# Color in Image Collections and Archives

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A

B

C

D

E

A: RAW Color Filter Array Data (CFA) stored by the Digital Camera

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B: After linearization, dark current subtraction, flare removal, and channel balancing: still RAW

C: Color interpolated to produce fully populated RGB color channels: still RAW format.

D: After color space conversion: scene-referred image data (ITU-R.BT709, RIMM RGB, XYZ, Lab).

E: After “preference” rendering to virtual display: output-referred image data (sRGB, Adobe RGB,…)

## What is an Image Archive?

- The purpose (and usage) of an image archive varies.
- Images either represent digital reproductions of original artwork…
- …or are the original digital artwork.
- Images should be accessible and usable indefinitely.
- Images should be easy to manage.

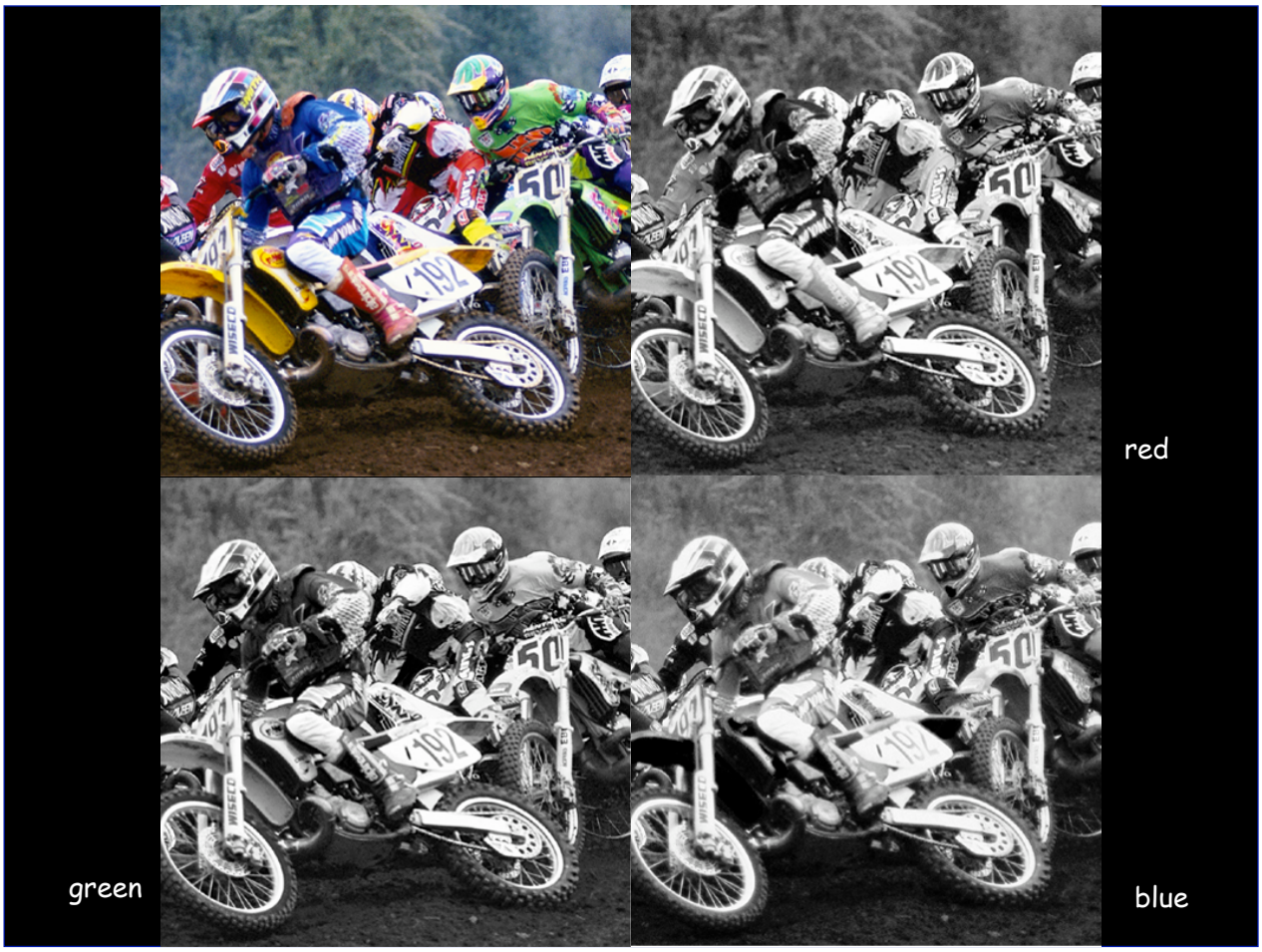
How to manage color during the initial capture stage, maintenance, and deployment of images in an archive?

## Usage of Digital Images

- The digital image is only used as a visual reference.
  - Consumer imaging, on-line visual representation (collections management systems), low-end print representation.
- The digital image is used for print reproduction.
  - Commercial image libraries, professional photographers, cultural institutions, consumer printing.
- The digital image represents a "replacement" of the original.
  - Cultural institutions with high quality demand and/or fragile original artwork.
- An image database may contain one or more representations (master/derivative files).

# Color Spaces and Encodings

- RGB:
  - Captured by the sensor
  - Displayed by the monitor
  - Usually encoded in file formats such as RAW or any RGB spaces (e.g. sRGB, Adobe RGB, ProPhoto RGB, ECI RGB)
  - Used for image processing
- XYZ (color matching functions):
  - Based on the human visual system (Basis for colorimetric RGB image encodings and opponent color encodings)
- LMS (cone responses):
  - Used primarily in psychophysics, rarely in imaging.



# Color Spaces and Encodings

- Additive (RGB):
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- LMS (cone responses):
  - Used primarily in psychophysics, rarely in imaging.
- Opponent (CIELAB, CIELUV, YCrCb)
  - Transforms from RGB
  - Used in "perceptual" encodings, such as CIELAB, CIELUV, CIECAM02
  - Used in color measurement and color evaluations
  - Used in compression (JPEG, JPEG2000)
  - Used in image processing

# Color Spaces [ISO 22028-1]

**Color Image Encoding**
**=**

**Color Space Encoding**
**=**

**Color Space**

+
Digital Encoding Method

+
Information necessary to properly Interpret the color values (image state, viewing environment, etc.)

# Color Space

- According to the CIE [CIE87], a color space is a "geometric representation of colors in space, usually of three dimensions."
  - colorimetric, color appearance, and device dependent.
- Colorimetric Color Space:
  - The relationship between the color space and CIE colorimetry is clearly defined.
  - Additive RGB color spaces
    - Primaries, linear transform to XYZ, color space white-point, and color component functions are defined.
  - CIEXYZ, CIELAB, CIELUV
    - XYZ under D65 is different from XYZ under D50.
  - YCC, YCrCb, etc.
    - Linear transform from RGB to more de-correlated, opponent color spaces.
    - Such color spaces are generally the basis for color image encodings used in compression.

# Color Space

- Color Appearance
  - Output of color appearance models, such as CIECAM02.
- Device Dependent:
  - No direct relationship with CIE colorimetry
  - Spectral characteristics, color component function, and white-point of an actual or idealized input device needs to be specified.

# Example: color space characteristics

| | sRGB | RIMM RGB |
|---|---|---|
| Color space type | Colorimetric RGB color space | Colorimetric RGB color space |
| Color component transfer function | $C'=12.92xC$ for $C \leq 0.0031308$<br>$C'=1.055xC^{1/2.4}-0.055$ for $C > 0.0031308$ | $C'=45xC/1.402$ for $C \leq 0.018$<br>$C'=(1.099xC^{1/2.2}-0.099)/1.402$ for $C > 0.018$ |
| Luma-Chroma matrix | N/A | N/A |
| Color space white point luminance | 80 $cd/m^2$ | 15'000 $cd/m^2$ |
| Color space white point chromaticity | D65 | D65 |

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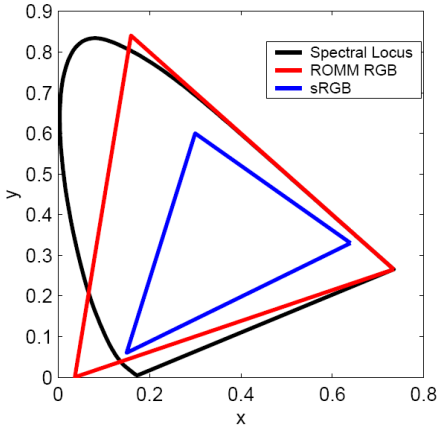
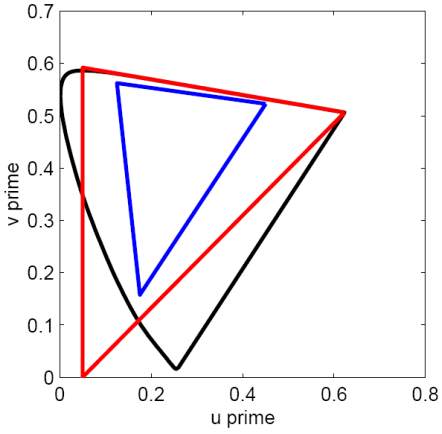
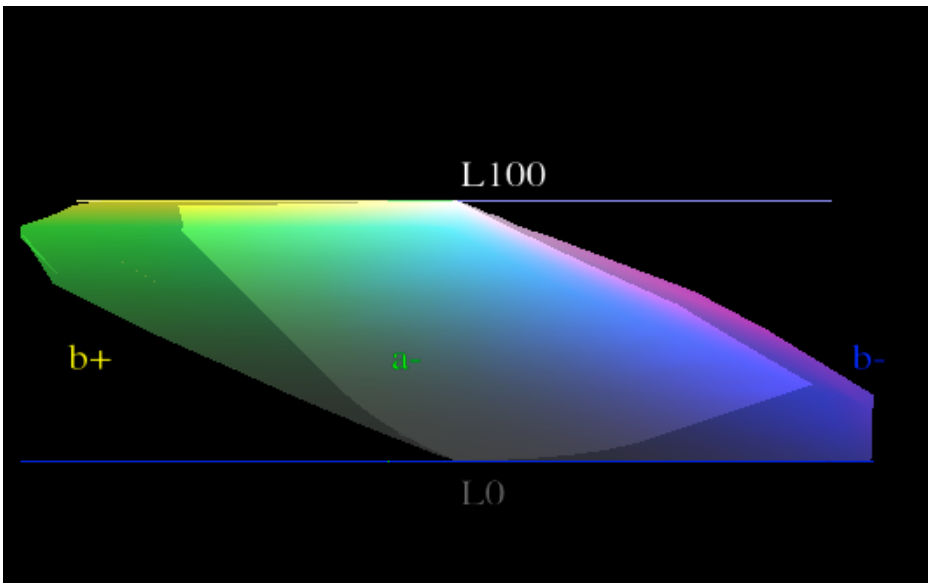
# Color Encodings

- Color Space plus digital encoding method
  - Digital code value range (8-bit, [0..255]) associated to color space range (RGB, [0..1])
  - The same color space can result in different color encodings. Example: sRGB and scRGB, ROMM RGB (ProPhoto RGB): 8 bit, 12-bit, 16-bit.
  - Using color space primaries and color space range, color encoding gamuts can be visualized.



# ROMM vs. sRGB Gamut




ROMM: large Gamut
sRGB: small Gamut

# Example: color encoding characteristics

| | sRGB | RIMM RGB |
|---|---|---|
| Color space value range | Linear RGB: [0..1] | Linear RGB: [0…2] |
| Color gamut | Video display-based | extended |
| Digital code value range | [0..255] ex.,<br>others allowed:<br>WDC=$2^n$-1, KDC=0 | [0..255] (8-bit)<br>[0..4,095] (12-bit)<br>[0..65,535] (16-bit) |

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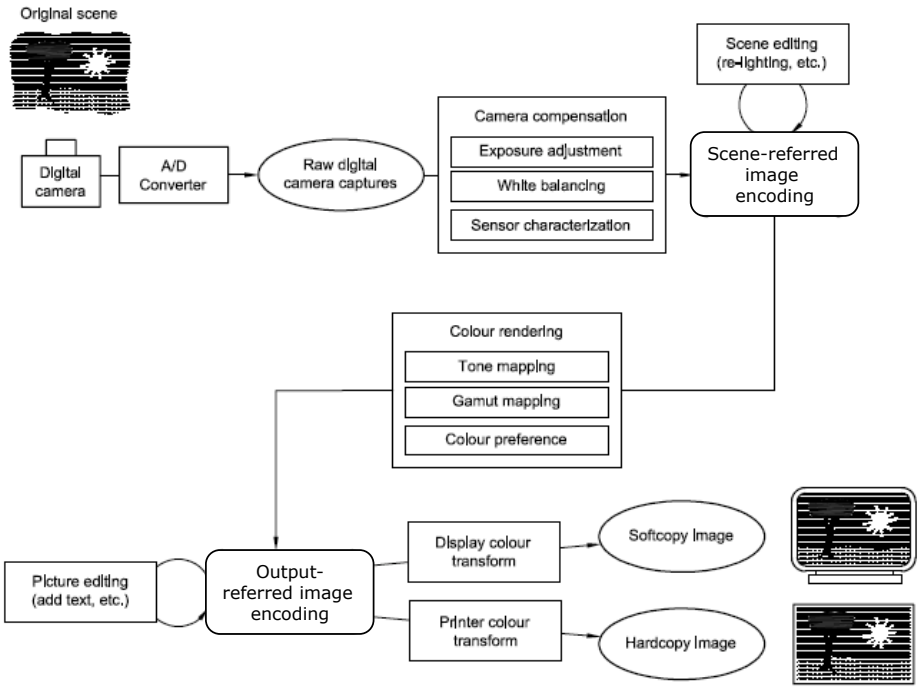
# Color Image Encoding

- Color Space Encoding plus parameters necessary to interpret the color values:
- Image State (color rendering of the image data):
  - Input-referred (scene or original): image data represents an estimate of the scene or original colorimetry (scRGB, RIMM RGB)
  - Output-referred: image data represents the colorimetry of the original data color rendered to a real or virtual output device (sRGB, ProPhoto).
- Reference Viewing Conditions:
  - Surround, adapted white-point, luminance of the adapting field, viewing flare
  - Output-referred additionally needs a reference imaging medium, either a real or virtual monitor or print.

# Generic Digital Photography Workflow




[ISO 22028]

# Example

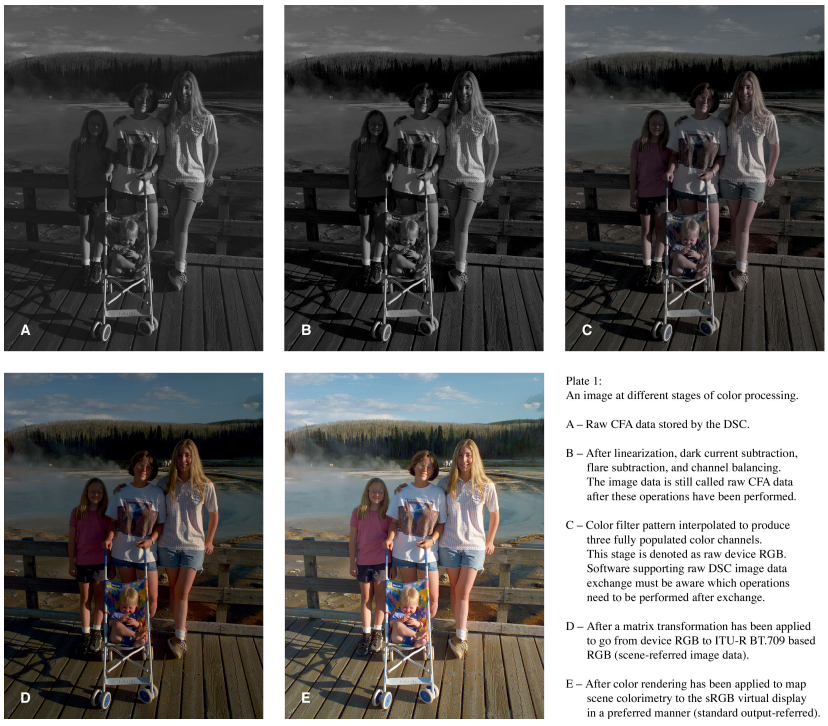



Plate 1:
An image at different stages of color processing.

A – Raw CFA data stored by the DSC.

B – After linearization, dark current subtraction, flare subtraction, and channel balancing. The image data is still called raw CFA data after these operations have been performed.

C – Color filter pattern interpolated to produce three fully populated color channels. This stage is denoted as raw device RGB. Software supporting raw DSC image data exchange must be aware which operations need to be performed after exchange.

D – After a matrix transformation has been applied to go from device RGB to ITU-R BT.709 based RGB (scene-referred image data).

E – After color rendering has been applied to map scene colorimetry to the sRGB virtual display in a preferred manner (standard output-referred).

J. Holm, I. Tastl, L. Hanlon, and P. Hubel, "Color Processing for Digital Photography," in *Colour Engineering: Achieving Device Independent Color*, Wiley, 2002.

## Example: color image encoding characteristics

| | sRGB | RIMM RGB |
|---|---|---|
| Image state | Output-referred (CRT) | Scene-referred |
| Image background / surround | 20% of display white-point luminance (16 cd/m$^2$)<br>20% reflectance of ambient luminance level (4.1 cd/m$^2$) | Surround:<br>20% of adapted white-point |
| Adapted white-point luminance | Not specified | 15’000 cd/m$^2$ |
| Adapted white-point chromaticity | Not specified | D50 |
| Luminance of adapting field | Not specified | Not specified (20% of adapted white-point luminance) |

## Example: color image encoding characteristics

| | sRGB | RIMM RGB |
|---|---|---|
| Viewing flare (typical viewing conditions) | 6.9% of color space white-point luminance | N/A |
| Valid relative luminance range (without flare or glare) | 0.0 to 1.0 | 0.0 to 2.0 |
| Reference medium white point luminance | 80 cd/m$^2$ | N/A |
| Reference medium white point chromaticity | D65 | N/A |
| Reference medium black point luminance | 1 cd/m$^2$ | N/A |
| Reference medium black point chromaticity | D65 | N/A |

## CIE TC8-09 (Archival Colour Space)

- Terms of References:
  - To recommend a set of techniques for the accurate capture, encoding and long-term preservation of colour descriptions of digital images that are either born digital or the result of digitizing 2D static physical objects, including documents, maps, photographic materials and paintings.
- Archive Requirements (poll of stakeholders):
  - Parameters of "Archival" color space, e.g. primaries, gamut, white point, gamma correction, bit depth, etc.
  - Method to evaluate and validate the accuracy of images.
  - Making color space conversion and rendering intent part of this discussion.
- Contact: Robert Buckley (rrbuckley@alum.mit.edu)

## Conclusions

- Color (RGB) can only be interpreted if the physical encoding parameters are known.
- There are several encoding strategies possible, each optimized for a given step in the color image processing workflow.
  - But none for archival yet! Work of CIE TC8-09.
- To be able to read and interpret images in the future, its color needs to be managed the same as all the other formats.
  - File format, support, etc.