

Audiovisuelle Dateiformate

Reto Kromer • AV Preservation by reto.ch

**Medienkunst:
Technologie und Erhaltungsstrategien III**
Akademie der bildenden Künste
Wien, 14.–15. Juni 2023

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Digitaler Ton

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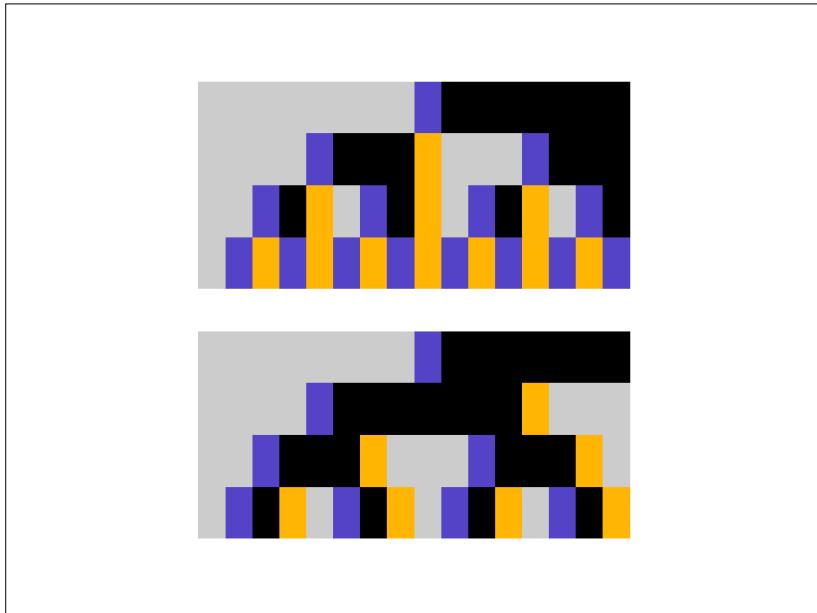
Inhalt

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

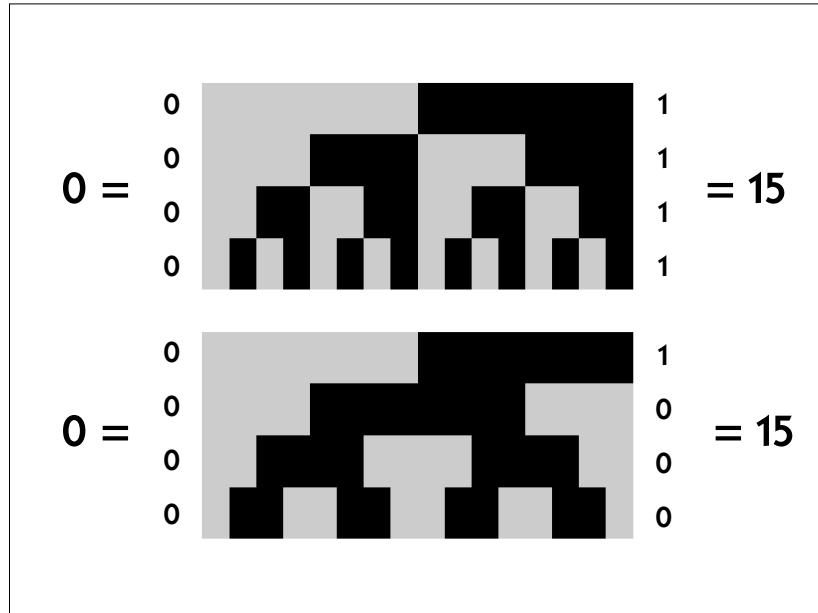
2

**Frank Gray
(1887–1969)**

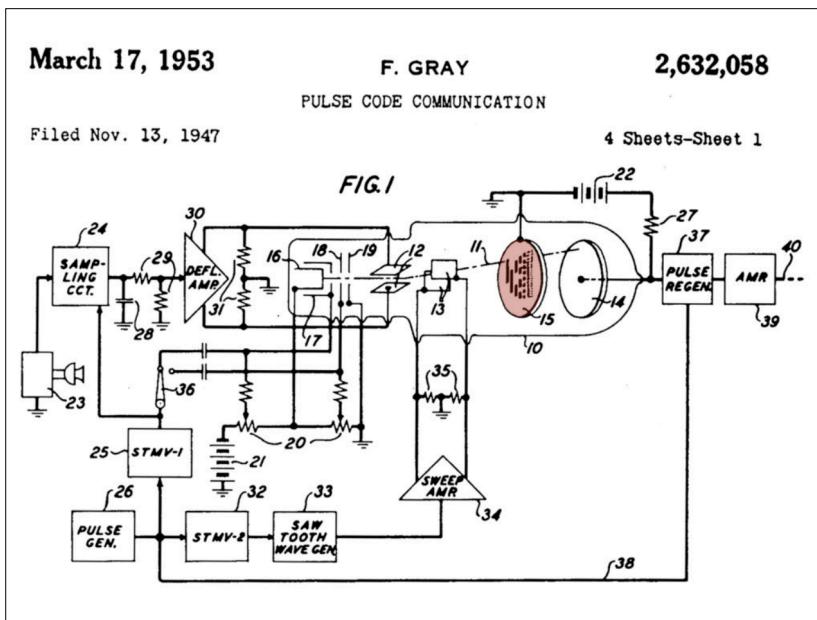
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5



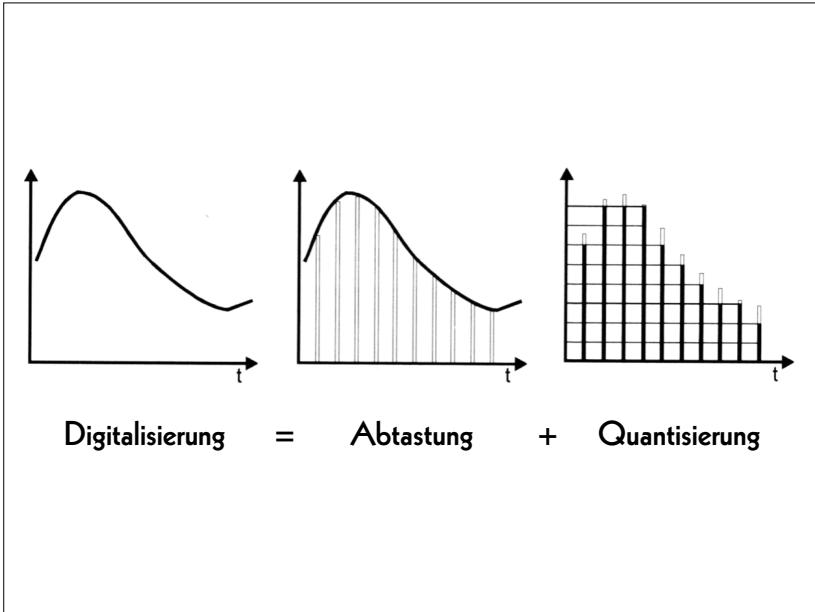
6



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8



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

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Digitales Bild

- Auflösung
- Quantisierungsaufösung
- 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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Quantisierungsaufösung

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

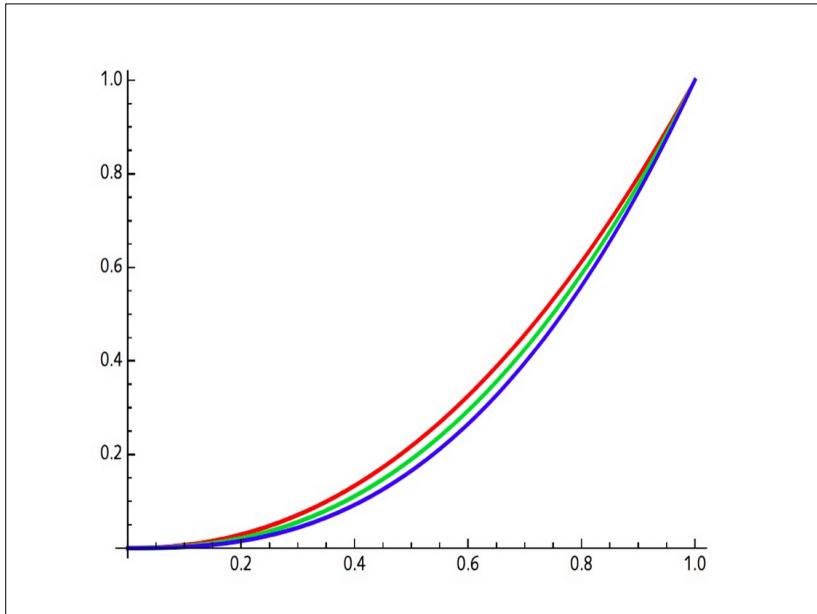
15

Linear, Potenz, Logarithmus

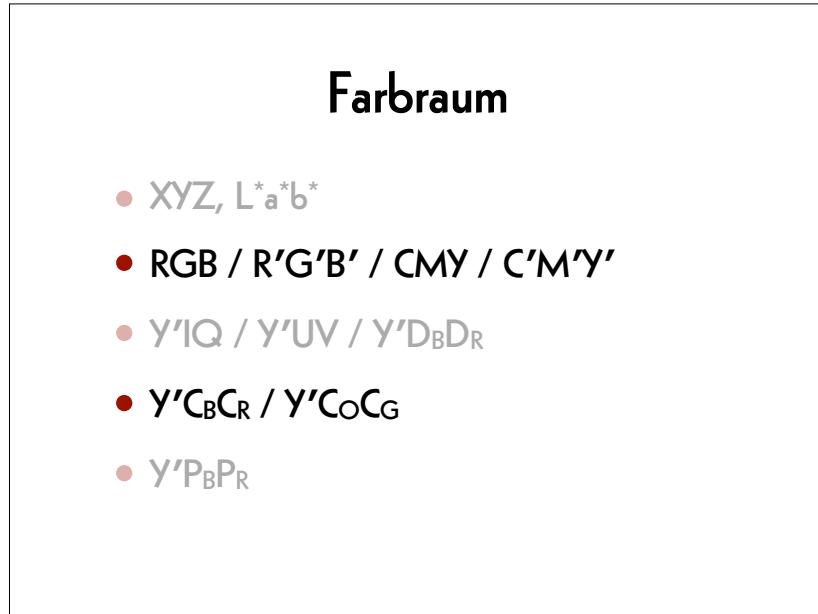
«Mittelgrau»

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

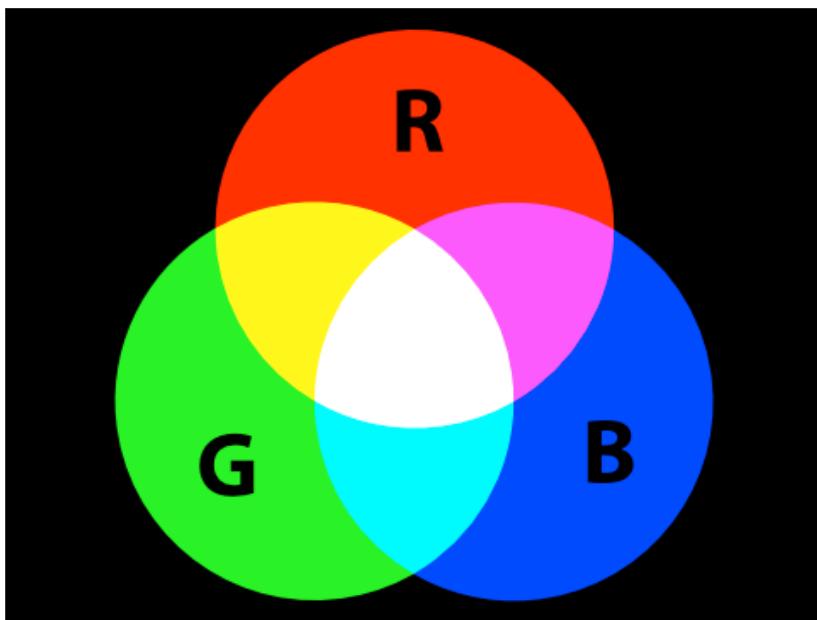
16



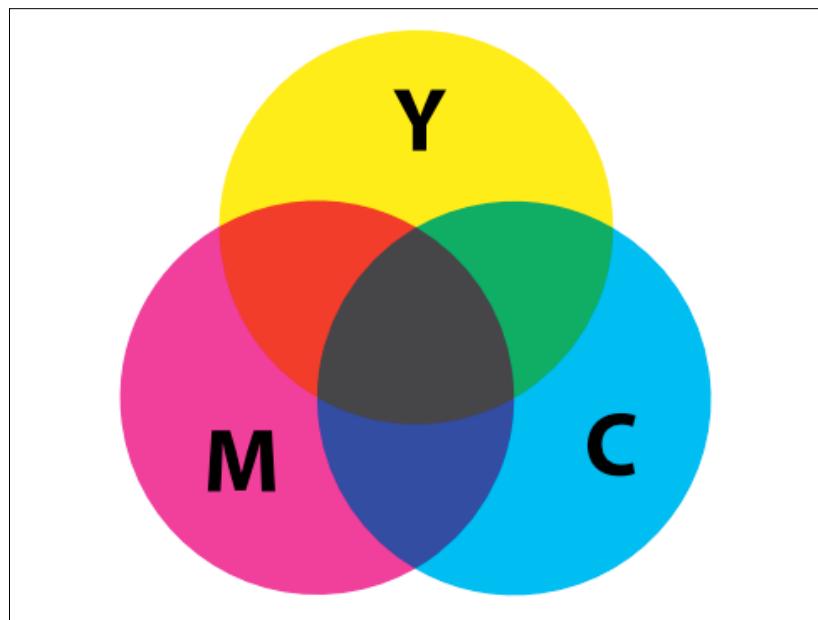
17



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20

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

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

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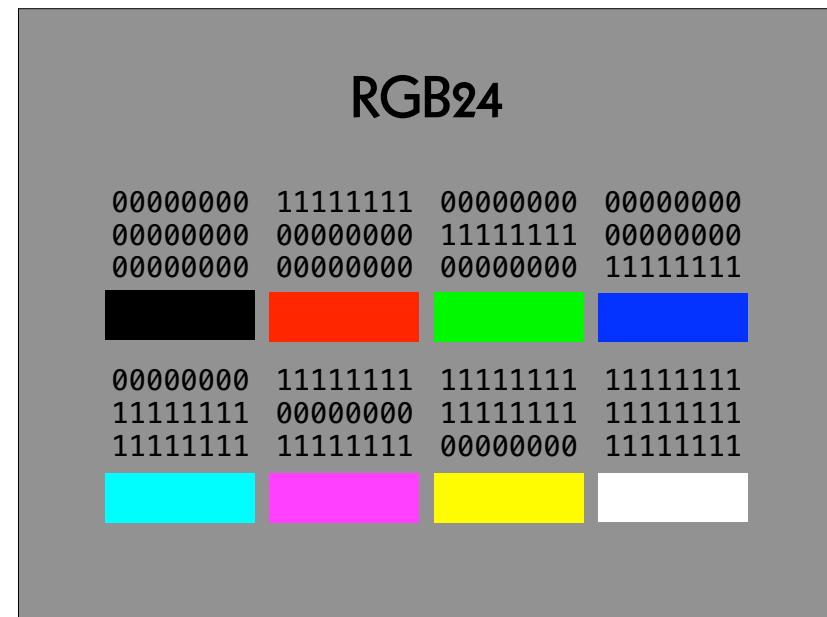
$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1 & 1 & -1 \\ 1 & 0 & 1 \\ 1 & -1 & -1 \end{pmatrix} \begin{pmatrix} Y' \\ C_O \\ C_G \end{pmatrix}$$

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

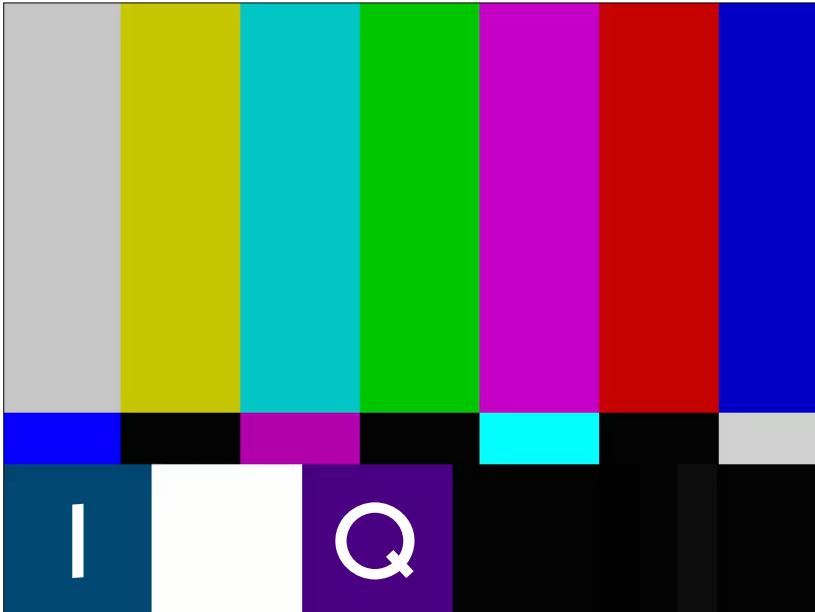
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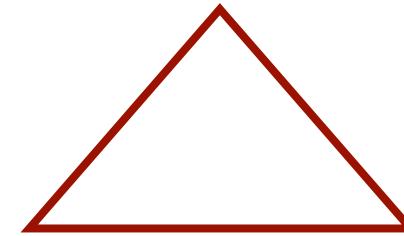


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Bildqualität



Codierungszeit

Dateigrösse

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Kompression

- nicht komprimiert
- verlustfrei komprimiert
- verlustbehaftet komprimiert
- Farbunterabtastung
- komprimiert generiert

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Nicht komprimiert

- + Daten sind leichter zu bearbeiten
- + Software läuft schneller
- grössere Dateien
- langsameres 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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Farbunterabtastung

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

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Verlustbehaftet komprimiert

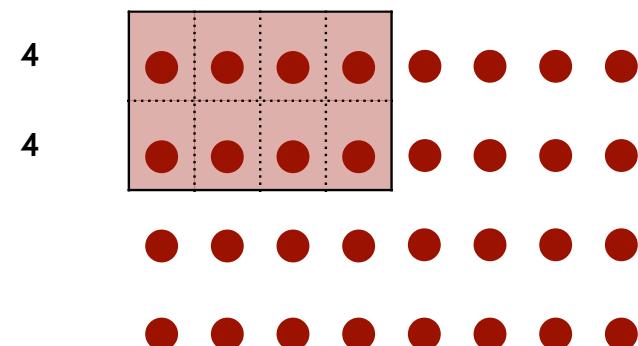
- optimiert für Aufnahme und/oder Postproduktion
- optimiert für Zugang und Distribution

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

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

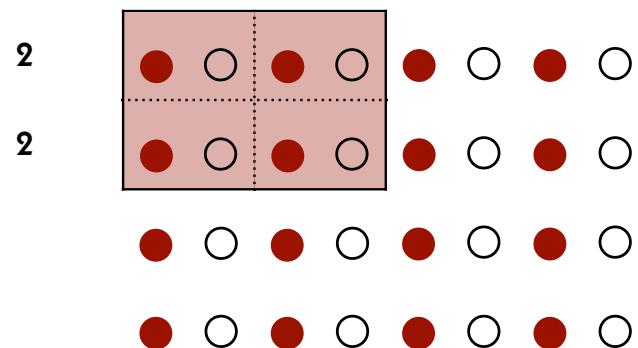
30

4:4:4



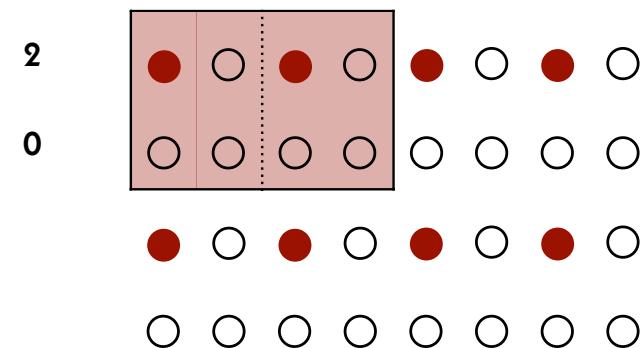
32

4:2:2



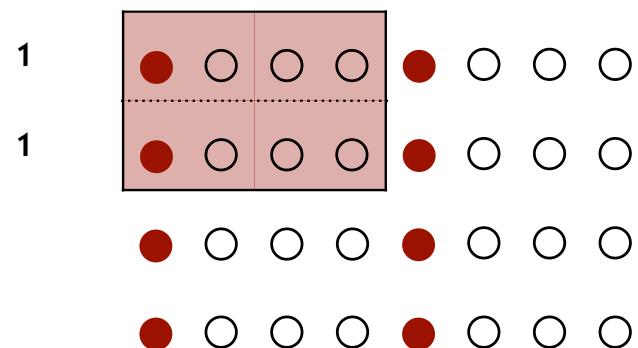
33

4:2:0



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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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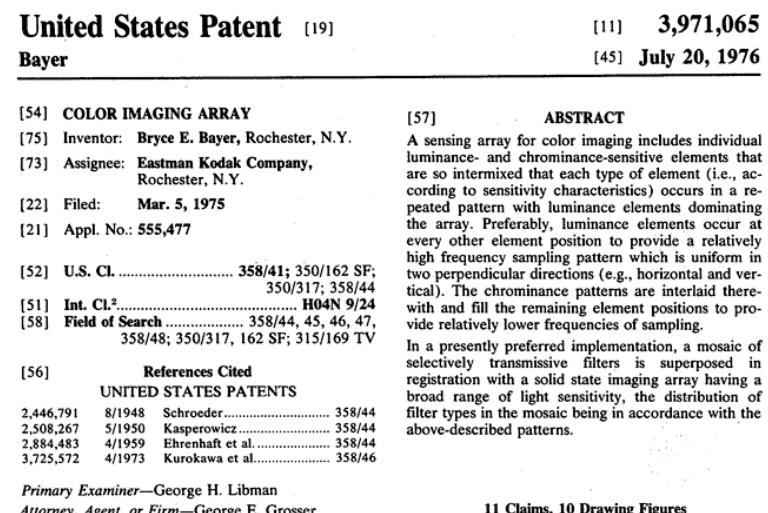
Unbequeme Tatsachen

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

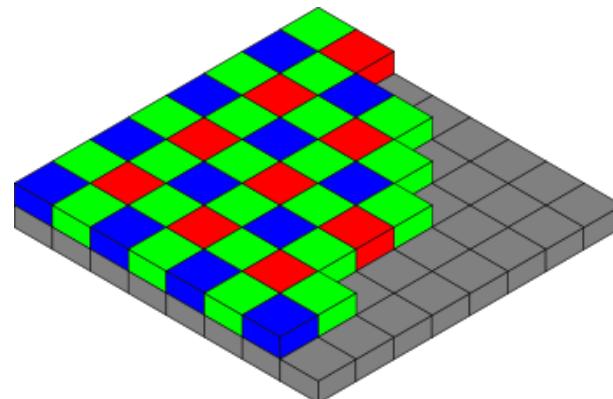
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Bryce E. Bayer (1929–2012)

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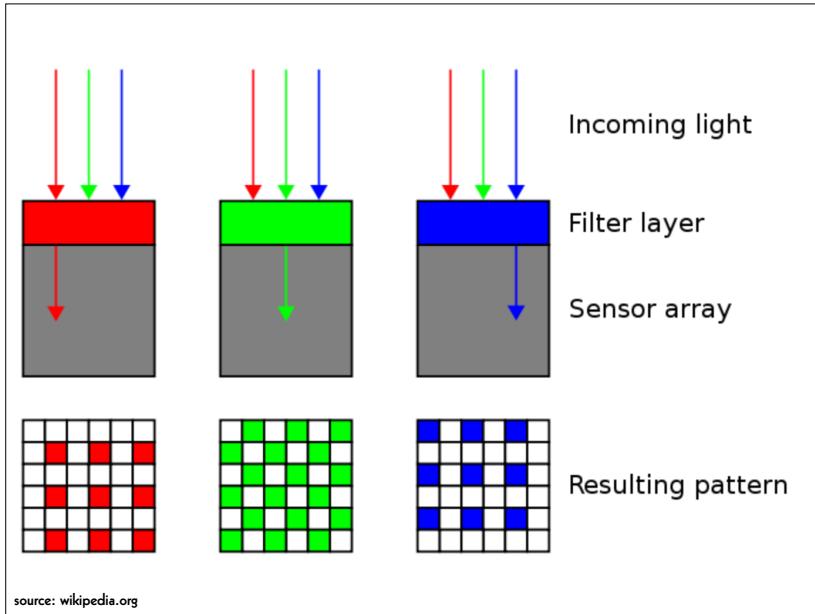


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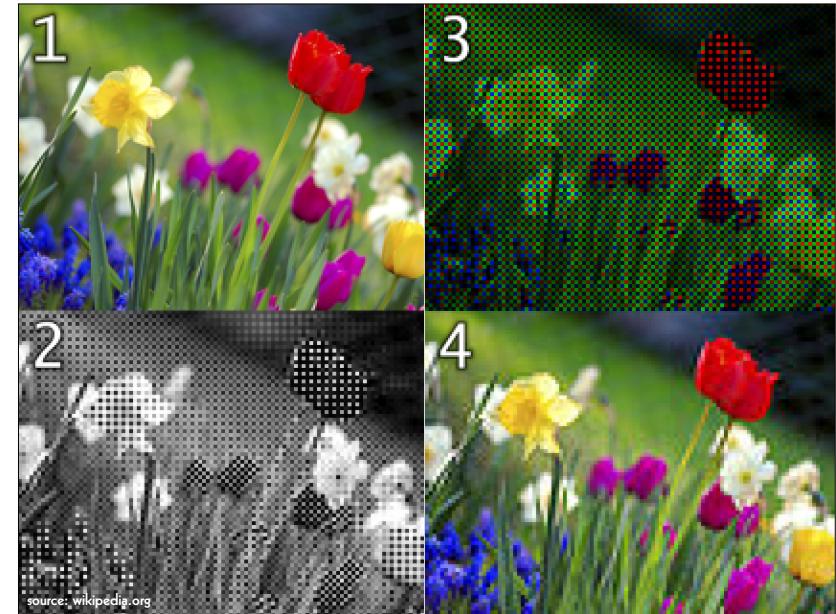


source: wikipedia.org

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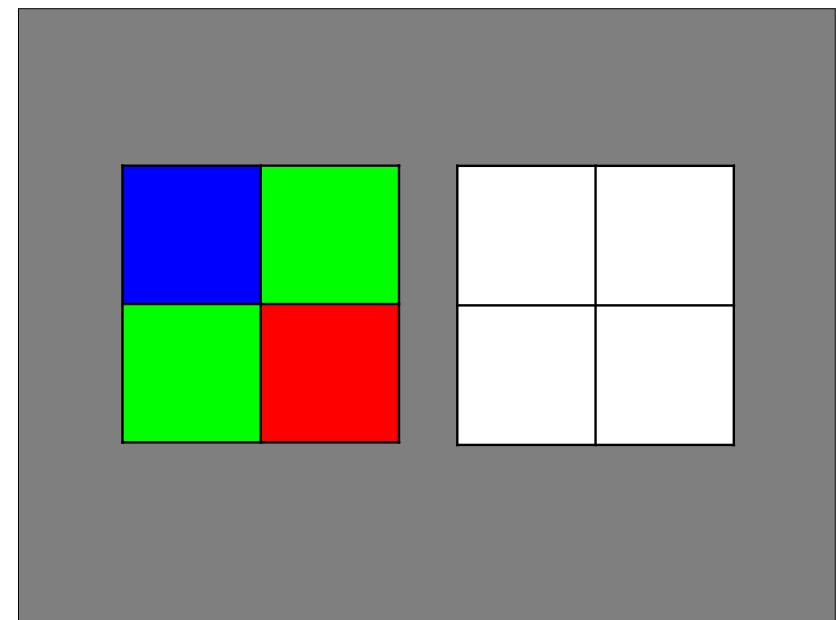
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0111010100101010100010110101011110
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0111010100101010100010110101011110
0001110101010101010100001011101010
011010101001010101000101110101111
0010101010101010000101110101010000
0111010100101010100010110101011110
01010101010101000010111010100110
1001011101010010101010001011010101
11100101010101010000101110101010
0111010100101010100010110101011110
01010101010101001101010100000001
0010100010101010101001010101010101

```

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44

000000000000 000000000000 110101010101	000000000000 010100001011
000000000000 101001010101 000000000000	101001010101 000000000000 000000000000

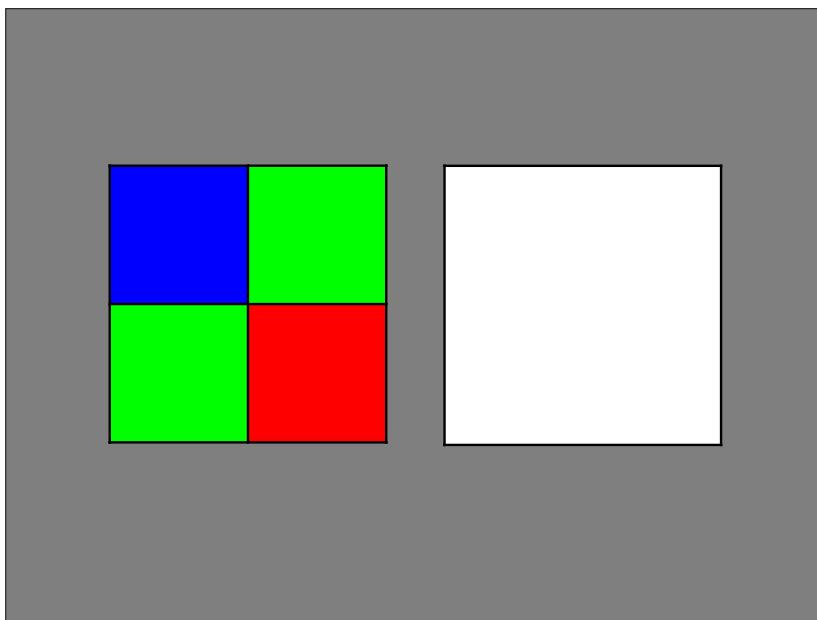
010010100101 101101000001 110101010101	011111011110 010100001011 100001100100
011000111001 101010011010 100001010111	101001010101 010011011110 010100010111

45

0 0 B	0 G₁ 0
0 G₂ 0	R 0 0

R G B	R G B
----------------------------------	----------------------------------

46

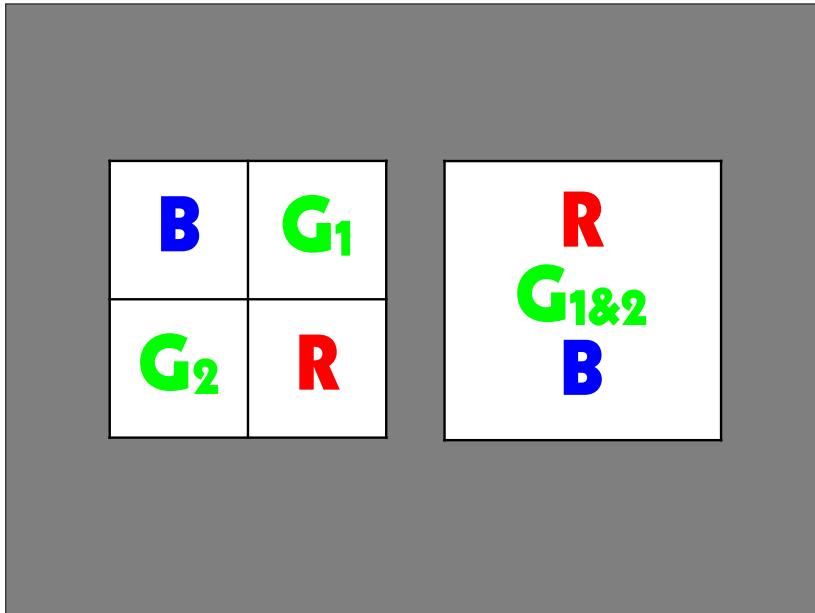


47

110101 010101	010100 001011
101010 011010	101001 010101

101001010101 011111010010 110101010101

48



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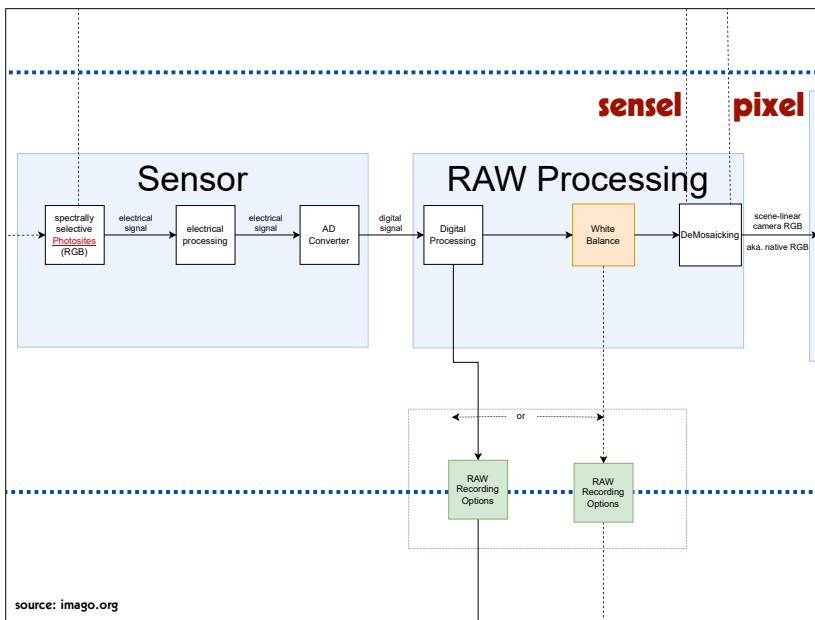
Bayer-Daten benützen

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

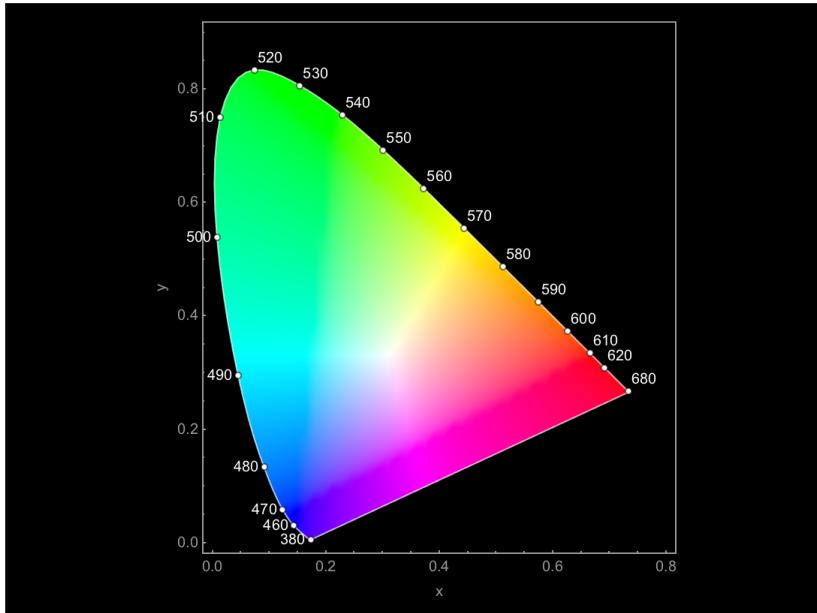
- pixel values generated by one de-mosaicking algorithm (digital blow-up)
- pixel values generated by mixing two green sensel values into one (digital reduction)
- raw sensel values

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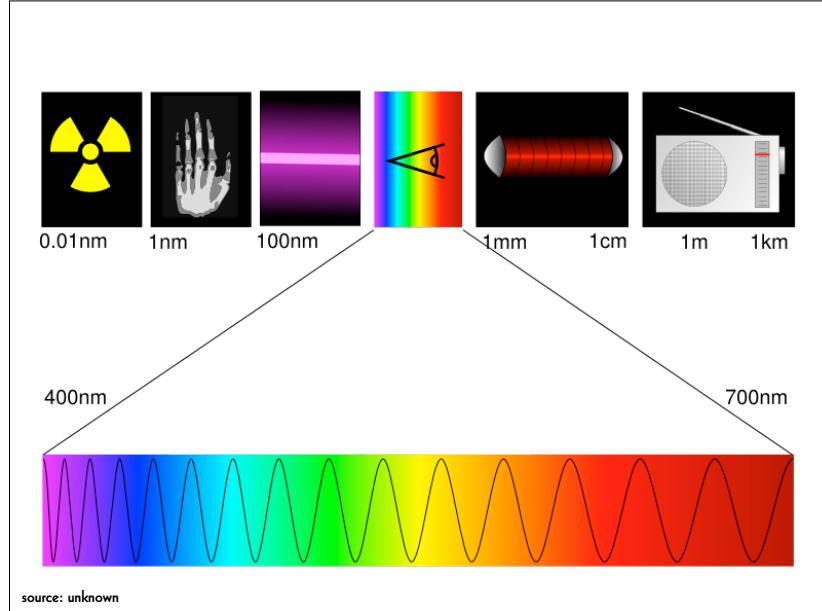
Normlicht

- D50
- D55
- D65
- D75

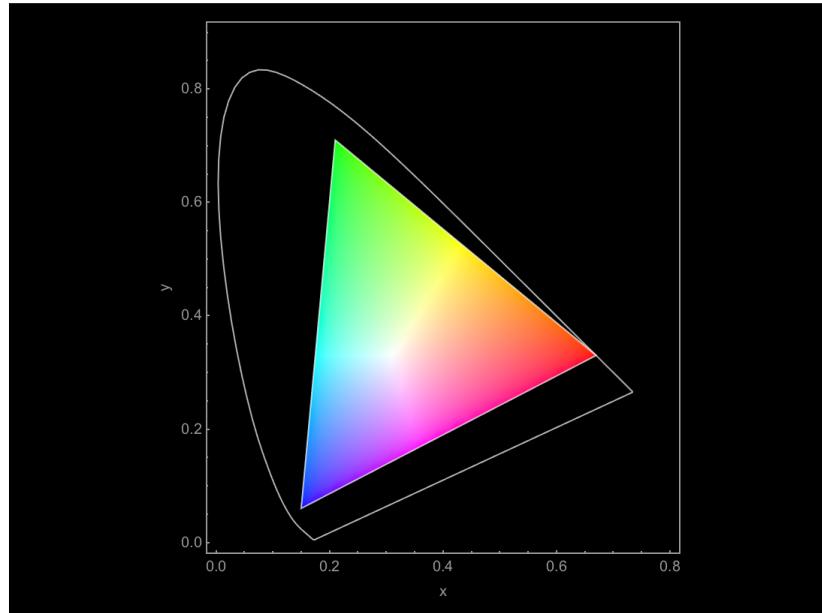
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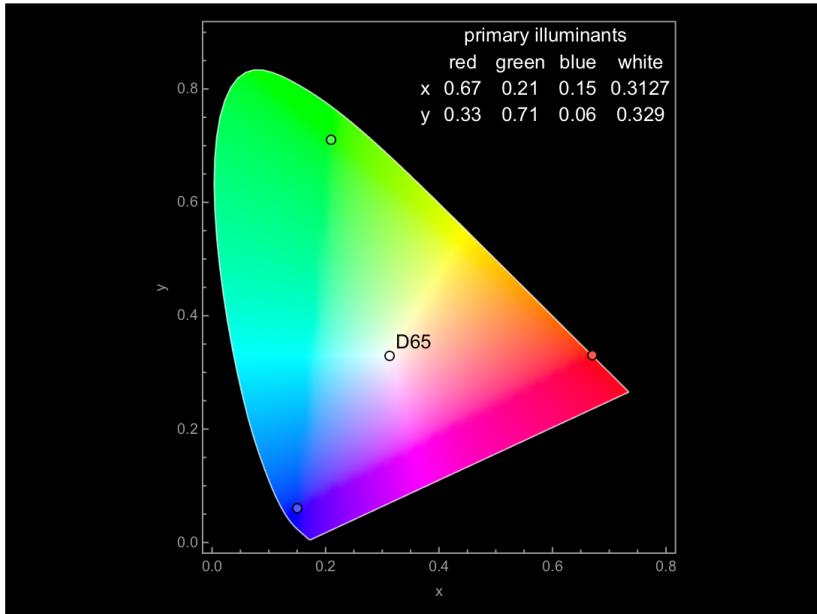
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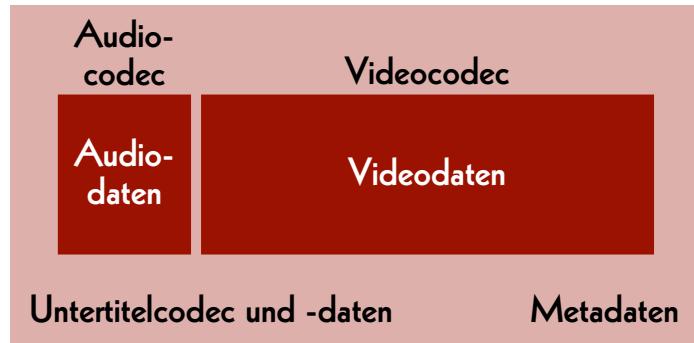
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Dateiaufbau

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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'CbCr 8 bit
- Y'CbCr 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

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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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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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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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Vor- und Nachteile

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Container:

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

Codec:

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

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Eine Brücke zwischen den zwei Welten

RAWcooked (CLI)

→ mediaarea.net/RAWcooked

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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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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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MXF / DPX

MXF

→ SMPTE RDD 48:2018

DPX

→ SMPTE ST 268M:2015

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SMPTE RDD 48:2018

SMPTE REGISTERED DISCLOSURE DOCUMENT



MXF Archive and Preservation Format Registered Disclosure Document

Page 1 of 113

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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

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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

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MXF / ProRes

MXF

→ SMPTE RDD 48:2018

ProRes 422, ProRes 4444

→ SMPTE RDD 36:2015

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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:

ProRes Program Office
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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Matroska / ProRes

Matroska (.mkv)

→ IETF Internet Draft

ProRes 422, ProRes 4444

→ SMPTE RDD 36:2015

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

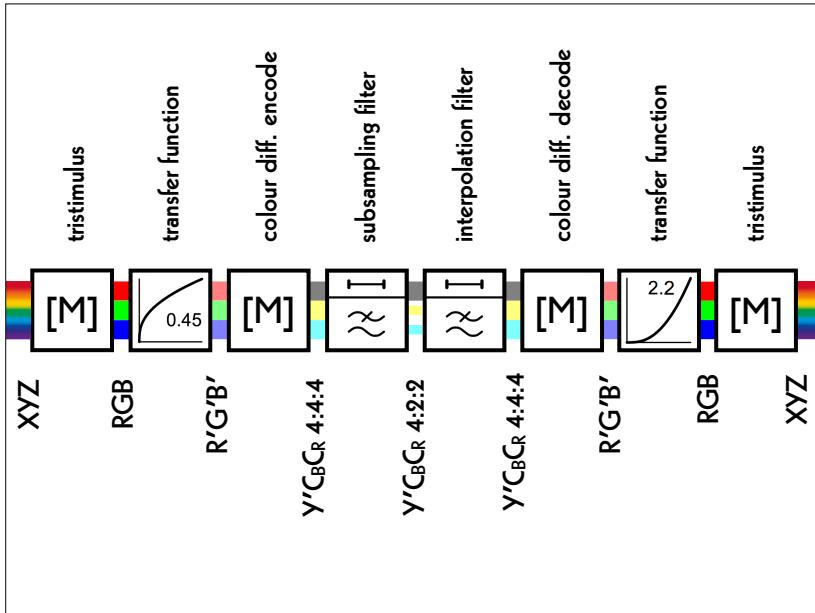
This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are candidates for 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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Umwandlungen

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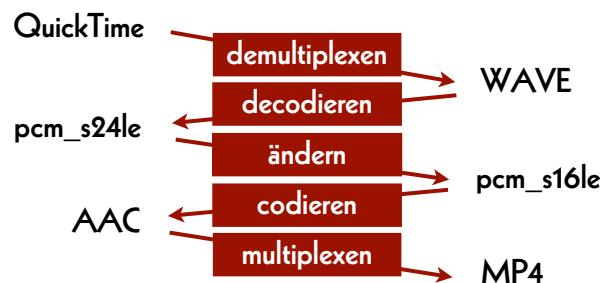
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Dateiumwandlungen



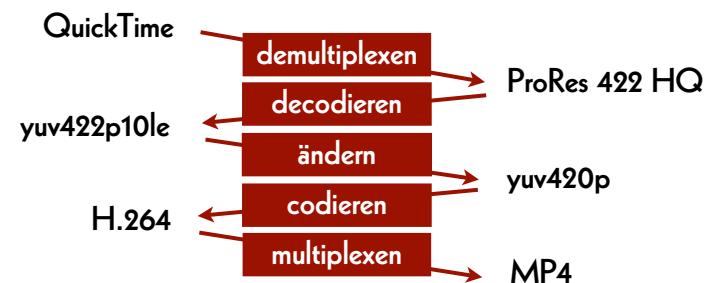
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Beispiel: Ton



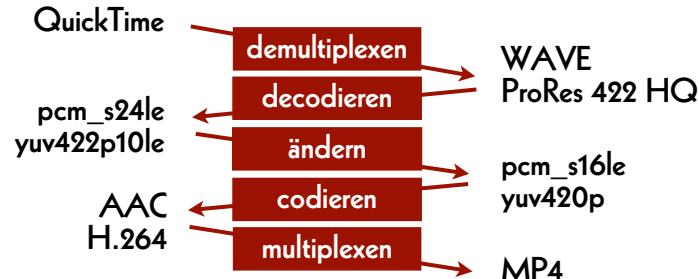
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Beispiel: Bild



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Beispiel: Bild und Ton



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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

102

Danksagung (2)

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

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AV Preservation by
reto.ch

Sandrainstrasse 3
3007 Bern
Switzerland

Web: reto.ch
Email: info@reto.ch



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