Introduction to Colour Science

NPGR025

Unit 8: WB, CAT, CAM

Computer
Graphics
Charles
University

Sources

Overview

- White Balance
- Colour Transforms
- CIECAM

White Balance
Colour Appearance Transforms (CAT)

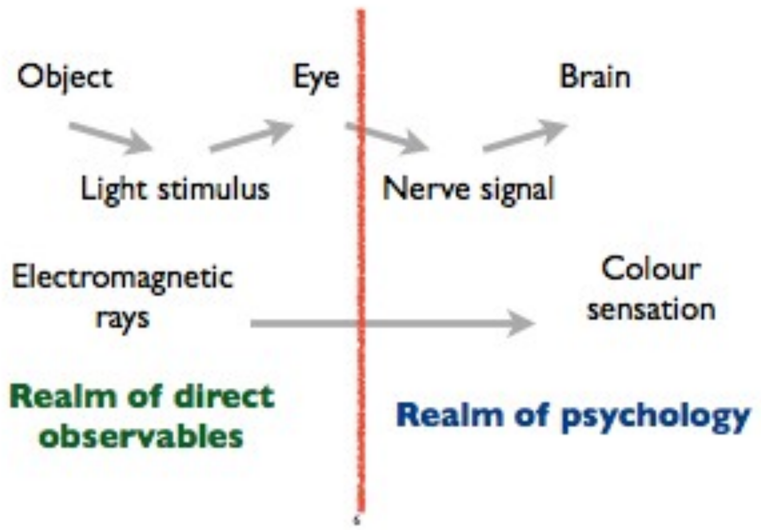
Terminology

- Colour Constancy (CC)
  - The name for the phenomenon
- Chromatic Adaptation (CA)
  - What your brain and eyes do to compensate ambient illumination colour casts
  - The name of the process behind CC
- White Balance (WB)
  - "What you do to images to make them look right"
  - Effectively simulation of CC/CA under different viewing conditions

Colour Transforms

- Colour values are dependent on the illuminant they are measured under
  - Reflected light = illumination x reflectance
- If only a colour value is known for an object, it is impossible to predict exactly what it will look like under a different illuminant
  - However, reasonable approximations of varying quality are possible
    - Von Kries, Bradford transform
  - These are referred to as "chromatic adaptation transforms" (CAT)

Colour - A Visual Sensation



Chromatic Adaptation: Example

Colour Correction

- Alternative name: white balance
- Attempts to replicate the illuminant hue compensation of the human visual system
- Overall goal: *evoke identical viewer response to captured or synthetic scenes, and reality*
- Problem: different viewing surrounds, different adaptation states of observer
  - Real scene: immersion
  - Captured scene (image): displayed on monitor
- Solution: *Colour Appearance Models*

CAM Overview

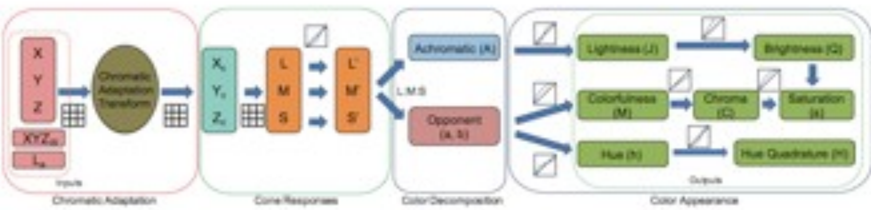
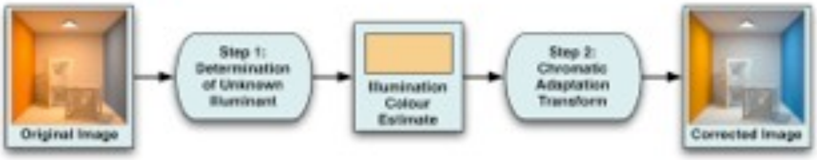


Figure from Kim, Weyrich, Kautz: Modeling Human Color Perception under Extended Luminance Levels, SIGGRAPH 2009

Colour Correction Workflow

- Colour Correction is a two-step process:
  - Determining the illuminant colour
  - Applying a transform that compensates for the illuminant
- *Step 1 is the tricky one if you only have image data at your disposal!*



State of the Art - Step 1

- Still a challenging task - many algorithms exist
  - Gray world, White patch, Retinex
  - Gamut constraint, Neural networks
- Large research area in computer vision
  - Goals are sometimes subtly different from computer graphics needs
- Almost all current algorithms are image based
  - Exception: Ward et al.
- Very sophisticated methods available
  - However, none are entirely robust!

Step 2 - Colour Appearance Transforms

- Colour values are dependent on the illuminant they are measured under
  - Reflected light = illumination x reflectance
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Linear Transform Chromatic Adaptation

- All colours are transformed within CIE XYZ space by a 3x3 matrix M

$$[X_D \quad Y_D \quad Z_D] = [X_S \quad Y_S \quad Z_S] \cdot [M]$$

(D - destination, S - source)

- The matrix M is dependent on the source and destination reference whites, which are also specified in CIE XYZ coordinates

Matrix Adaptation

- Transform the CIE XYZ value you want to adapt to a cone response domain (ρ, γ, β)
- Scale the (ρ, γ, β) components in this domain, based on the (ρ, γ, β) components of the two white points
- Transform the (ρ, γ, β) coordinates back to CIE XYZ with the inverse transform
- Executive Summary: you use source and destination white as input, and you get a 3x3 transformation matrix

Matrix Notation

$$[X_D \quad Y_D \quad Z_D] = [X_S \quad Y_S \quad Z_S] \cdot [M]$$

$$[M] = [M_A] \begin{bmatrix} \rho_D / \rho_S & 0 & 0 \\ 0 & \gamma_D / \gamma_S & 0 \\ 0 & 0 & \beta_D / \beta_S \end{bmatrix} [M_A]^{-1}$$

$$[\rho_S \quad \gamma_S \quad \beta_S] = [X_{WS} \quad Y_{WS} \quad Z_{WS}] \cdot [M_A]$$

$$[\rho_D \quad \gamma_D \quad \beta_D] = [X_{WD} \quad Y_{WD} \quad Z_{WD}] \cdot [M_A]$$

Cone Response Matrices

- **Von Kries - older approach**

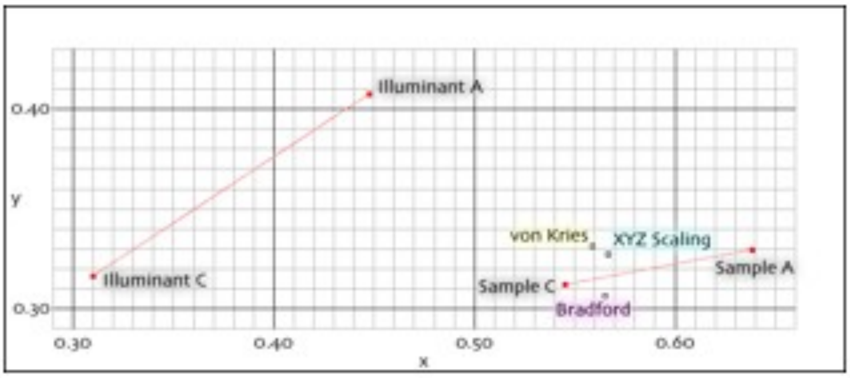
$$[M_A] = \begin{bmatrix} 0.40024 & -0.22630 & 0.00000 \\ 0.70760 & 1.16532 & 0.00000 \\ -0.08081 & 0.04570 & 0.91822 \end{bmatrix}$$

- **Bradford - newer, used within Photoshop**

$$[M_A] = \begin{bmatrix} 0.8951 & -0.7502 & 0.0389 \\ 0.2664 & 1.7135 & -0.0685 \\ -0.1614 & 0.0367 & 1.0296 \end{bmatrix}$$

CAT Performance Example

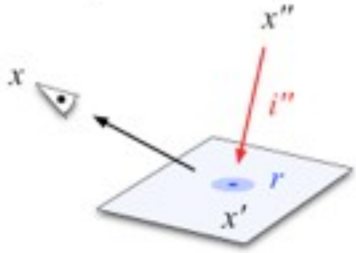
- **Illuminant and red Macbeth patch CIE (x,y) coordinates:**



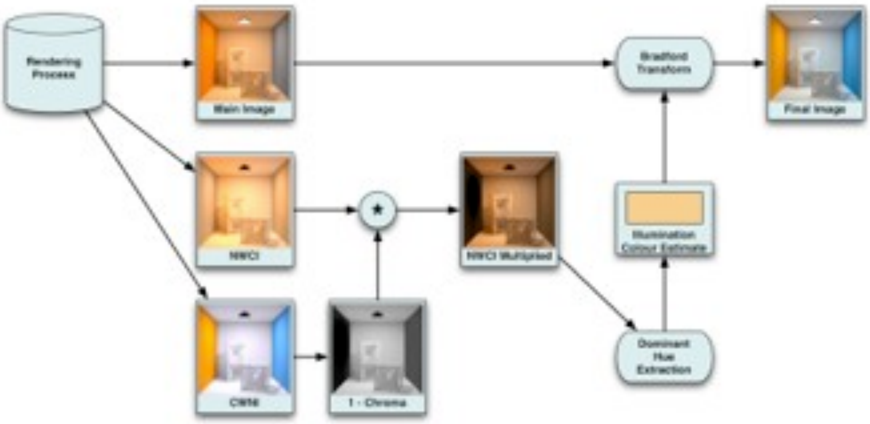
A Technique for Determining Relevant Illumination in Renderings

Algorithm Overview

- Two additional images are computed during rendering
  - All directly viewed surfaces set to neutral
  - All lights set to neutral on directly viewed surfaces
- Cheap to compute as by-product of rendering
- Sub-sampling possible
- Images processed to get actual illumination estimate

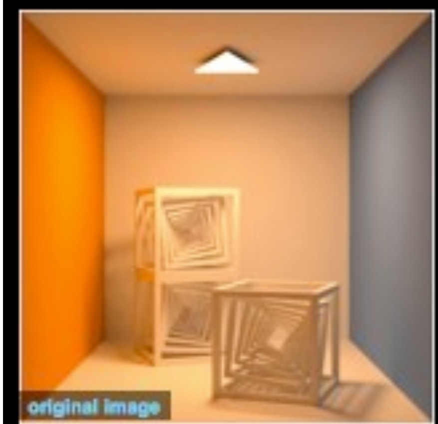


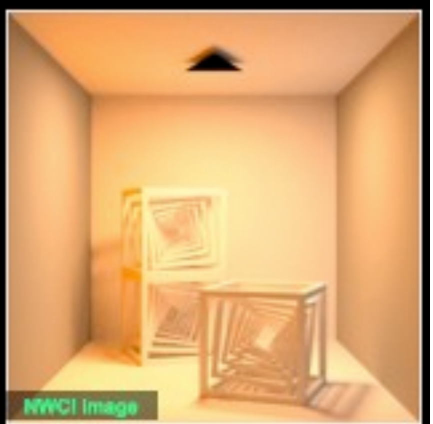
Illumination Estimator - Overview



NWCI Image

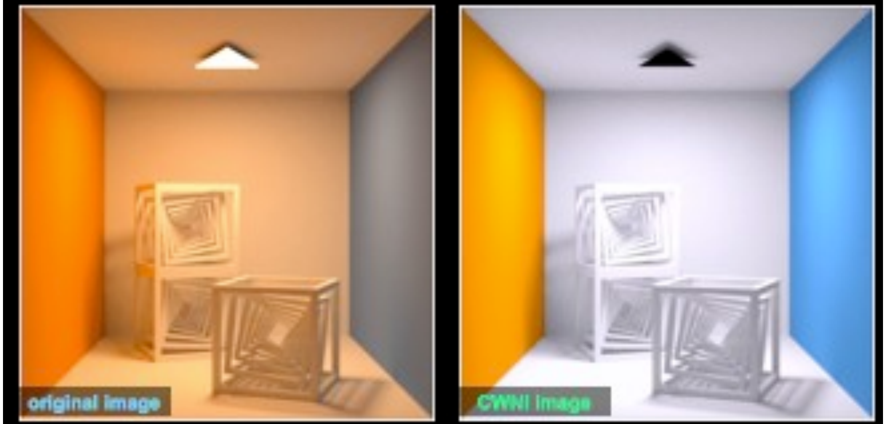
NWCI stands for Neutral World, Coloured Illuminants



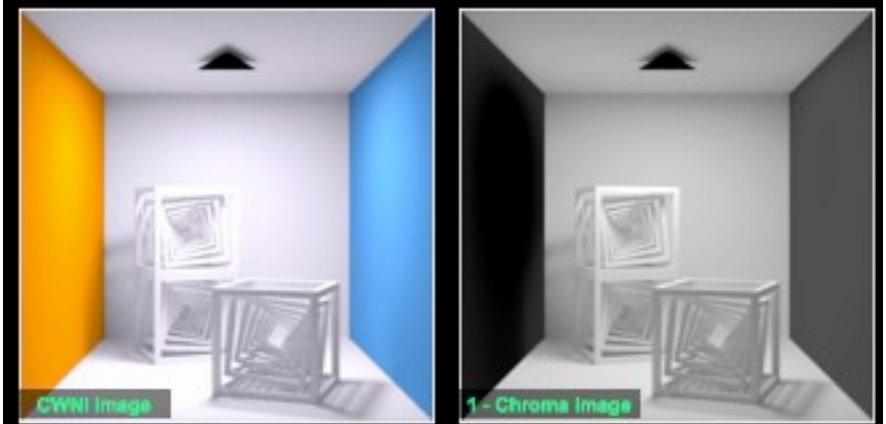


CWNI Image

NWCI stands for Coloured World, Neutral Illuminants



1 - Chroma Image



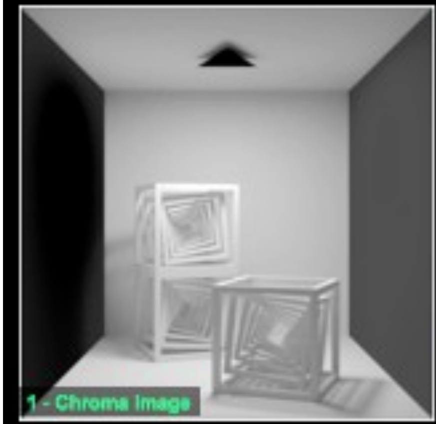
1 - Chroma Image

- CWNI image is converted to LCH space
- Compute min, max chroma and luminance values for entire image

$$g = \left(\left(1 - \frac{C_{pixel} - C_{\min}}{C_{\max} - C_{\min}} \right) \cdot \frac{L_{pixel}}{L_{\max}} \right)^{w}$$

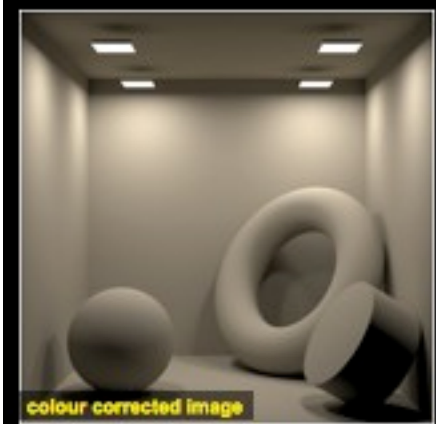
- Parameter w allows control of how much emphasis is placed on reference white objects

NWCImul Image



Results

White vs. Orange World



white box, orange light

orange box, white light

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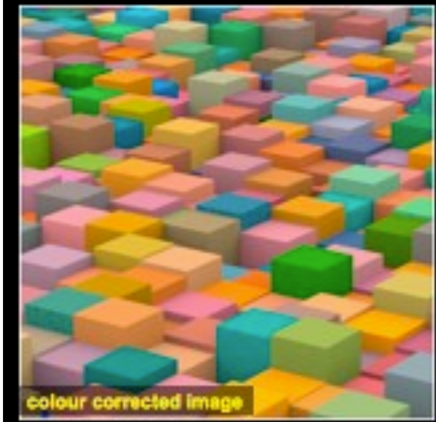
3D Mondrian, Yellow Illuminant



no white object present

one white block in scene

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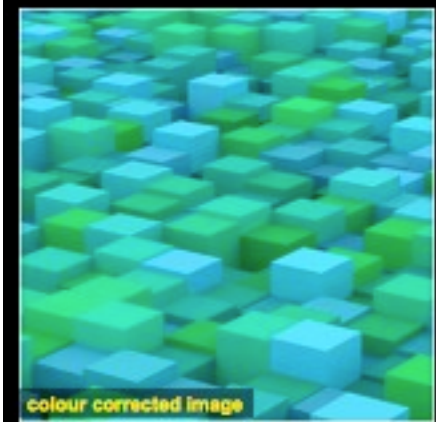
Green-Blue 3D Mondrian, Blue Light



no white object present

one white block in scene

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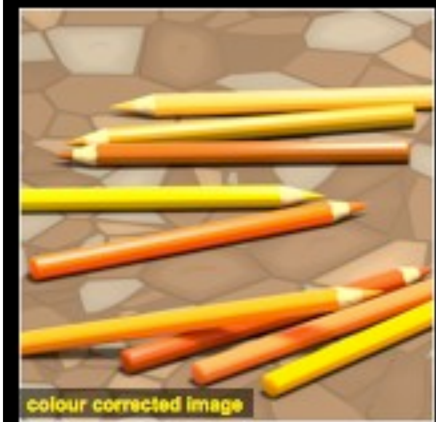
Adaptation for Reference White Objects

Influence of Parameter *w*

Additional Examples



Realistic Scene, Various Illuminants

Conclusion

- Technique to reliably extract relevant illuminant colour from renderings
- Cheap to compute
- Caters for influence of larger influence of white objects on illuminant colour perception
- How this information is then used is up to the tone reproduction / CAM used
  - Bradford transform appears to be sufficient

Chromatic Adaptation Models (CAM)

CIELab & CIELuv Appearance Prediction

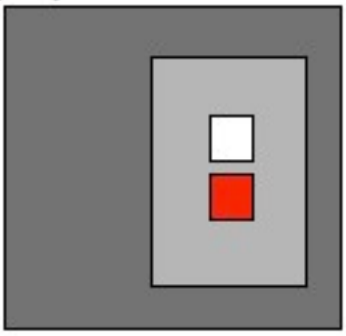
- CIE Lab & CIE Luv are limited in their applicability
  - Theoretically only valid for small viewing angles
  - Surround and observer status are not included in the model
- For prediction of object appearance under varying conditions, CATs have to be used
  - Inherently inaccurate
- Integrated models are needed!

Colour Appearance Models - CIECAM

- A Colour Appearance Model is a model of colour vision, which is capable of predicting colour appearance under different viewing conditions
- A CAM must
  - Account for chromatic adaptation
  - Have correlates for at least lightness, chroma and hue
    (CIE TC 1-34, 1992)

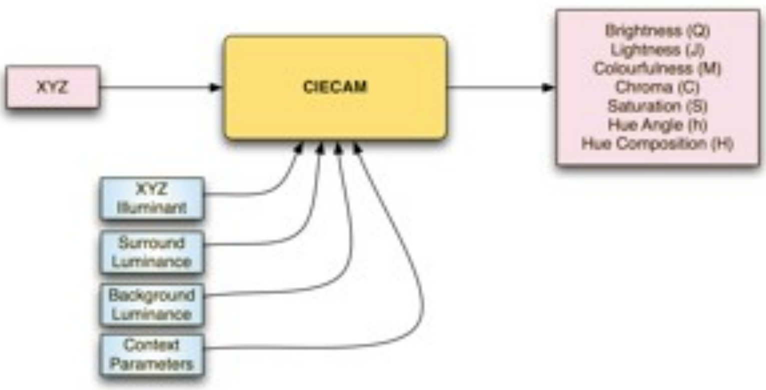
CIECAM 97 and 02

- First CIE CAM published in 1997, revised in 2002 (CIECAM 02 replaces 97)
- Complex model with many input parameters:
  - Illuminant colour / reference white
  - Surround luminance
  - Background luminance
  - Colour value
  - Context parameters



CIECAM I/O

- Transforms XYZ data to a perceptual space



CAM Overview

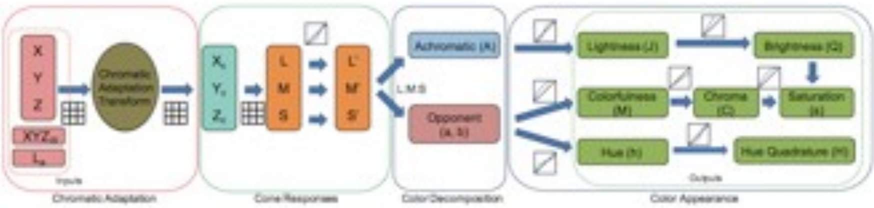


Figure from Kim, Weyrich, Kautz: Modeling Human Color Perception under Extended Luminance Levels, SIGGRAPH 2009

CAT vs. CAMs in Image Reproduction