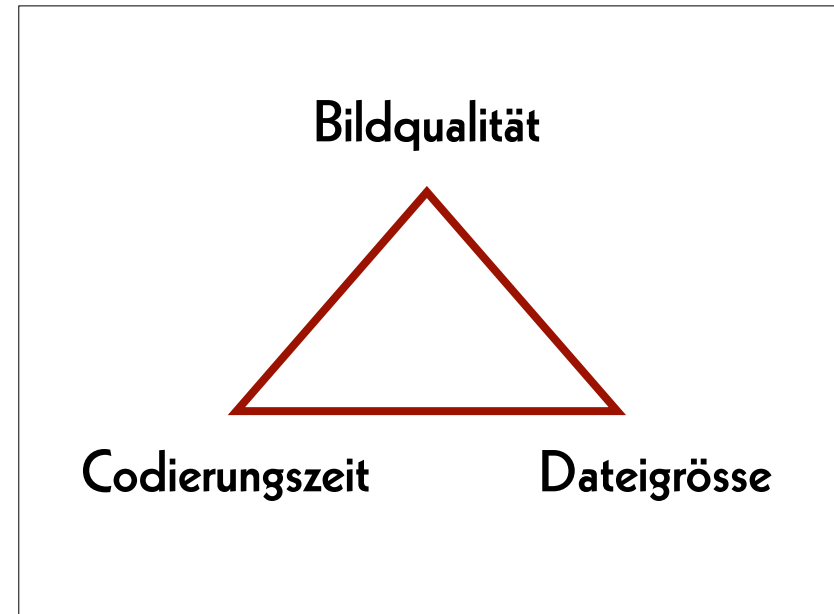
RGB24



24



25



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Kompression

- nicht komprimiert
- verlustfrei komprimiert
- verlustbehaftet komprimiert
- Farunterabtastung
- komprimiert generiert

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Nicht komprimiert

- + Daten sind leichter zu bearbeiten
- + Software läuft schneller
- grössere Dateien
- langsames Schreiben, Übermitteln und Lesen der Dateien

Beispiele: TIFF, DPX, DNG, OpenEXR

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Verlustfrei komprimiert

- + kleinere Dateien
- + schnelleres Schreiben, Übermitteln und Lesen der Dateien
- Daten sind komplexer zu bearbeiten
- Software läuft langsamer

Beispiele: JPEG 2000, FFV1

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Verlustbehaftet komprimiert

- optimiert für Aufnahme und/oder Postproduktion
- optimiert für Zugang und Distribution

Beispiele (Mezzanine): ProRes 422, ProRes 4444; DNxHD, DNxHR

Beispiele (Zugang): H.264 (AVC), H.265 (HEVC), H.266 (VVC); AV1

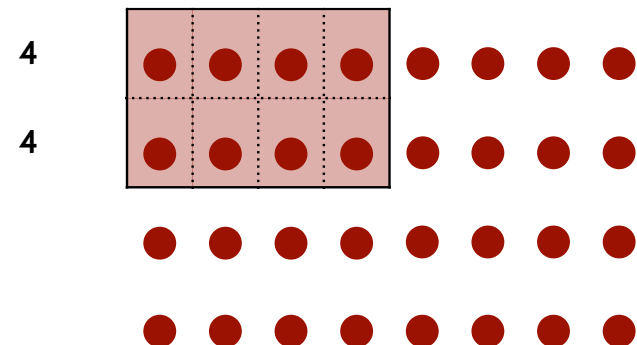
30

Farbunterabtastung

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

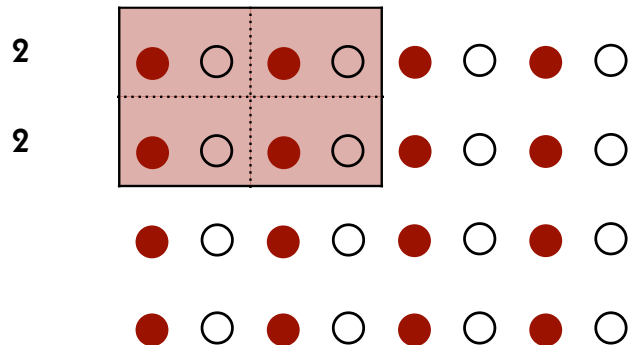
31

4:4:4



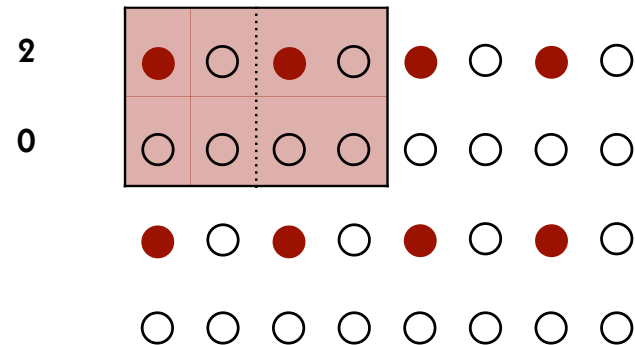
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4:2:2



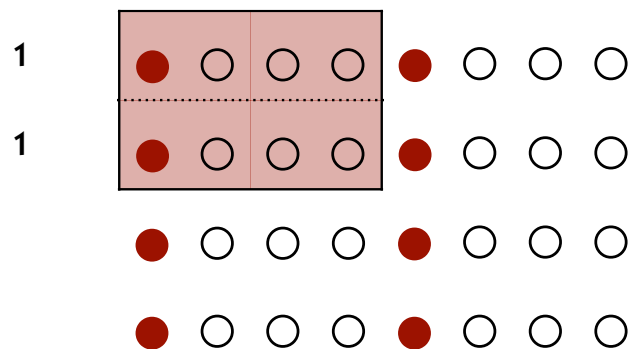
33

4:2:0



34

4:1:1



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Komprimiert generiert

- sowohl für Aufnahme als auch für Postproduktion optimiert

Beispiele: CineForm RAW, ProRes RAW, Blackmagic RAW

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Unbequeme Wahrheiten

- Sensoren sind farbenblind
- Bayer-Sensoren erzeugen kein vollständiges RGB-Bild

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Bryce E. Bayer (1929–2012)

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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

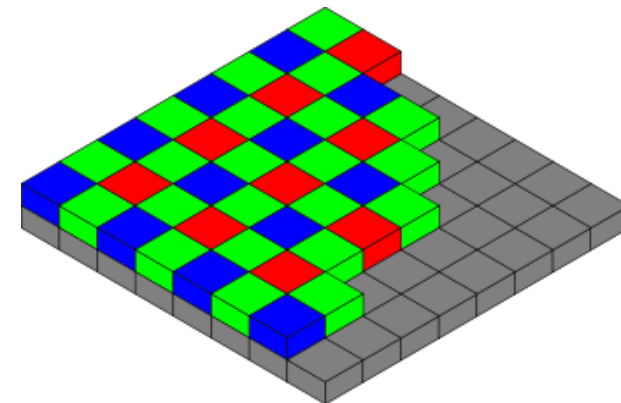
Primary Examiner—George H. Libman
Attorney, Agent, or Firm—George E. Grosser

11 Claims, 10 Drawing Figures

[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.

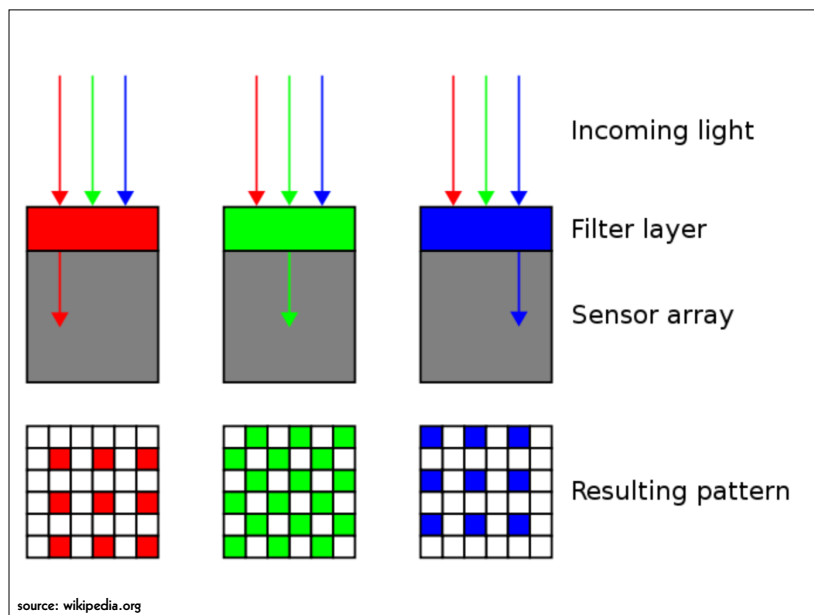
In a presently preferred implementation, a mosaic of selectively transmissive filters is superposed in registration with a solid state imaging array having a broad range of light sensitivity, the distribution of filter types in the mosaic being in accordance with the above-described patterns.



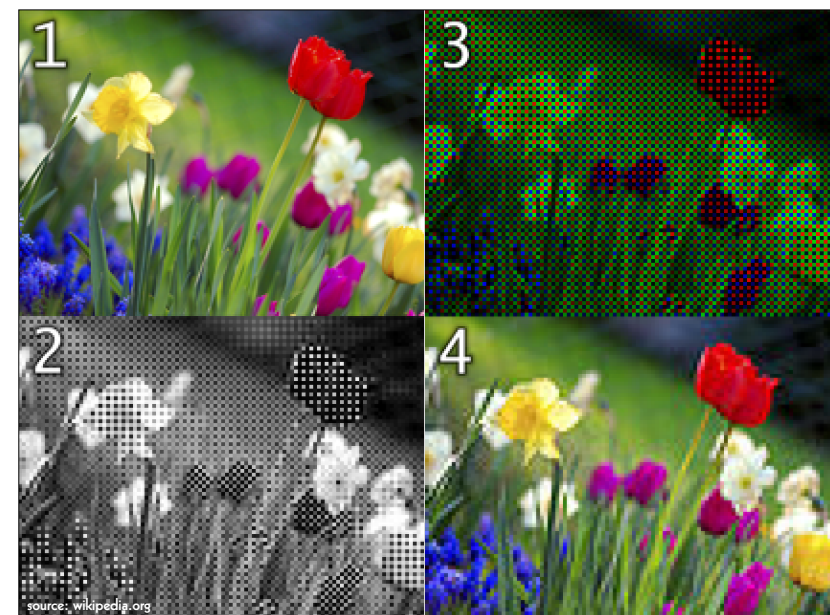
source: wikipedia.org

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40



41



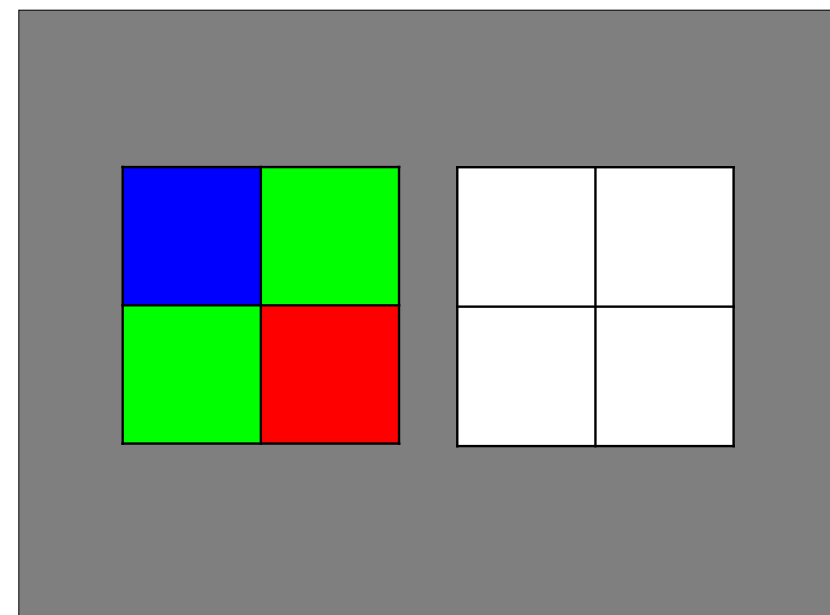
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010011010101010101010100001011101010
011101010010101010100010110101011110
000111010101010101010100001011101010
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011101010010101010100010110101011110
010101010101010101000010111010100110
100101110101001010101000101101010101
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43



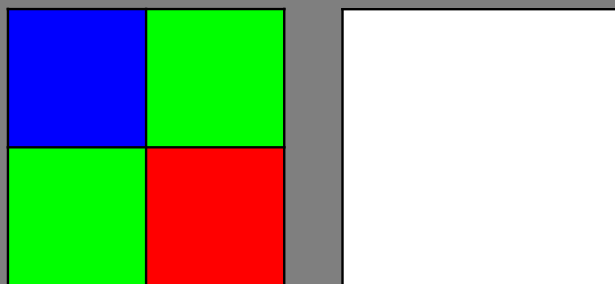
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000000000000 000000000000 110101010101	000000000000 010100001011 000000000000	010010100101 101101000001 110101010101	011111011110 010100001011 100001100100
000000000000 101010011010 000000000000	101001010101 000000000000 000000000000	011000111001 101010011010 100001010111	101001010101 010011011110 010100010111

45

0 0 B	0 G ₁ 0	R G B	R G ₁ B
0 G ₂ 0	R 0 0	R G ₂ B	R G B

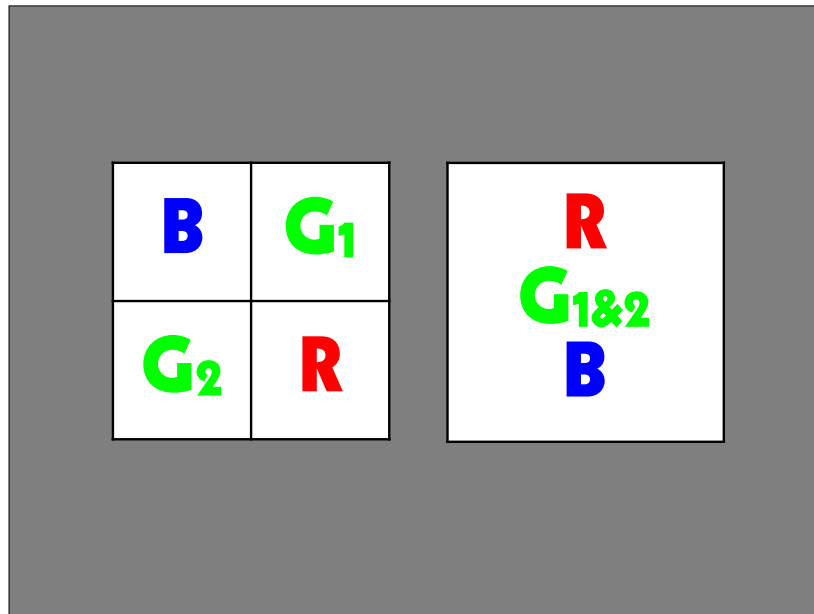
46



47

110101 010101	010100 001011	101001010101 011111010010 110101010101
101010 011010	101001 010101	

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Bayer-Daten benützen

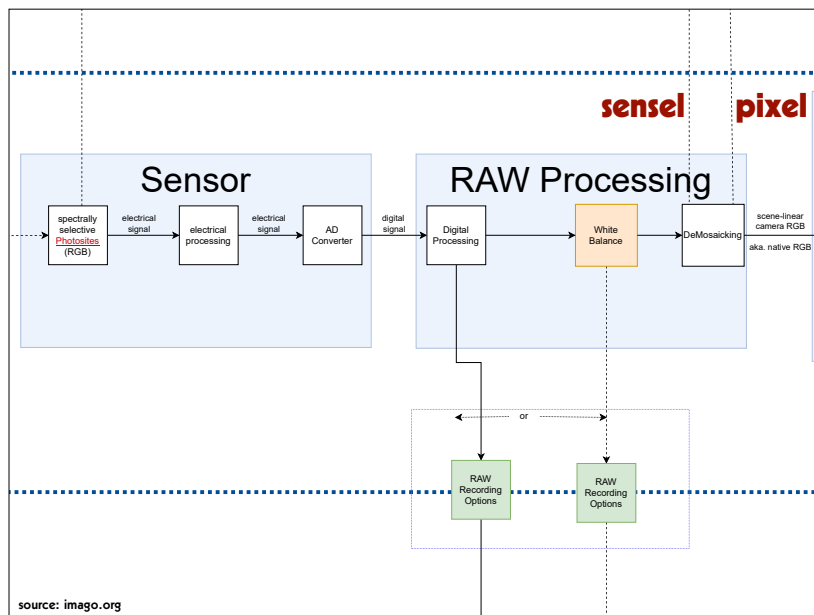
digitales Aufblasen auf RGB

- die generierten Daten werden verdreifacht
- die Datei hat die volle Sensorauflösung
- nur die Hälfte der Daten ist real

digitale Reduktion auf RGB

- drei Viertel der generierten Daten sind gespeichert
- die Datei hat die halbe Sensorauflösung
- die gesamten Daten sind real

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Bayer-Daten speichern

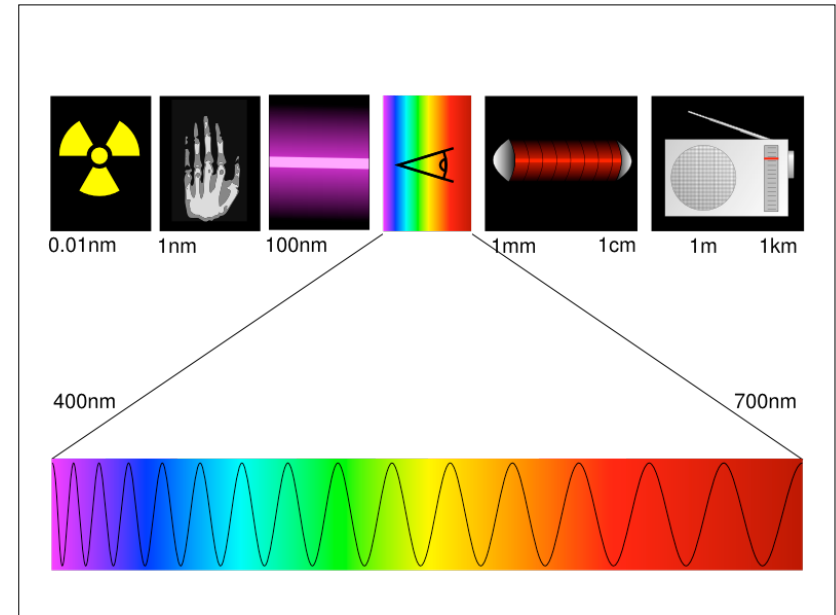
- pixel values generated by one de-mosaicking algorithm (digital blow-up)
- pixel values generated by mixing two green sensel values into one (digital reduction)
- raw sensel values

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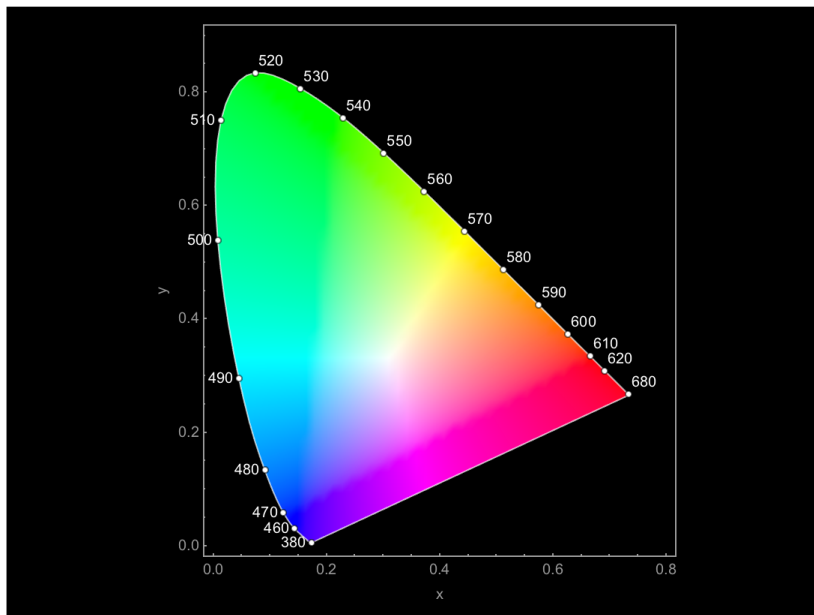
Normlicht

- D50
- D55
- D65
- D75

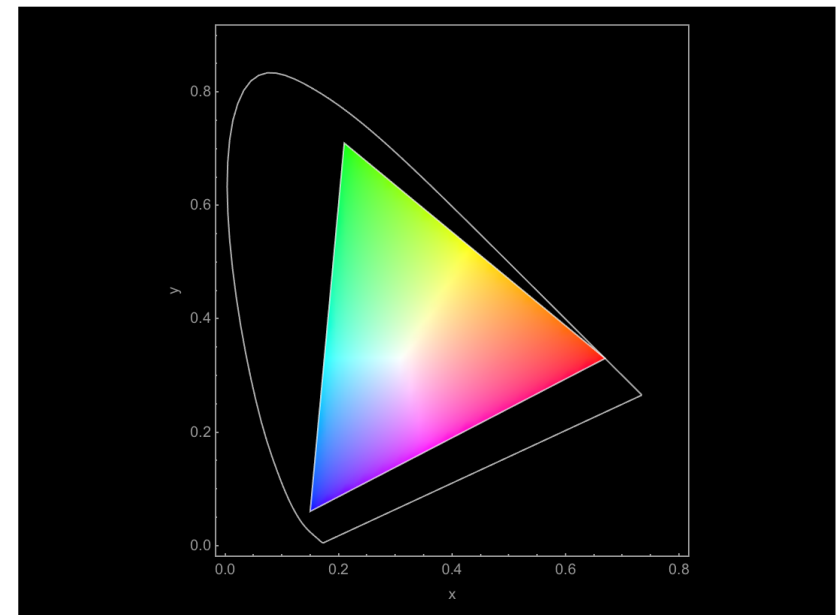
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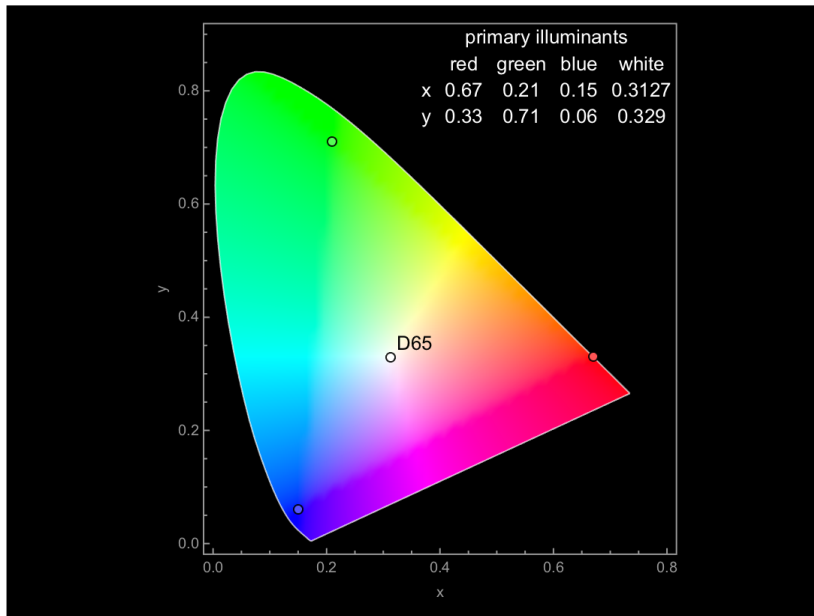
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55



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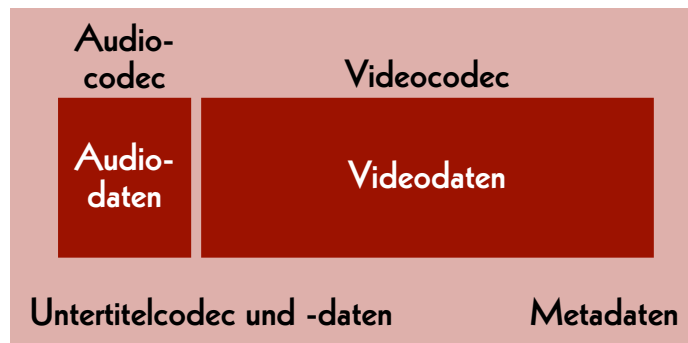
57

Dateiaufbau

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Dateiaufbau

Container (Wrapper)



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Container für Datenfluss

- MP4
- QuickTime (.mov)
- AVI

- MXF
- Matroska (.mkv)

- Flash

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Container für Einzelbilder

- Ordner
- TAR
- ZIP
- MXF
- Matroska (.mkv)
- CinemaDNG
- Motion JPEG

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Audiocodec

- WAVE
- BWF
- AAC
- MP3
- FLAC

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Videocodec (Master)

Einzelbilder

- TIFF
- DPX
- JPEG 2000
- OpenEXR
- DNG

Datenfluss

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

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Videocodec (Mezzanine)

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

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Videocodec (Zugang)

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

- AV1

65

RAW data are cooked.

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Audiodaten

- pcm_s16le
- pcm_s24le
- pcm_s32le

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Videodaten

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

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What is inside my DPX?

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

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Dateiformate

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Grundsätze

- **Ein Archiv muss seine Dateien pflegen und handhaben können.**
- Open Source
- einfache Bedienung und ausführliche Dokumentation
- weite Verbreitung

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Formate für verschiedene Anwendungszwecke

Archivmasterformat

→ zur Erhaltung und Archivierung

Mezzanine-Format

→ zur Bearbeitung und Postproduktion

Distributionsformat

→ zur Verbreitung und Zugänglichmachung

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Elena Rossi-Snook:

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

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Archivmaster (heute)

«Film» (Einzelbilder)

- Ordner, TIFF, 2K oder 4K, RGB, 16 bit
- MXF, DPX, 2K oder 4K, R'G'B', 10 bit

«Video» (Datenfluss)

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

Ton

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

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Mezzanine (heute)

Bild

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

Ton

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

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Zugang (heute)

MP4

Bild

- H.264, SD, Y'C_BC_R 4:2:0, 8 bit, lossy
- H.264, «HD», Y'C_BC_R 4:2:0, 8 bit, lossy

Ton

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

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Archivmaster und Mezzanine

«Film» (Einzelbilder)

- Matroska, FFV1, 4K oder 2K, RGB, 16 bit
- Matroska, FFV1, 4K oder 2K, R'G'B', 12 bit

«Video» (Datenfluss)

- Matroska, FFV1, «HD», Y'C_BC_R 4:2:2, 10 bit
- Matroska, FFV1, «HD», Y'C_BC_R 4:2:2, 12 bit

Ton

- Matroska, FLAC, 192 kHz, 24 bit

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Zugang

MP4

Bild

- H.265, «HD», Y'C_BC_R 4:2:0, 8 bit, lossy
- H.266, «HD», Y'C_BC_R 4:2:0, 8 bit, lossy
- AV1, «HD», Y'C_BC_R 4:2:0, 8 bit, lossy

Ton

- AAC, 96 kHz, 16 bit

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Bibliografie

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

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

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Vor- und Nachteile

80

Container:

- Ordner
- TAR
- ZIP
- MXF
- Matroska
- AXF

Codec:

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

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	Vorteile	Nachteile
TIFF DPX OpenEXR	Daten leichter zu bearbeiten	grössere Dateien
JPEG 2000 FFV1	kleinere Dateien	Daten komplexer zu bearbeiten

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Eine Brücke zwischen den zwei Welten

RAWcooked (CLI)

→ mediaarea.net/RAWcooked

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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

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MXF-Container (.mxf)

Videocodec

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

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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:

Kate Murray
Library of Congress
101 Independence Ave, S.E.
Washington, DC 20540-1300

Email: kmur@loc.gov

86

MXF / DPX

MXF

→ SMPTE RDD 48:2018

DPX

→ SMPTE ST 268M:2015

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MXF / JPEG 2000

MXF

→ SMPTE RDD 48:2018

JPEG 2000

→ ISO/IEC 15444-1:2019

→ usw.

88

MXF / DNx

MXF

→ SMPTE RDD 48:2018

DNxHD, DNxHR

→ nicht veröffentlicht

89

MXF / ProRes

MXF

→ SMPTE RDD 48:2018

ProRes 422, ProRes 4444

→ SMPTE RDD 36:2015

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SMPTE REGISTERED DISCLOSURE DOCUMENT

SMPTE RDD 36:2015

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

Email: ProRes@apple.com

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Matroska-Container (.mkv)

Videocodec

- FFV1
- ProRes 422, ProRes 4444

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Matroska / FFV1

Matroska (.mkv)

→ IETF Internet Draft

FFV1

→ IETF RFC 9043

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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>.

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Matroska / ProRes

Matroska (.mkv)

→ IETF Internet Draft

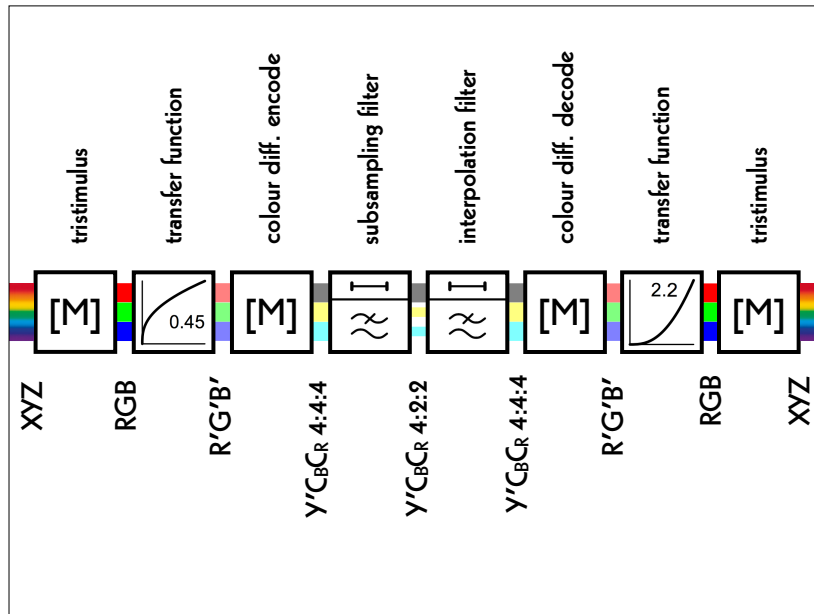
ProRes 422, ProRes 4444

→ SMPTE RDD 36:2015

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Umwandlungen

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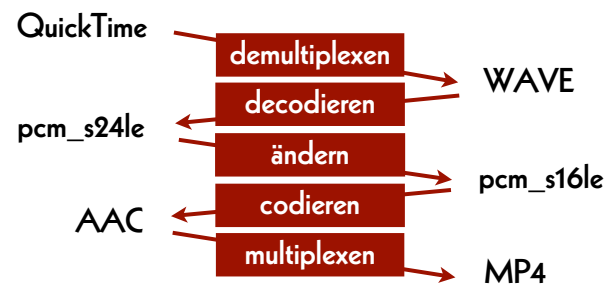
97

Dateiumwandlungen



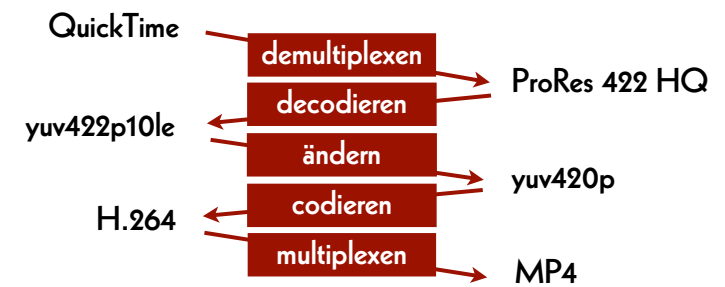
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Beispiel: Ton



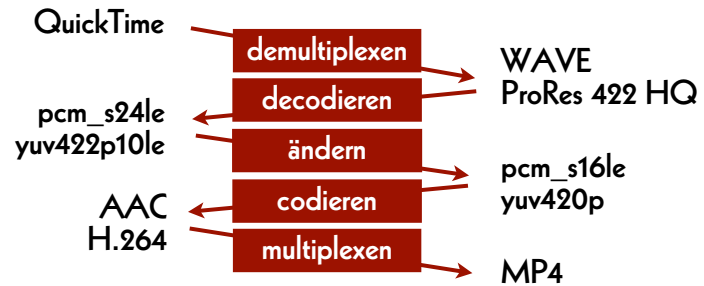
99

Beispiel: Bild



100

Beispiel: Bild und Ton



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Datenwartung

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Plan the Next Migration

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

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File Naming (Example)

- title_codec.container
- title_codec_container_algorithm.txt
- film_H264.mp4
- film_H264_mp4_md5.txt

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Checksums

cryptographic

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

non-cryptographic

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

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Longterm

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

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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)

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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

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read | script | write

script to modify

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

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#1: ProRes-born Content

from:

- ProRes stored in a QuickTime (.mov) container

to:

- ProRes stored in a Matroska (.mkv) container

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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

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#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

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Container and Codec

- read file from source LTO
- demultiplex file
- decode file
 - $Y'CbCr$, 4:2:2, 8 bit, uyvy422
- encode file
- multiplex file
- write file to destination LTO

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Container and Codec

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

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#3: Filename

from:

- Title_YUV422.mkv

to:

- Title_YCbCr422_9d5084b5b0a08d5022b39e0e75241d12.mkv

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#3: Filename

from:

- Title_YUV422.mkv

to:

- Title_YCbCr422_9d5084b5b0a08d5022b39e0e75241d12.mkv

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Always remember:

To do nothing
is *never* an option!

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Danksagung (1)

- Eidgenössische Technische Hochschule
- Massachusetts Institute of Technology
- Kinemathek Lichtspiel, Bern
- Charles Poynton
- Dave Rice und Misty De Meo
- Agathe Jarczyk und David Pfluger

118

Danksagung (2)

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

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