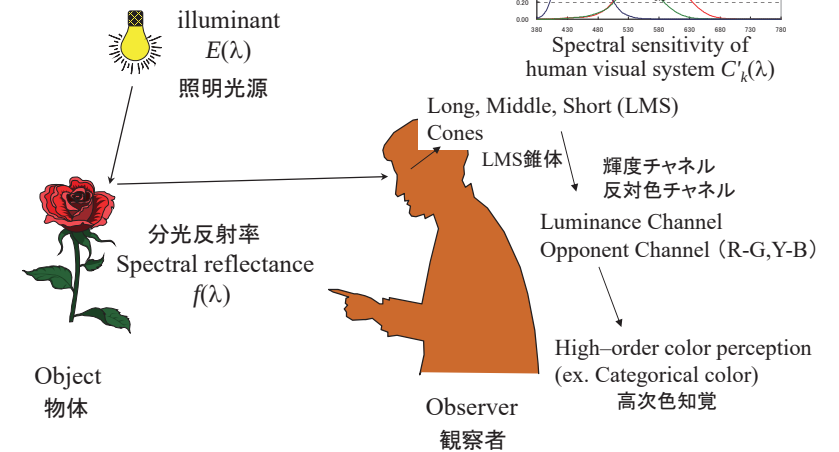


光画像工学 Optical imaging and image processing (IX)

4.1 Color spaces

4.1 色空間

Color perception by human observer

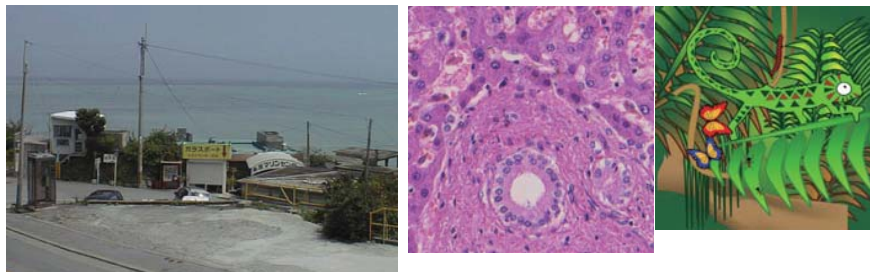


LMS Cone Sensitivity
<http://www.psychologie.uni-kiel.de/golz/publications/2003a/LMS.html>
V.C. Smith and J. Pokorny, "Spectral sensitivity of the foveal cone photopigments between 400 and 500 nm," Vis. Res. 15, 161-171 (1975).

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4. Color Imaging

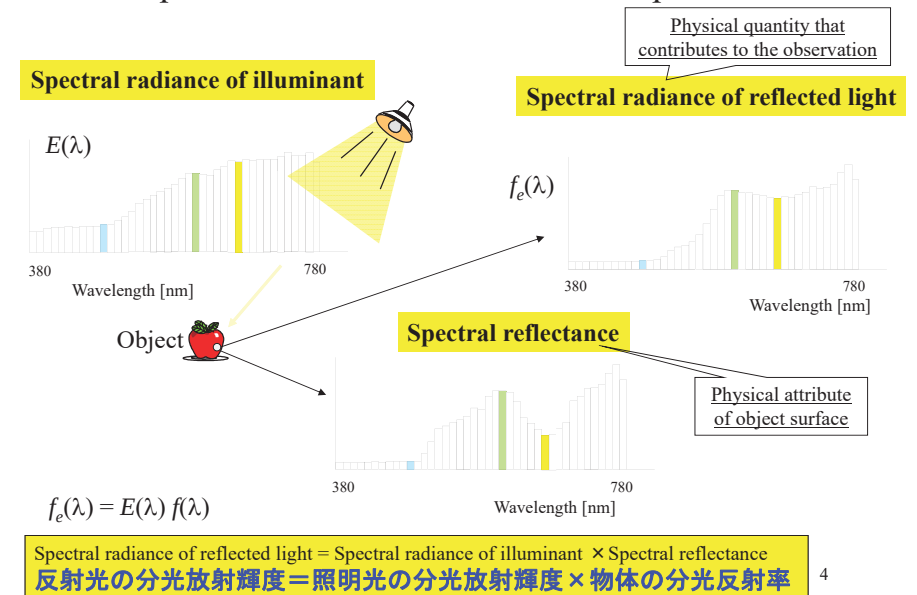
4. カラー画像



- What is "color space" ?
- How are colors reproduced in digital imaging systems?
- Limitation in color reproduction of conventional systems...

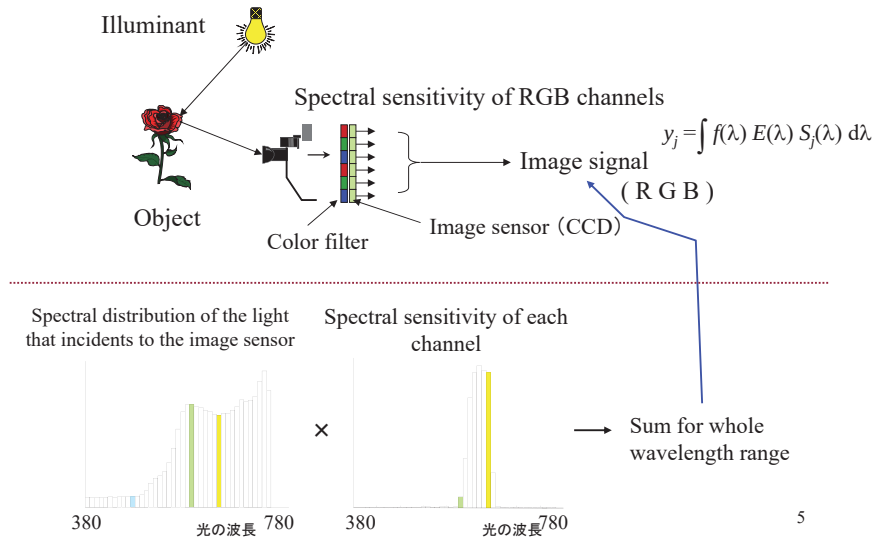
2

Spectral reflectance and illuminant spectrum



4

Input of color



5

Vector-matrix representation

Sampling of wavelengths

Spectral reflectance $\Rightarrow \mathbf{f}$ (N-dimensional vector) $\mathbf{f} = \begin{pmatrix} f(\lambda_1) \\ f(\lambda_2) \\ \vdots \\ f(\lambda_N) \end{pmatrix}$

The image signal y_j is calculated as:

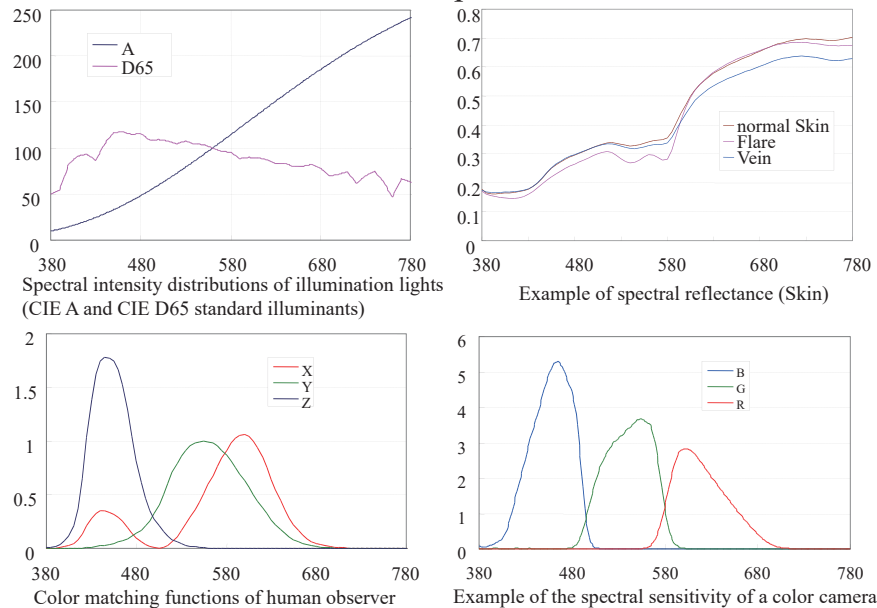
$$y_j = \int f(\lambda) E(\lambda) S_j(\lambda) d\lambda$$

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \end{pmatrix} = \begin{pmatrix} S_1(\lambda_1) & S_1(\lambda_2) & \cdots & S_1(\lambda_N) \\ S_2(\lambda_1) & S_2(\lambda_2) & \cdots & S_2(\lambda_N) \\ S_3(\lambda_1) & S_3(\lambda_2) & \cdots & S_3(\lambda_N) \end{pmatrix} \begin{pmatrix} E(\lambda_1) & \cdots & 0 \\ & E(\lambda_2) & \vdots \\ \vdots & & \ddots \\ 0 & \cdots & E(\lambda_N) \end{pmatrix} \begin{pmatrix} f(\lambda_1) \\ f(\lambda_2) \\ \vdots \\ f(\lambda_N) \end{pmatrix}$$

$$\mathbf{y} = \mathbf{S} \mathbf{E} \mathbf{f} = \mathbf{S} \mathbf{f}_e$$

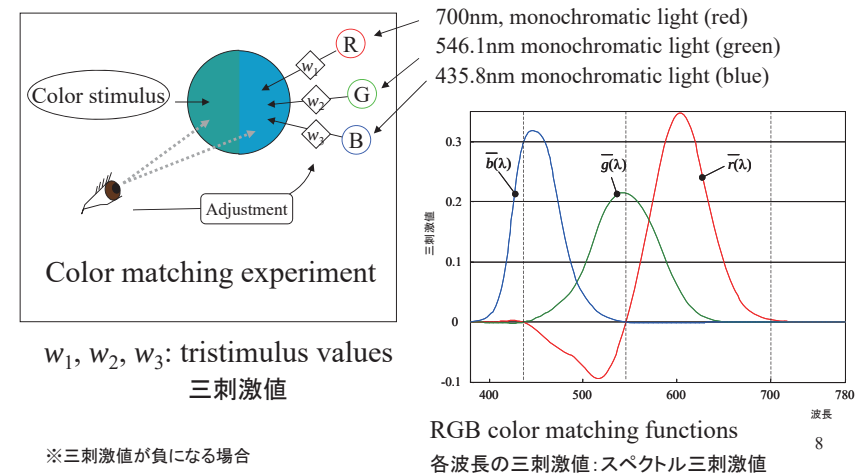
7

Examples



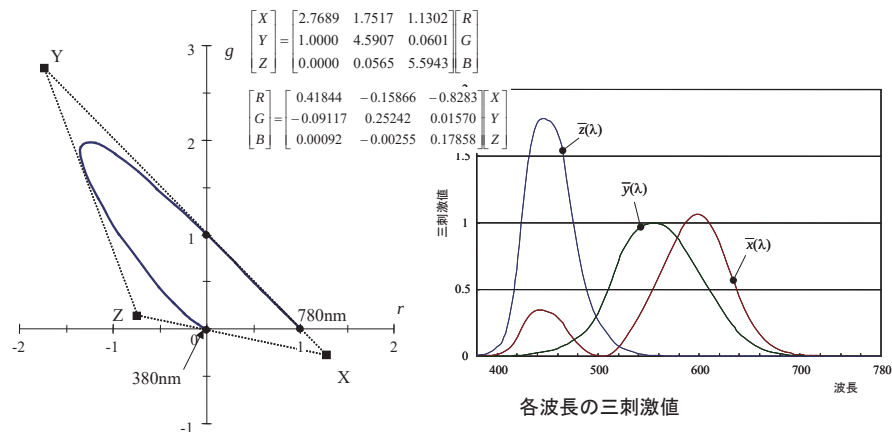
How were color spaces defined?
色空間はどのようにして定められたのか？

- Additive mixture of three-primary colors 3原色の加法混色



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XYZ Color Matching Functions (CMF) Color is represented by three positive variables XYZ等色関数: 3つの正の数で色を表す



XYZ primary colors on
r-g color coordinates

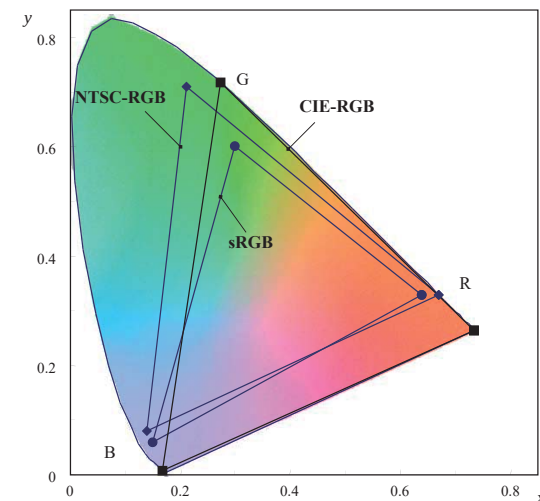
CIE 1931 XYZ CMF

CIE 1931XYZ CMF (2 degrees)
CIE 1964XYZ CMF (10degrees)

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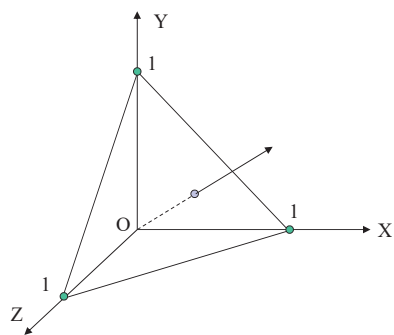
RGB three primary colors RGB 3原色

→12/3

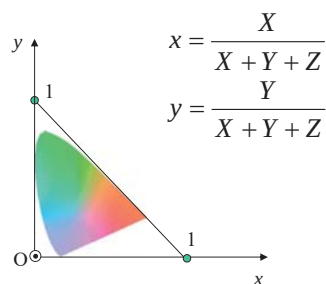


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XYZ color space, xy-chromaticity diagram XYZ色空間、xy-色度図



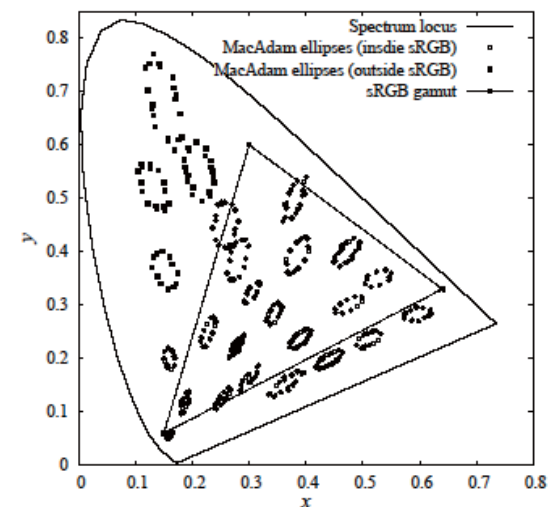
XYZ color space



xy-chromaticity diagram

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Nonuniformity of color discrimination MacAdam ellipses (Just Noticeable Difference magnified 10 times)

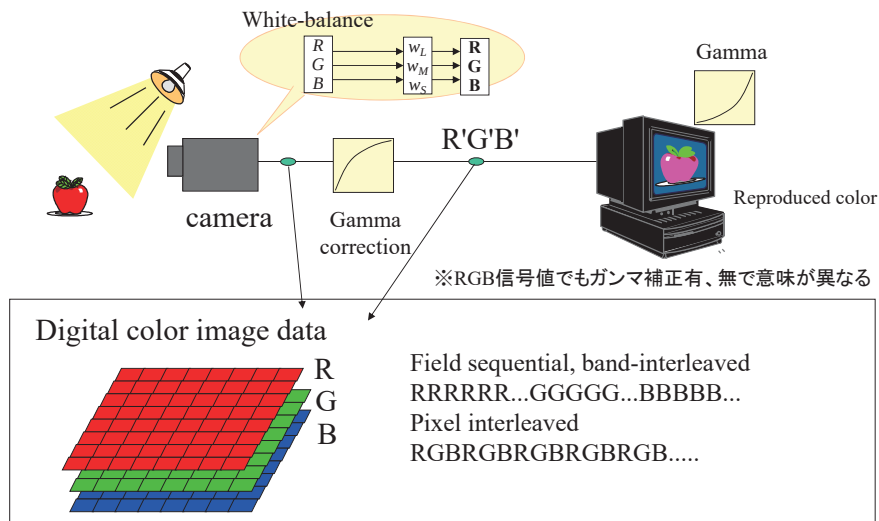


[http://www.akasaka.nict.go.jp/document/NVreport/H14\(still%20image\)/5.pdf](http://www.akasaka.nict.go.jp/document/NVreport/H14(still%20image)/5.pdf)

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4.2 Color imaging and display systems

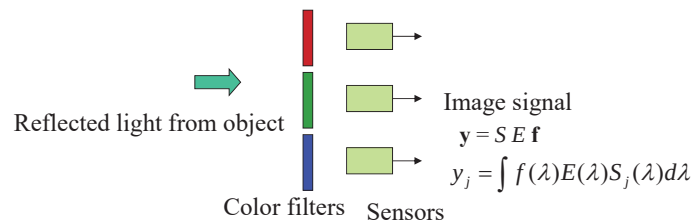
4.2 カラーイメージングとディスプレイシステム



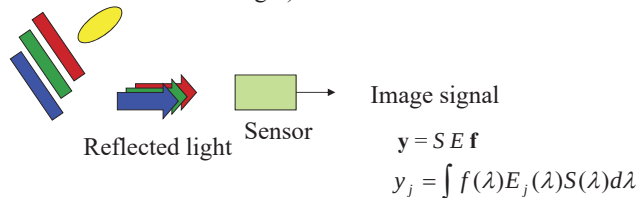
4.2.1 Input of color images カラー画像の入力

Color image input devices

- Color camera, scanner, ..., endoscopy



(Modulation of illumination light)

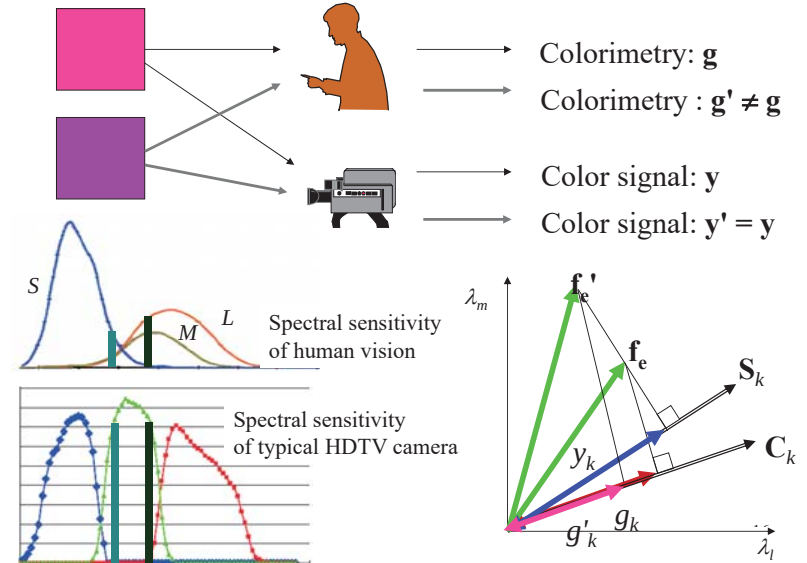


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Problem

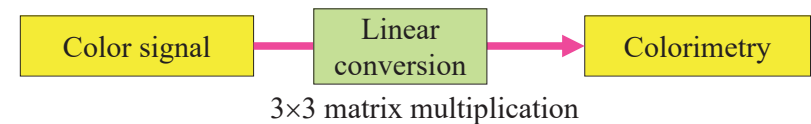
- Two color objects

Impossible to discriminate !



Luther condition

- If the space spanned by S_k covers the space spanned by C_k
- 任意の分光分布を持つ物体に対して、色信号値から三刺激値を誤差なく求めるための条件
- g is derivable from y for arbitrary f_e
- $g = My$



- Conversion matrix
- $y = SEf$
- $g = CEf$

$$M = C S^t (S S^t)^{-1}$$

$$g_e = M y$$

$$= C S^t (S^t S)^{-1} S E f = C E f = g$$

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4.2.2 Color display カラーディスプレイ

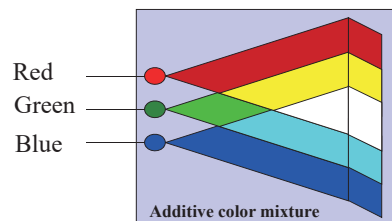
- Spectral radiance of j -th primary color : $P_j(\lambda)$
- Color signal for j -th primary color: $\{r\}_j = r_j$
- Spectral radiance of reproduced color : $Q(\lambda) = \sum_{j=R,G,B} r_j P_j(\lambda)$
- Reproduced color $\mathbf{q}$

$$q_k = \int Q(\lambda) C_k(\lambda) d\lambda = \int \sum_{j=R,G,B} r_j P_j(\lambda) C_k(\lambda) d\lambda = \sum_{j=R,G,B} \alpha_{jk} r_j$$

- $\mathbf{q} = \mathbf{A} \mathbf{r}$

Additive color mixture in 3D color space

加法混色の原理



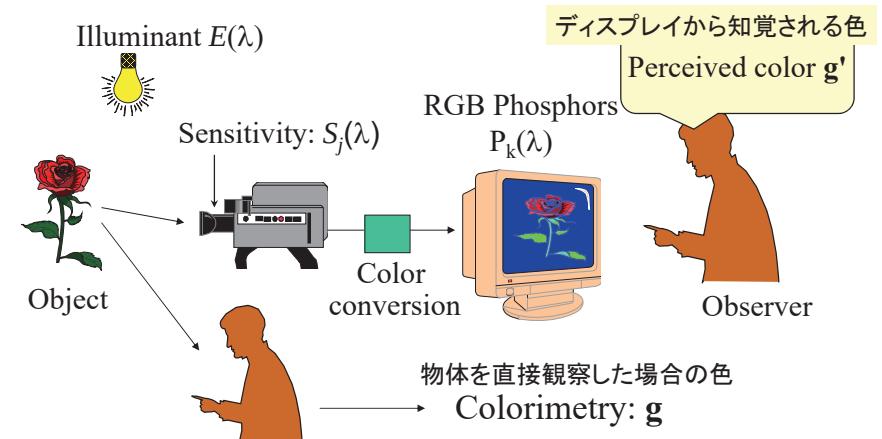
※ 3原色の加法混色で全ての色を表示できる訳ではない！

Not all colors can be reproduced by the additive mixture of 3-primary colors. ... Why?

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4.3 Color reproduction

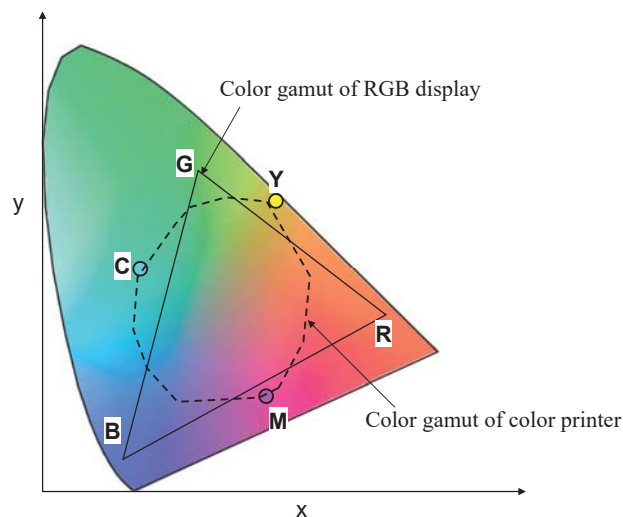
4.3 色再現



Conversion such that $\mathbf{g} = \mathbf{g}'$: Colorimetric color reproduction
測色的色再現

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Color gamut 色域



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4.3.1 Objectives in color reproduction

色再現の分類 (R. W. G. Hunt)

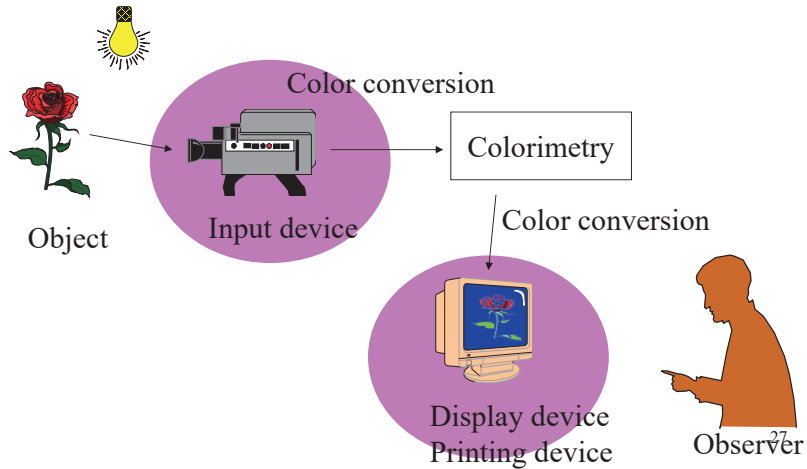
- Spectral color reproduction 分光色的色再現
- Exact color reproduction 正確な色再現
 - Tristimulus values are reproduced
- Colorimetric color reproduction 測色的色再現
 - Do not care luminance
- Equivalent color reproduction 等価な色再現
 - Tristimulus values do not agree with original, but matching the color appearance
 - Luminance should be similar to the original
- Corresponding color reproduction 対応する色再現
 - Tristimulus values do not agree with original, but matching the color appearance
- Preferred color reproduction 好ましい色再現

※消費者向け機器の開発では「好ましい色再現」が重要とされてきた！

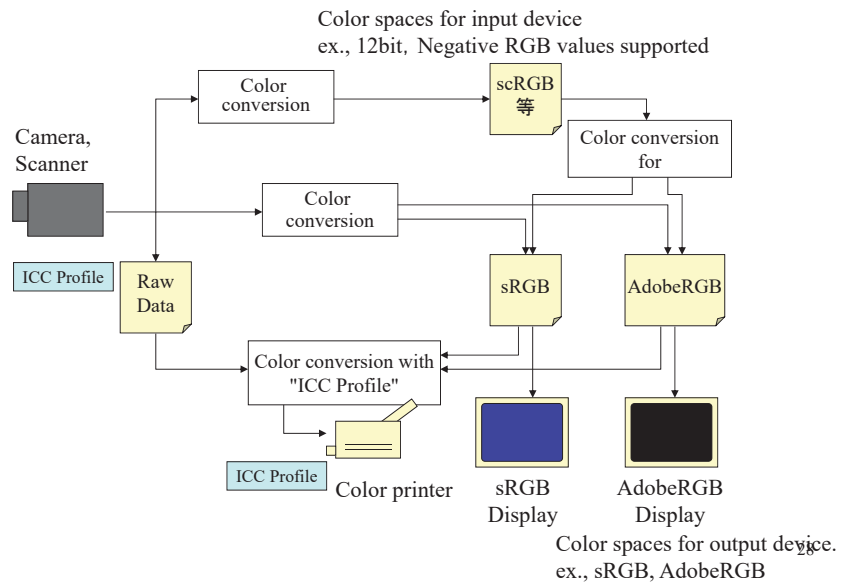
4.3.2 Color management カラーマネージメント、色管理

• Device independent color reproduction

– Device characterization



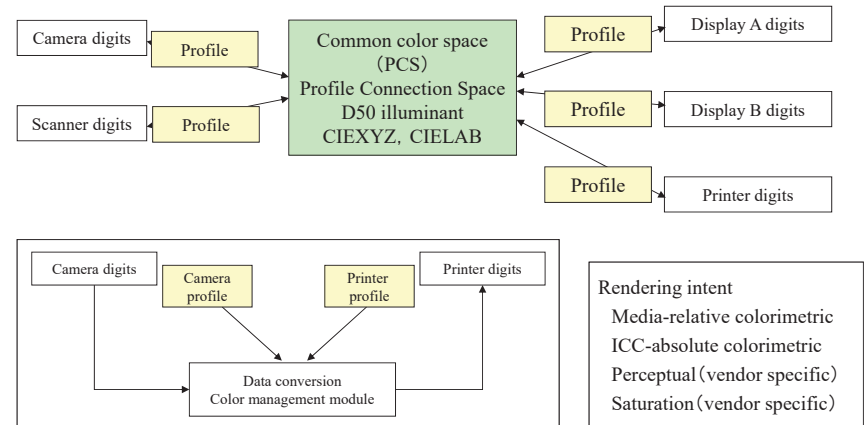
Color spaces for input and output devices 入力用の色空間、出力用の色空間



ICC Profile

ICC: International Color Consortium

- Supported in PDF, TIFF, or Photoshop
- Tools for making ICC profile of a device using a color chart or color sensor.
- Note that the rendering intent includes not only colorimetric color reproduction but also perceptual color reproduction.



Color spaces used in color images カラー画像に使われている各種の色空間

- NTSC RGB (1953)
 - SMPTE 170M RGB (Current NTSC) ※現在のNTSCはBT.709に近い
 - ITU-R BT.709 RGB (HDTV)
 - IEC 61966-2-1 (sRGB)
 - IEC 61966-2-2 (scRGB)
 - Adobe RGB
 - sYCC (sRGB to YCC)
 - ITU-R BT.709 Y Cb Cr
 - xvYCC
 - Others
- Physical Standards: CIERGB, CIEXYZ, CIELAB
Perceptual: Muncell Color Space, Natural Color System