

# Audiovisuelle Dateiformate

Reto Kromer • AV Preservation by reto.ch

**Fmpeg-Workshop**  
Contemporary Art and Media  
Hochschule der Künste Bern, 6. Mai 2026

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# Inhalt

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

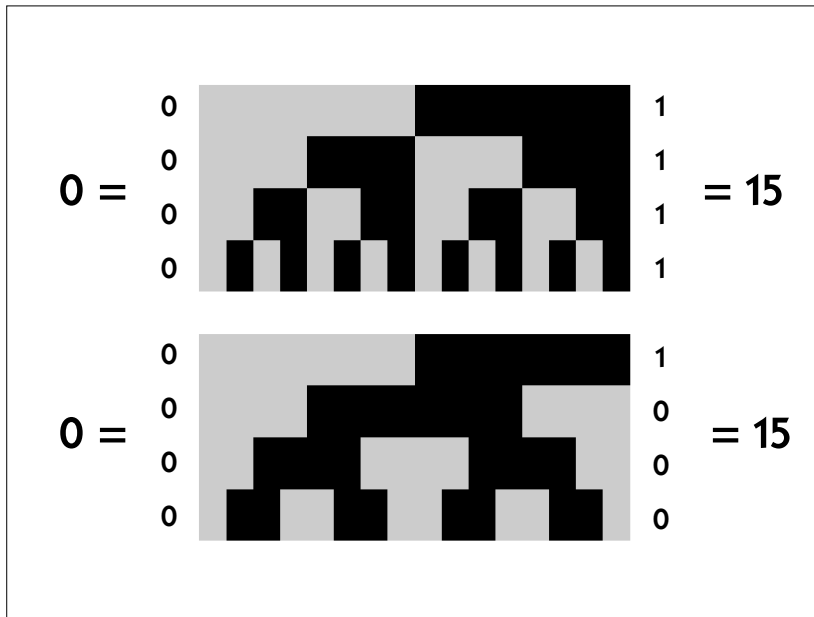
2

# Digitaler Ton

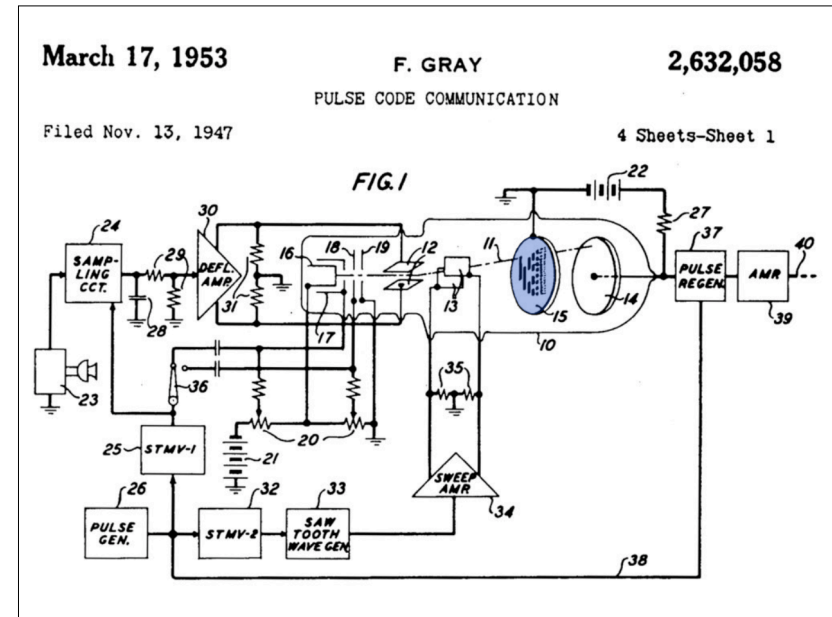
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**Frank Gray  
(1887–1969)**

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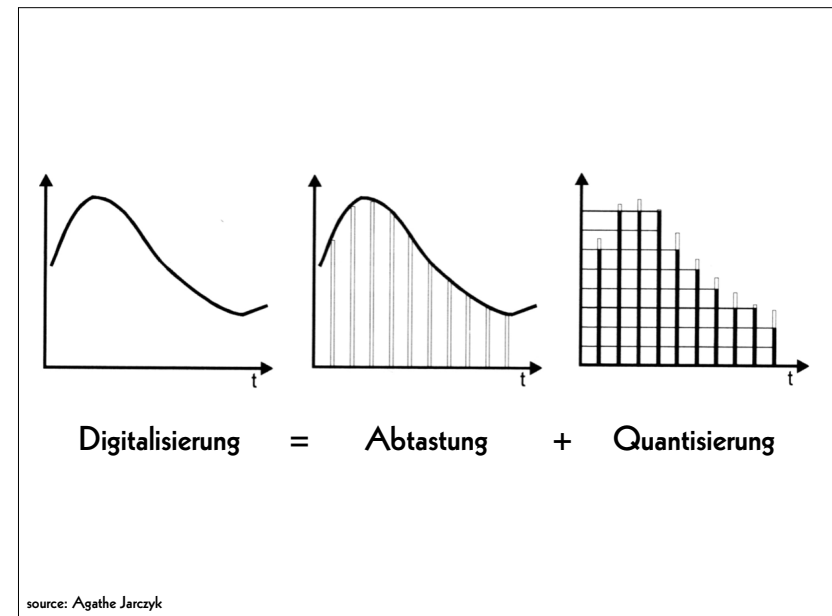


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## Digitaler Ton

- Abtastung
- Quantisierung
- Kompression

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## Abtastrate

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

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## Quantisierungsauflösung

- 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

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

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## Bildauflösung

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

Oft wird sie auch kurz «Auflösung» genannt.

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

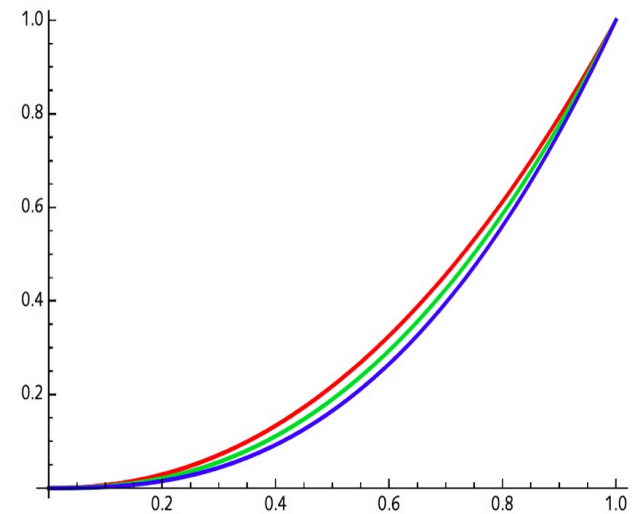
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## Linear, Potenz, Logarithmus

«Mittelgrau»

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

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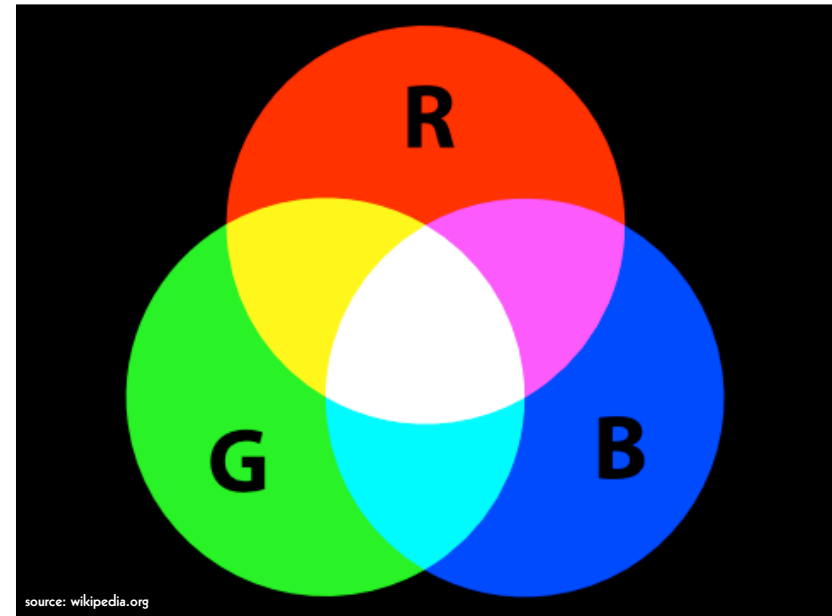


16

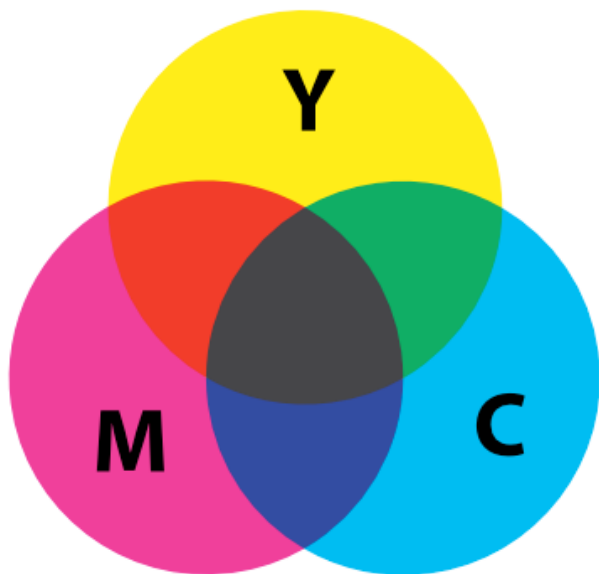
## Farbraum

- XYZ, L\*a\*b\*
- RGB / R'G'B' / CMY / C'M'Y'
- Y'IQ / Y'UV / Y'D<sub>B</sub>D<sub>R</sub>
- Y'C<sub>B</sub>C<sub>R</sub> / Y'CoC<sub>G</sub>
- Y'P<sub>B</sub>P<sub>R</sub>

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

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

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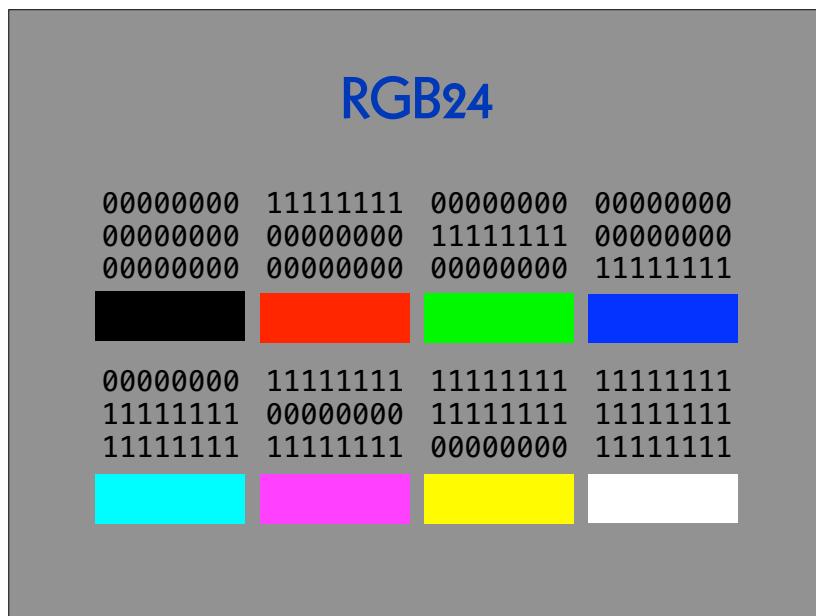
$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1 & 1 & -1 \\ 1 & 0 & 1 \\ 1 & -1 & -1 \end{pmatrix} \begin{pmatrix} Y' \\ C_O \\ C_G \end{pmatrix}$$

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

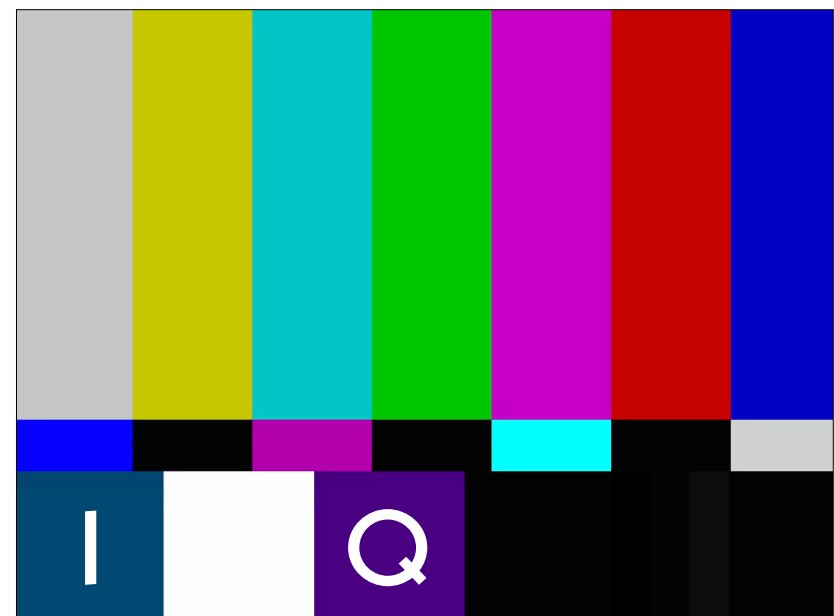
21



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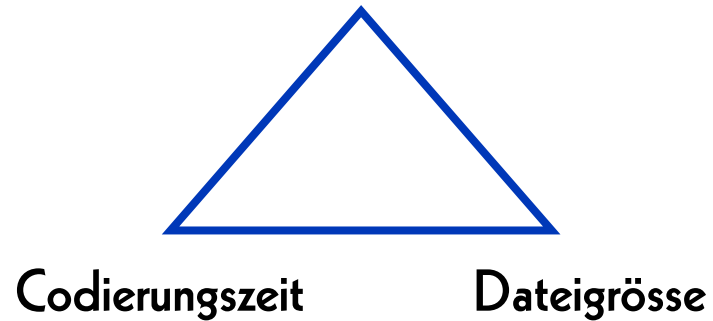


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## Bildqualität



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## Kompression

- nicht komprimiert
- verlustfrei komprimiert
- verlustbehaftet komprimiert
- Farbrunterabtastung
- 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

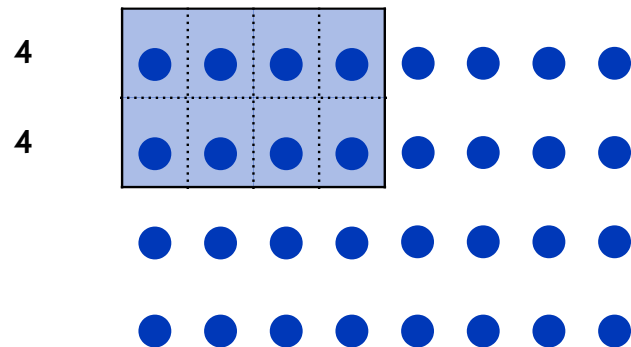
29

## Farbunterabtastung

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

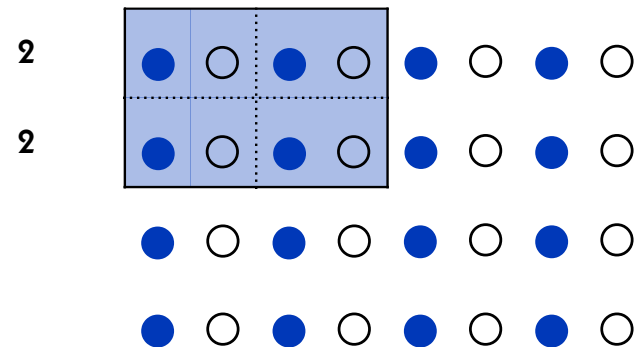
30

### 4:4:4

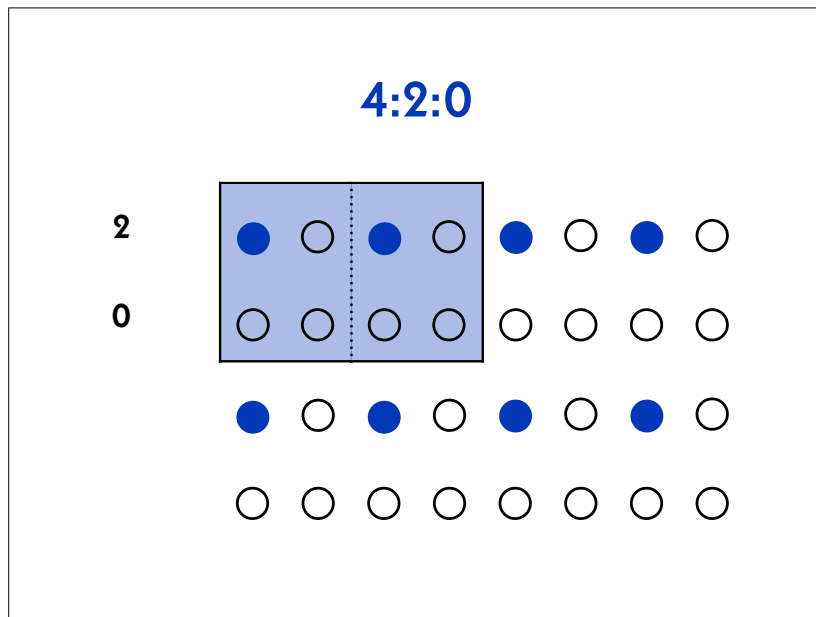


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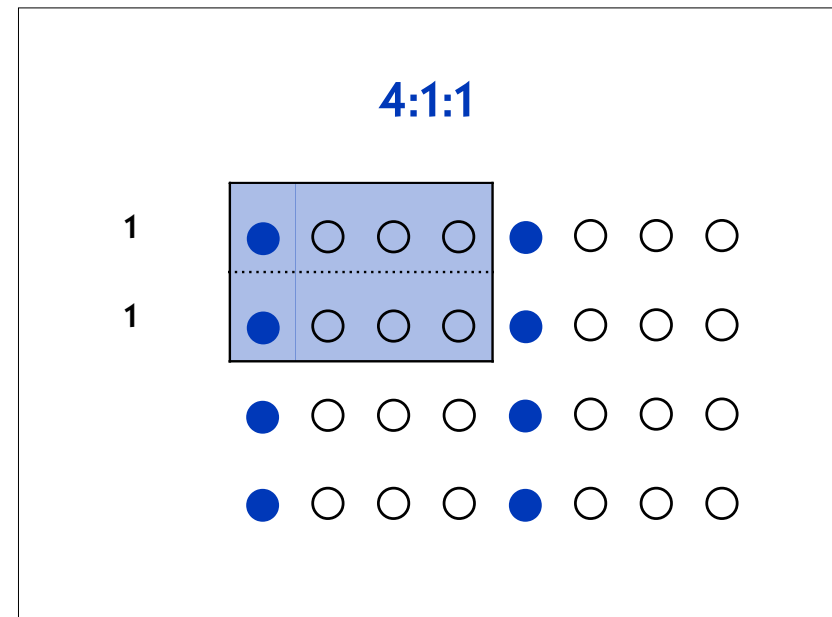
### 4:2:2



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## Komprimiert generiert

- sowohl für Aufnahme als auch für Postproduktion optimiert

Beispiele: CineForm RAW, ProRes RAW, Blackmagic RAW, ARRIRAW

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## Unbequeme Tatsachen

- die meisten Sensoren sind farbenblind
- Bayer-Sensoren erzeugen kein vollständiges RGB-Bild, sondern nur einen Drittel davon

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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.<sup>2</sup> ..... **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

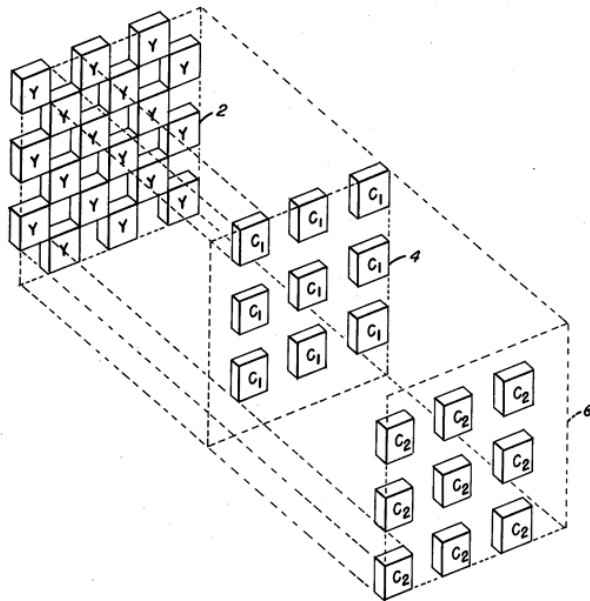
[57] **ABSTRACT**

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.

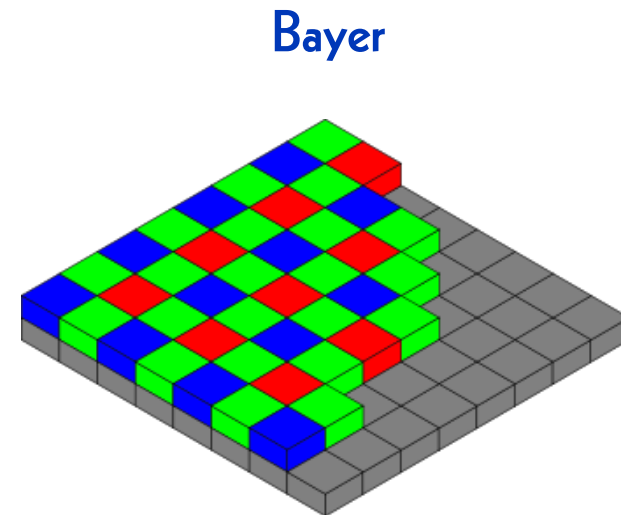
In a presently preferred implementation, a mosaic of selectively transmissive filters is superposed in registration with a solid state imaging array having a broad range of light sensitivity, the distribution of filter types in the mosaic being in accordance with the above-described patterns.

**11 Claims, 10 Drawing Figures**

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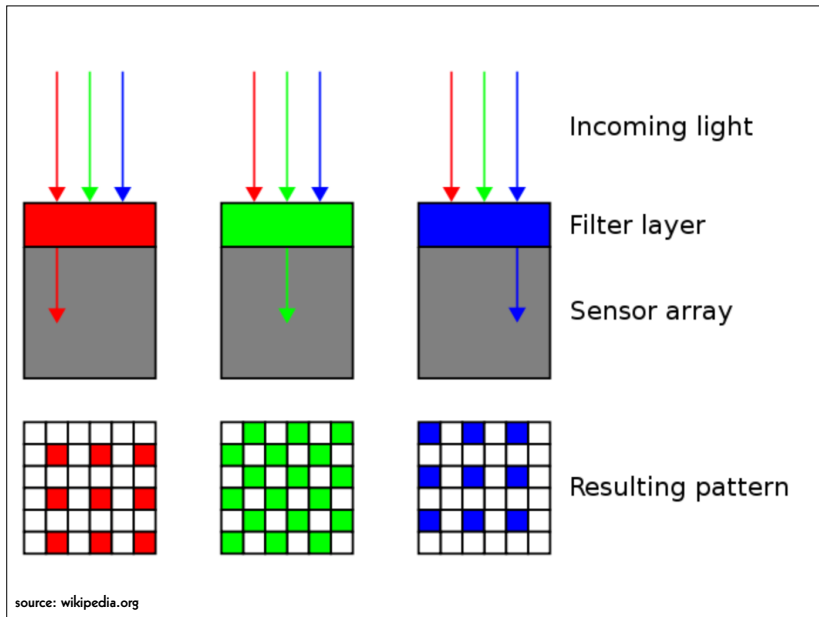


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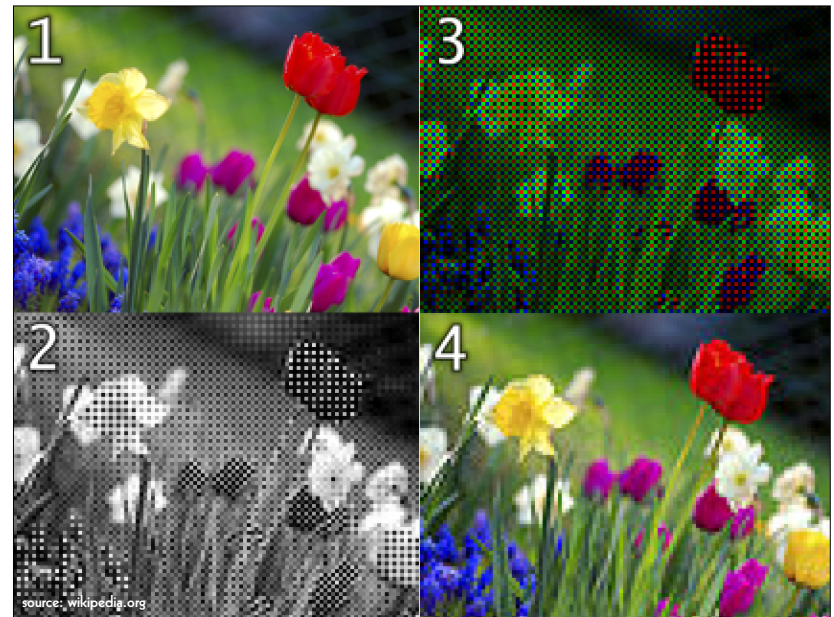


source: wikipedia.org

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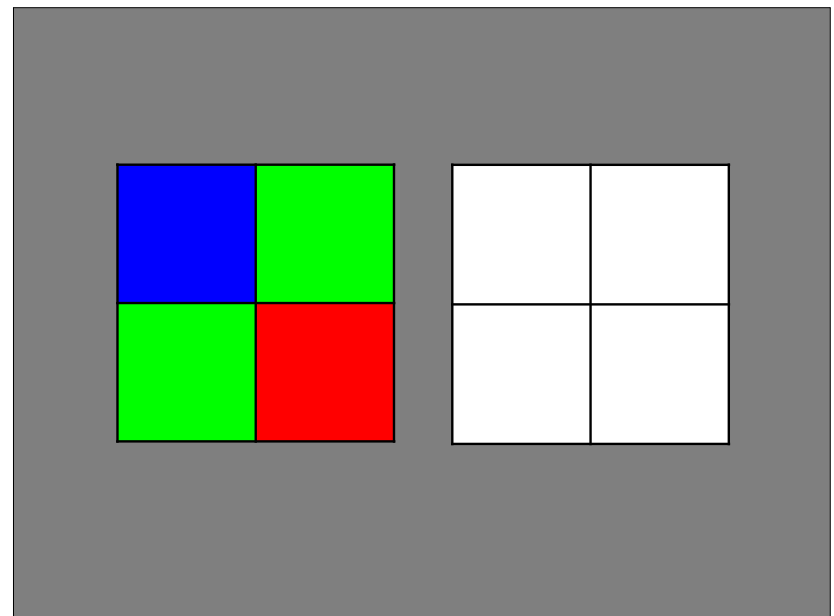
42

```

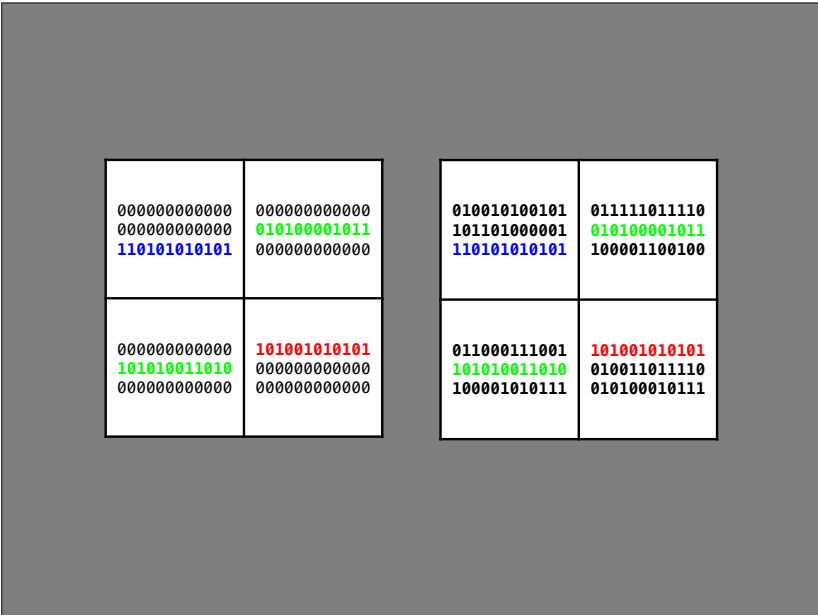
0111010100101010100010110101011110
010011010101010101010100001011101010
011101010010101010100010110101011110
0001110101010101010100001011101010
0110101010101010100010111010101111
00101010101010101000101110101010000
011101010010101010100010110101011110
010101010101010101000010111010100110
100101110101001010101000101101010101
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010101010101010101001101010100000001
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```

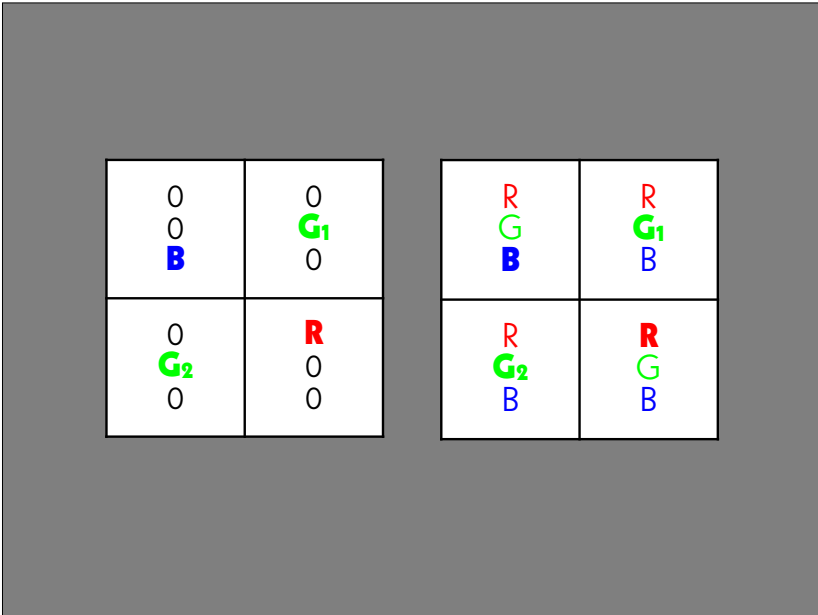
43



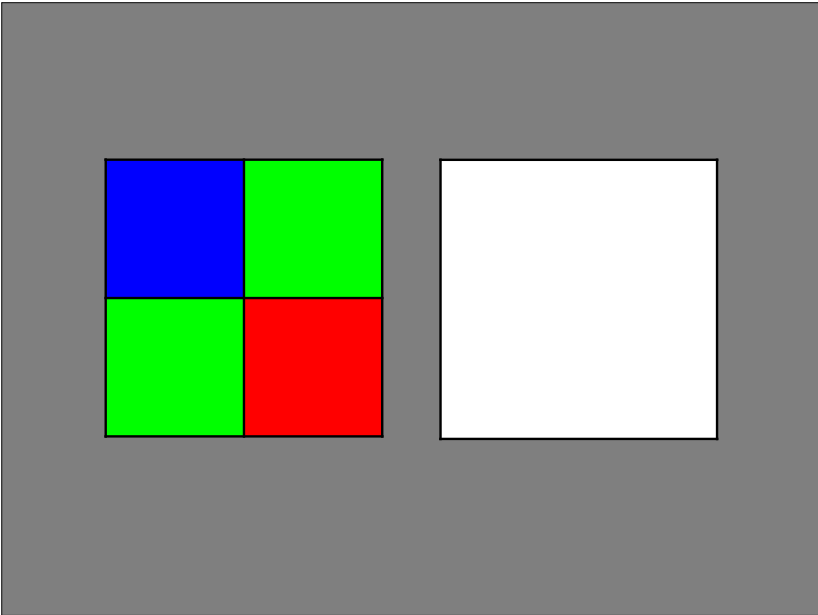
44



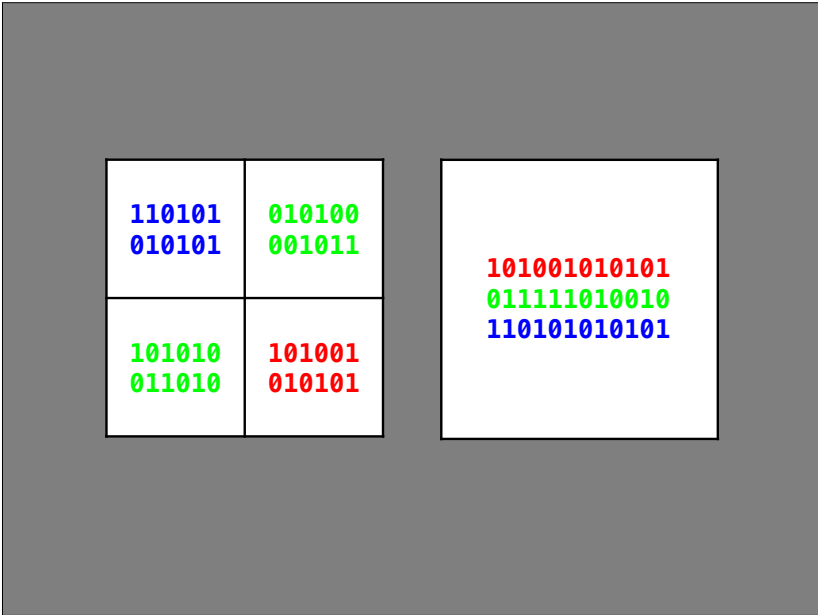
45



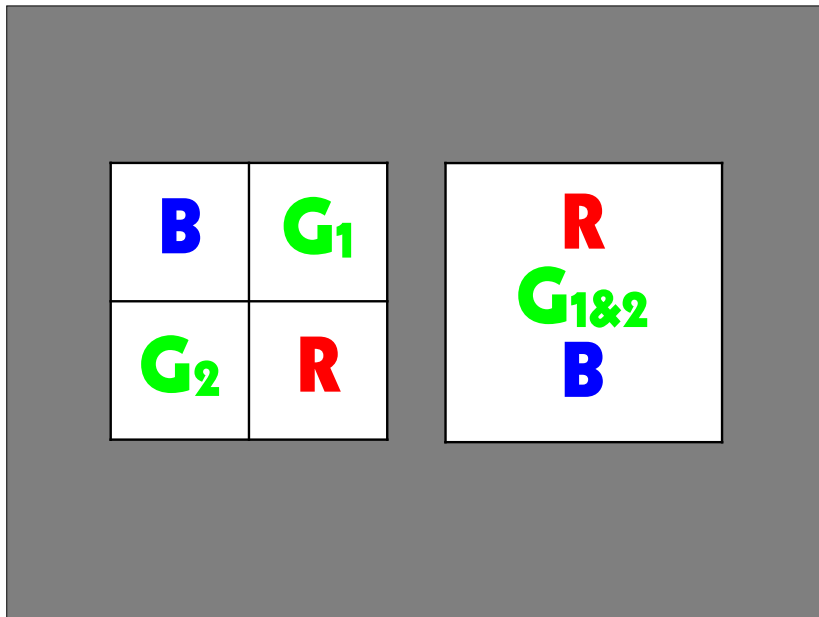
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## Bayer-Daten benützen

**digitales Aufblasen auf RGB**

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

**digitale Reduktion auf RGB**

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

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```

Terminal
~/Desktop -- less - man movimenc

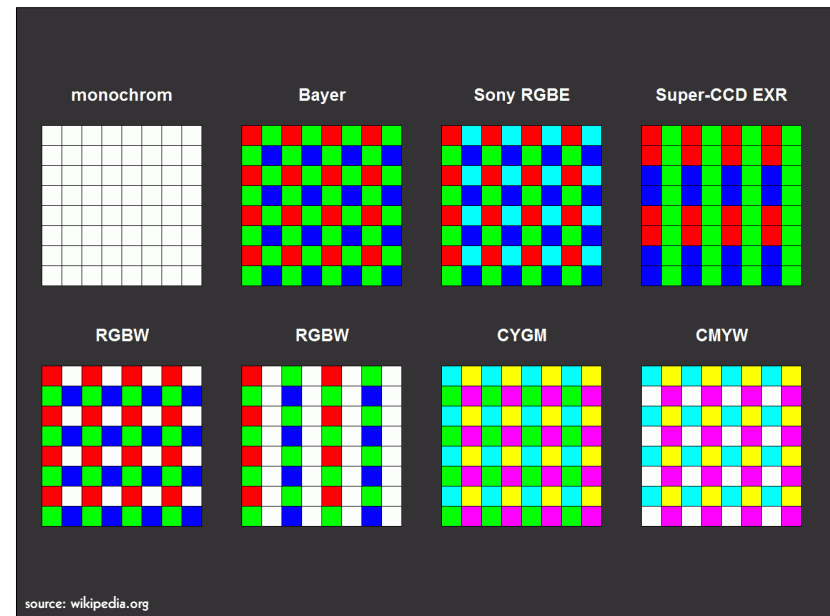
--demaosaic=(BLI|BCI|LR|VNG|SI|PG|AMZE|HQLI|AHD|DLMSEE)
demaosaic a Bayer-encoded input_file into an RGB output_file

This option allows to choose between different demosaicing
algorithms, because the results may vary a lot, depending on the
image content.

The following algorithms are implemented:
- BLI = bilinear interpolation
- BCI = bicubic interpolation
- LR = Lanczos resampling
- VNG = variable number of gradients
- SI = spline interpolation
- PG = pixel grouping
- AMZE = aliasing minimisation and zipper elimination
- HQLI = high-quality linear interpolation (Malvar, He and Cutler.
IEEE 2004)
- AHD = adaptive homogeneity-directed (Hirakawa and Parks. IEEE
2005)
- DLMSEE = directional linear minimum mean square-error estimation
(Zhang and Xiaolin. IEEE 2005)

INFORMATIVE OPTIONS
-h, --help
  
```

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source: wikipedia.org

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## Proposed Terminology

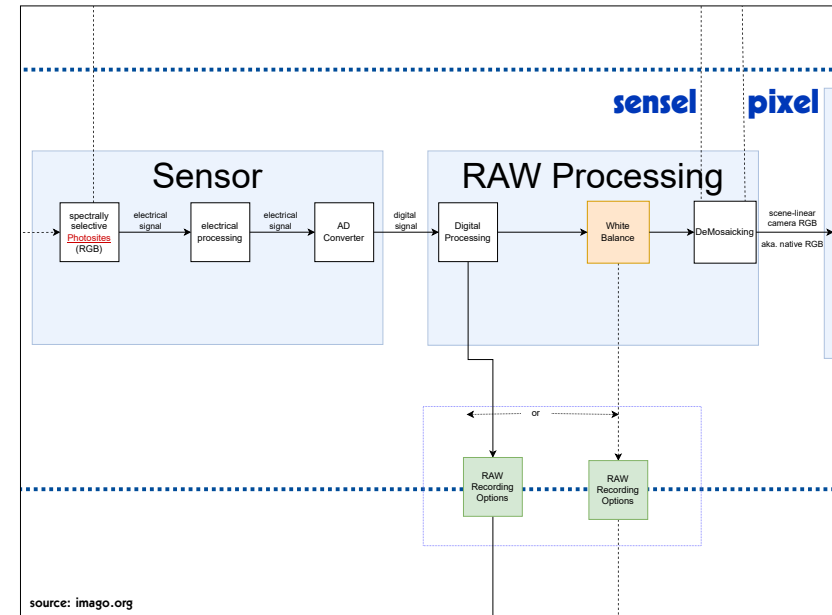
### pixel

= picture element

### sensel

= sensor element

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## Bayer-Daten speichern

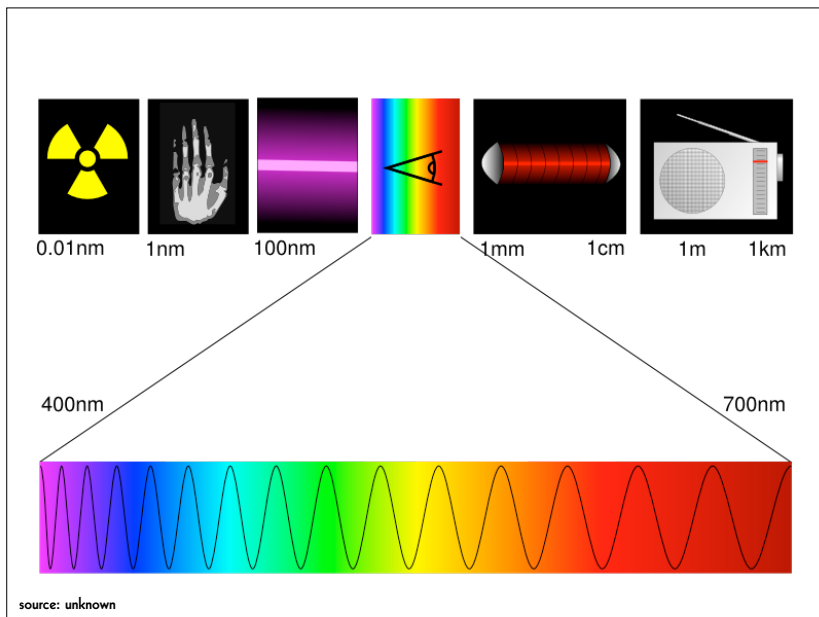
- pixel values generated by one de-mosaicking algorithm (digital blow-up)
- pixel values generated by mixing two green sensel values into one (digital reduction)
- raw sensel values

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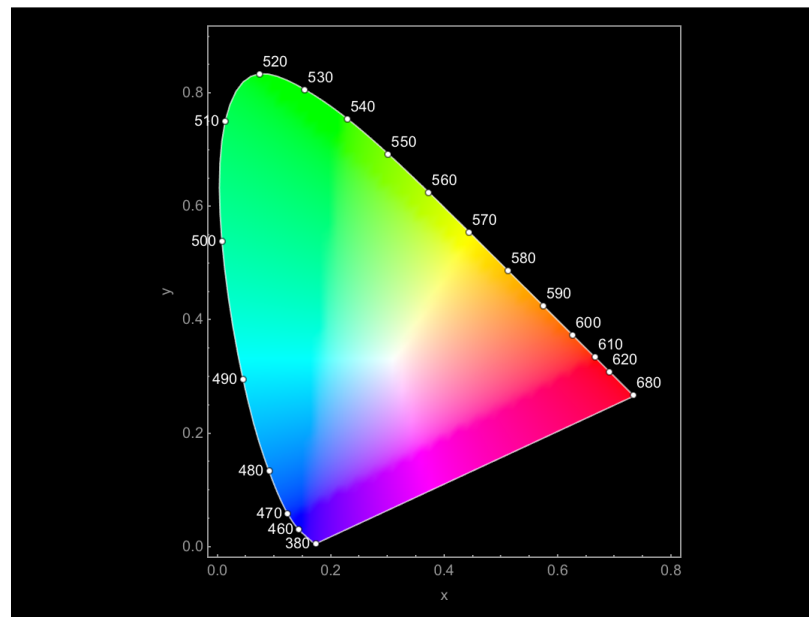
## Normlicht

- D50
- D55
- D65
- D75

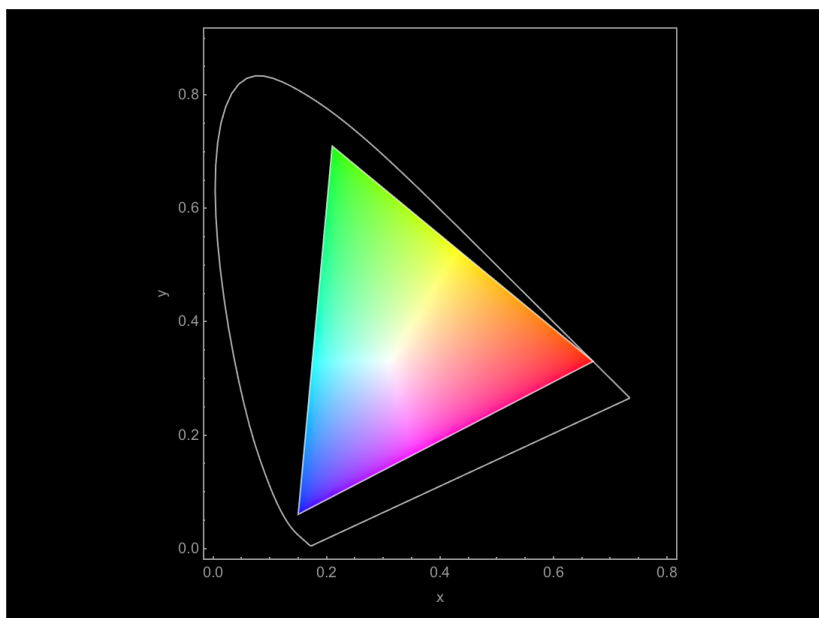
56



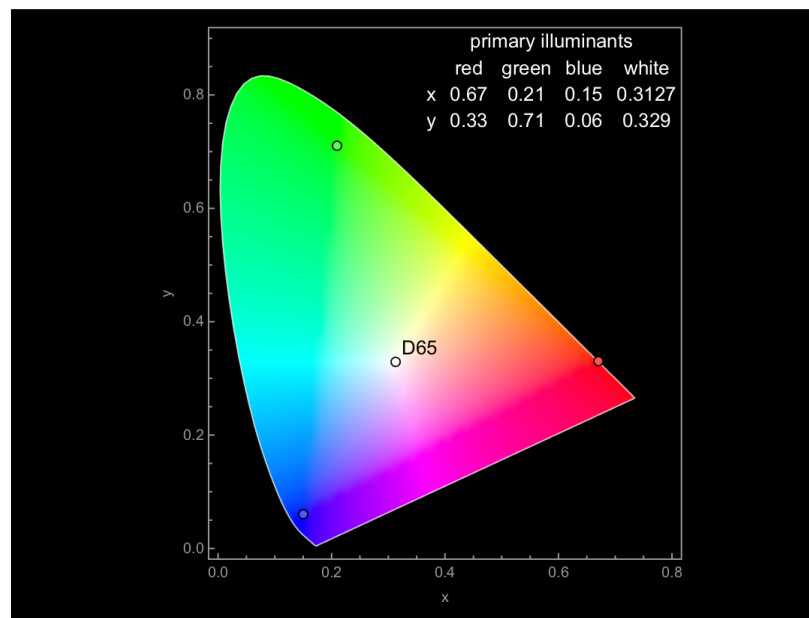
57



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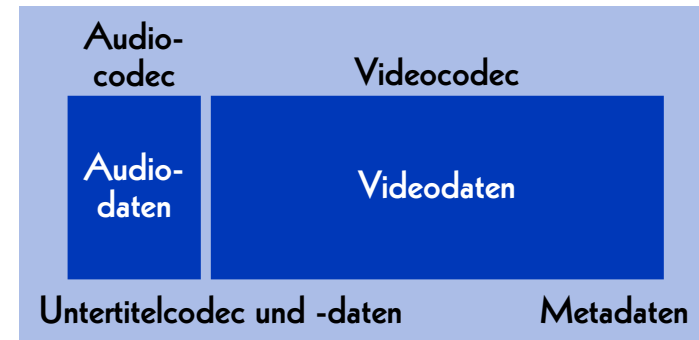
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# Dateiaufbau

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## Dateiaufbau

Container (Wrapper)



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## Container für Datenfluss

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

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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 (Archiv)

### 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
- rgb24
- rgb72le
- bayer\_bggr16le
- bayer\_bggr24le
- yuv444p16le
- yuv422p10le
- uyvy422
- yuv420p
- yuv444p24le

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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)

### Einzelbilder («Film»)

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

### Datenfluss («Video»)

- AVI, «raw», HD, Y'CbCr 4:2:2, 10 bit
- Matroska, FFV1, HD, Y'CbCr 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'CbCr 4:2:0, 8 bit, lossy
- H.264, «HD», Y'CbCr 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

### Einzelbilder («Film»)

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

### Datenfluss («Video»)

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

### Ton

- Matroska, FLAC, 192 kHz, 24 bit

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## Zugang

### MP4

#### Bild

- H.264, «HD», Y'CbCr 4:2:0, 8 bit
- H.265, «HD», Y'CbCr 4:2:0, 8 bit
- H.266, «HD», Y'CbCr 4:2:0, 8 bit
- AV1, «HD», Y'CbCr 4:2:0, 8 bit

#### Ton

- AAC, 96 kHz, 16 bit
- AAC, 48 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](https://retokromer.ch/publications/JFP_96.html)

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

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## Eine Brücke zwischen den zwei Welten

**RAWcooked** (CLI)

→ [mediaarea.net/RAWcooked](http://mediaarea.net/RAWcooked)

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## RAWcooked

- encoding into Matroska container using FFV1 video codec and FLAC audio codec
- significantly fewer files
- all metadata preserved
- decoding with bit-by-bit reversibility
- possibility to embed sidecar files such as checksum manifest, LUT, XML and PDF
- 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**



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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 / 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.

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# MXF / DN<sub>x</sub>

**MXF**  
→ SMPTE RDD 48:2018

**DN<sub>x</sub>HD, DN<sub>x</sub>HR**  
→ 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 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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Proponent contact information:

ProRes Program Office  
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## Matroska-Container (.mkv)

### Videocodec

- FFV1
- ProRes 422, ProRes 4444

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## Matroska / FFV1

### Matroska (.mkv)

→ IETF RFC 9559

### FFV1

→ IETF RFC 9043

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## 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 RCF 9559

ProRes 422, ProRes 4444

→ SMPTE RDD 36:2015

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## OpenEXR-Dateiformat (.exr)

OpenEXR

→ 3-Klausel-BSD-Lizenz

→ nicht von einer offiziellen Stelle normiert

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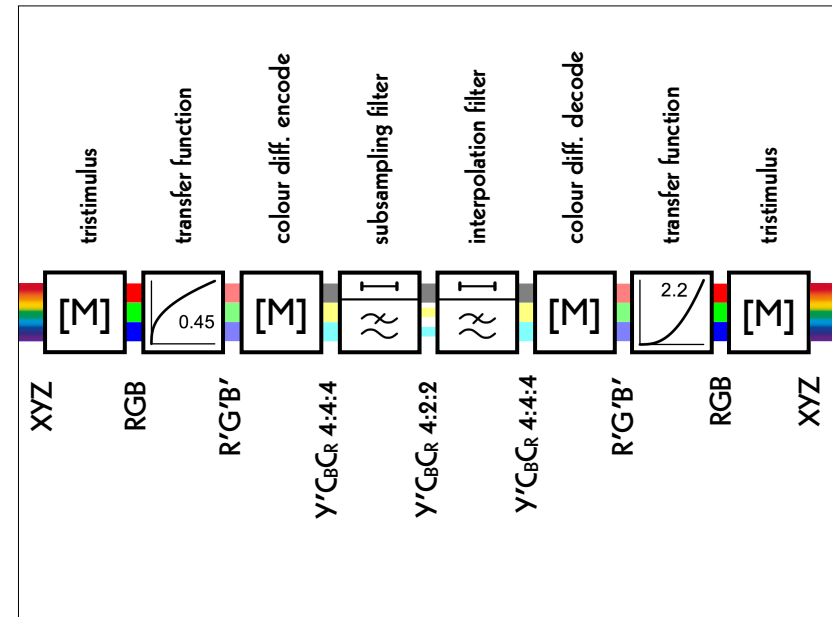
## Umwandlungen

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

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

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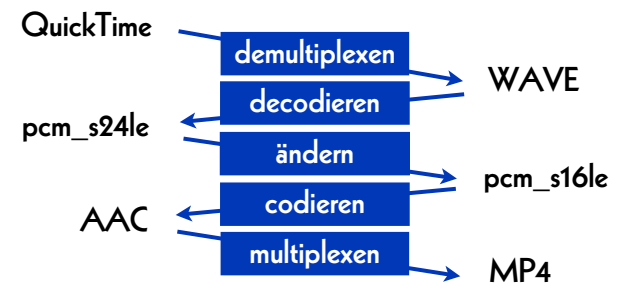
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## Dateiumwandlungen



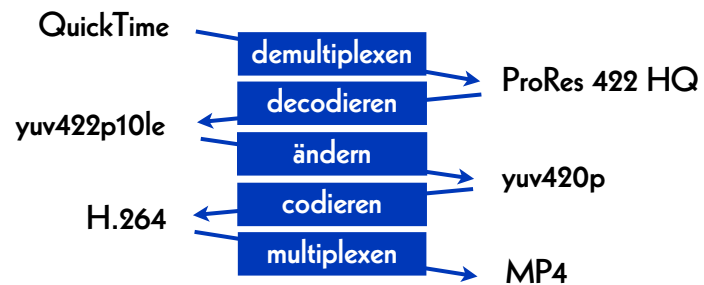
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## Beispiel: Ton



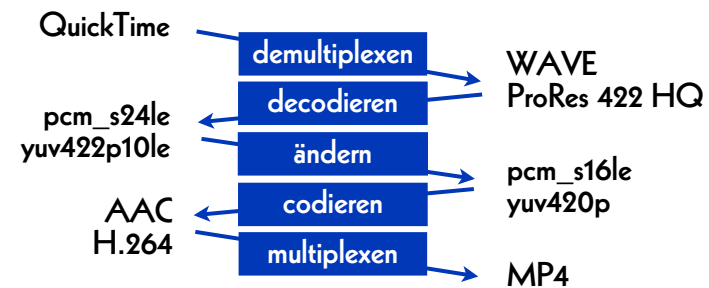
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## Beispiel: Bild



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## Beispiel: Bild und Ton



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# 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)

### 2014–2025

- a hundred data 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](http://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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Always remember:  
  
To do nothing  
is **never** an option!

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## Danksagung (1)

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