Formats de fichiers audiovisuels

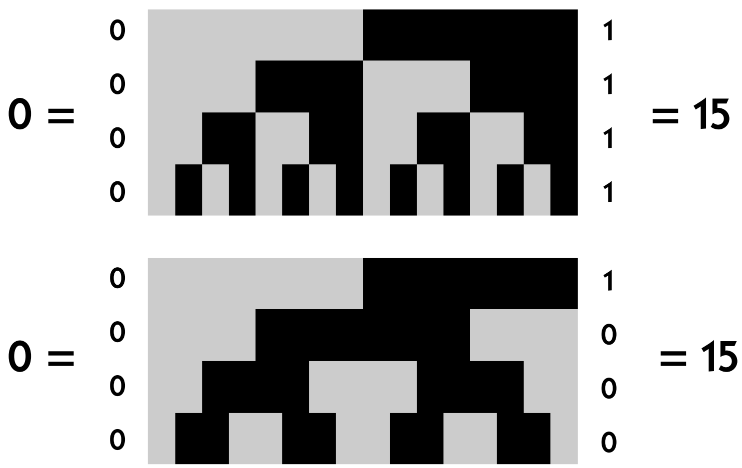
Reto Kromer • AV Preservation by reto.ch

Atelier Memoriav
Cours avancé de FFmpeg
Berne, 20 mars 2026

Table des matières

Audio numérique

Frank Gray (1887–1969)



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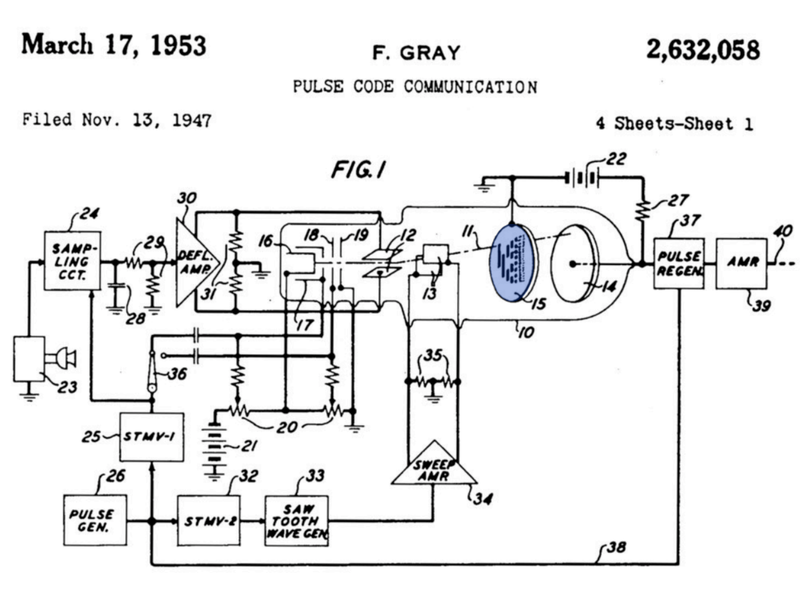

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Audio numérique

- échantillonnage
- quantification
- compression

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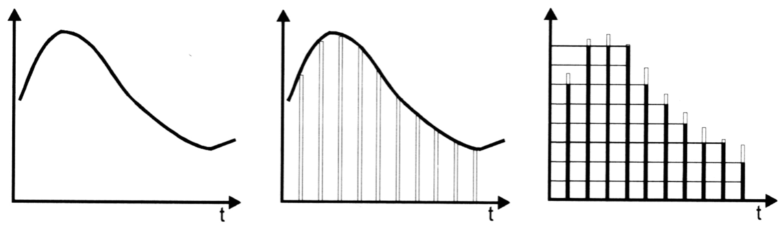

numérisation = échantillonnage + quantification

source: Agathe Jarczyk

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Échantillonnage

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

Quantification

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

Vidéo numérique

Vidéo numérique

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

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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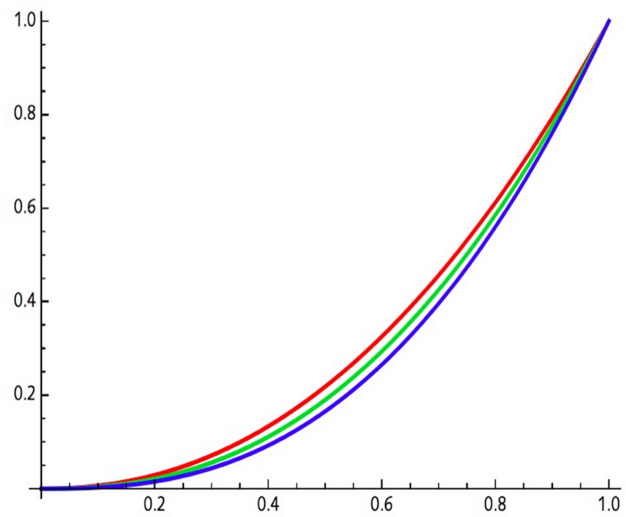

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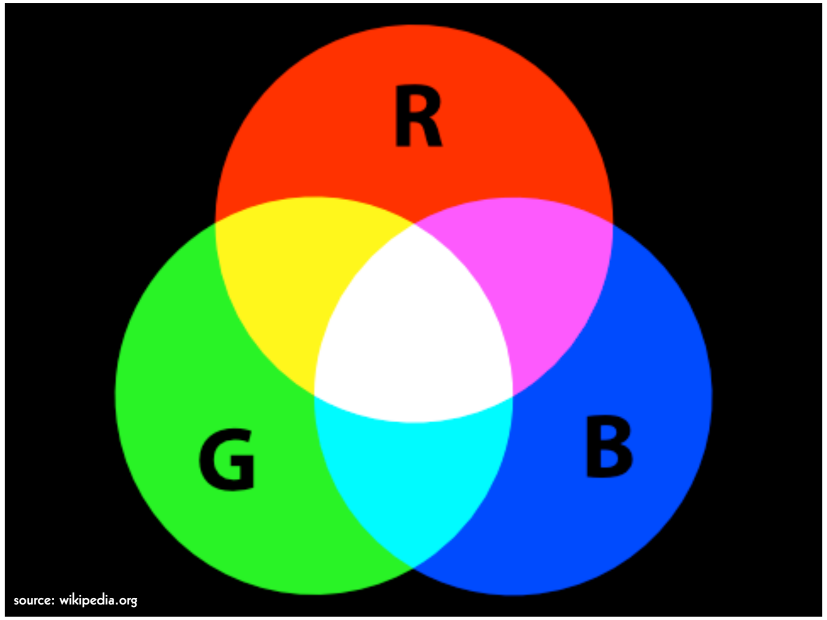
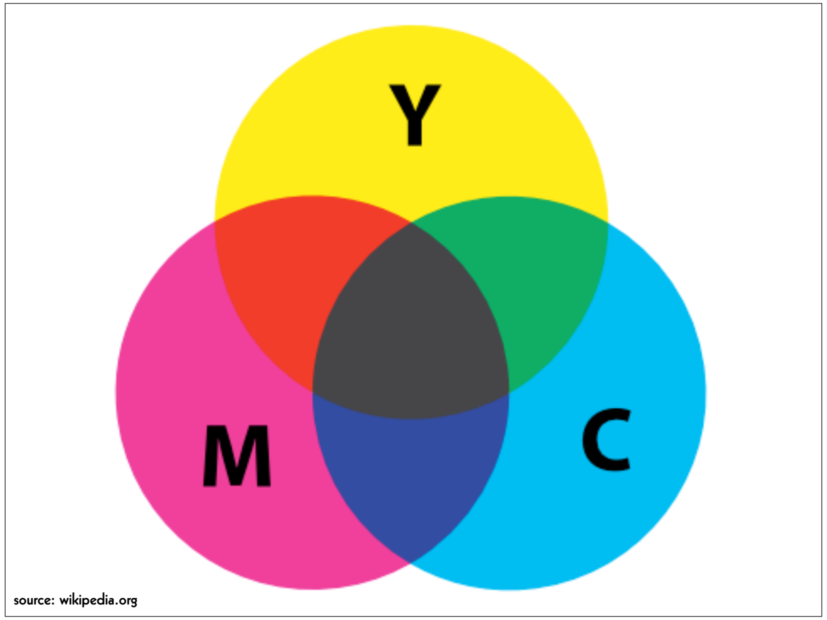
Espace colorimétrique

- XYZ, L*a*b*
- RGB / R'G'B' / CMY / C'M'Y'
- $Y'IQ$ / $Y'UV$ / $Y'D_BD_R$
- $Y'C_BC_R$ / $Y'C_OC_G$
- $Y'P_BP_R$





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

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

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

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

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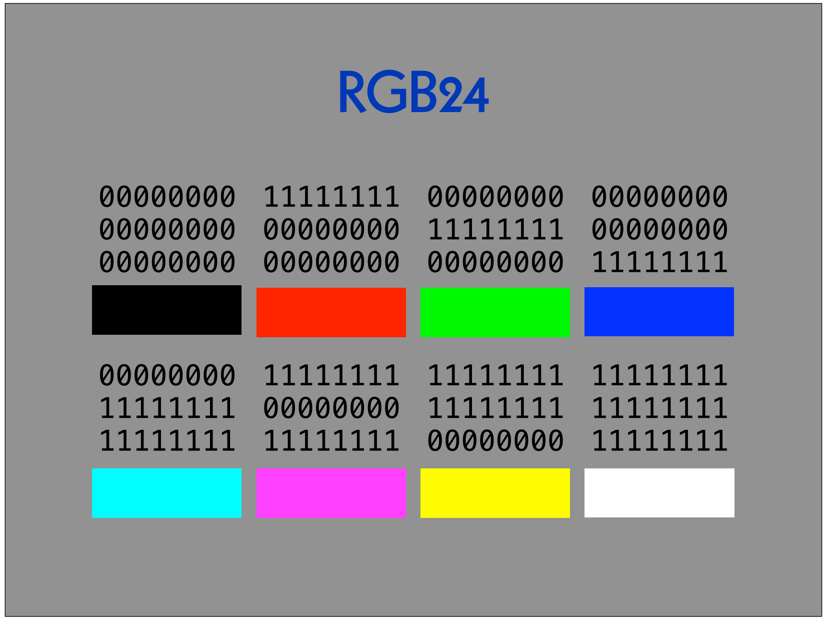

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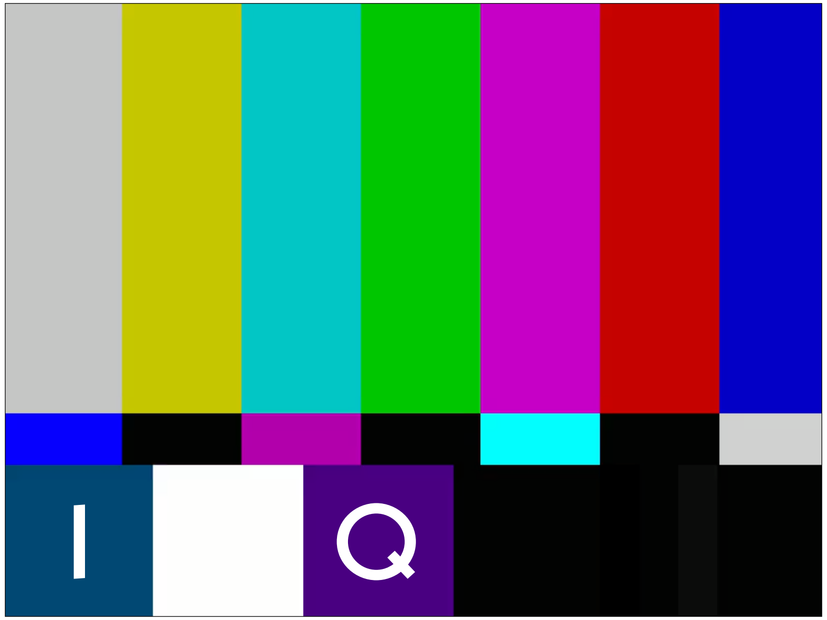

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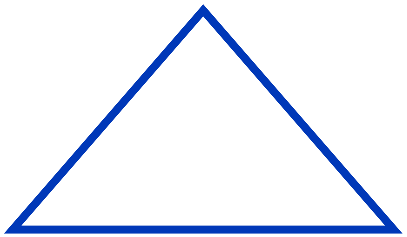
qualité de l'image



temps d'encodage — taille du fichier

Compression

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

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

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

Compressé avec perte

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

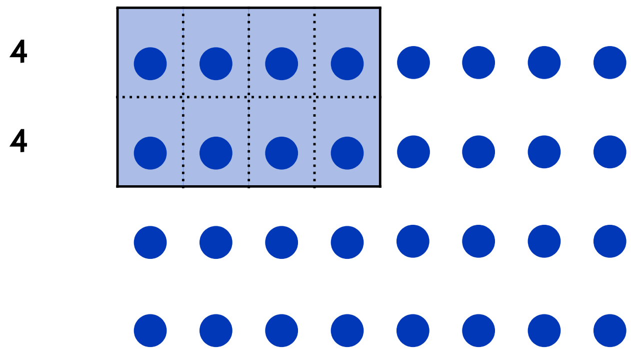
Exemples (mezzanine): ProRes 422, ProRes 4444; DNxHD, DNxHR

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

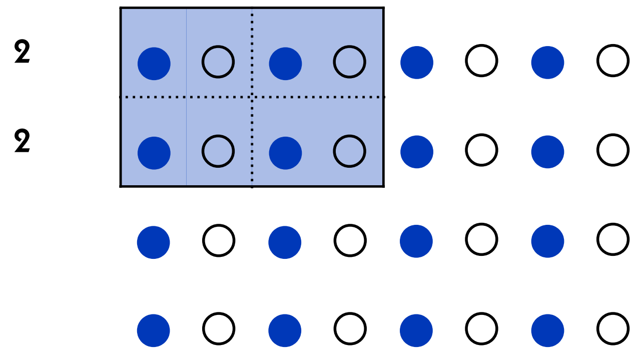
Sous-échantillonnage

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

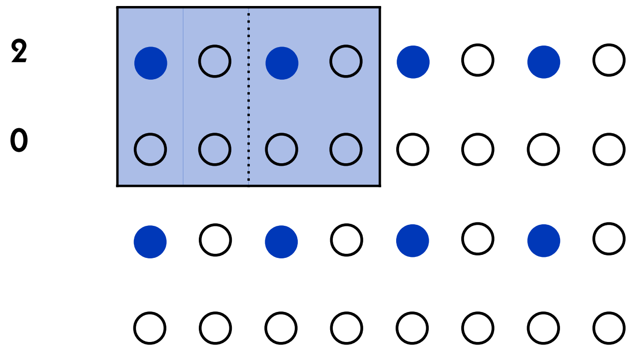
4:4:4



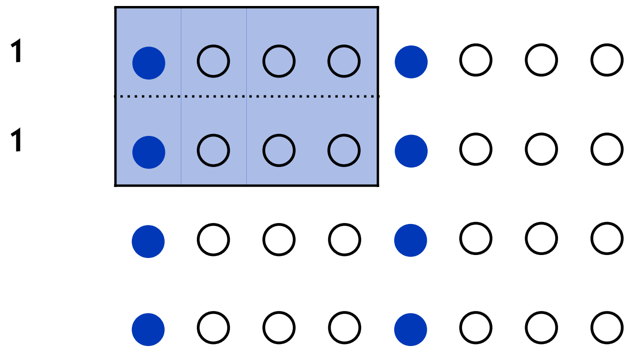
4:2:2



4:2:0



4:1:1



Compressé à la création

- optimisé tant pout l'acquisition que pour la postproduction

Exemples: CineForm RAW, ProRes RAW, Blackmagic RAW

Faits gênants

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

Bryce E. Bayer (1929–2012)

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United States Patent [19] [11] **3,971,065**

Bayer [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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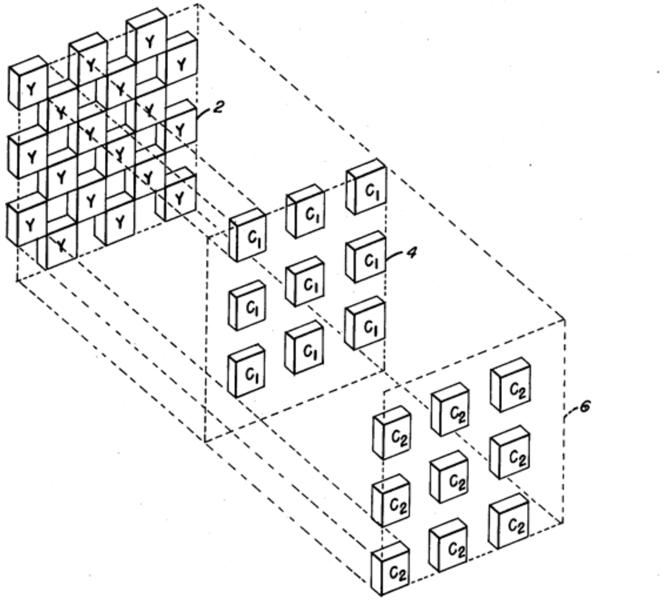

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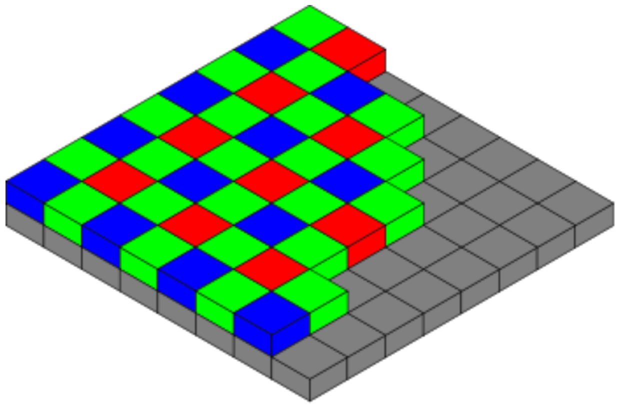
Bayer



source: wikipedia.org

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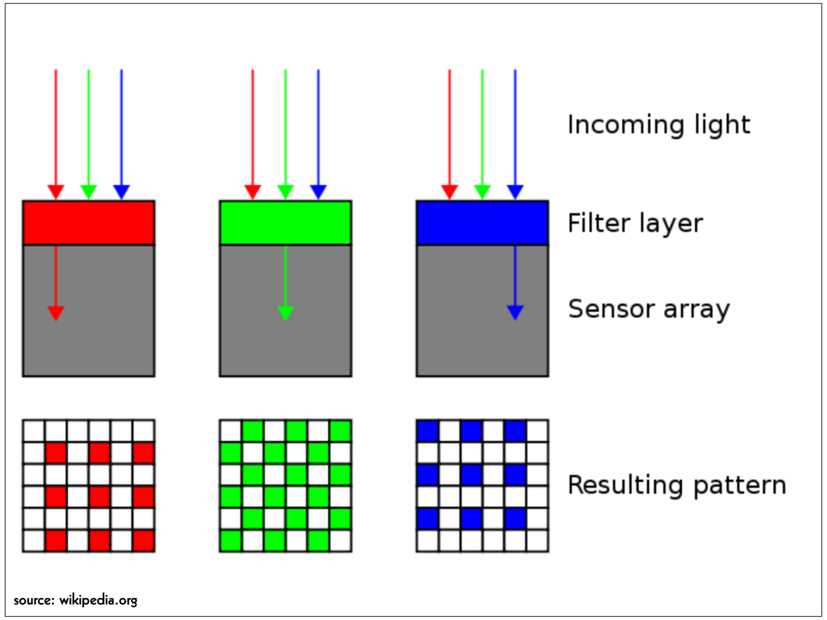

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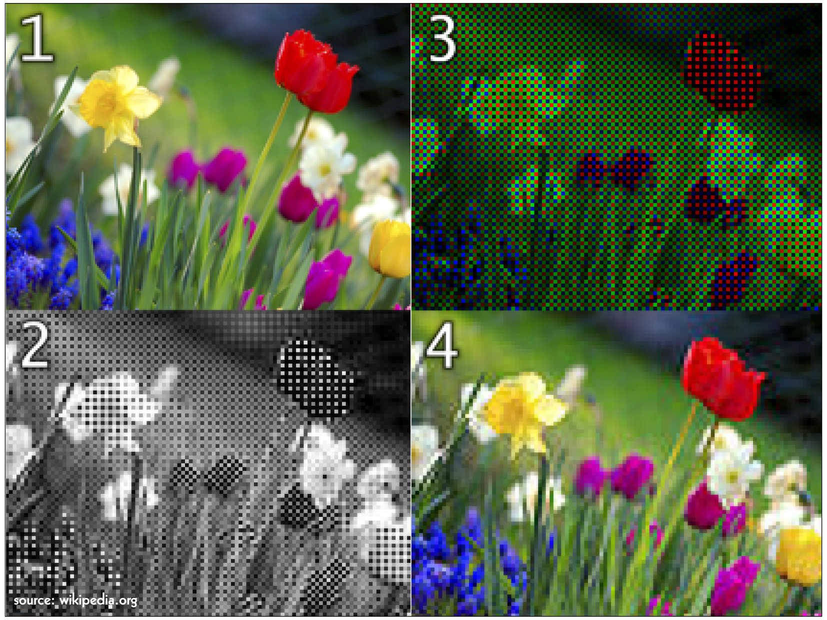

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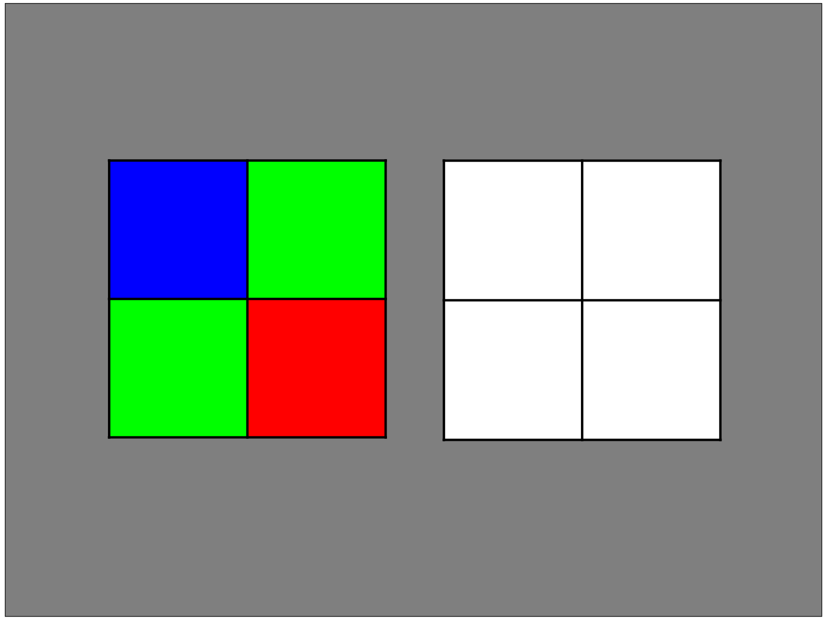

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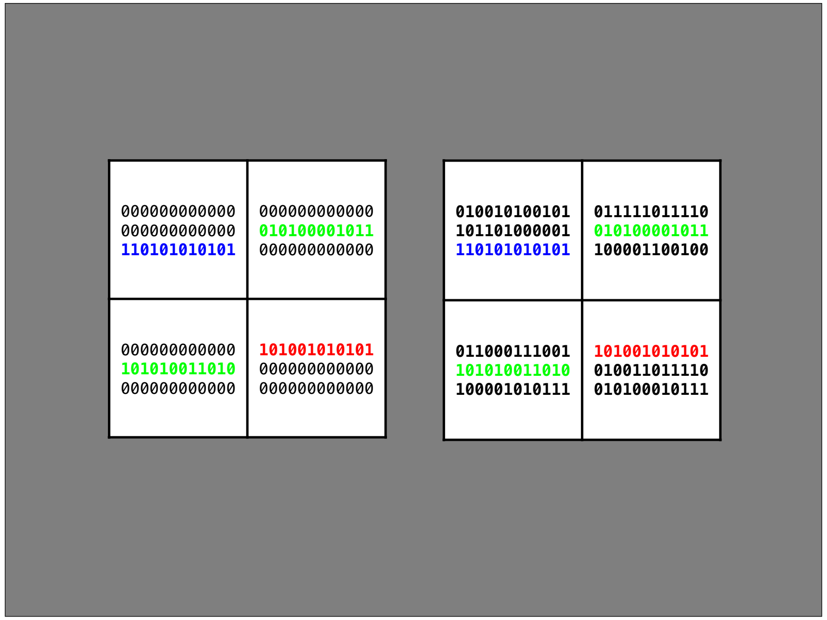
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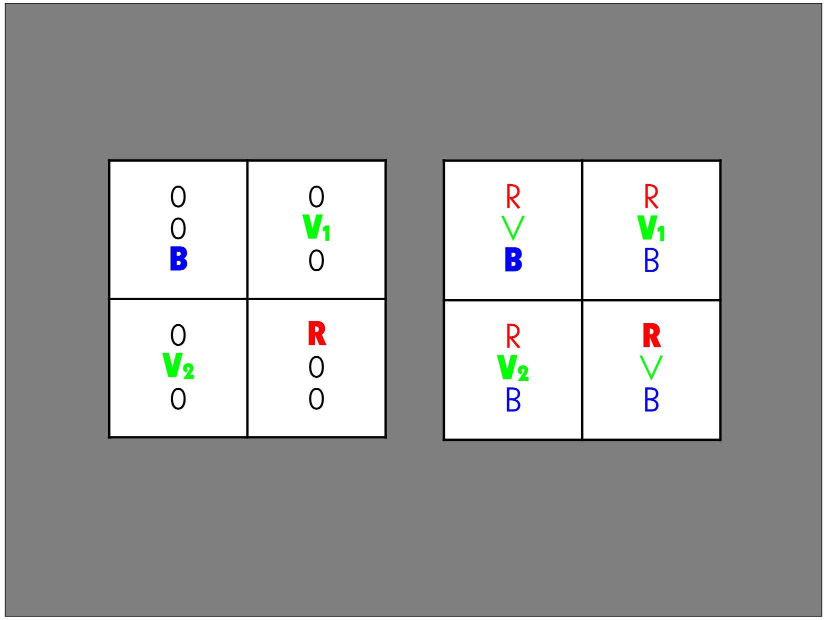
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B
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V1
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V2
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V1
B
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B
R
V
B

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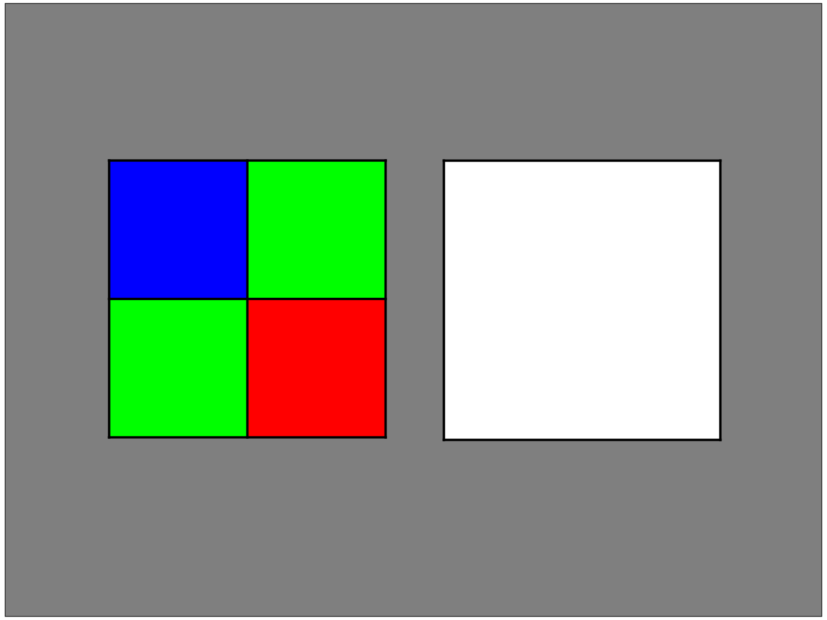

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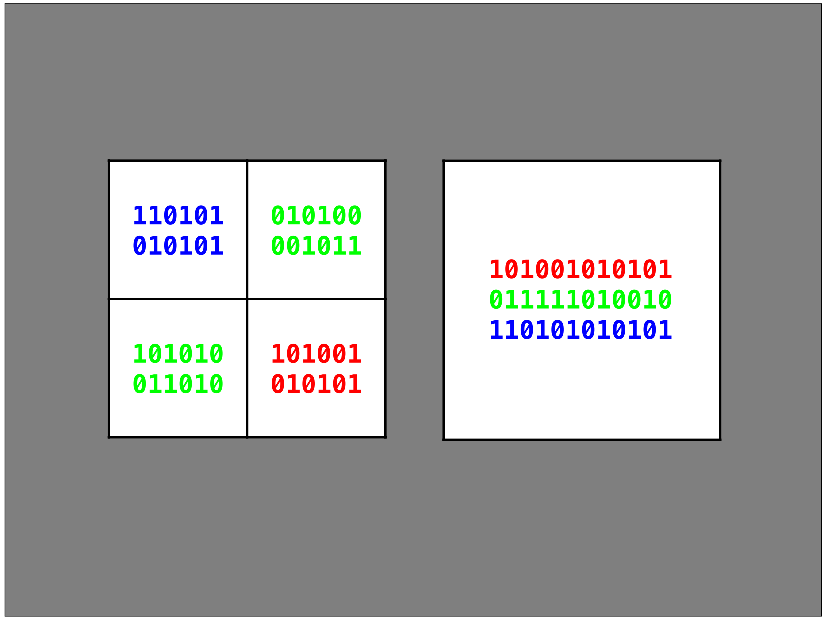
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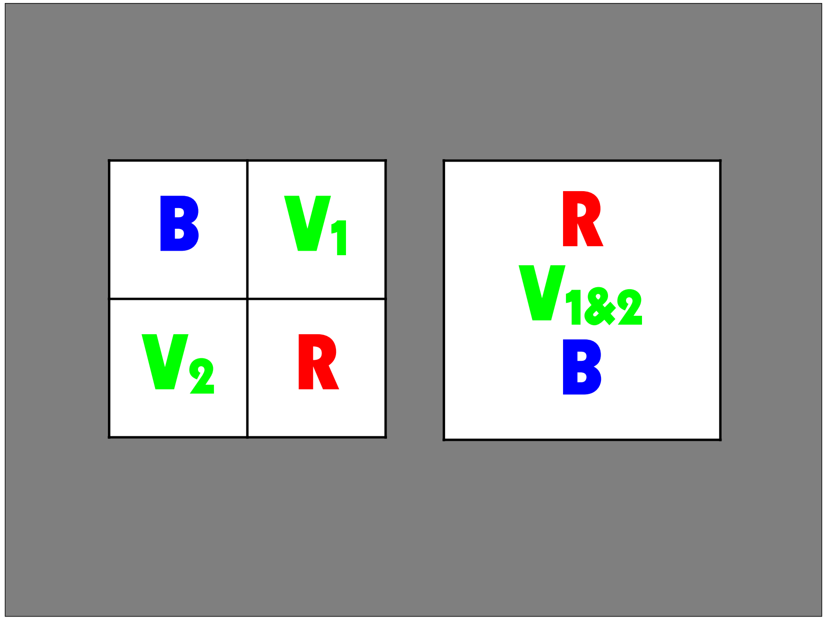
48



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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

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

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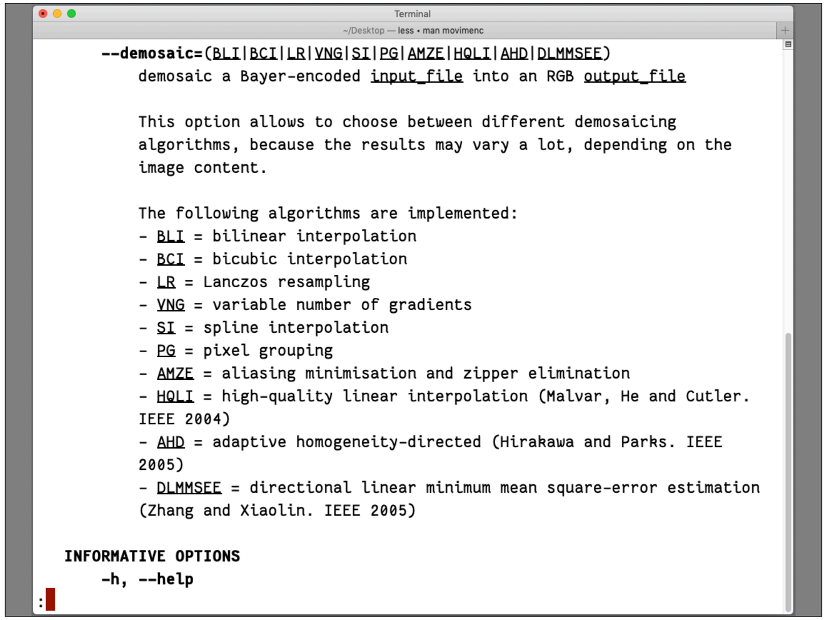

```
--demosaic=(BLI|BCI|LR|VNG|SI|PG|AMZE|HQLI|AHD|DLMMSEE)
    demosaic a Bayer-encoded input_file into an RGB output_file

    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)
    - DLMMSEE = directional linear minimum mean square-error estimation
    (Zhang and Xiaolin. IEEE 2005)

INFORMATIVE OPTIONS
    -h, --help
```

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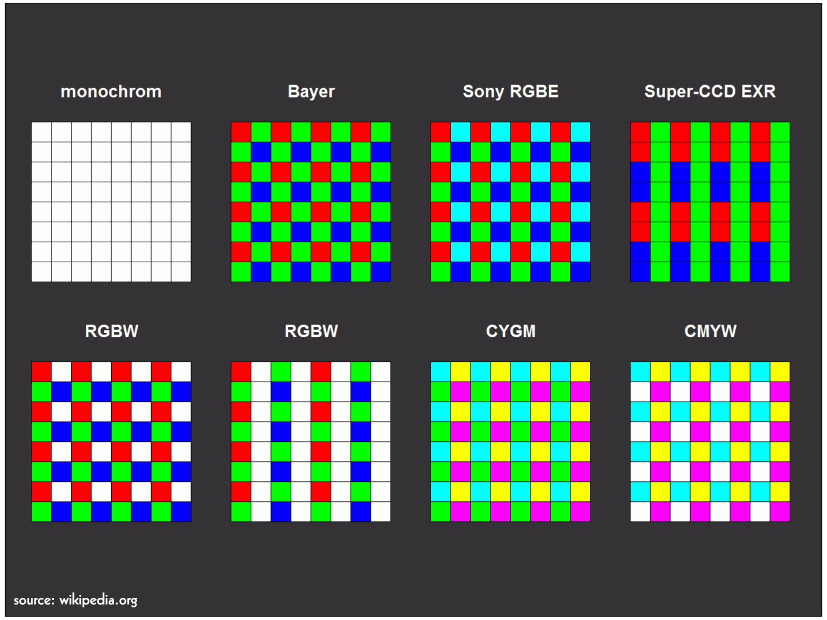

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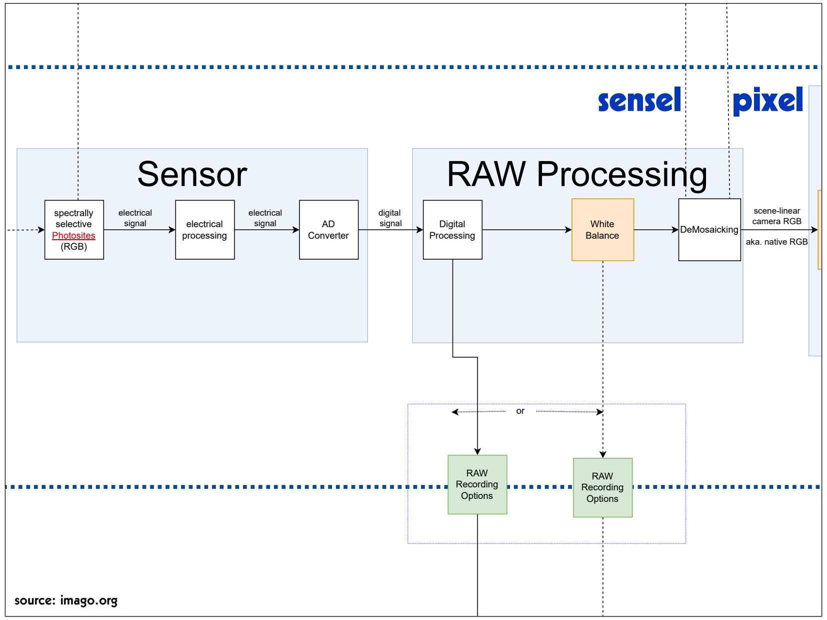
Proposed Terminology

pixel

= picture element

sensel

= sensor element

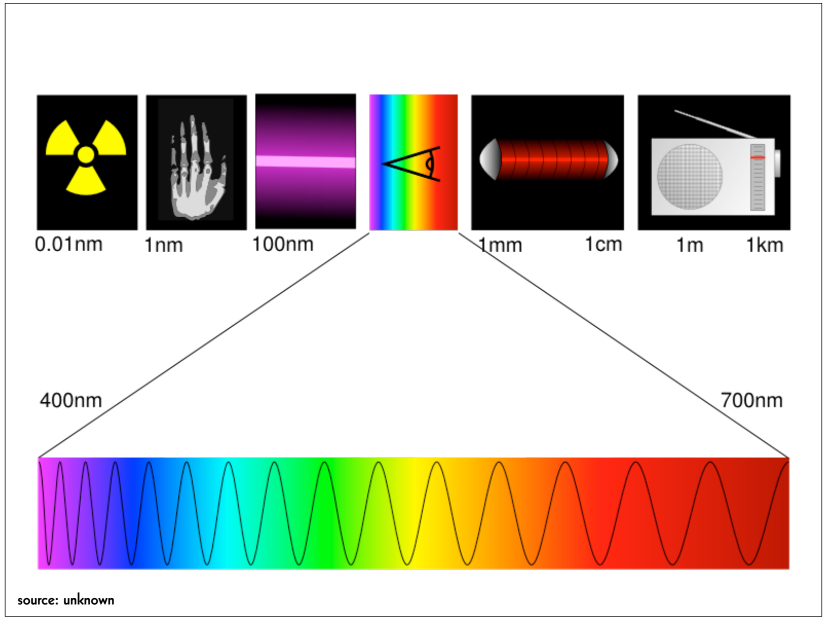


Stockage des données Bayer

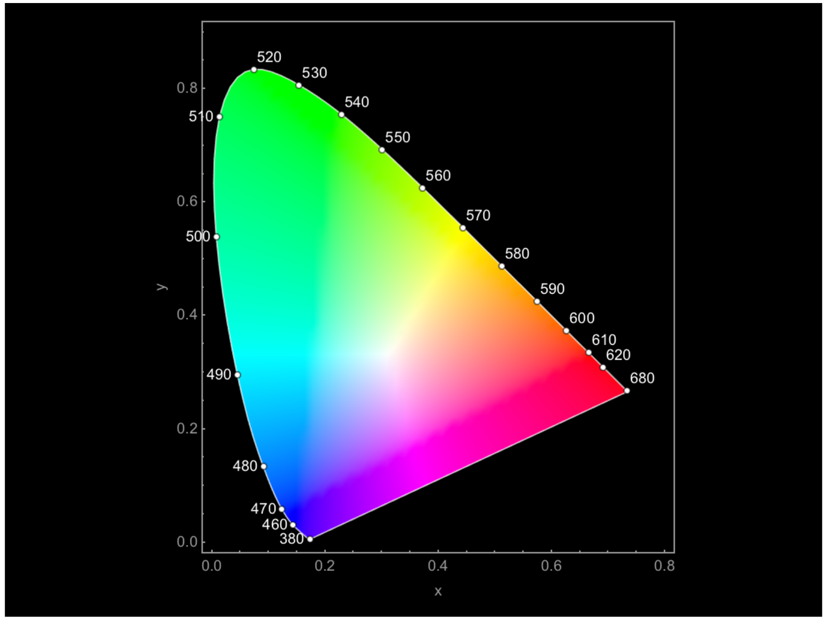
- pixel values generated by one de-mosaicking algorithm (digital blow-up)
- pixel values generated by mixing two green sensel values into one (digital reduction)
- raw sensel values

Illuminant

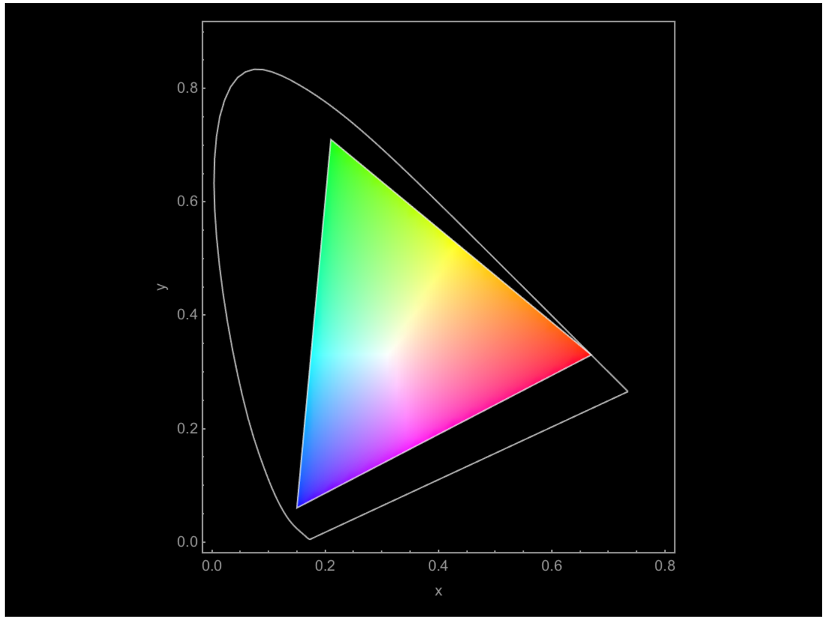
- D50
- D55
- D65
- D75


0.01nm
1nm
100nm
1mm
1cm
1m
1km
400nm
700nm
source: unknown

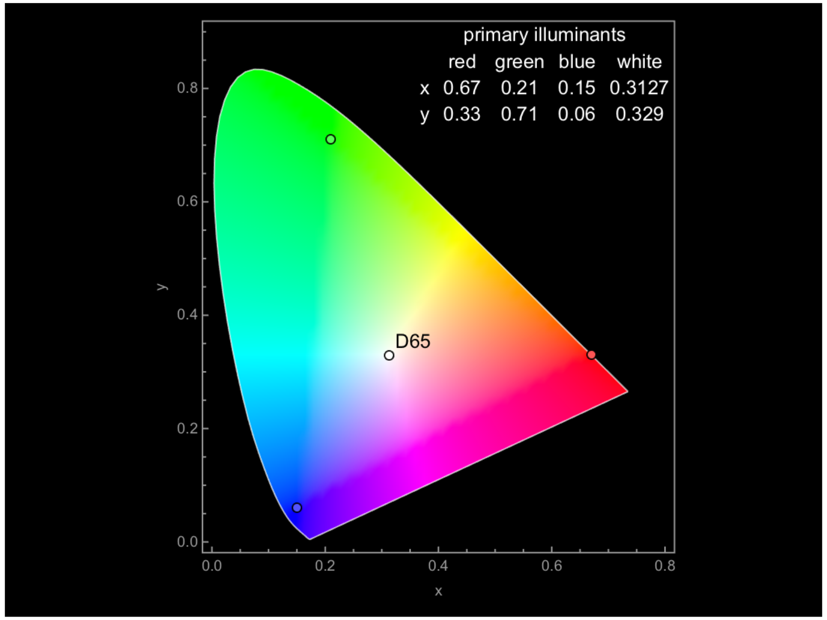
57


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

58


y
x

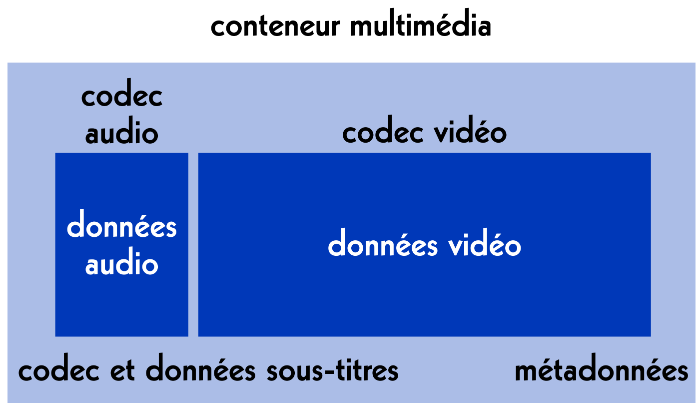
59


primary illuminants
red green blue white
x 0.67 0.21 0.15 0.3127
y 0.33 0.71 0.06 0.329
D65
y
x

60

Structure des fichiers

Structure des fichiers



Conteneur multimédia

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

Images individuelles

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

Codec audio

- WAVE
- BWF
- AAC
- MP3
- FLAC

Codec vidéo (archive)

images

- TIFF
- DPX
- JPEG 2000
- OpenEXR
- DNG

flux vidéo

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

Codec vidéo (mezzanine)

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

Codec vidéo (accès)

- H.264 (AVC)
- H.265 (HEVC)
- H.266 (VVC)
- AV1

RAW data are cooked.

Données audio

- pcm_s16le
- pcm_s24le
- pcm_s32le

Données vidéo

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

Que contient mon DPX?

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

Formats de fichiers

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

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

Elena Rossi-Snook:

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

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, $Y'C_BC_R$ 4:2:2, 10 bit
- Matroska, FFV1, HD, $Y'C_BC_R$ 4:2:2, 10 bit

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

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

Formats de distribution (actuel)

MP4

vidéo
- 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

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

Format d'archive et mezzanine

images individuelles («film»)
- Matroska, FFV1, 4K ou 2K, R'G'B', 12 bit
- Matroska, FFV1, 4K ou 2K, RGB, 16 bit

flux de données («vidéo»)
- Matroska, FFV1, «HD», $Y'C_BC_R$ 4:4:4, 12 bit
- Matroska, FFV1, «HD», $Y'C_BC_R$ 4:4:4, 10 bit

son
- Matroska, FLAC, 192 kHz, 24 bit

Formats de distribution

MP4

vidéo

- 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

audio

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

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

Avantages et inconvénients

conteneur

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

codec

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

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

Un pont entre les deux mondes

RAWcooked (CLI)

→ mediaarea.net/RAWcooked

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

Conteneur MXF (.mxf)

codec vidéo

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

SMPTE RDD 48:2018

SMPTE REGISTERED DISCLOSURE DOCUMENT

MXF Archive and Preservation Format Registered Disclosure Document

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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

SMPTE RDD 36:2015

SMPTE REGISTERED DISCLOSURE DOCUMENT

Apple ProRes Bitstream Syntax and Decoding Process

Page 1 of 39 pages

The attached document is a Registered Disclosure Document prepared by the sponsor identified below. It has been examined by the appropriate SMPTE Technology Committee and is believed to contain adequate information to satisfy the objectives defined in the Scope, and to be technically consistent.

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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.

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Conteneur Matroska (.mkv)

codec vidéo

- FFV1
- ProRes 422, ProRes 4444

Matroska / FFV1

Matroska (.mkv)
→ IETF RFC 9559

FFV1
→ IETF RFC 9043

Stream:	Internet Engineering Task Force (IETF)
RFC:	9043
Category:	Informational
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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 RFC 9559

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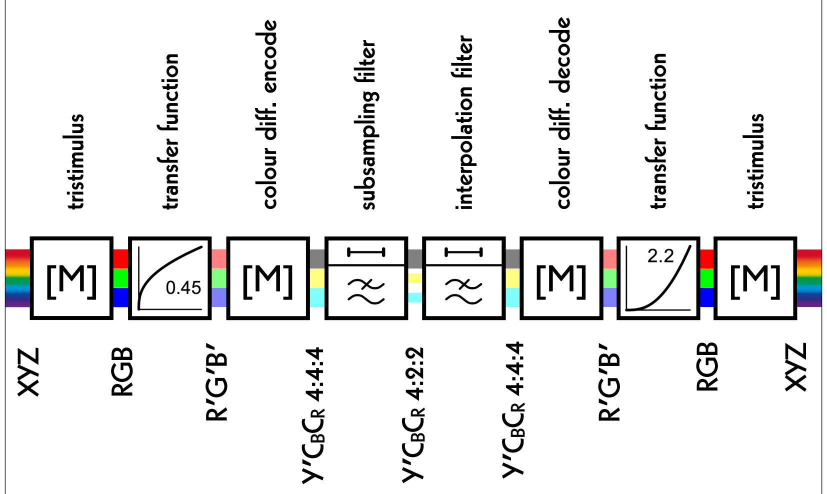
$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.140251 \\ 1 & -0.393931 & -0.580809 \\ 1 & 2.028398 & 0 \end{bmatrix} \cdot \begin{bmatrix} Y'_{601} \\ U \\ V \end{bmatrix}$$

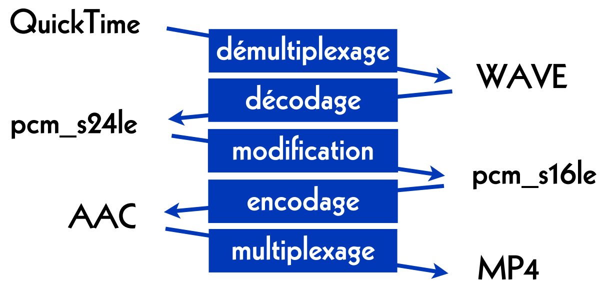
$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0.956295 & 0.621025 \\ 1 & -0.272558 & -0.646709 \\ 1 & -1.104744 & 1.701157 \end{bmatrix} \cdot \begin{bmatrix} Y'_{601} \\ I \\ Q \end{bmatrix}$$



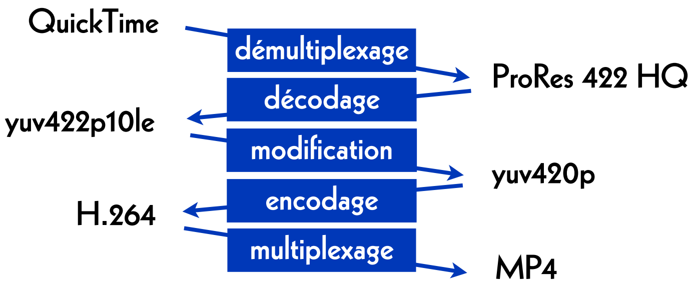
Transformations de fichiers

- démultiplexage
- décodage
- modification
- encodage
- multiplexage

Exemple: audio



Exemple: vidéo



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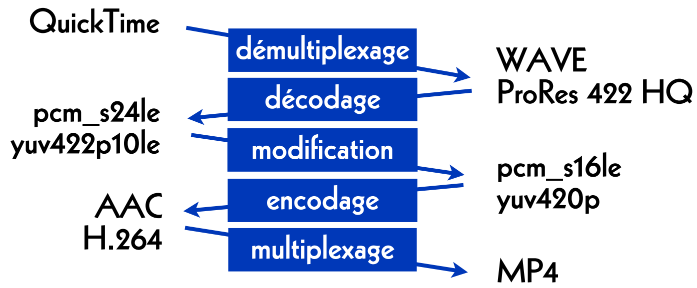
Exemple: audio et vidéo



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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

Checksums

cryptographic

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

non-cryptographic

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

Longterm

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

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)

Reading

Reto Kromer: **On the Bright Side of Data Migrations**, in «IASA Journal», n. 49 (December 2018), IASA, p. 18–22

→ retokromer.ch/publications/IASA_49.html

read | script | write

script to modify

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

#1: ProRes-born Content

from:

- ProRes stored in a QuickTime (.mov) container

to:

- ProRes stored in a Matroska (.mkv) container

Update the Container

→ read file from source LTO

→ demultiplex file

- ProRes 422, 10 bit [yuv422p10le]
- ProRes 4444, 10 bit [yuv444p10le or yuva444p10le] or 12 bit [yuv444p12le]

→ multiplex file

→ write file to destination LTO

#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

Container and Codec

→ read file from source LTO
→ demultiplex file
→ decode file

- $Y'C_BC_R$, 4:2:2, 8 bit, uyvy422

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

Container and Codec

→ read file from source LTO
→ demultiplex file
→ decode file

- $Y'C_BC_R$, 4:2:2, 10 bit, yuv422p10le

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

#3: Filename

from:

- Title_YUV422.mkv

to:

- Title_YCbCr422_9d5084b5b0a08d5022b39e0e75241d12.mkv

Always remember:

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

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