

Formats de fichiers audiovisuels

Reto Kromer • AV Preservation by reto.ch

Initiation à FFmpeg
Lichtspiel / Cinémathèque Berne
13 février 2026

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Table des matières

- audio numérique et vidéo numérique
- conteneur, codec, «raw data»
- différents formats pour différentes utilisations
- transformation de fichiers audiovisuels
- sauvegarde et migration des données

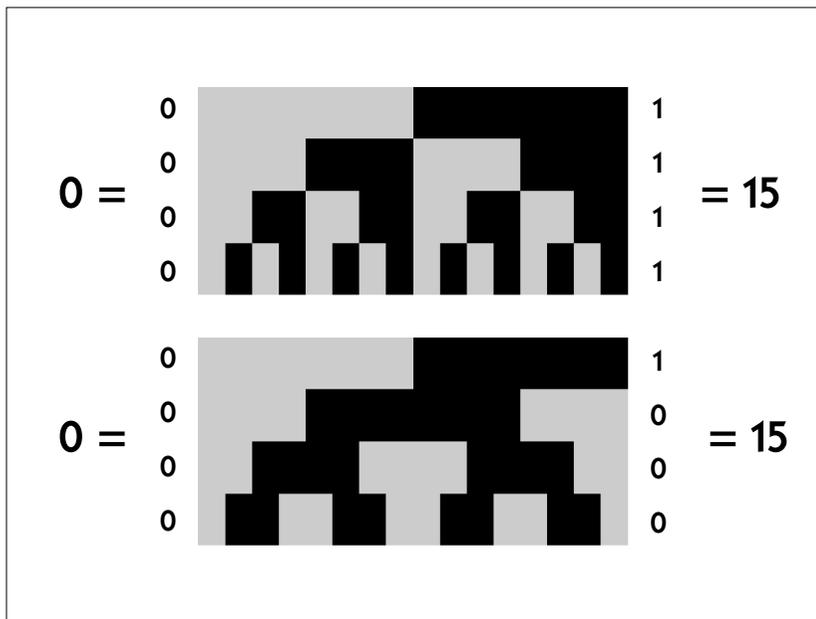
2

Audio numérique

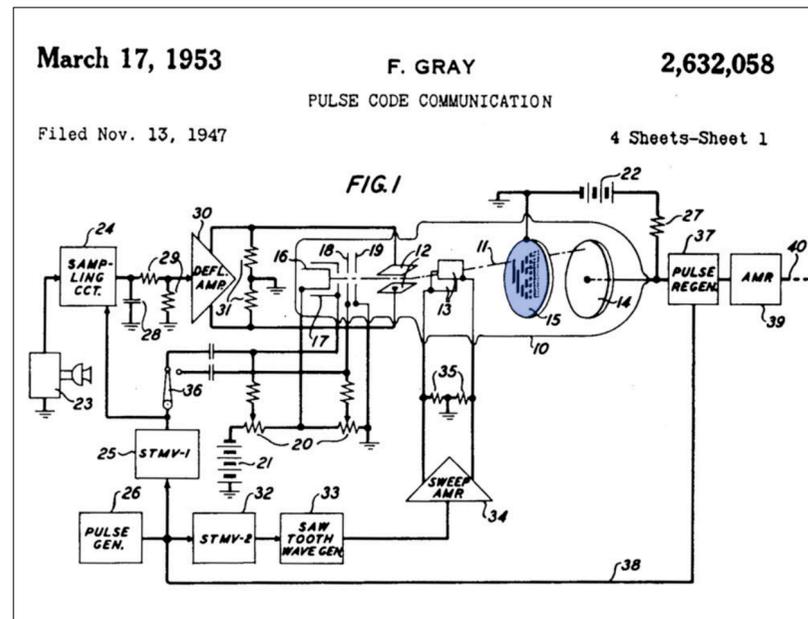
3

Frank Gray
(1887–1969)

4



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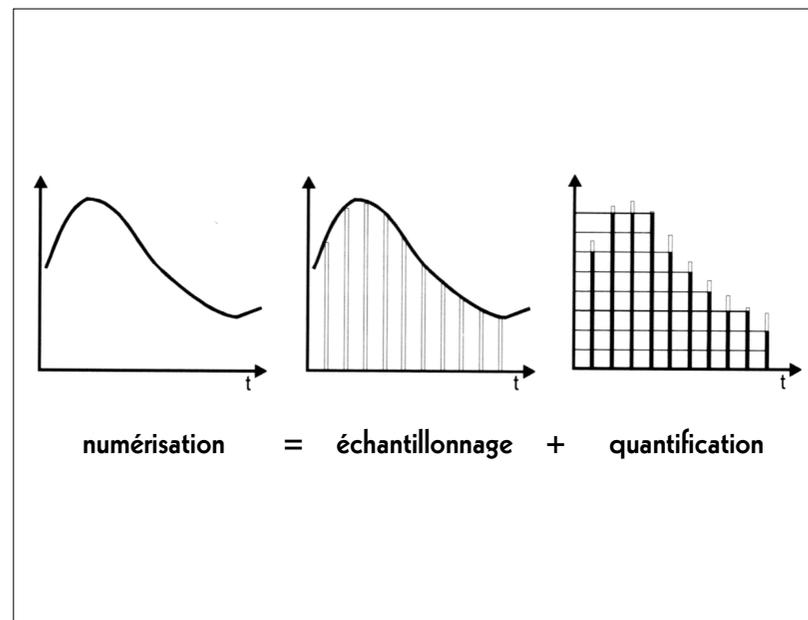


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Audio numérique

- échantillonnage
- quantification
- compression

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Échantillonnage

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

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Quantification

- 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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Vidéo numérique

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Vidéo numérique

- définition
- profondeur des couleurs
- codage linéaire, exponentiel, logarithmique
- espace colorimétrique
- compression et sous-échantillonnage
- illuminant

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Définition

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

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Profondeur des couleurs

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

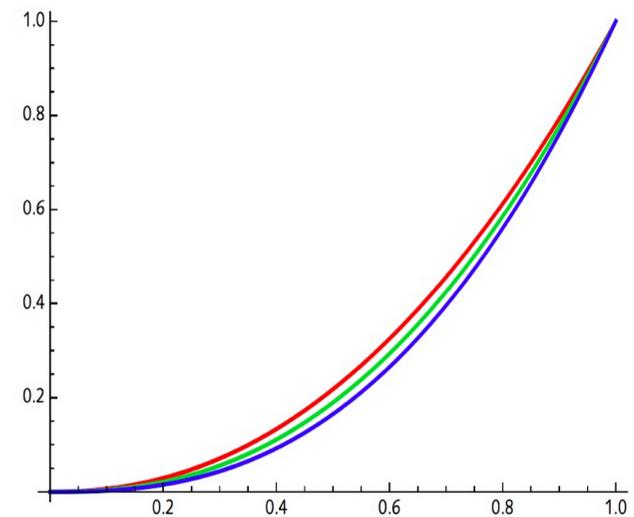
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Codage linéaire, exponentiel, logarithmique

«gris moyen»

- fonction linéaire: environ 18 %
- fonction exponentielle: 50 %
- fonction logarithmique: 50 %

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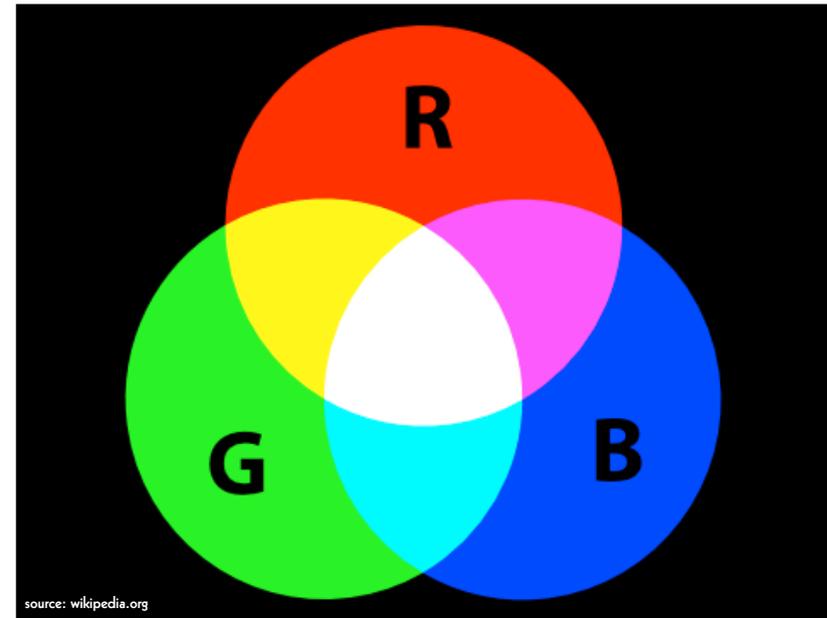


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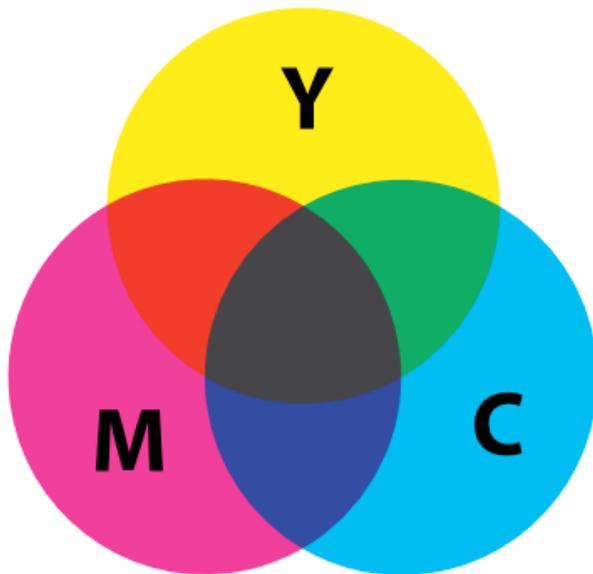
Espace colorimétrique

- 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'CoC_G
- Y'P_BP_R

17



18



19

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

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

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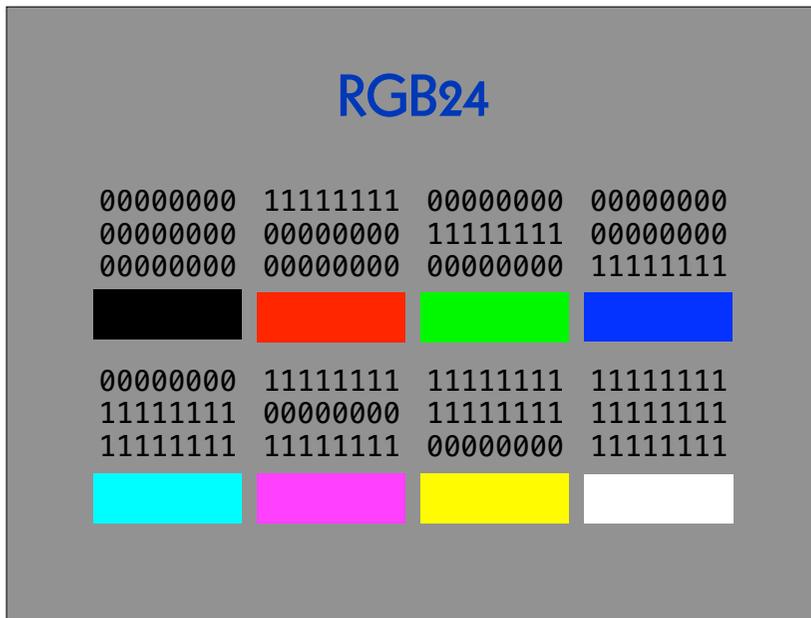
$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \begin{pmatrix} 1 & 1 & -1 \\ 1 & 0 & 1 \\ 1 & -1 & -1 \end{pmatrix} \begin{pmatrix} Y' \\ C_O \\ C_G \end{pmatrix}$$

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

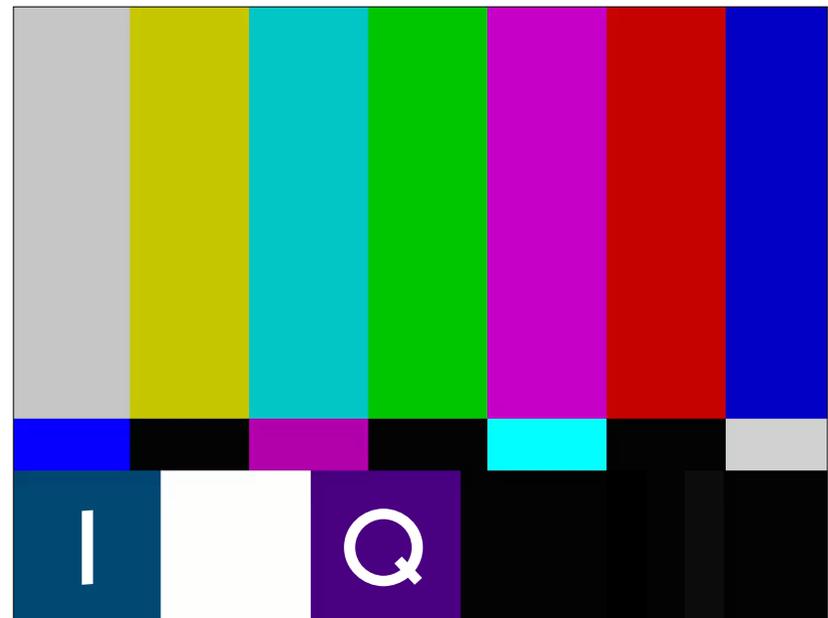
21



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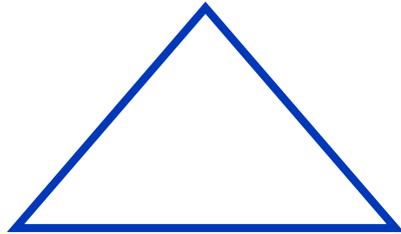


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qualité de l'image



temps d'encodage taille du fichier

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Compression

- non compressé
- compressé sans perte
- compressé avec perte
- sous-échantillonnage
- compressé à la création

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Non compressé

- + données plus faciles à traiter
- + logiciels plus rapides à exécuter
- fichiers plus lourds
- fichiers plus lents à écrire, transmettre et lire

Exemples: TIFF, DPX, DNG, OpenEXR

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Compressé sans perte

- + fichiers plus légers
- + plus rapide à écrire, transmettre et lire
- données plus complexes à traiter
- logiciels plus lents à exécuter

Exemples: JPEG 2000, FFV1

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Compressé avec perte

- optimisé pour l'acquisition et/ou pour la postproduction
- optimisé pour l'accès et la diffusion

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

Exemples (distribution): H.264 (AVC), H.265
(HEVC), H.266 (VVC); AV1

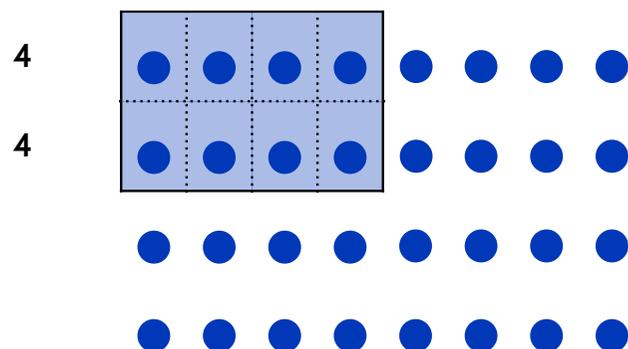
29

Sous-échantillonnage

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

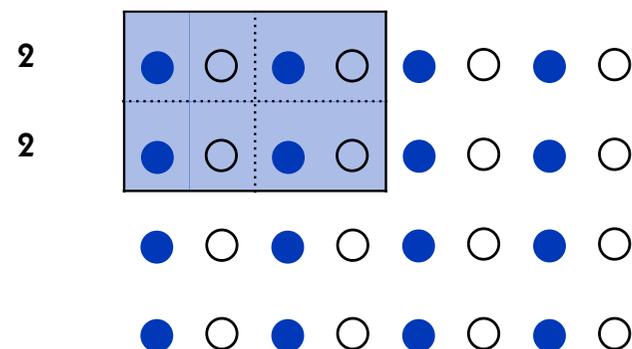
30

4:4:4



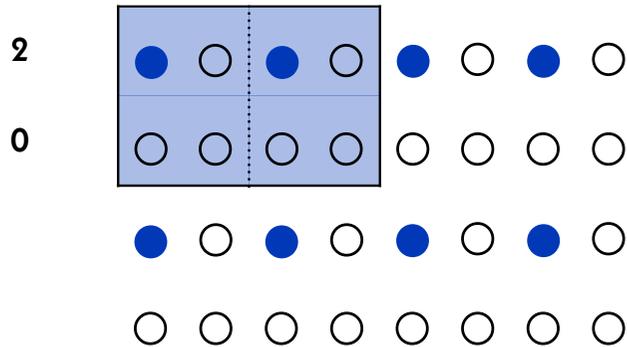
31

4:2:2



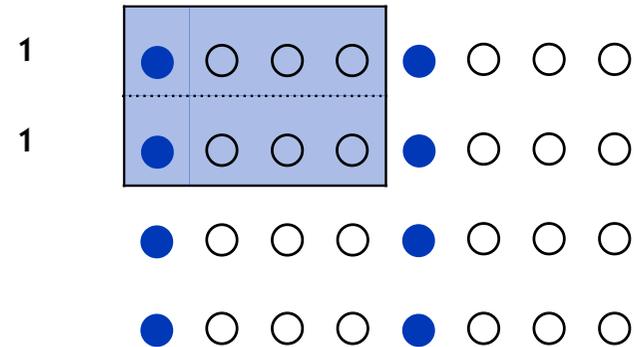
32

4:2:0



33

4:1:1



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Compressé à la création

- optimisé tant pour l'acquisition que pour la postproduction

Exemples: CineForm RAW, ProRes RAW, Blackmagic RAW

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Faits gênants

- les capteurs sont daltoniens
- les capteurs Bayer ne produisent pas une image RVB complète, mais seulement un tiers de celle-ci

36

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

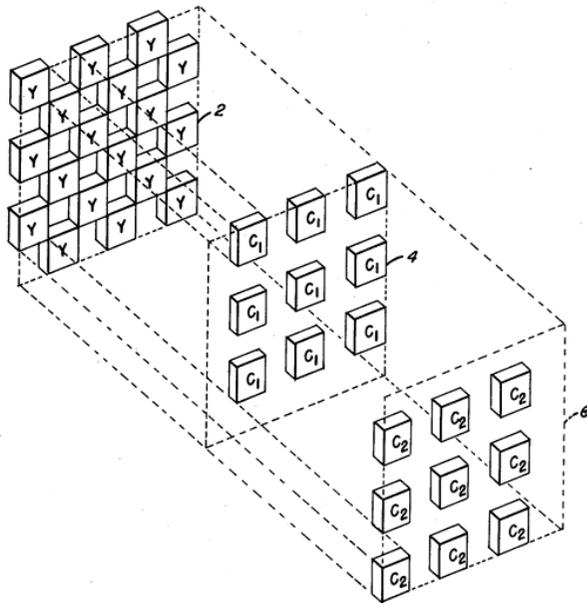
[57] **ABSTRACT**

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.

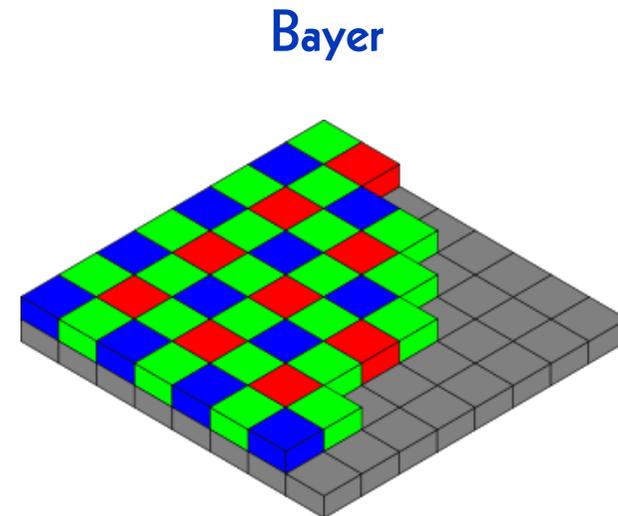
In a presently preferred implementation, a mosaic of selectively transmissive filters is superposed in registration with a solid state imaging array having a broad range of light sensitivity, the distribution of filter types in the mosaic being in accordance with the above-described patterns.

11 Claims, 10 Drawing Figures

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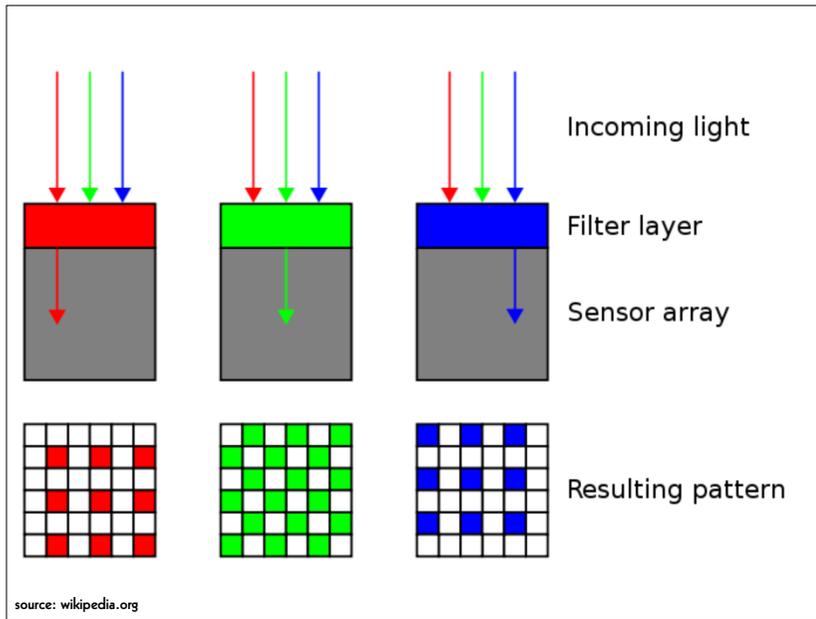


39

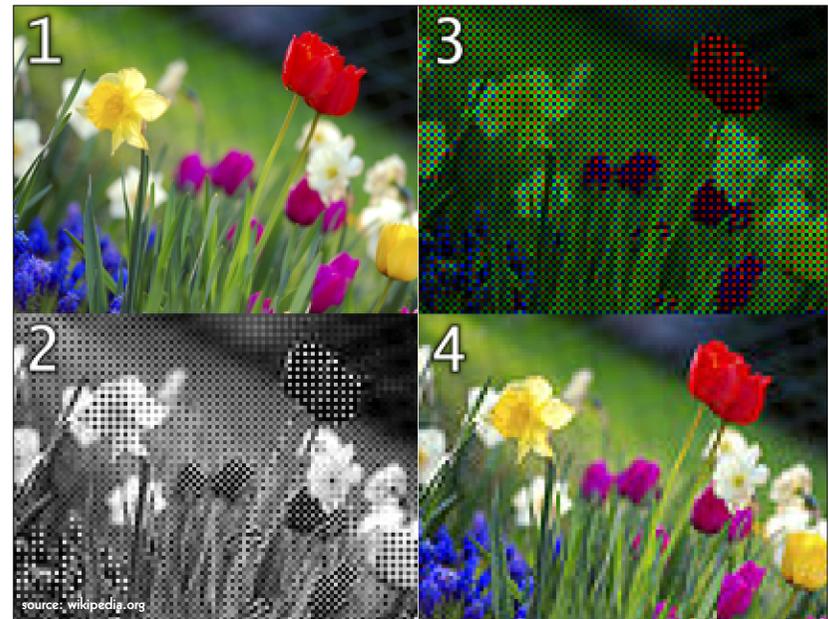


source: wikipedia.org

40



41



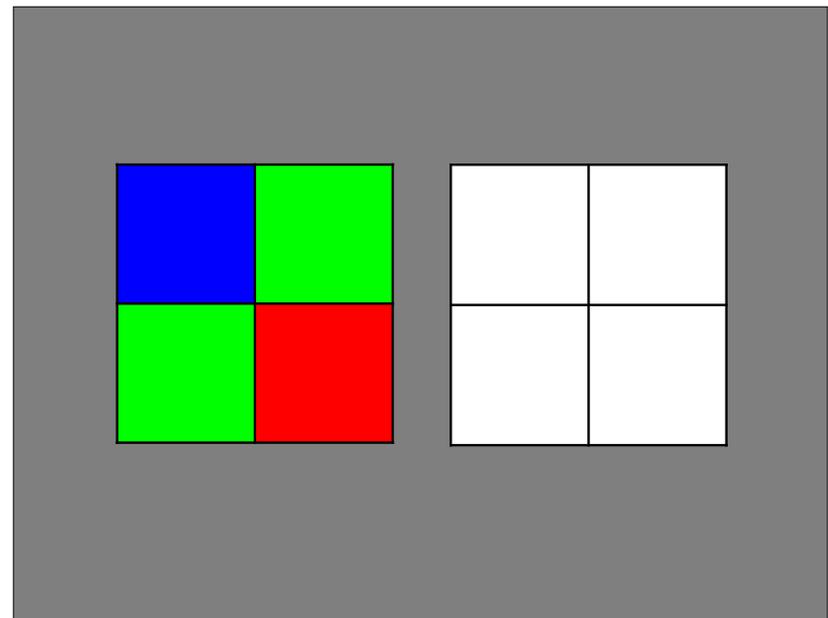
42

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0111010100101010100010110101011110
010011010101010101010100001011101010
011101010010101010100010110101011110
000111010101010101010100001011101010
0110101010101010101010001011101010111
001010101010101010000101110101010000
011101010010101010100010110101011110
010101010101010101000010111010100110
100101110101001010101000101101010101
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43



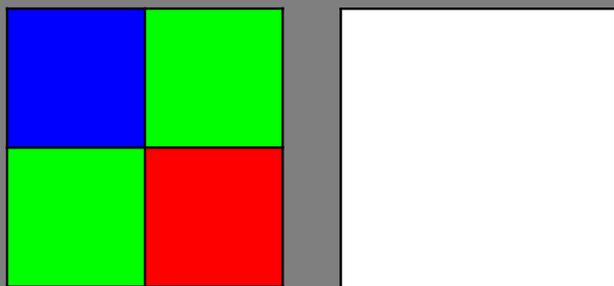
44

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 V ₁ 0	R V B	R V ₁ B
0 V ₂ 0	R 0 0	R V ₂ B	R V B

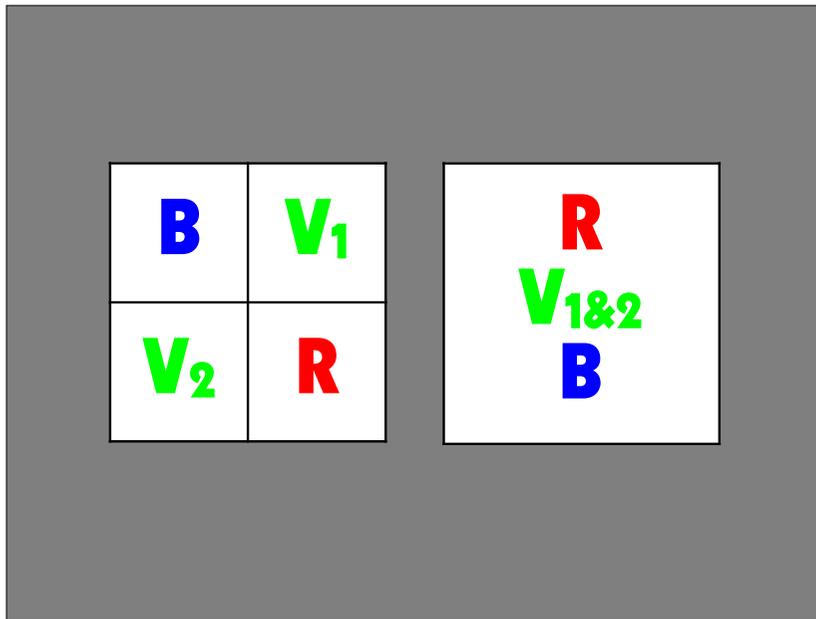
46



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110101 010101	010100 001011	101001010101 011111010010 110101010101
101010 011010	101001 010101	

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Utilisation des données Bayer

gonflage numérique à RVB

- les données générées sont triplées
- le fichier possède la définition maximale du capteur

réduction numérique à RVB

- trois quarts des données générées par le capteur sont sauvegardées
- le fichier possède la moitié de la définition du capteur

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```

Terminal
~/Desktop -- less - man movimenc

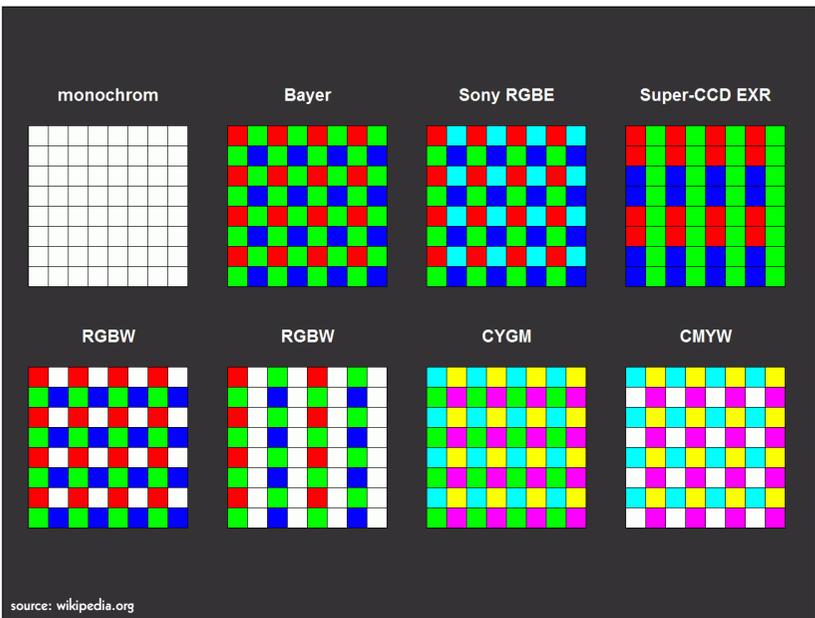
--demaosaic=(BLI|BCI|LR|VNG|SI|PG|AMZE|HQLI|AHD|DLMSEE)
demaosaic a Bayer-encoded input_file into an RGB output_file

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

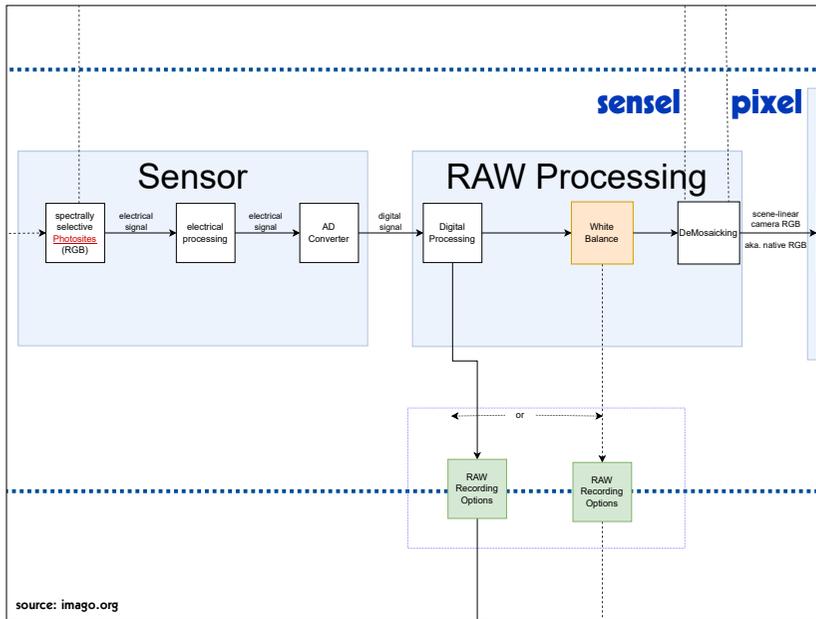
The following algorithms are implemented:
- BLI = bilinear interpolation
- BCI = bicubic interpolation
- LR = Lanczos resampling
- VNG = variable number of gradients
- SI = spline interpolation
- PG = pixel grouping
- AMZE = aliasing minimisation and zipper elimination
- HQLI = high-quality linear interpolation (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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Stockage des données Bayer

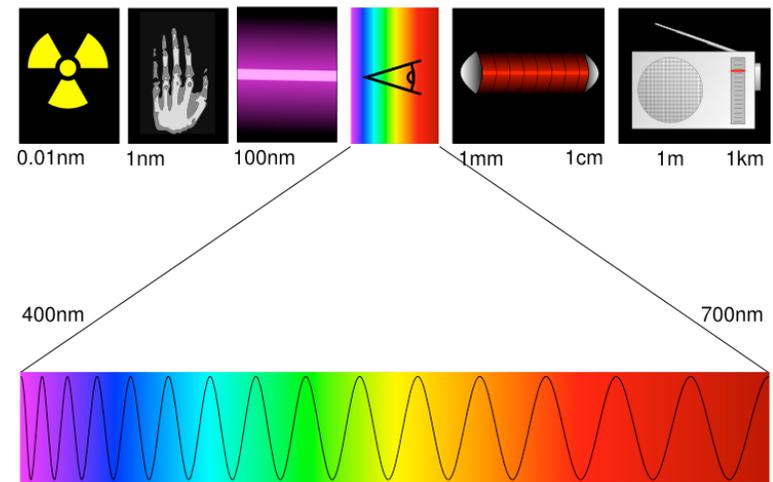
- pixel values generated by one de-mosaicking algorithm (digital blow-up)
- pixel values generated by mixing two green sensel values into one (digital reduction)
- raw sensel values

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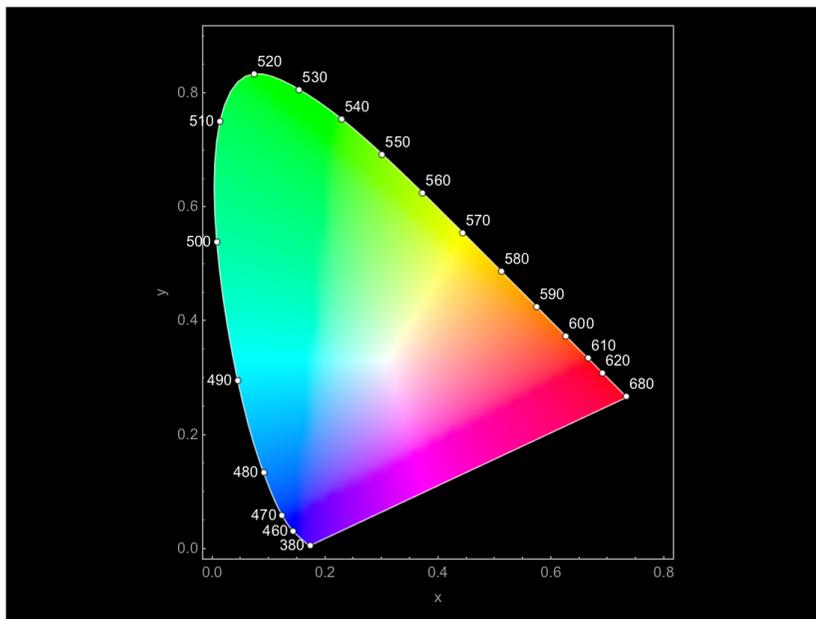
Illuminant

- D50
- D55
- D65
- D75

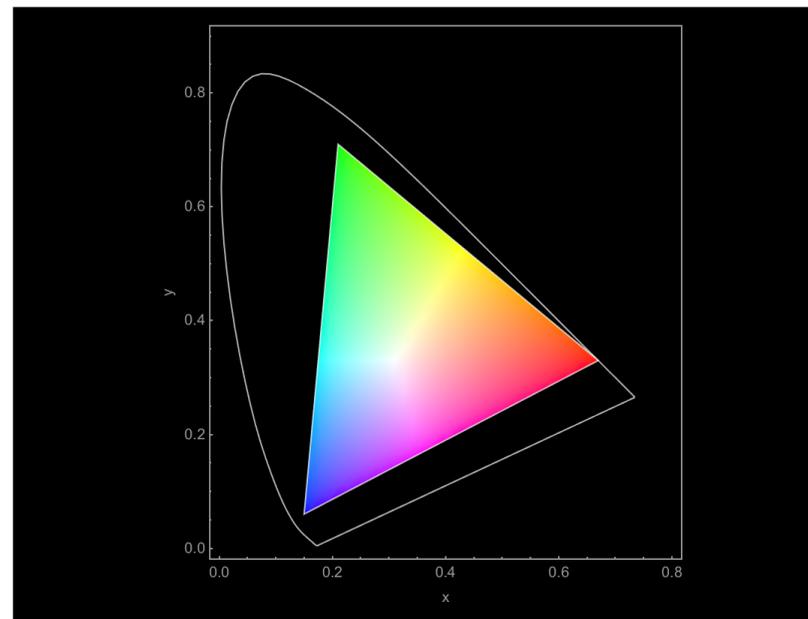
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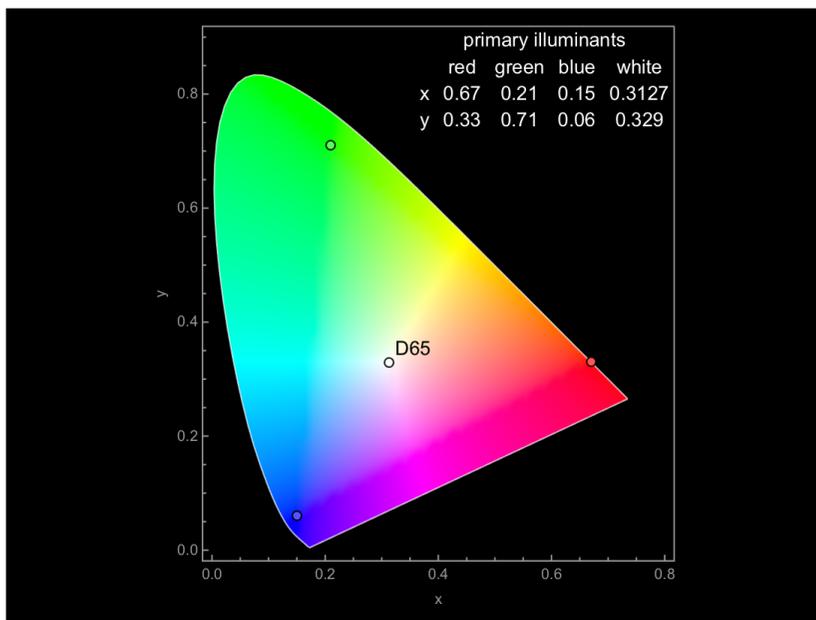
56



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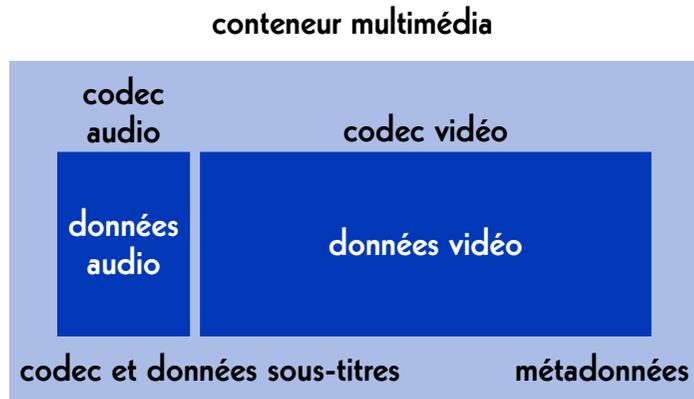


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**Structure
des fichiers**

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Structure des fichiers



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Conteneur multimédia

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

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Images individuelles

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

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Codec audio

- WAVE
- BWF
- AAC
- MP3
- FLAC

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Codec vidéo (archive)

images

- TIFF
- DPX
- JPEG 2000
- OpenEXR
- DNG

flux vidéo

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

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Codec vidéo (mezzanine)

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

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Codec vidéo (accès)

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

- AV1

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RAW data are cooked.

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Données audio

- pcm_s16le
- pcm_s24le
- pcm_s32le

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Données vidéo

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

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Que contient mon DPX?

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

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Formats de fichiers

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Principes

- **Une archive soit être en mesure de traiter les formats de fichiers qu'elle possède.**
- open source
- simple à utiliser et bien documenté
- largement utilisé par la communauté

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Différents formats pour différentes utilisations

master d'archivage

→ pour la préservation et l'archivage

formats mezzanine

→ pour le montage et la postproduction

formats de distribution

→ pour la diffusion et l'accès

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Elena Rossi-Snook:

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

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Format d'archive (actuel)

images individuelles («film»)

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

flux de données («vidéo»)

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

audio

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

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Formats mezzanine (actual)

vidéo

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

audio

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

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Formats de distribution (actuel)

MP4

vidéo

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

audio

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

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Format d'archive et mezzanine

images individuelles («film»)

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

flux de données («vidéo»)

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

son

- Matroska, FLAC, 192 kHz, 24 bit

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Formats de distribution

MP4

vidéo

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

audio

- AAC, 96 kHz, 16 bit, lossy
- AAC, 48 kHz, 16 bit, lossy

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Bibliographie

Reto Kromer: **Matroska and FFV1: One File Format for Film and Video Archiving?**, in «Journal of Film Preservation», n° 96 (avril 2017), FIAF, Bruxelles, Belgique, p. 41–45

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

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Avantages et inconvénients

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conteneur

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

codec

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

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	avantages	inconvénients
TIFF DPX OpenEXR	traitement plus simple	fichiers plus lourds
JPEG 2000 FFV1	fichiers plus légers	traitement plus complexe

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Un pont entre les deux mondes

RAWcooked (CLI)

→ 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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Conteneur MXF (.mxf)

codec vidéo

- 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

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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 / 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

→ etc.

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MXF / DNx

MXF

→ SMPTE RDD 48:2018

DNxHD, DNxHR

→ non publié

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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

**SMPTE REGISTERED
DISCLOSURE DOCUMENT**

Apple ProRes Bitstream Syntax
and Decoding Process 

Page 1 of 39 pages

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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:

ProRes Program Office
Apple Inc.
1 Infinite Loop, MS: 77-2YAK
Cupertino, CA 95014
USA
Email: ProRes@apple.com

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Conteneur Matroska (.mkv)

codec vidéo

- 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.

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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)

→ en cours de publication par l'IETF

ProRes 422, ProRes 4444

→ SMPTE RDD 36:2015

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Format OpenEXR (.exr)

OpenEXR

→ 3-Clause BSD License

→ pas normalisé par une instance officielle

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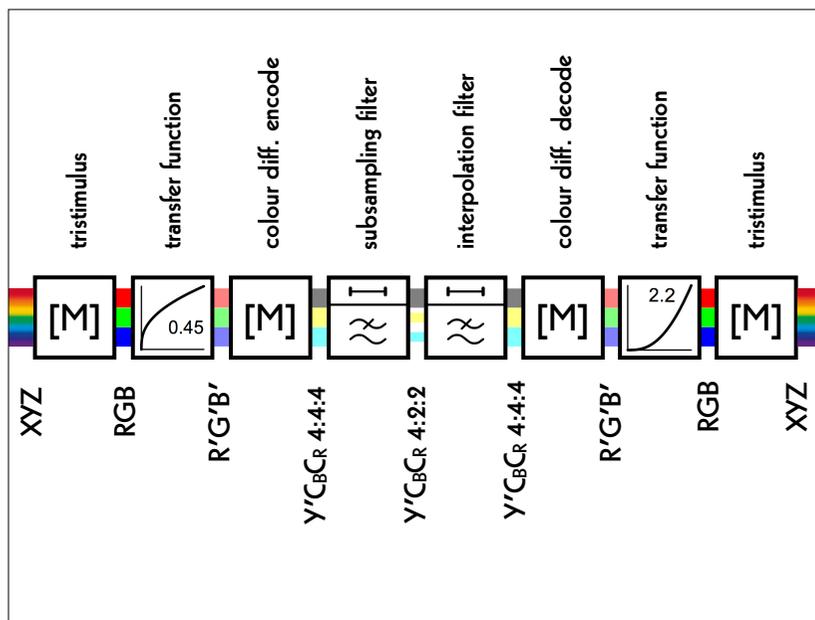
Transformations

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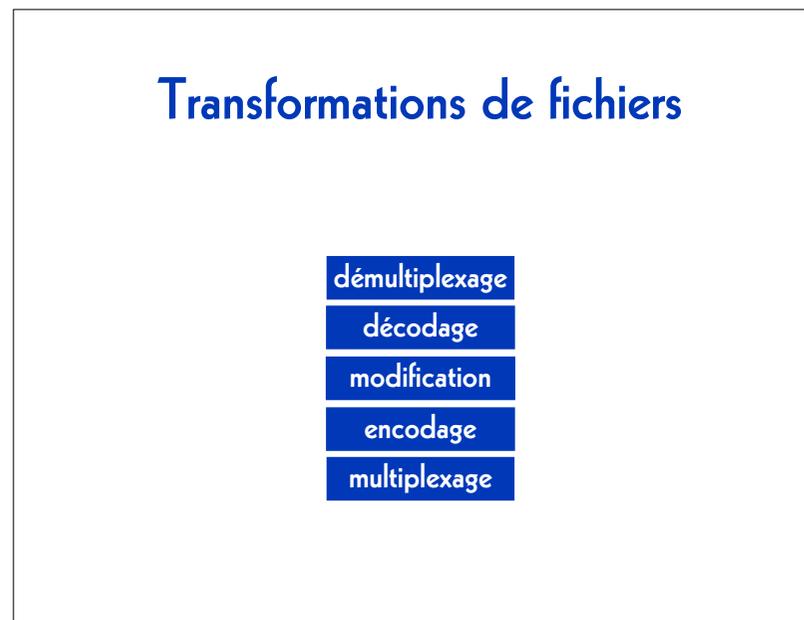
$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.140251 \\ 1 & -0.393931 & -0.580809 \\ 1 & 2.028398 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y'_{601} \\ U \\ V \end{bmatrix}$$

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

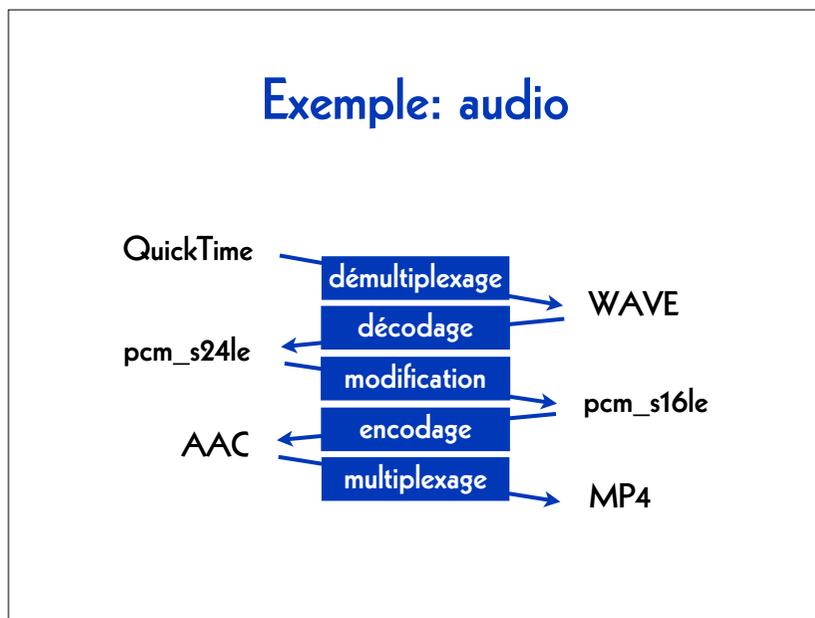
100



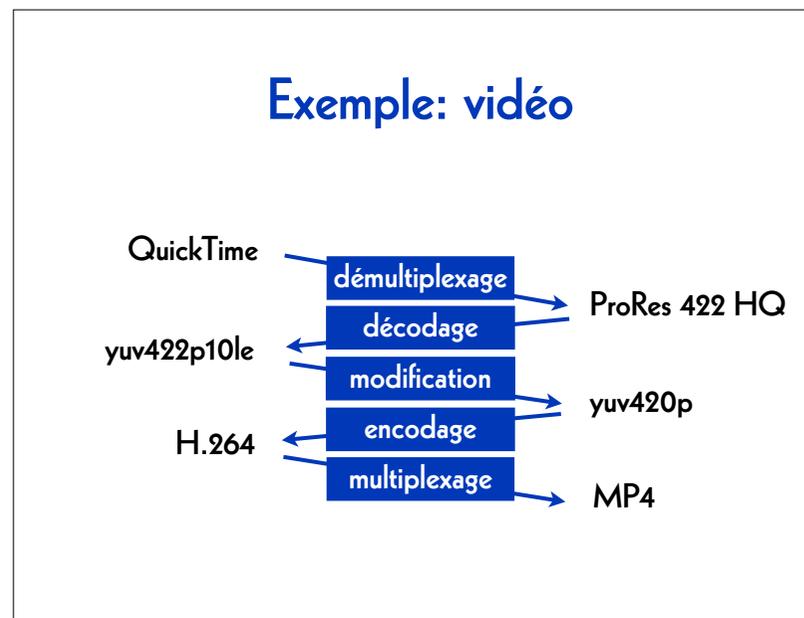
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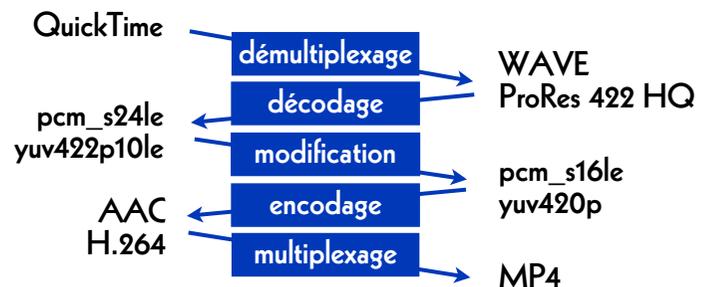


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Exemple: audio et vidéo



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Sauvegarde et migration

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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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Always remember:

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

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AV Preservation by
reto.ch

Sandrainstrasse 3/7
3007 Bern
Switzerland

reto.ch
info@reto.ch



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