Assessment of Color Displays

Learning Objectives
1. Human color vision
2. CIE color spaces
3. ICC color management
4. Color measurements
5. Medical standards for color

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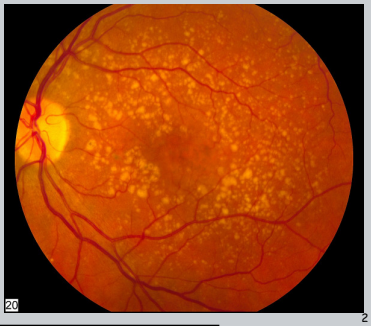
Introduction

In medicine, color display is of particular significance for clinical images obtained in Ophthalmology, Pathology, and Dermatology.

Retinal fundus image showing intermediate age-related macular degeneration.

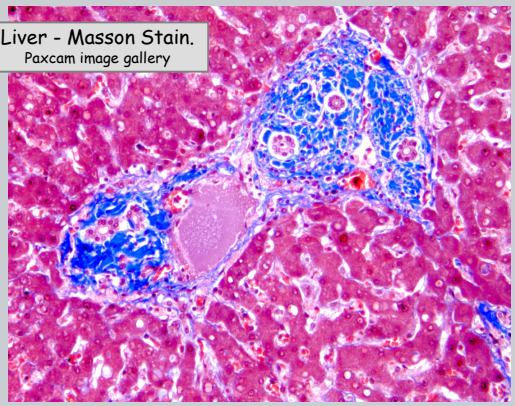
National Eye Institute, NIH
Ref#: EDA22



Introduction

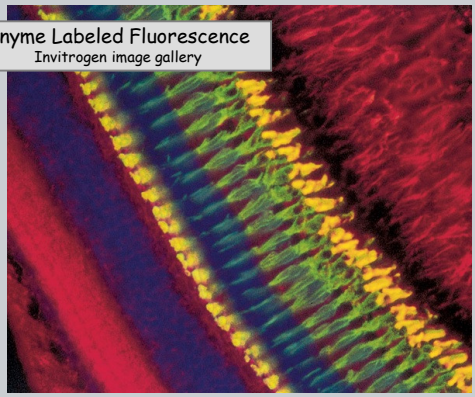
Pathology

Liver - Masson Stain.
Paxcam image gallery



Introduction

Pathology



Enyme Labeled Fluorescence
Invitrogen image gallery

Introduction

Dermatology

Lyme Disease
Delayed Rash
US CDC

Introduction

- In Radiology the primary concern is the white point of monitors used for interpreting grayscale images.
- Additionally, consistency in presenting pseudo-color images is important in Nuclear Medicine and Ultrasound.

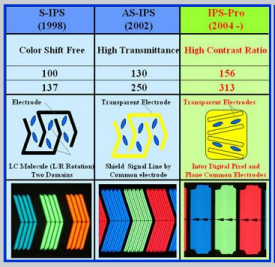
Medical 3MP monitors

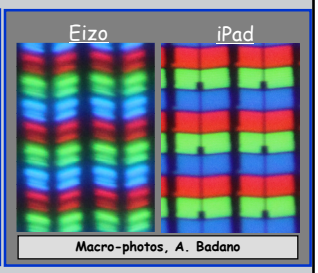
- Improved backlight efficiency has led to color 3 MP monitors with brightness that is the same as for traditional 3MP monochrome monitors.
- The present market cost for color 3MP monitors is only slightly more than for monochrome devices.

Note: monochrome monitors with very high brightness are also available, but are not required in Radiology.

Improved IPS pixel structures

- The traditional IPS structure suffers from poor transmission associated with a low fill factor.
- As series of improvements have eliminated this problem.





30 bit professional graphic monitors

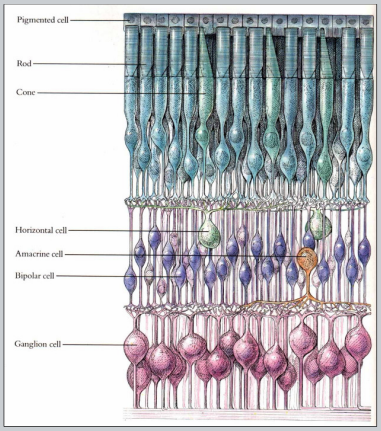
- A significant development in the market involves the introduction of professional graphic monitors at attractice cose
  - with wide color gamut (aRGB) and 30 bit color.
- 30 bit color support (10 bits for R, G, & B) is now supported by;
  - Windows 7 as a color object
  - Recent graphic cards
  - Display port monitor interface
  - Professional graphic monitors
- Monitor suppliers
  - NEC
  - Apple
  - HP
  - Dell
  - ....
- 24", 27", 30" wide format
- 2560 x 1440 array (16:9)

The Human Vision System (HVS) and the tristimulus model

HVS: Rods and Cones

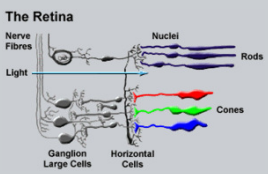
160 million rods
- high sensitivity
- gray response

6-7 million cones
- low sensitivity
- color response



HVS: Cone spectral response

- The pigments for three different types of cone receptors have varying spectral response.
- The spectral response was measured in 1965 and are often labeled as beta(blue), gamma (green) and rho(red).



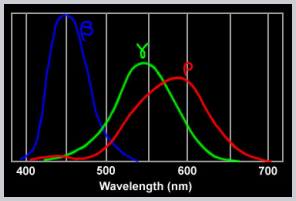
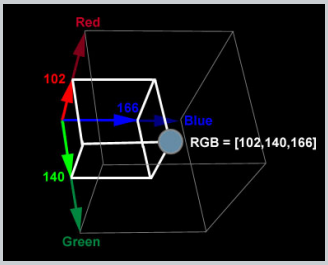


Illustration from Photo.net (Ed Scott)

HVS: The Color Cube

The perception of color can be modeled using a tristimulus 3D space formed by vectors for the rho, gamma, and beta cone response.



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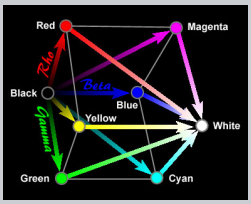
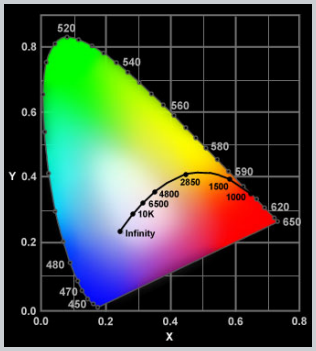
HVS: CIE Color Representation

The CIE color system describes chrominance using two coordinates that correspond to surfaces of the color cube.





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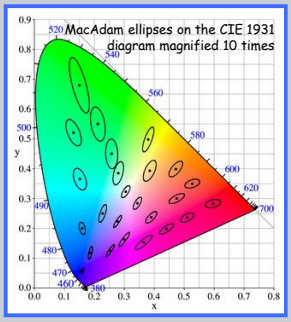
MacAdam ellipses

For the foveal vision, related to a visual field of 2° , the non uniformity of the chromatic scale has been measured by D. MacAdam in 1942 and is graphically represented by ellipses on the chromaticity diagram



Poor visual detection of color changes makes the color perturbation of a grayscale imperceptable.

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CIE Color Spaces

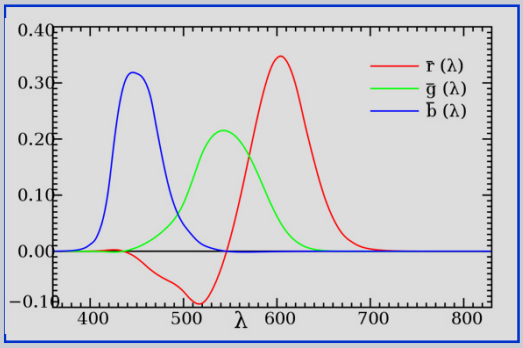
COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

The International Commission on Illumination - also known as the CIE from its French title, the Commission Internationale de l´Eclairage - is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology.

With strong technical, scientific and cultural foundations, the CIE is an independent, non-profit organization that serves member countries on a voluntary basis. Since its inception in 1913, the CIE has become a professional organization and has been accepted as representing the best authority on the subject and as such is recognized by ISO as an international standardization body.

www.cie.co.at

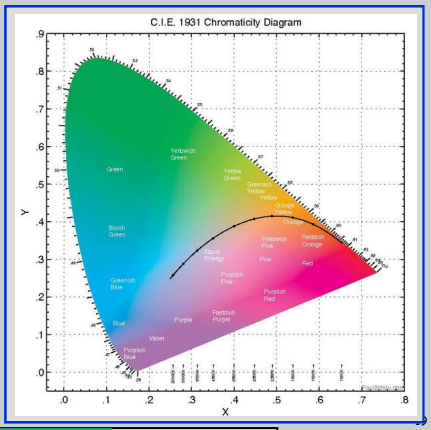
CIE Color Matching Functions



CIE Color Spaces

CIE XYZ
1931

X, Y describe Color (chrominance) and Z is proportional to luminance

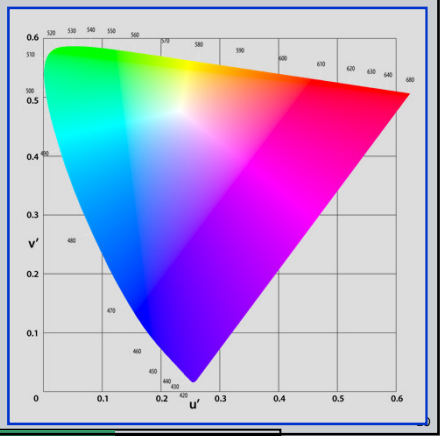


CIE Color Spaces

CIE LUV
1976

u' and v' are linear functions of X, Y, Z

The MacAdam ellipses are more uniform in u',v' space



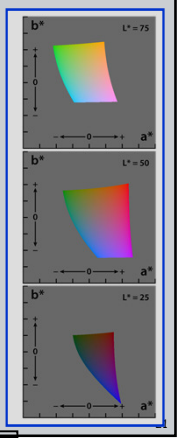
CIE Color Spaces

CIE LAB
1976

The 1976 LAB color space is inherently three dimensional with a*,b* coordinates transformed differently as a function of luminance, L.

However, just noticeable color differences are particulary uniform in LAB space.

The CIE2000 color difference formula, with 10 degree matching functions, is now the preferred difference measure.



ICC color management

Adapted from ICC 2003

International Color Consortium

- An industry consortium
- Established in 1993 by eight industry vendors
- Now approximately 70 members
- Goal: Create, promote and encourage evolution of an open, vendor-neutral, cross-platform colour management system architecture and components

Adapted from ICC 2003

International Color Consortium

Founders:

Adobe Systems Incorporated
Agfa-Gevaert N.V.
Apple Computer, Inc.
Eastman Kodak Company
FOGRA-Institute (Honorary)
Microsoft Corporation
Silicon Graphics Inc.
Sun Microsystems, Inc.
Taligent, Inc.

The ICC

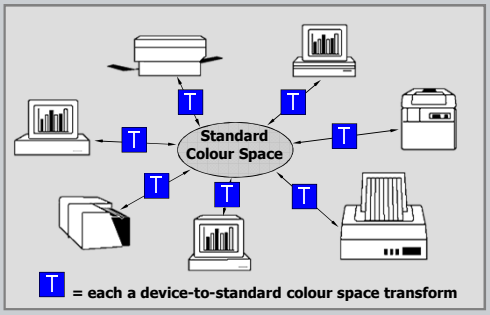
Adapted from ICC 2003

- ICC develops and promotes a standard colour profile specification (ICC Profile).
- Available as PDF at
  www.color.org
- The current version of the ICC Profile Specification is 4.2.0.0 (ICC.1:2004-10).
- This version is essentially the same as ISO 15076-1:2005, which is available from ISO.

ICC color management

Adapted from ICC 2003

Device-independent colour transformation



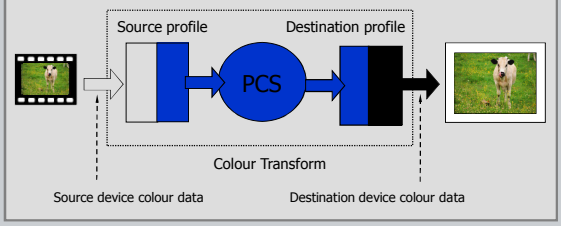
ICC color management

Adapted from ICC 2003

- The transforms from device to standard colour space are embedded in the ICC profile.
- The standard colour space is called PCS (profile connection space).

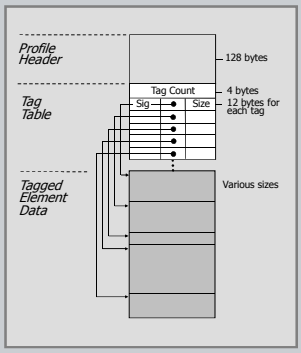
ICC color management

Adapted from ICC 2003



ICC Profiles and the PCS

Adapted from ICC 2003

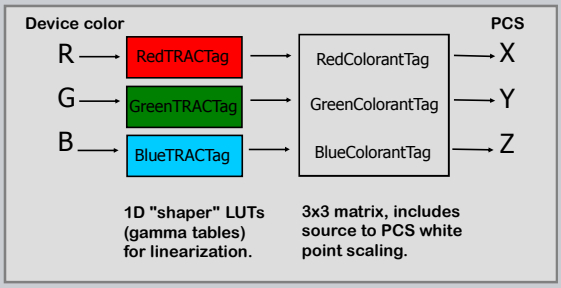


- 128 byte header
- Tag-based (like TIFF)
- Public required tags
- Public optional tags
- Private tags

ICC Profiles and the PCS

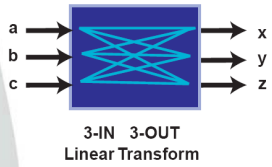
Adapted from ICC 2003

Invertible profile for simple RGB and grayscale devices



ICC Profiles and the PCS

- White point scaling is done by computing the colorants as a linear combination of the input values.
- This is conveniently expressed as a matrix, often called a matrix/shaper.
- The input values must be in linear additive units.



3-IN 3-OUT
Linear Transform

$$x = 1.0 \cdot a + 1.4 \cdot b + 0.8 \cdot c$$
$$y = 0.0 \cdot a + 2.5 \cdot b + 0.6 \cdot c$$
$$z = 1.3 \cdot a + 1.4 \cdot b + 1.3 \cdot c$$

$$\begin{pmatrix} 1.0 & 1.4 & 0.8 \\ 0.0 & 2.5 & 0.6 \\ 1.3 & 1.4 & 1.3 \end{pmatrix}$$

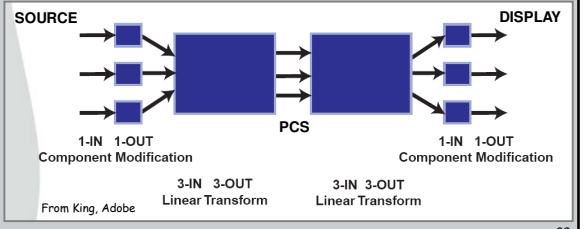
3 x 3 Matrix

From King, Adobe

ICC Profiles and the PCS

Color managed presentation of an image from an RGB camera

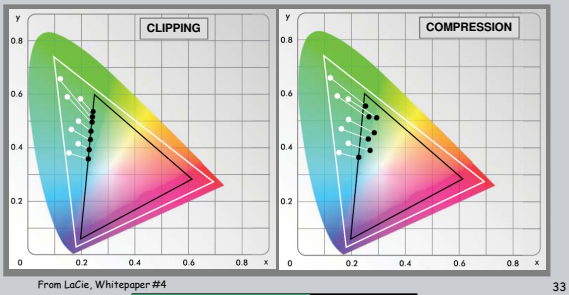
- Linearization and matrix transformation of the source camera data to PCS coordinates.
- Matrix transformation of the PCS values and non-linear colorant modification..



From King, Adobe

ICC Four Rendering Intents

When the camera color gamut is larger than the display color gamut, some compromise must be made in the presentation.



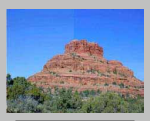
From LaCie, Whitepaper #4

Color Managed Applications

- Source profiles are typically embedded in an image header using digital camera acquisition application.
- The ICC standard defines how to embed an ICC profile into JPEG, GIF and TIFF headers.
- DICOM defines how to embed an ICC profile into a color image object.

ICC Color Management Browser Test, www.color.org

Internet Explorer
No profile support



Firefox v3
Full profile support

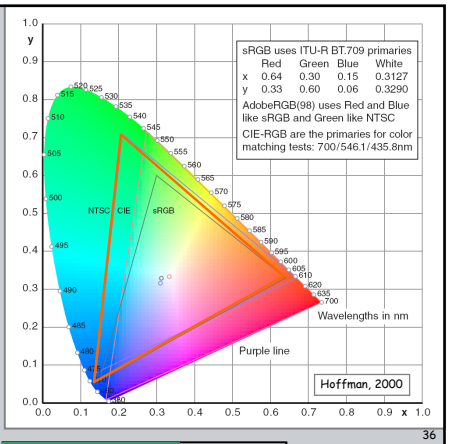
Calibration

Calibration of a camera or a display monitors is done to establish a device color gamut that matches a defined standard color gamut.

Calibration

sRGB is modest in saturation and common for consumer monitors.

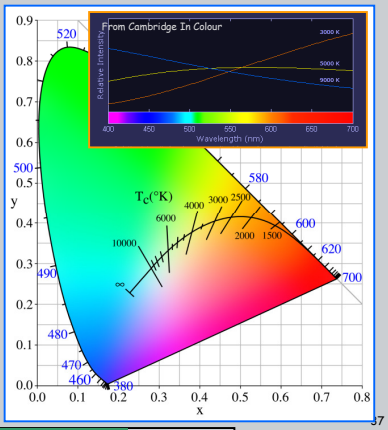
aRGB has improved saturation and is used in many professional graphics applications.



Calibration

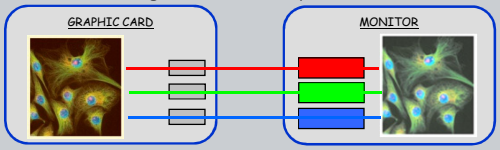
The white point for color calibration is often specified as the color associated with the spectrum from a blackbody radiator of specific temperature.

6500 degrees is a common specification for LCD monitors.

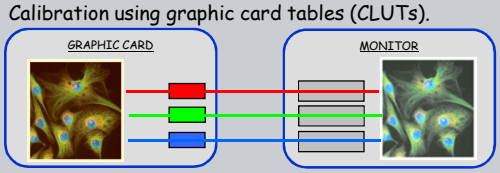


Calibration

Calibration using monitor look-up tables (CLUTs).



Calibration using graphic card tables (CLUTs).



Calibration

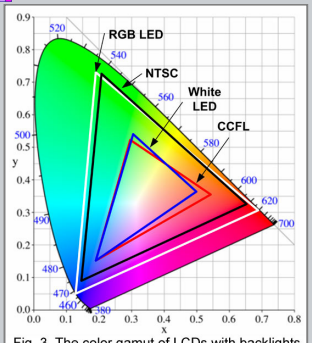


Fig. 3. The color gamut of LCDs with backlights employing CCFL, white LEDs and RGB LEDs are shown here along with the NTSC (television) color gamut.

New technology offers significant improvement in display color gamut.

- Individual R, G, and B LED illuminators for each sub-pixel
- Organic Light Emitting Devices (OLED)

Profiling

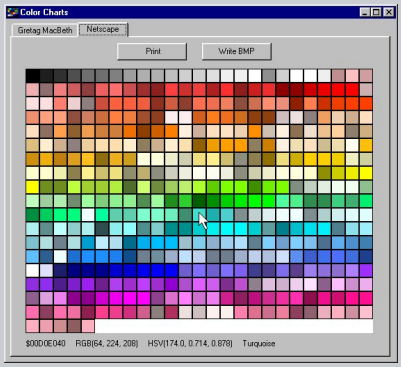
Profiling of a camera or a display monitors is done to describe a calibrated device color gamut to support color managed software applications.

Profiling

- Profiling of a display monitor is done using a software application that puts up a series of color patches with varying color and brightness.
- The color point of each is measured with a colorimeter.
- Generation of an accurate profile requires ~800 patches.
- For matrix/shaper profiles, a best fit 3x3 matrix and 3 LUTs are deduced and coded into a profile (.icc or .icm)

Profiling

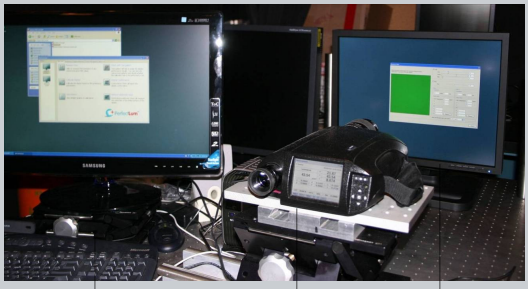
Accurate profiles require a large number of color test patterns.



From EFGs computer lab, www.efg2.com

Color Measurements

University of Arizona

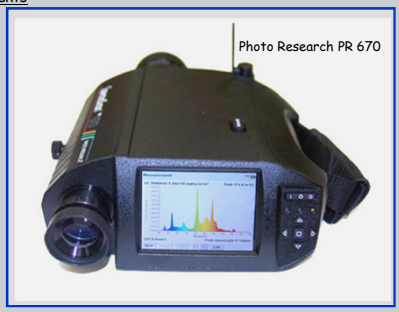


PR 670 Spectro-Photometer

Primary Monitor

Display Under Test

~$15K



Laboratory spectro-photometers accurately measure the emission spectrum from a spot. LUV or LAB coordinates can then be computer from appropriate RGB color matching functiton.

Field Measurements

~$200 - 800

Colorimeters use 3 to 6 sensors with different color filters to estimate X,Y or u',v'.

Open Source Software

Argyll CMS documentation index (V1.4)

Graeme Gill, www.argyllcms.com

- ArgyllCMS is an ICC compatible color management system, available as Open Source.
- ICC profile creation for cameras.
- calibration and profiling of displays.
- Drivers for most colorimeters & spectrophotometers.
- Comprehensive documentation is provided and a general guide to using the tools is also available.
- A listserver supports more advanced usage.

Standardization Efforts

Standard efforts

- IEC 62563-1:2010:
  - Medical image display systems - Evaluation methods
  - Initially focused on monochrome performance.
  - A maintenance team is is now addressing color.
- AAPM TG 18 (2005) :
  - Assessment of Display Performance for Medical Imaging Systems
  - focused on monochrome performance
- AAPM TG 196 (2010-?):
  - Requirements and Methods for Color Displays in Medicine
  - focused on color performance

Standard efforts

- TG 196 and the IEC MT are both chaired by A. Badano and many committee members serve on both.
- Both committees are agreed to recommend CIE 1964 (10°) D65 (~6500°, x,y = 0.3138,0.3310) as the calibration white point for medical monitors.
- Currently working on white point tracking with measures made at 17 luminance values.
- An inter-comparison of laboratory reference measures in now being done with two medical monitors sent to four different laboratories.
- Evaluation of the accuracy of low cost colorimeters with various software is planned next.

Recommended Reading

Color Vision and Colorimetry,
Theory and Applications.
Second Edition 2011
Daniel Malacara
SPIE Press

161 pages of easily understood material

Questions?