

Lecture 6

Colour





Lecture Outline

- › Colour – Fundamental concepts
 - Human Colour perception
- › Colour spaces/models
- › Distance in colour space
 - Perceptually meaningful
- › Applications
 - Using colour information

Fundamental Concepts

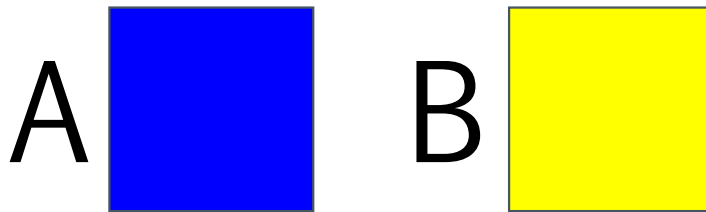






Let's take some simple tests...

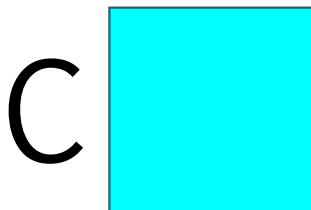
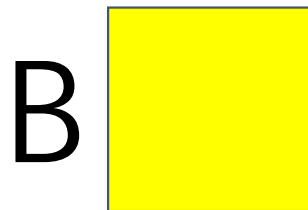
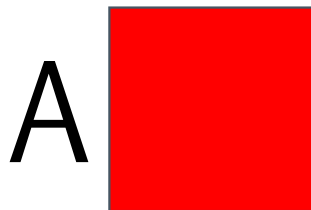
$$\text{Red Square} + \text{Green Square} = ?$$





How about this...

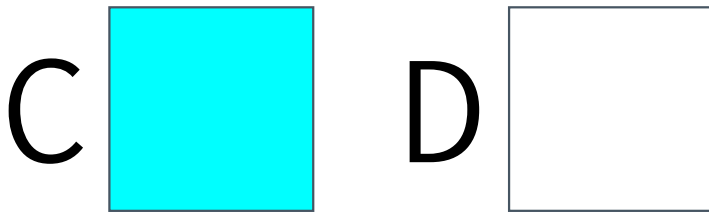
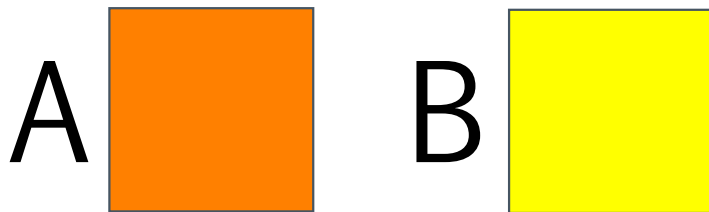
$$\text{Green Square} + \text{Blue Square} = ?$$





And this...

$$\text{Red Square} + \text{Green Square} = ?$$

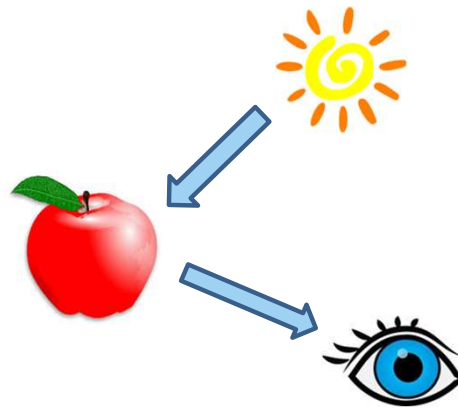




Colour

> What is colour?

- The result of interaction between physical light in the environment and our visual system
- A psychological property of our visual experiences when we look at objects and lights, not a physical property of those objects or lights

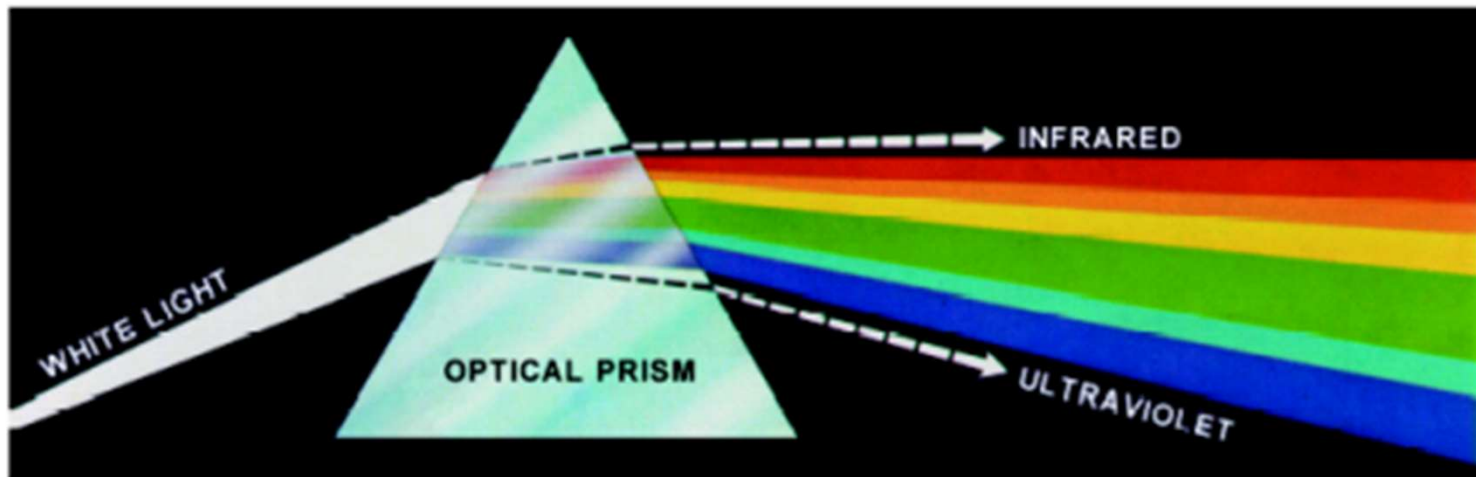


Source: Vision Science: Photons to Phenomenology (Palmer 1999)



Colour

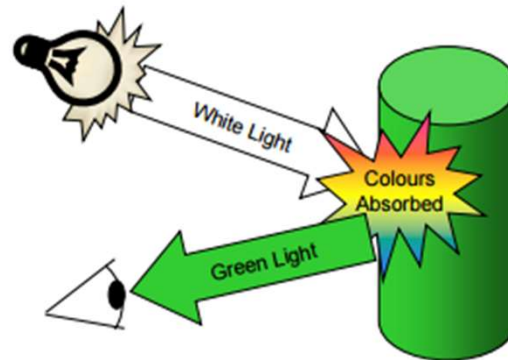
- › In 1666, Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam is split into a spectrum of Colours





Colour

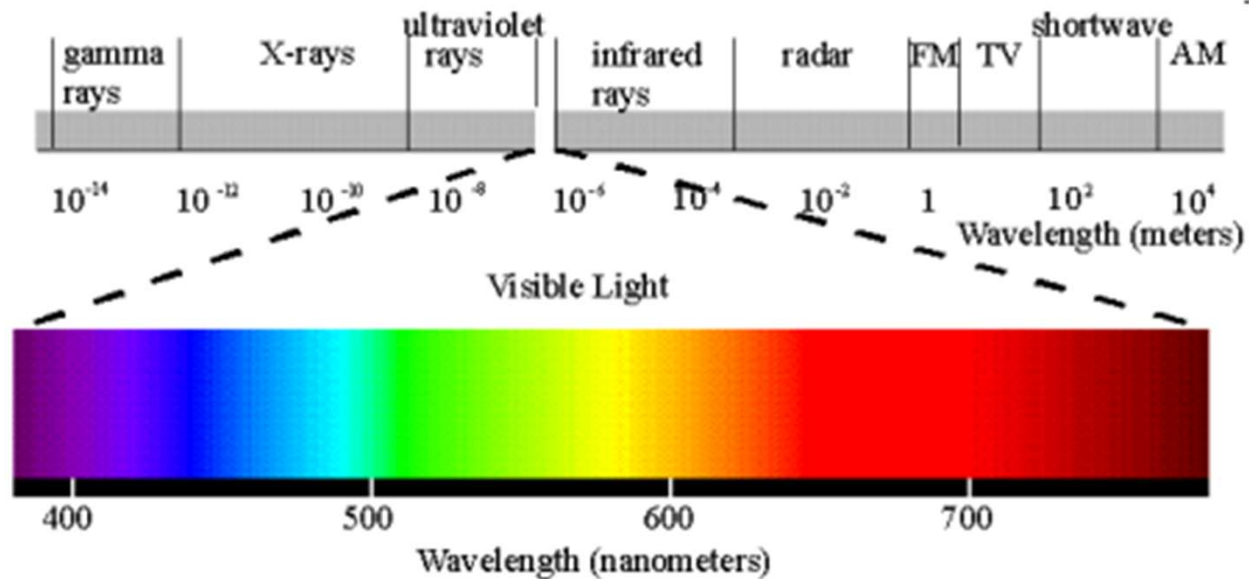
- › The colours that humans and most animals perceive in an object are determined by the nature of the light reflected from the object
 - E.g. Green objects reflect light with wavelengths primarily in the range 500-570 nm while absorbing most of the energy at other wavelengths





Colour

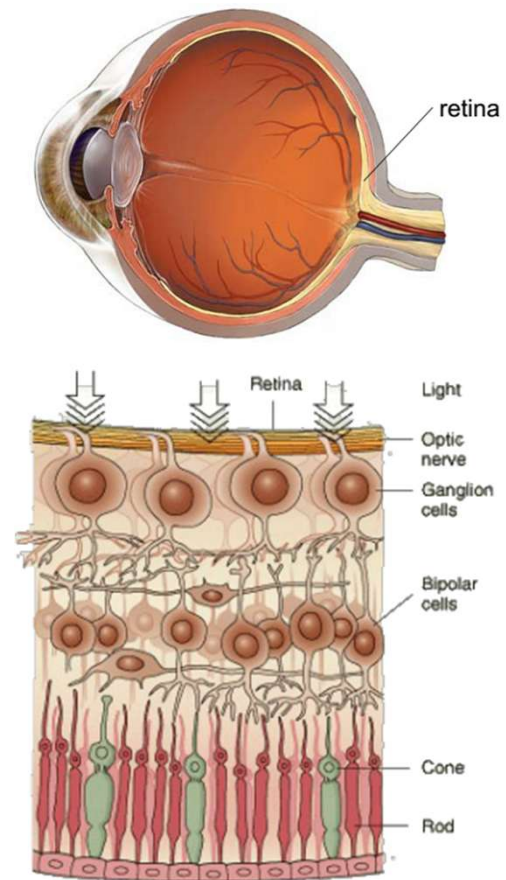
- › Chromatic light spans the electromagnetic spectrum from approximately 400 to 700 nm





Human Colour Perception

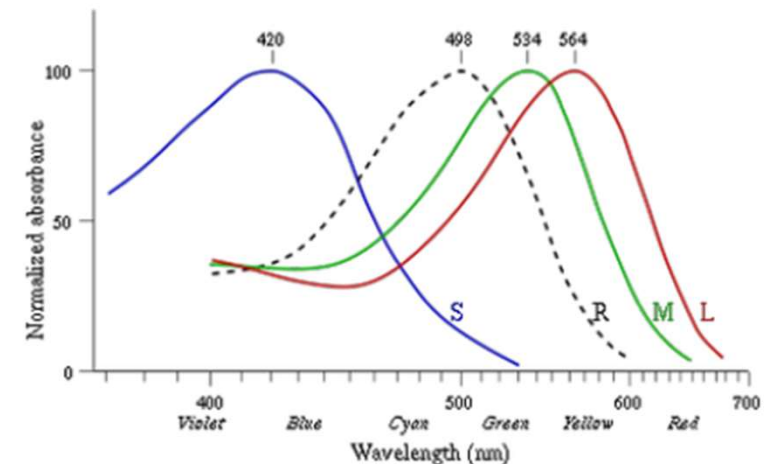
- › Human eye has retina that senses light
- › Human retina has 2 kinds of light receptors (or *photoreceptor* cells)
- › **Rods:**
 - Sensitive to amount of light
 - operate more at night
 - gray-scale vision
- › **Cones:**
 - Sensitive to lights of different wavelengths
 - operate in high light
 - Colour vision





Human Colour Perception

- › 3 kinds of cones:
 - **Short (S)**: most sensitive to **blue**
 - **Medium (M)**: most sensitive to **green**
 - **Long (L)**: most sensitive to **red**
(~ 66% of all cones, the most)
- › Cone sends signals to brain
- › Brain interprets mixture of signals as colours
- › That is why colours are coded with 3 primary values
- › Different coding schemes give different colour spaces



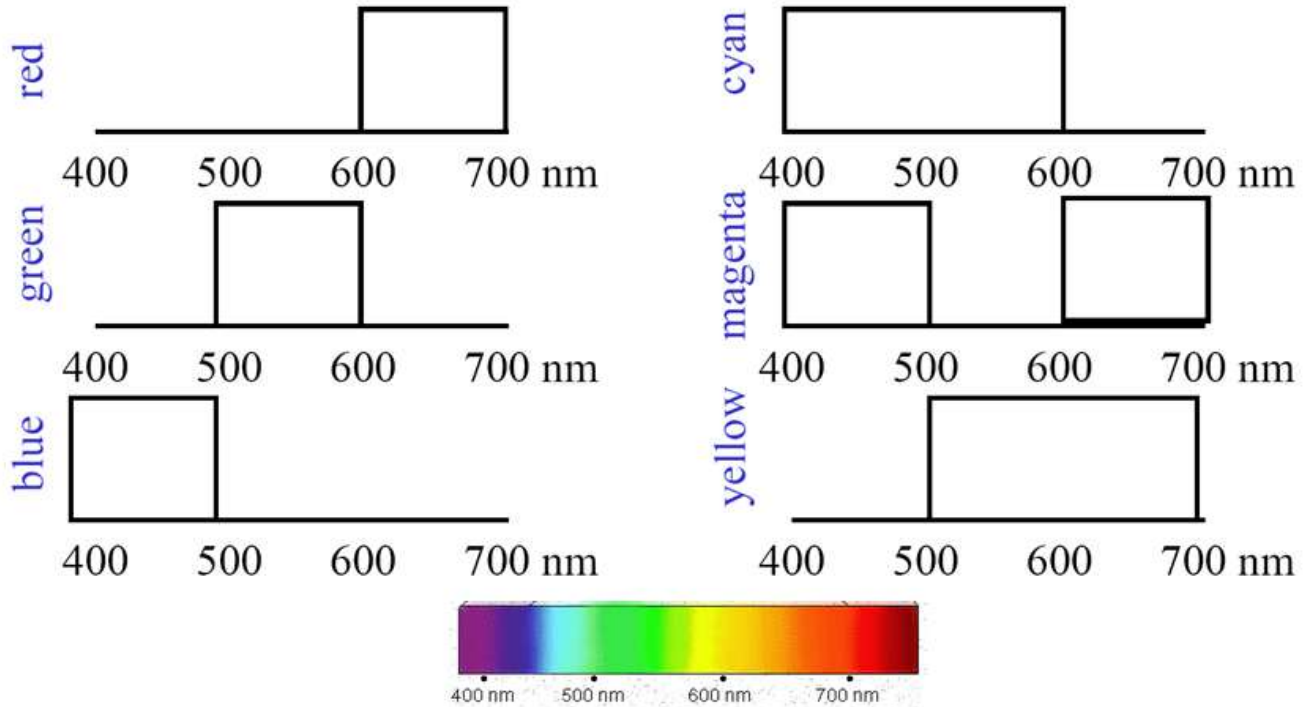
- › Fun fact:
 - Mantis shrimp has 12-16 cones

Source: National Geographic
(<https://www.nationalgeographic.com/science/article/natures-most-amazing-eyes-just-got-a-bit-weirder>)



Colour Mixing

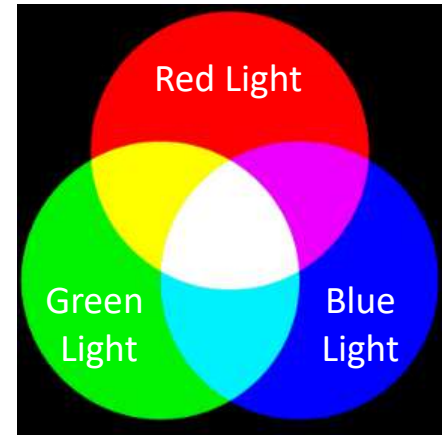
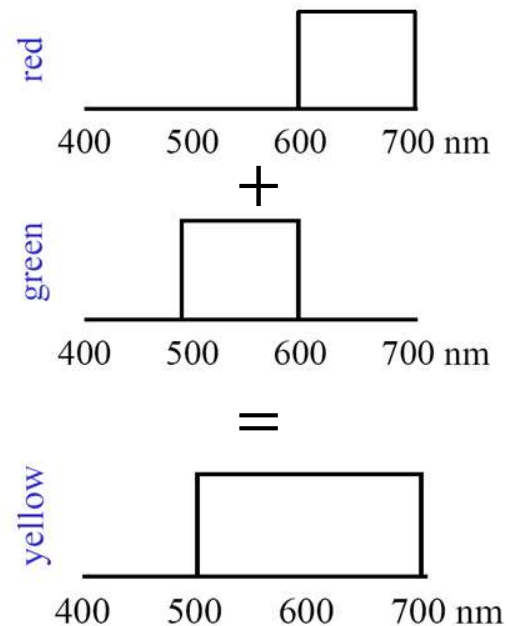
› Spectra for Colour names:





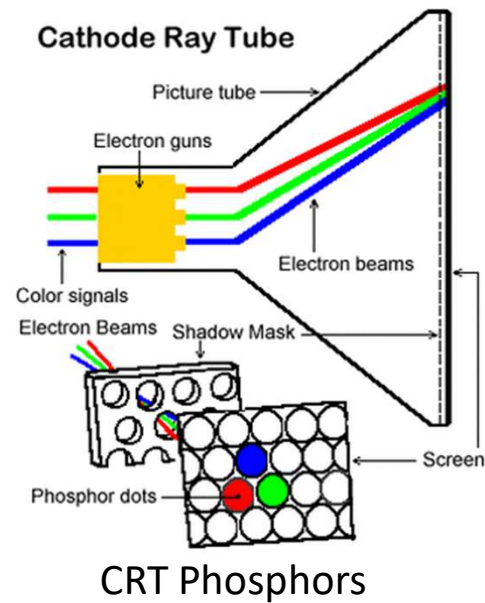
Additive Colour Mixing

- › Colours are combined by **adding** to the colour spectra
- › The **light** colours are added on to the black so it **becomes white when all colours are added**
- › Different from mixing paint





Example of additive colour systems

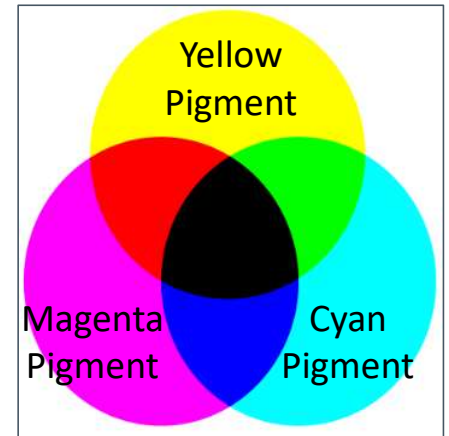
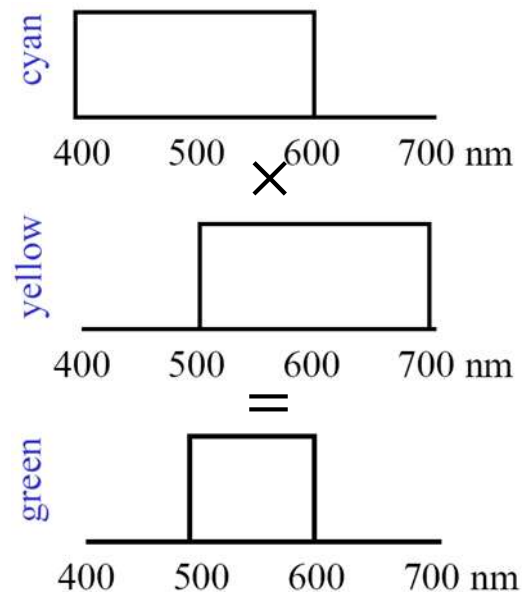


Multiple projectors



Subtractive Colour Mixing

- › Colours are combined by **multiplying** to the colour spectra
- › The **pigments remove colour** from white so it becomes black when all colours are removed
- › This is mixing paint
 - And also film photography





Example of subtractive colour systems

- › Printing on paper
- › Photographic film





Problems with Processing Colour Images

- › When processing colour images, the following problems (amongst others) have to be dealt with:
 - **The images are vectorial** → 3 numbers are associated with each pixel.
 - The colours recorded by a camera are heavily **dependent on the lighting conditions**.



Lighting conditions

- › The lighting conditions of the scene have a large effect on the colours recorded.

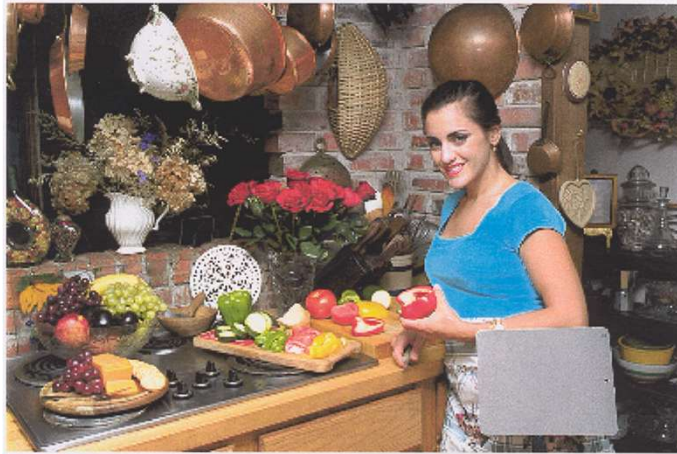


Image taken lit by a flash.

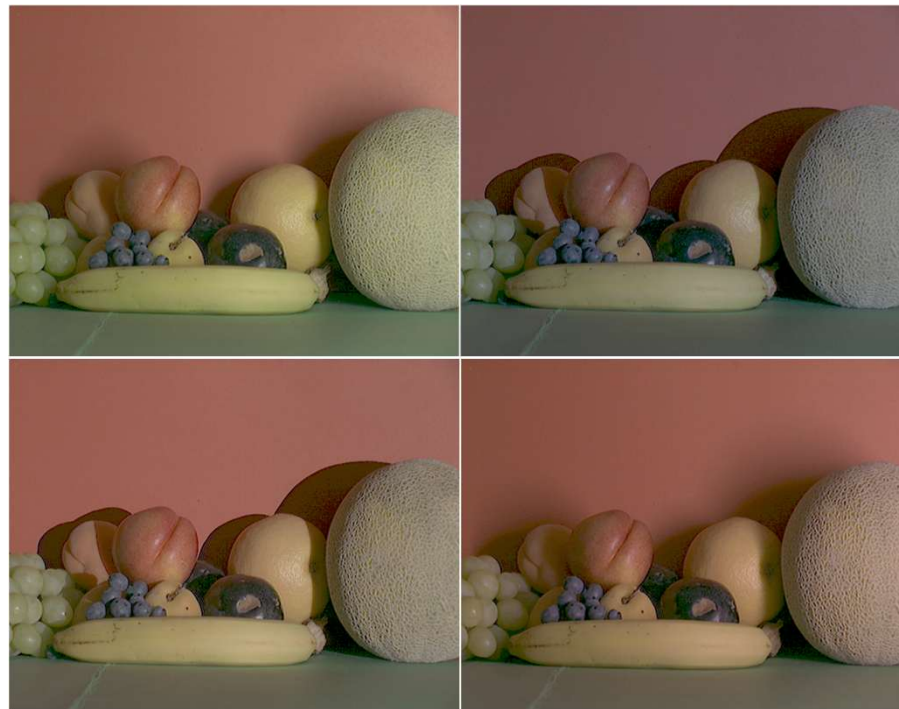


Image taken lit by a tungsten lamp.



Lighting Conditions

- › The following four images of the same scene were acquired under different lighting conditions:





Dealing with Lighting Changes

- › **Knowing just the RGB values is not enough** to know everything about the image.
 - The R, G and B primaries used by different devices are usually different.
- › For **scientific work**, the camera and lighting should be calibrated.
- › For **multimedia applications**, this is more difficult to organise:
 - Algorithms exist for estimating the illumination colour.

Colour Spaces / Models





Colour space/model

› Colour space/model

- to facilitate the specification of colours in some standard
 - specification of a coordinate system and a subspace within the system where each colour is represented by a single point
- › Most colour models are oriented either toward specific hardware or application



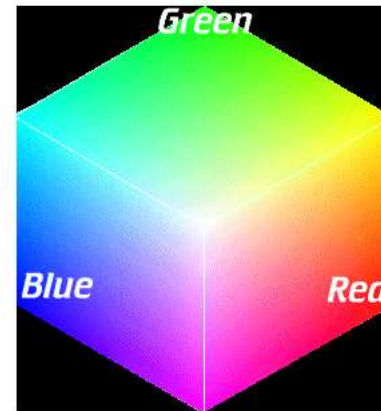
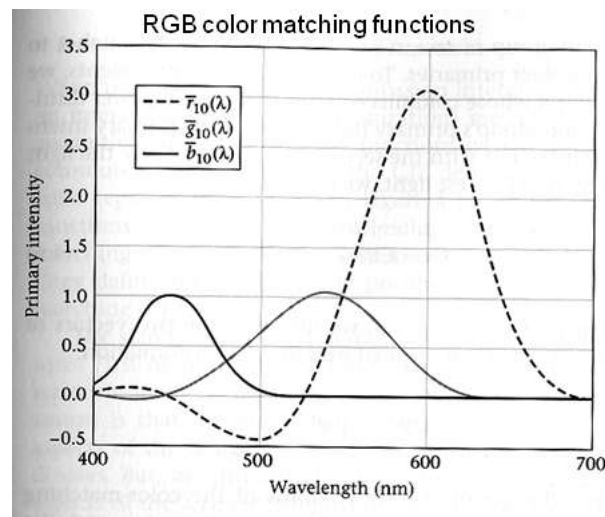
Standard colour spaces

- › Use a common set of primitives/colour matching functions
- › **Linear** colour spaces
 - RGB, CMY, NTSC, YCbCr
 - CIE XYZ, CIE Lab
(Commission internationale de l'éclairage / International Commission on Illumination)
- › **Non-linear** colour space
 - HSV (or HSB/HSI)



RGB Color Space

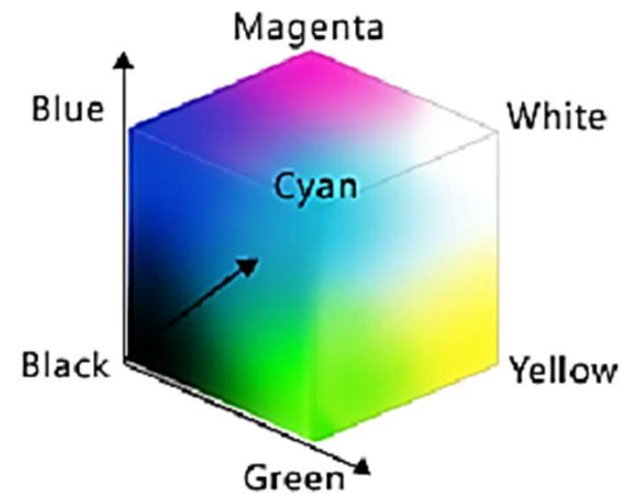
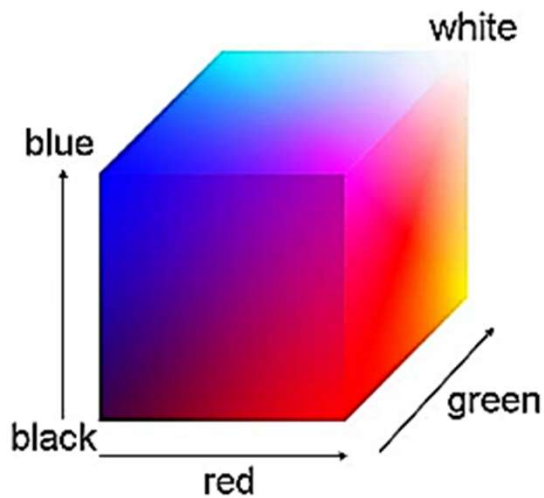
- › Single wavelength primaries
- › Good for devices (e.g. phosphors for monitor), but not for perception
- › Suitable for displays (additive colour model)





RGB Colour Space

- › Colour is coded with a triplet: (red, green, blue)
- › The three values are known as the **primary colours**





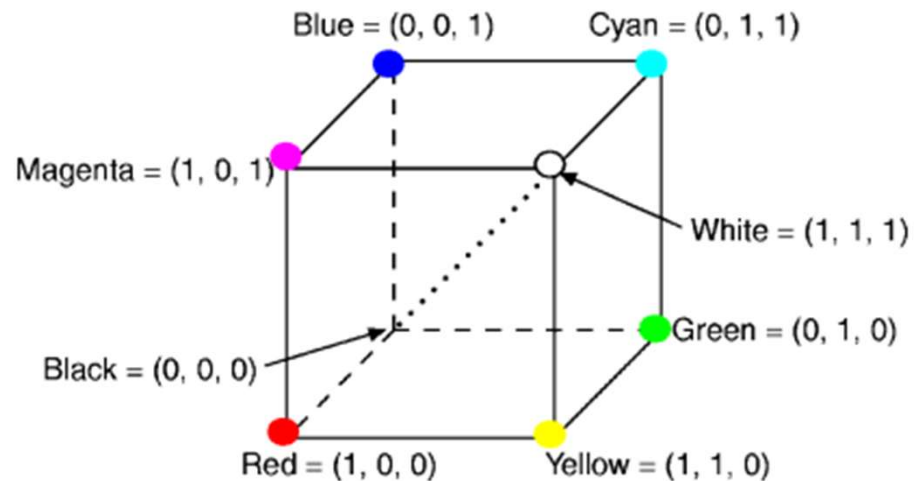
3 “Primary” Colours

- › **Common misconception of the word “primary”:**
 - Widely misinterpreted to mean that the three primaries, when mixed in various proportions, can produce *all* visible colours
- › We can only **approximate** all the spectrum colours by mixing the primaries



RGB Model

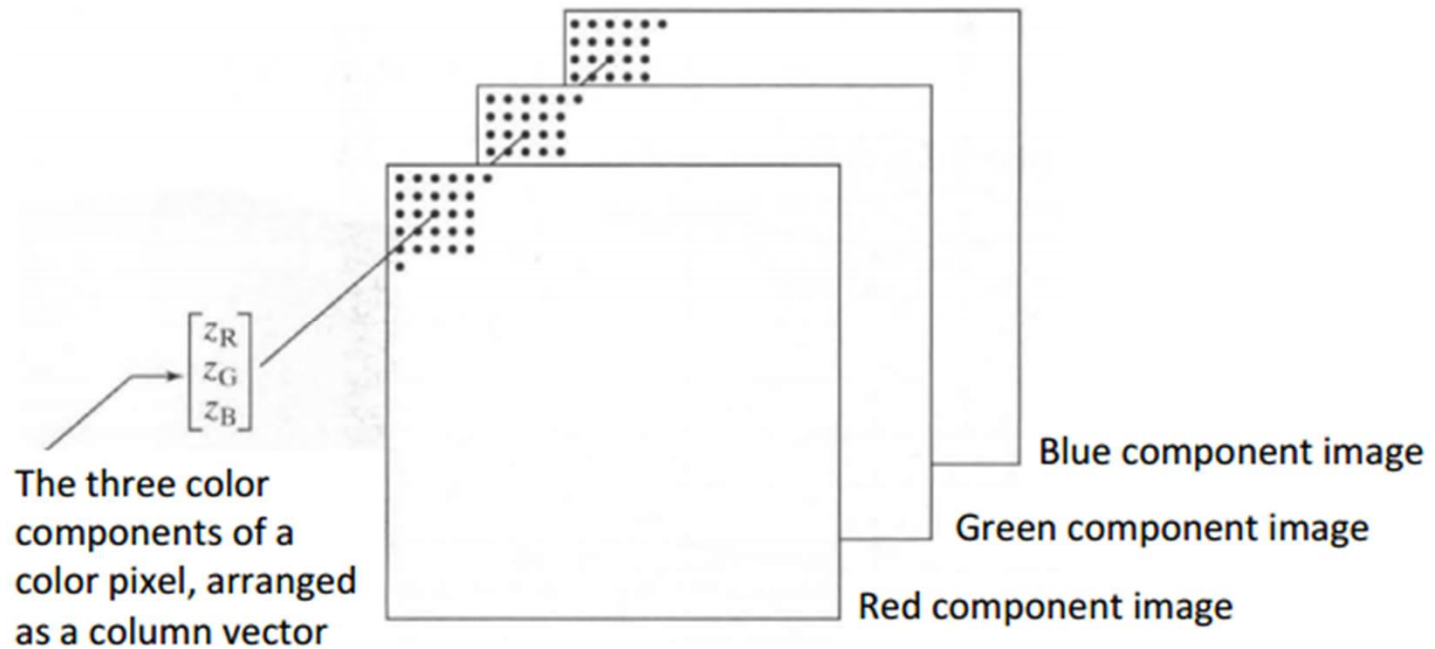
- › This model is based on a Cartesian coordinate system
- › Colour subspace is in a cube: RGB primary values are at three corners; black is at the origin while white is at the corner farthest from the origin





RGB Model

- › Can be viewed as a “stack” of 3 grayscale images

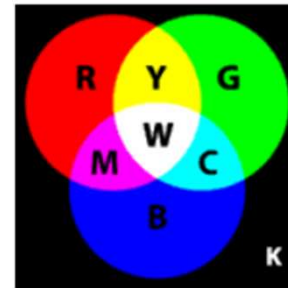




CMY (CMYK) Model

› The primary colors (R, G, B) can be added to produce the **secondary** colors

- Red + Blue = Magenta
- Green + Blue = Cyan
- Red + Green = Yellow



› It takes cyan, magenta and yellow as “primary colors”

› Easily converted from RGB model by

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

where all color values
have been normalized
to the range [0, 1]



CMY (CMYK) Model

- › In theory: Equal amounts of cyan, magenta and yellow (pigment primaries) should produce “black”
 - But such a method usually generates quite a muddy black (not a true black)
- › To produce “true black”, a 4th color, “black” is added, giving rise to a CMYK color model (K stands for “black inK”)
 - Suitable for printing (subtractive color model)



Test-It-Yourself (TIY)

1. Convert the following color (0.4, 0.7, 1.0) from CMY to RGB
 - A. (-0.4, -0.7, -1.0)
 - B. (0.4, 0.7, 1.0)
 - C. (-0.6, -0.3, 0.0)
 - D. (0.6, 0.3, 0.0)



Test-It-Yourself (TIY)

2. Make a good guess what colours are represented by these RGB values.

$$C_1 = (1.0, 0.5, 0.0)$$

- A. Red?
- B. Orange?
- C. Yellow?
- D. Green?





Test-It-Yourself (TIY)

3. Make a good guess what colours are represented by these RGB values.

$$C_2 = (0.5, 0.0, 0.5)$$

- A. Red?
- B. Pink?
- C. Magenta?
- D. Blue?





Test-It-Yourself (TIY)

4. Make a good guess what colours are represented by these RGB values.

$$C_3 = (0.6, 0.6, 0.6)$$

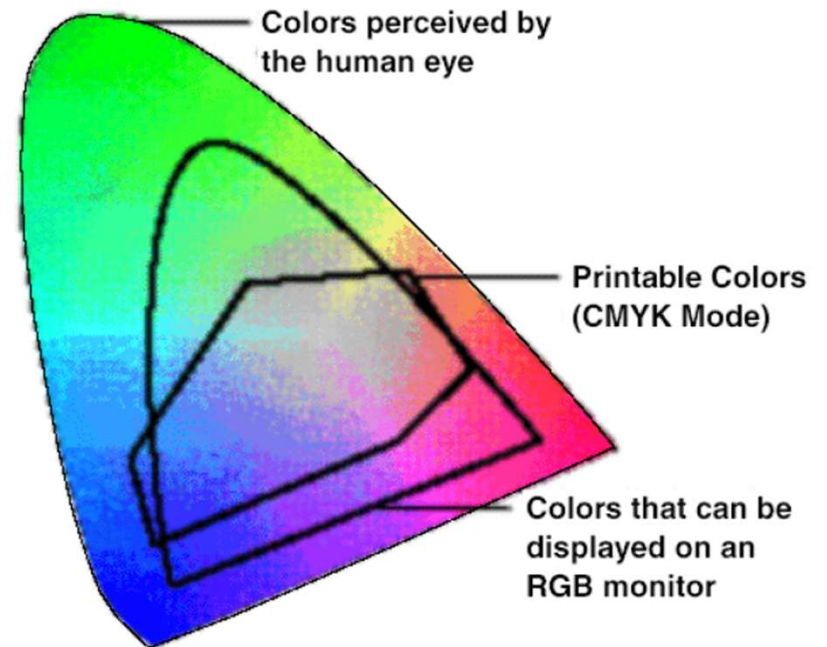
- A. White?
- B. Cyan?
- C. Grey?
- D. Black?





Colour Gamut

- › **Gamut:** Colour range of a model
 - RGB model has larger gamut than CMY
- › Some colours on screen (RGB) may not be printable (CMY)
 - Replaced by closest colour in the CMY gamut

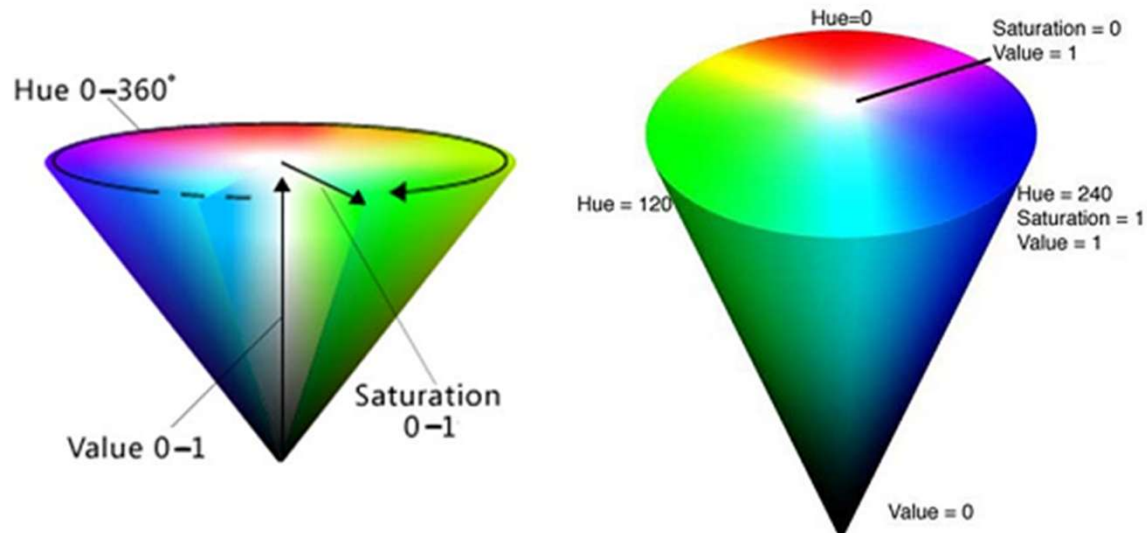


Chromaticity Diagram



HSV (or HSI) Colour Space

- › Colour coded as hue, saturation and value
 - Also called HSB (B for brightness) or HSI (I for intensity) sometimes





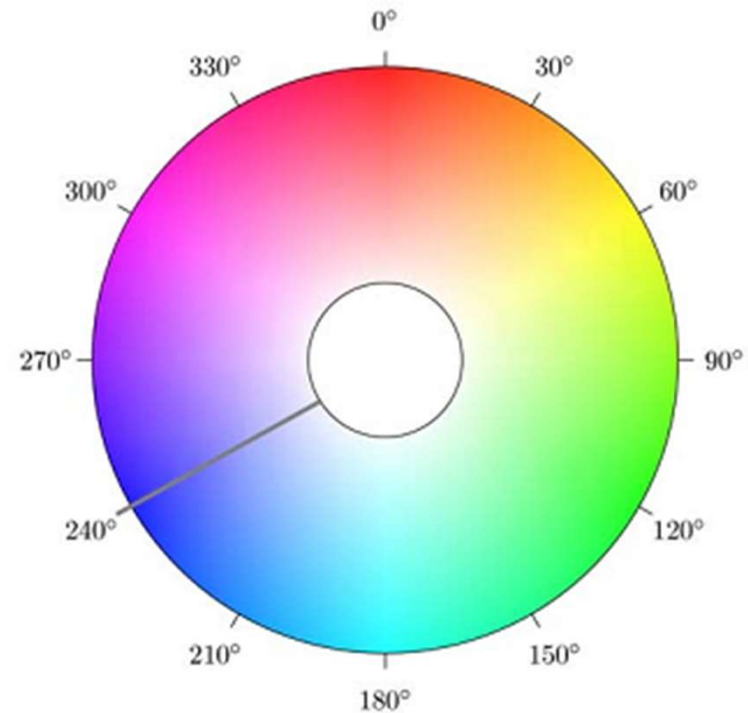
HSV (or HSI) Colour Space

- › **Closer to human perception** – More intuitive than RGB
 - **Hue**: Dominant colour as perceived by the observer
 - **Saturation** (purity): Relative amount of white light mixed with the hue
 - **Value or Brightness**: Amount of light, or intensity of the hue
- › Hue and Saturation together are called **Chromaticity** which are properties related to the perceived colour or “*chroma*”



HSV (or HSI) Model

- ⊙ Hue
 - colour type
 - 0° (red) to 360°
- ⊙ Saturation
 - Colourfulness
 - 0 to 1 (full colour)
- ⊙ Value
 - Brightness
 - 0 (black) to 1 (white)





Comparison between colour spaces



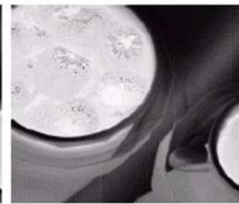
Full color



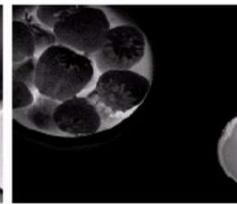
Cyan



Magenta



Yellow



Black



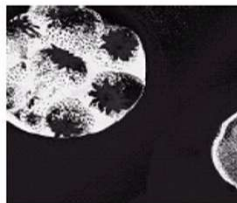
Red



Green



Blue



Hue



Saturation



Intensity

Key to understand these grayscale images:
'1' (white) is "full of it"
'0' (black) is "empty" or the "lack of it"



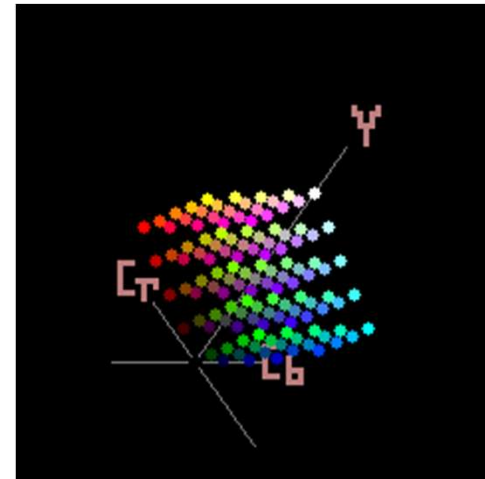
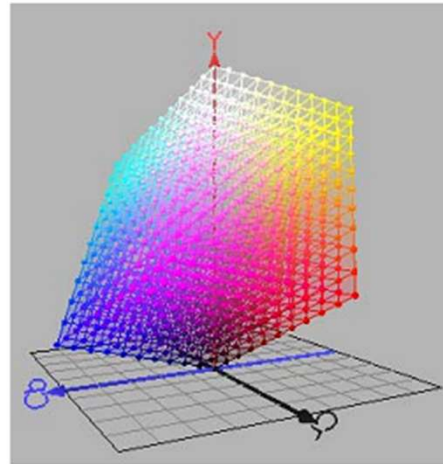
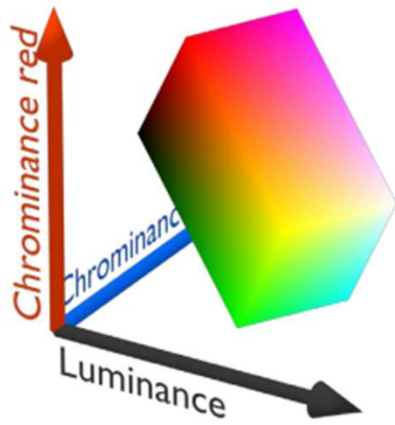
YCbCr Model

- › **YCbCr** color space is extensively used in digital video
 - **Y**: Luminance
- Color information is stored as two colour-difference components:
 - **Cb**: Difference between blue and reference component
 - **Cr**: Difference between red and reference component
- › Conversion from RGB to YCbCr

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \begin{bmatrix} 65.481 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112.000 \\ 112.000 & -93.786 & -18.214 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



YCbCr Model



Source: Wikipedia



YCbCr Model

RGB image



Luminance component



Cb component



Cr component



Distance in colour space

and knowing what “perceptually meaningful” means





Colour Difference

- › Consider two colours C_1 and C_2
- › How to measure difference between C_1 and C_2 ?
- › Simplest difference measure: Euclidean distance

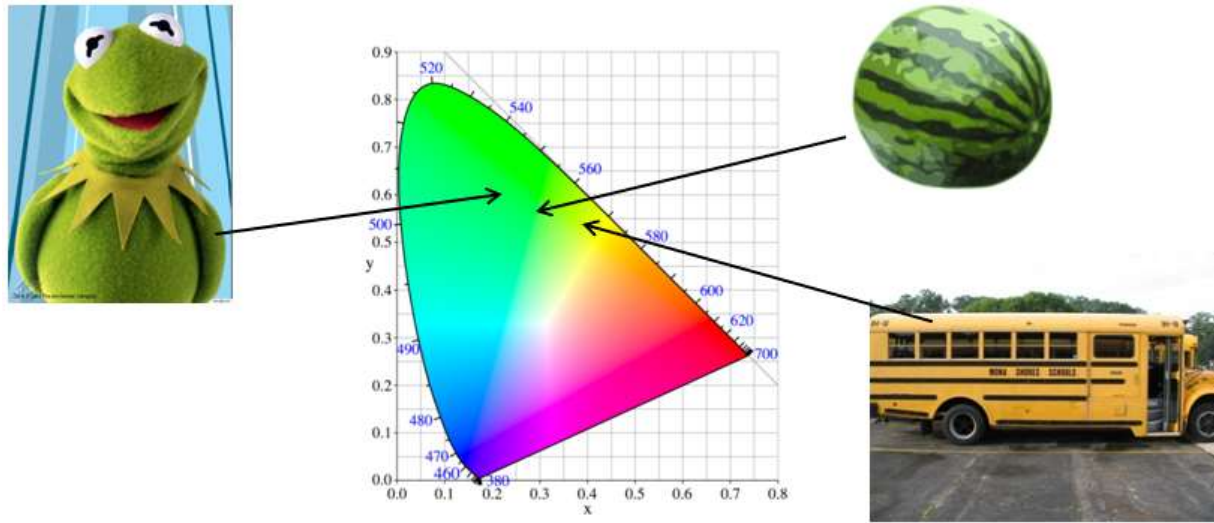
$$d(C_1, C_2) = \sqrt{(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2}$$

- › Straight line distance in colour space (in this e.g. RGB)



Distances in colour space

- › Are distance between points in a colour space **perceptually meaningful**?





Color Difference

- › Not necessary
- › RGB space is **not perceptually uniform**
 - magnitude of differences in coordinates are poor indicator of colour “distance”
 - Equal colour distance \neq Equal perceptual difference
 - Inappropriate if need to match human perception
- › HSV, YCbrCr also **not perceptually uniform**
- › Perceptually (more) uniform colour spaces:
 - **CIE LAB, CIE LUV**



Uniform colour spaces

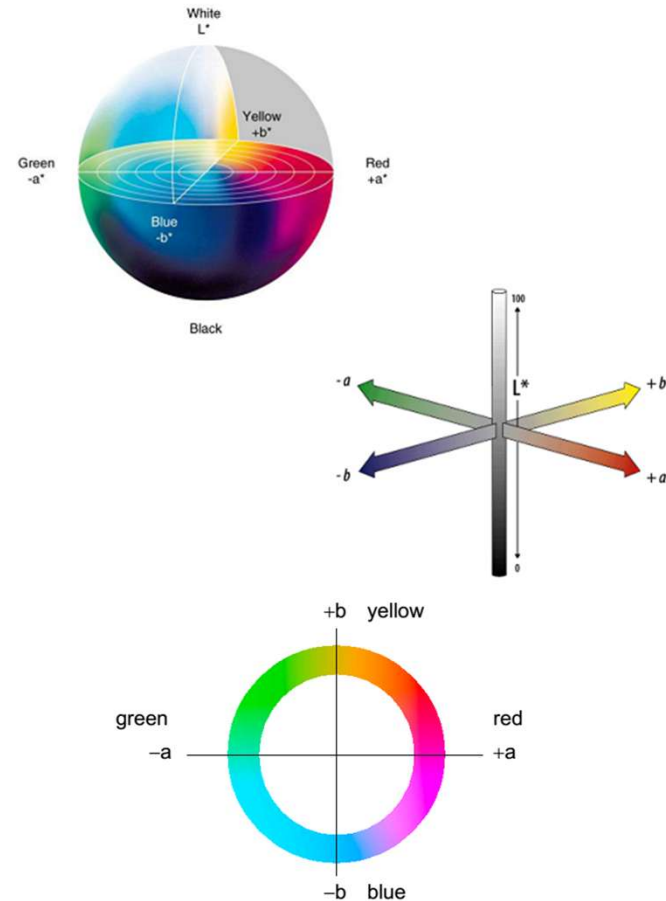
- › Attempt to correct this limitation by re-mapping colour space so that just noticeable differences are contained in more circular spots and they are **separated more uniformly**

⇒ **distances more perceptually meaningful**



CIE LAB and CIE LUV

- › **CIE 1976 L*a*b** color space
 - **L***: matches human perception of lightness
 - From 0 (black) to 100 (white)
 - **a***, **b***: hue
- › **CIE 1976 L*u*v** color space
 - Similar to CIE LAB color space
 - **L***: range from 0 to 100
 - **u***, **v***: typically range from -100 to +100



Applications

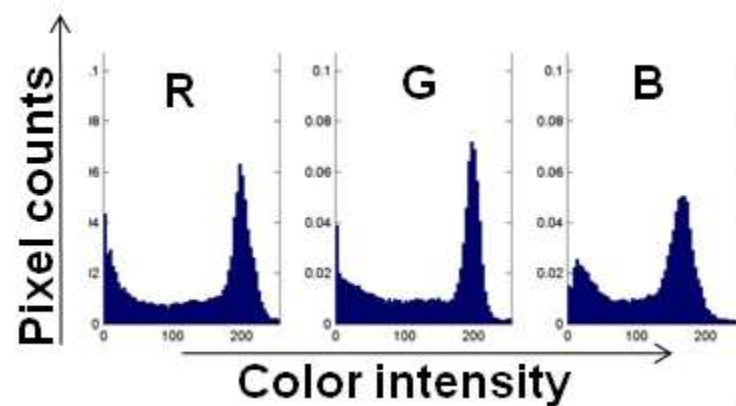
Using colour information





Colour as a low-level cue for CBIR

- › **CBIR**: Content-Based Image Retrieval
- › **Color histograms**
 - Use distribution of colors to describe image
 - No spatial info – invariant to translation, rotation, scale





Color-based image retrieval

› Given **collection (database) of images**

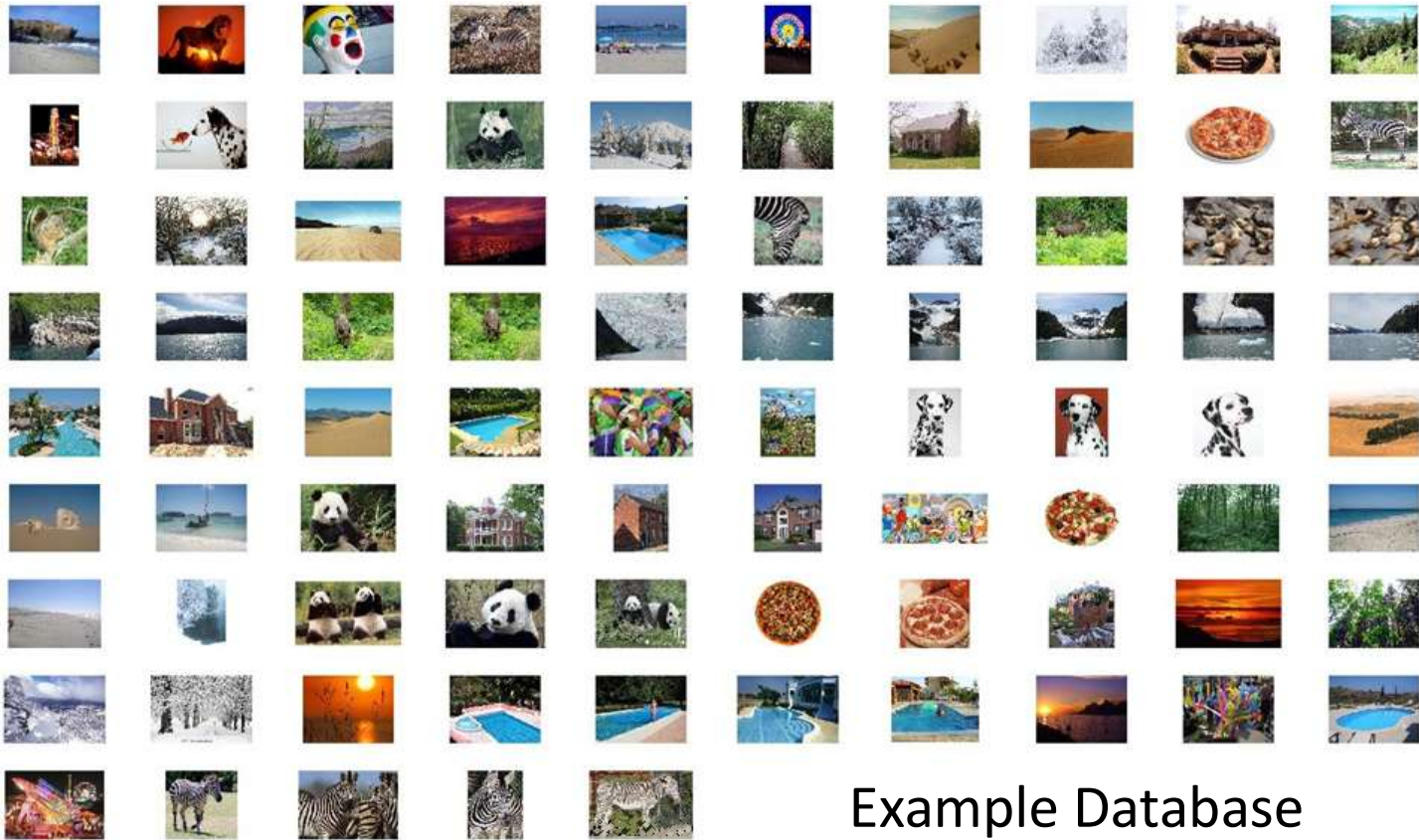
- Extract and store one color histogram per image

› Given **new query image**

- Extract its color histogram (similar way as before)
- For each database image, compute distance between query histogram and database histogram
- Sort distances (**smallest score = most similar image**)
- Rank database items relative to query based on this sorted order



Colour-based image retrieval

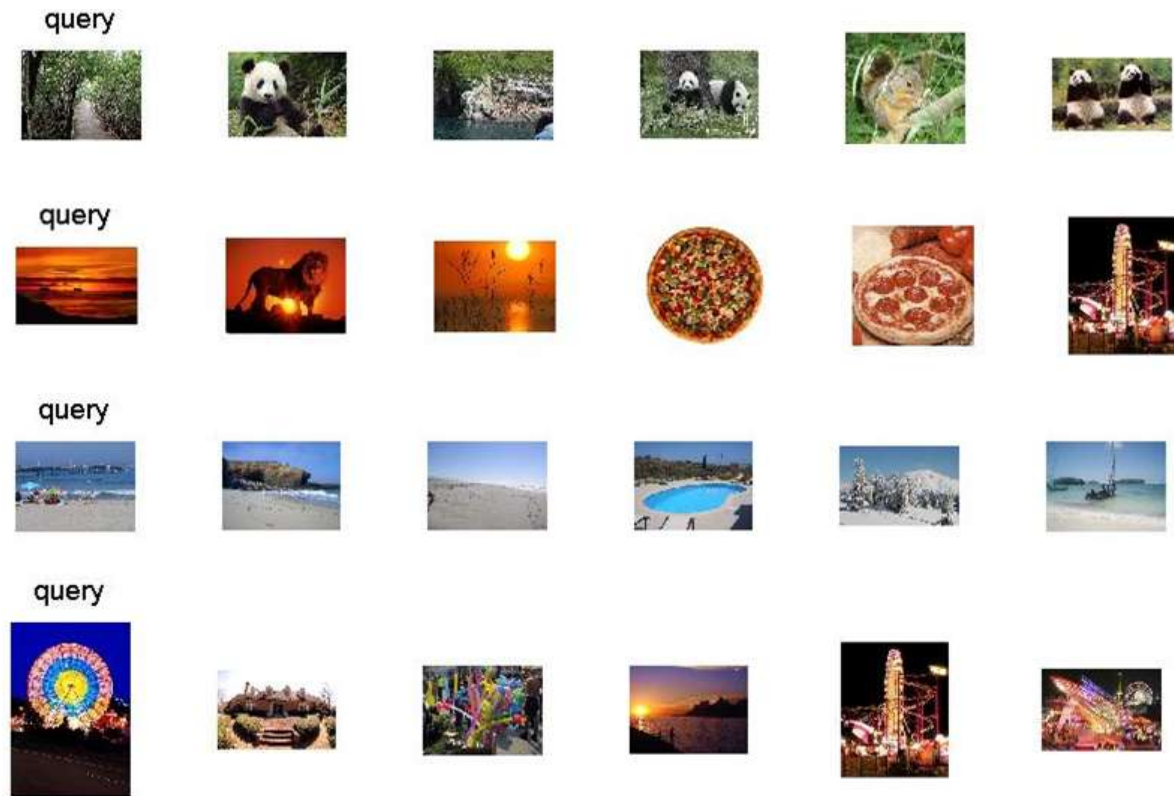


Example Database

Source: Kristen Grauman



Colour-based image retrieval

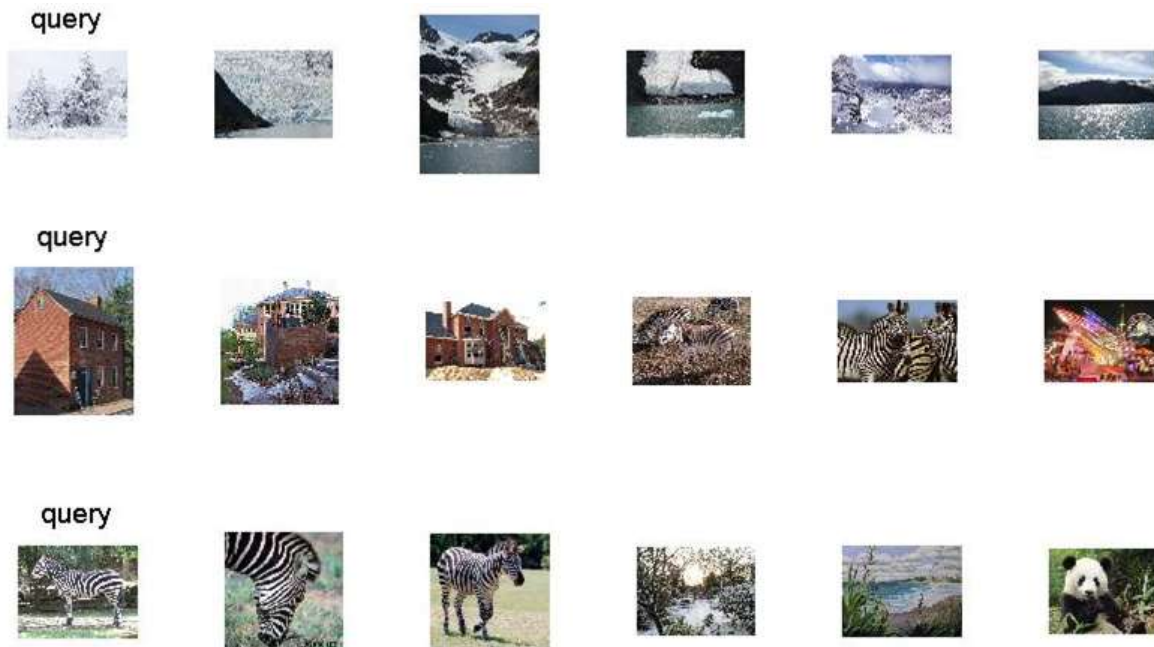


Example Retrievals

Source: Kristen Grauman



Color-based image retrieval

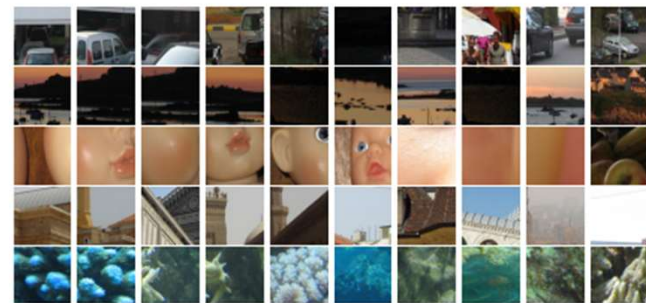
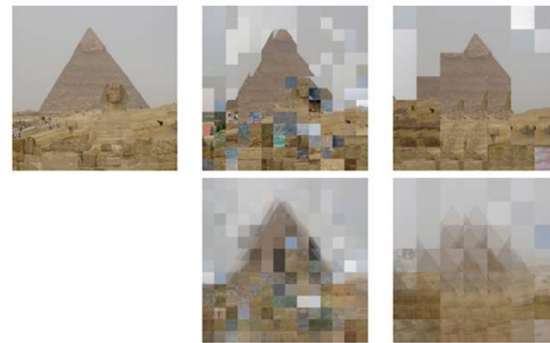
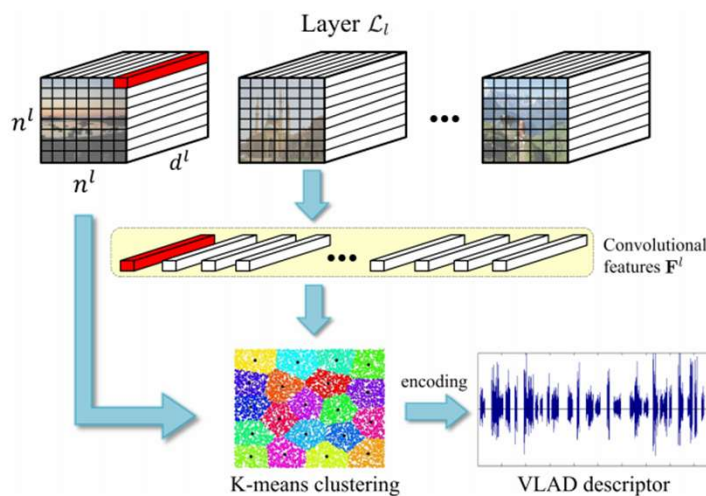


Example Retrievals

> What can you observe from the results?



Exploiting Local Features from Deep Networks for Image Retrieval



Yue-Hei Ng, J., Yang, F., & Davis, L. S. (2015). Exploiting local features from deep networks for image retrieval. In *Proceedings of the IEEE conference on computer vision and pattern recognition workshops* (pp. 53-61)



Colour-based Skin Detection



Jones, M. J., & Rehg, J. M. (2002). Statistical color models with application to skin detection. *International Journal of Computer Vision*, 46(1), 81-96.



Colour-based Skin Model for Face Detection

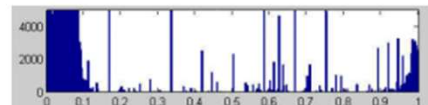
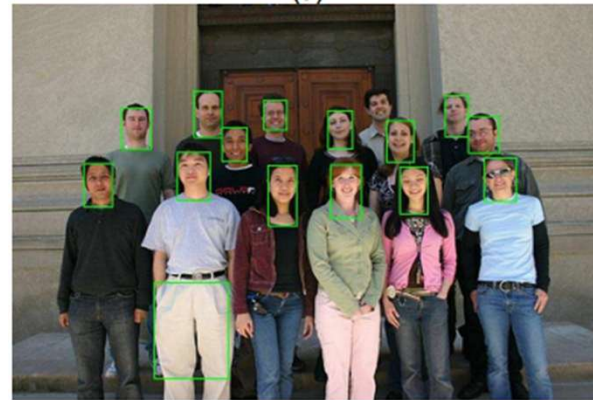


Figure 4. Distribution of the H (Hue) channel

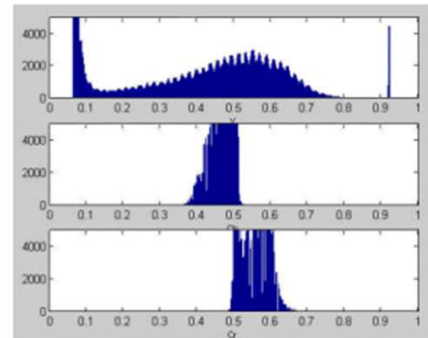
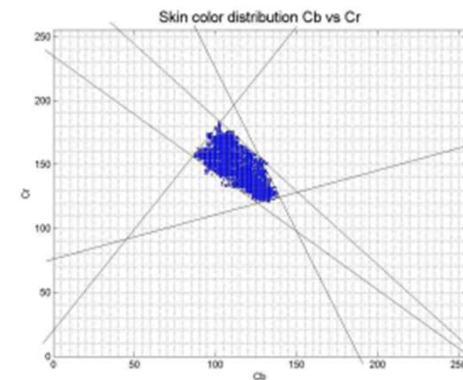


Figure 5. Distribution of Y, Cb and Cr



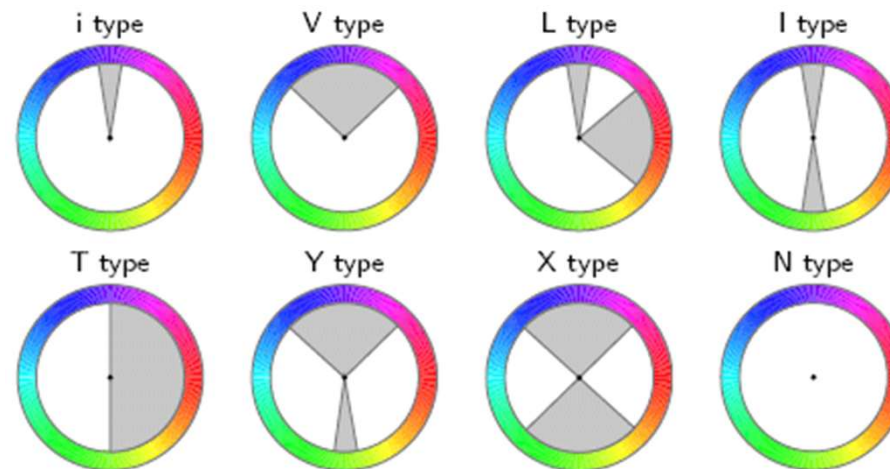
**RGB-H-CbCr Fusion
Color Space**

(Nusirwan, Kit & See, 2006)



Colour harmonization

- › **Harmonic colours** are sets of colours that are aesthetically pleasing in terms of human visual perception
- › **Colour harmonization** is an artistic technique to adjust the colours of a given image to enhance their visual harmony.



M. Tokumaru, N. Muranaka, and S. Imanishi. Color design support system considering color harmony. Proc. of IEEE Fuzzy Systems, 1:378–383, 2002.



Colour harmonization

› Image colour harmonization



original image



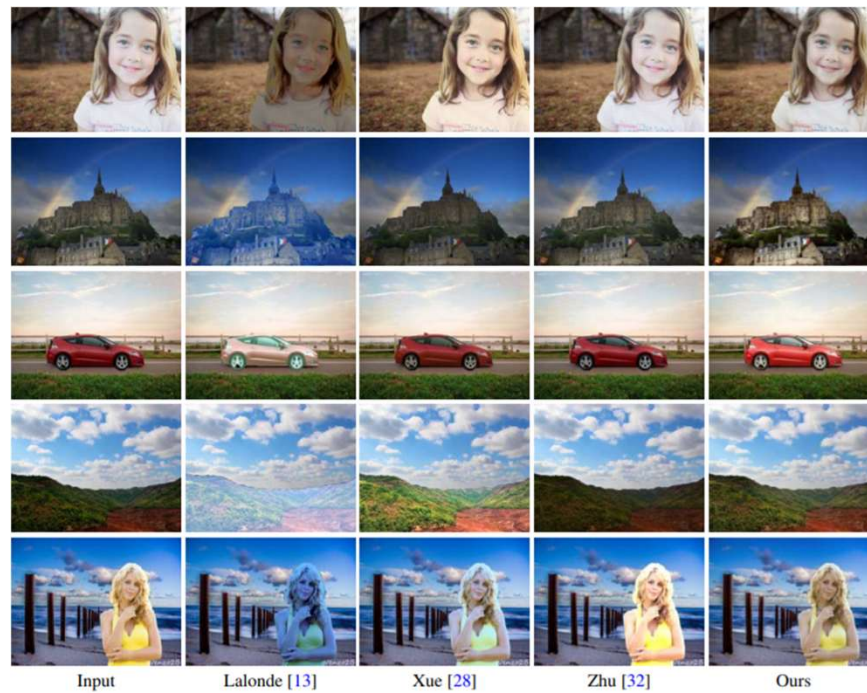
harmonized image

Cohen-Or, D., Sorkine, O., Gal, R., Leyvand, T., & Xu, Y. Q. (2006, July). **Color harmonization**. In *ACM Transactions on Graphics (TOG)* (Vol. 25, No. 3, pp. 624-630). ACM.



Color Harmonization

› Deep Image Harmonization



Tsai, Y. H., Shen, X., Lin, Z., Sunkavalli, K., Lu, X., & Yang, M. H. (2017). Deep image harmonization. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* (pp. 3789-3797).



Colourization



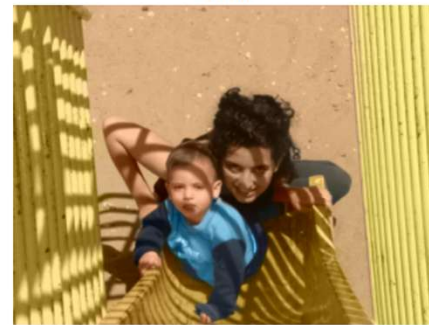
Marked B/W image



Result



Marked B/W image



Result

Levin, A., Lischinski, D., & Weiss, Y. (2004, August). **Colorization using optimization.** In *ACM transactions on graphics (TOG)* (Vol. 23, No. 3, pp. 689-694). ACM.



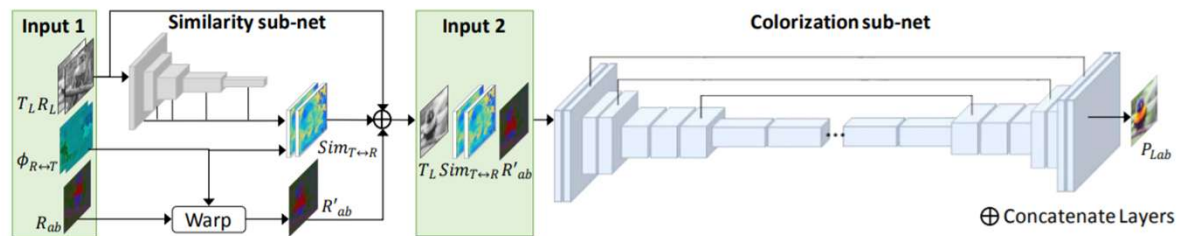
Colorization

Deep Exemplar-based Colorization*

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Figure 1: Colorization results of black-and-white photographs. Our method provides the capability of generating multiple plausible colorizations by giving different references. Input images (from left to right, top to bottom): Leroy Skalstad/pixabay, Peter van der Sluijs/wikimedia, Bollywood Hungama/wikimedia, Lorri Lang/pixabay, Aamir Mohd Khan/pixabay, Official White House Photographer/wikimedia, Anonymous/wikimedia and K. Krallis/wikimedia.



He, M., Chen, D., Liao, J., Sander, P. V., & Yuan, L. (2018). **Deep exemplar-based colorization**. ACM Transactions on Graphics (TOG), 37(4), 47.

SUMMARY

- › Colour – Fundamental concepts
 - › Human Colour perception
- › Colour spaces/models
 - › RGB, CMY, CIE XYZ, HSV, NTSC, YCbCr
 - › CIE LAB, CIE LUV
- › Distance in colour space
 - › Perceptually meaningful
- › Applications
 - › Content-based image retrieval
 - › Color-based skin detection
 - › Color harmonization
 - › Image colorization
- › Next
 - › Textures
- › Recommended Reading
 - › [Gonzalez & Woods] Chapter 6
 - › [Forsyth & Ponce] Chapter 3

