CS 565 Computer Vision

Nazar Khan
PUCIT

Lecture 4: Colour

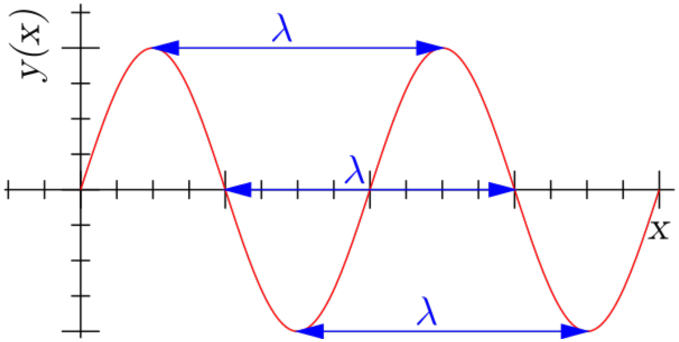
Topics to be covered

- Motivation for Studying Colour
- Physical Background
- Biological Background
- Technical Colour Spaces

Motivation

- Colour science or colour vision
  - highly interdisciplinary area
  - influences from physics, biology, psychology, physiology, electrical engineering, computer science, and mathematics
- Understanding the mechanisms of colour perception is crucial for
  - calibrating scanners, colour monitors, colour printers, and digital cameras
- Many brilliant minds have done research on colour
  - Newton, Goethe, Graßmann, Maxwell, Helmholtz, Schroedinger.
  - Not always successful

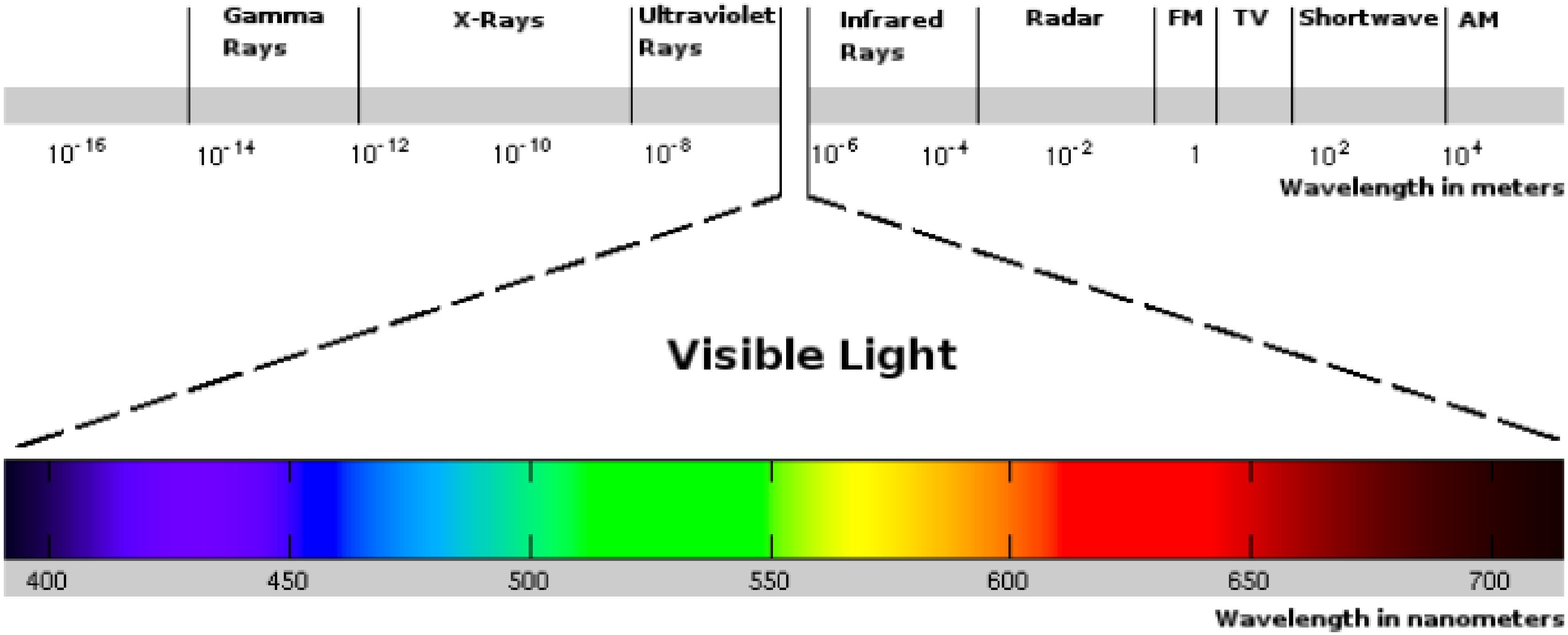
Physical Background



The wave length λ is the distance between two consecutive points with the same phase.
Source: http://en.wikipedia.org/wiki/Wavelength

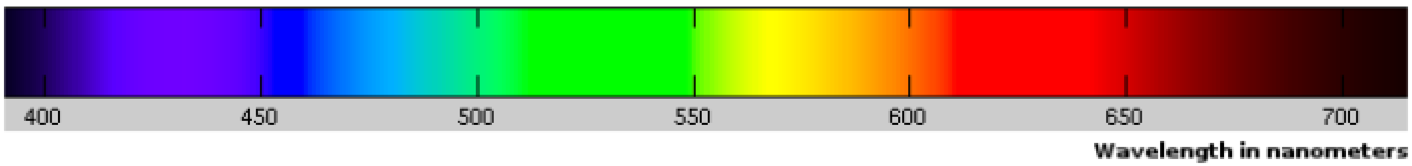
- Electromagnetic waves propagate with the speed of light
  - c = 299, 792, 458 m/s in vacuum).
  - If f denotes their frequency, wave length λ is defined via $c = \lambda f$.
- Visible light consists of electromagnetic waves with wave lengths λ between 380 and 750 nm (nanometers)
  - 1 nm = 10^{-9} m
- Light is emitted from atoms when outer electrons change their orbits and loose energy.

Physical Background



Visible light constitutes only a small part of the entire electromagnetic spectrum. Author: N. Khan (2005).

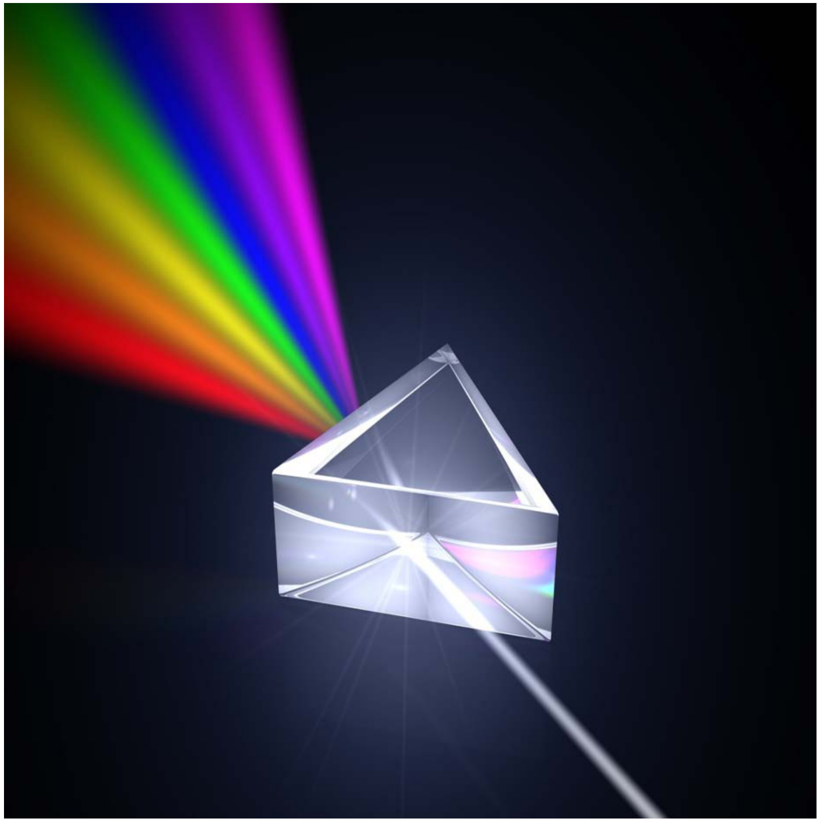
Physical Background



- Visible range of the electromagnetic spectrum is the main range in which the Sun's rays can pass the atmosphere
- The visible range is not the same for all animals
  - Insects can perceive ultraviolet light very well
  - Humans whose eye lenses have been removed by a surgeon also perceive ultraviolet light down to 300 nm
- The visible spectrum contains seven colours
  - red, orange, yellow, green, blue, indigo, violet
  - with decreasing wavelength or increasing frequency

Physical Background

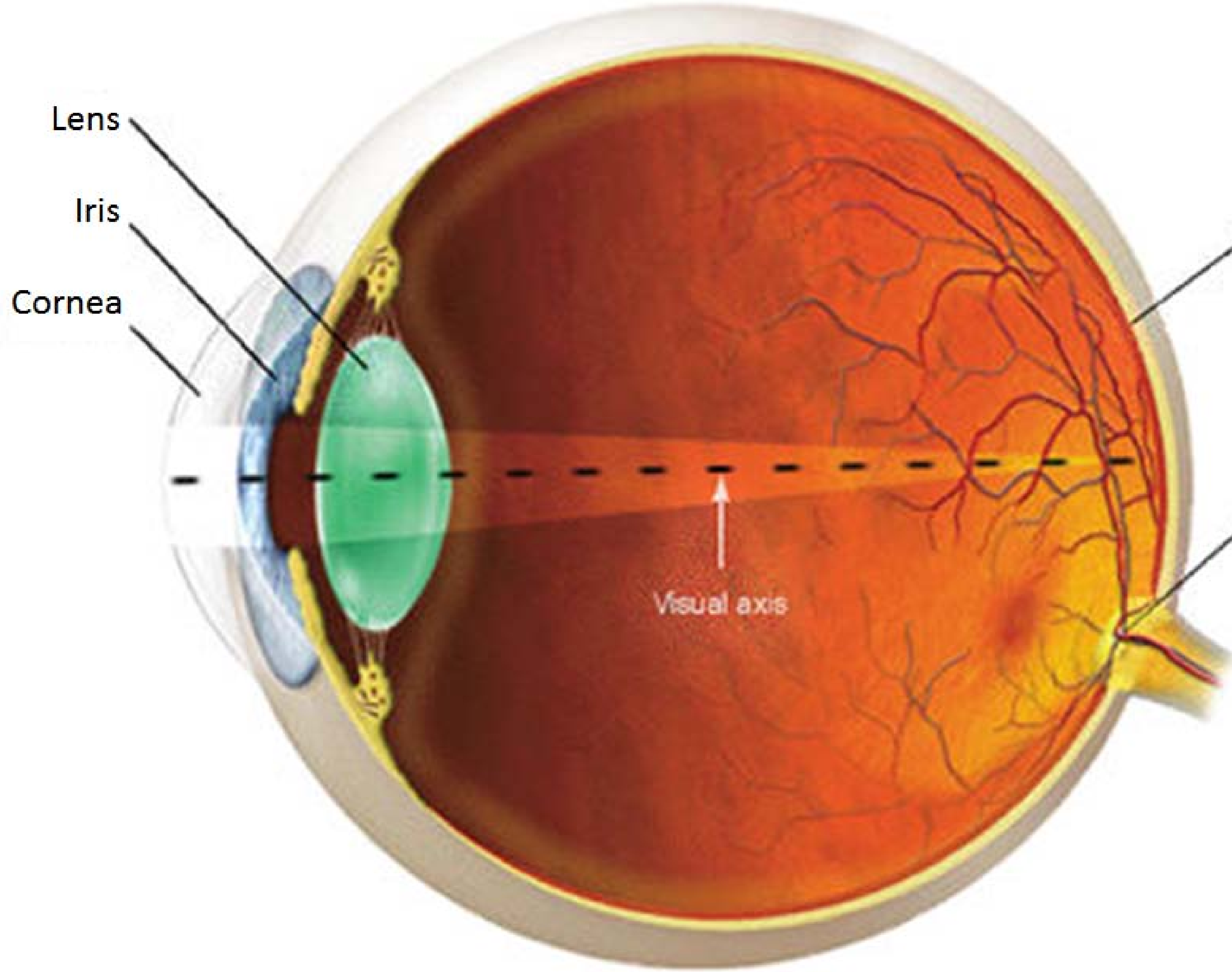
- Colours that we usually perceive are a mixture of numerous frequencies.
- Pure spectral colours consisting of a single frequency are rare
  - They exist e.g. in rainbows, in light rays that pass through a prism, and in lasers.



Source: http://www.theinquirer.net/IMG/847/94847/light-split-into-spectrum-by-prism.jpg

Physical Background

- However, biological and technical systems do not exploit all frequencies of a perceived colour
  - They use a more compact representation.
- To understand this, let us consider the biology of colour perception.



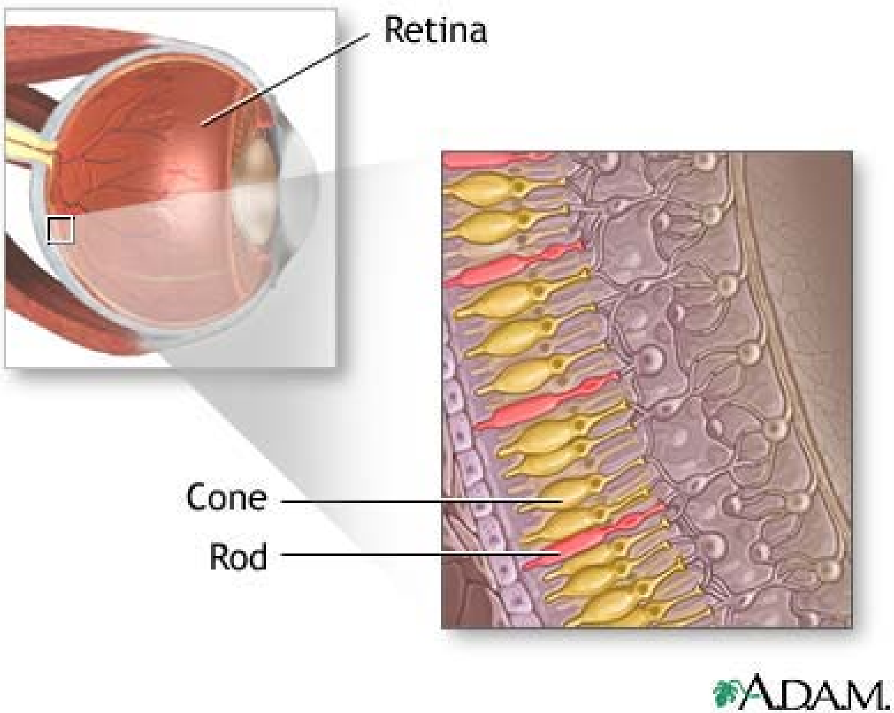
The Eye
(Adapted from
http://www.soundandvision.com/images/archivesart/204eye.3.jpg)

Biological Background

- Retina contains **photoreceptor cells**
  - a neuron in the retina that converts light into a signal.
- The brain processes this signal to make sense of the light, i.e. vision.
- Two kinds of photoreceptor cells
  - Rods (responsible for night vision, i.e., grayscale)
  - Cones (responsible for daylight vision , i.e., colour)

Biological Background

- The human retina consists of two classes of photo receptors:
  - ~120 million rods distributed over the whole retina.
  - ~6 million cones, mainly in the centre of the retina.



The Retina
http://www.pennmedicine.org/health_info/body_guide/reftext/images/retina_section.jpg

Biological Background

- For night vision, rods dominate.
  - Very sensitive, but allows only poor sharpness and no colour perception
- Day vision is dominated by cones.
  - Low sensitivity, but very good perception of sharpness and colours.
- Humans can distinguish only ~40 different grayscales, but ~2 million colours.
- Our focus – day vision.

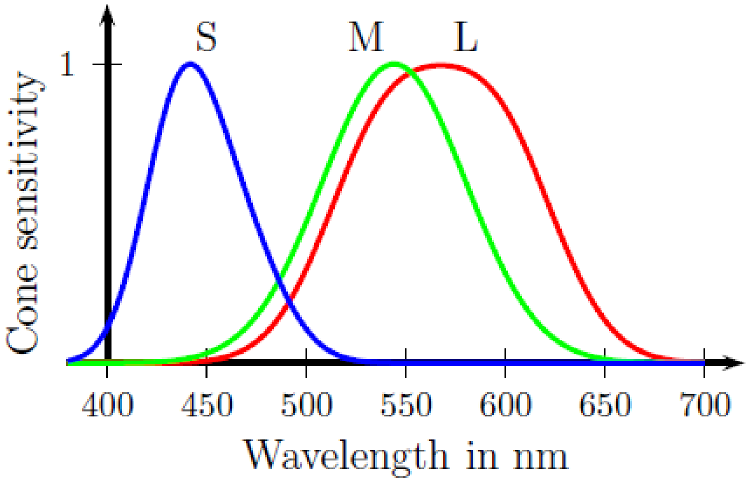
Rods vs. Cones

Rods	Cones
Used for vision under low light conditions	Used for vision under high light conditions
Very light sensitive	Not very light sensitive
Loss causes night blindness	Loss causes legal blindness
Multiple rods are connected to a single nerve, low spatial resolution	Each cones is connected to a single nerve, high spatial resolution
Slow response to light, stimuli added over time	Fast response to light, can perceive more rapid changes in stimuli
More pigment, so can detect lower light levels	Less pigment, require more light to detect images
About 120 million rods distributed around the retina	About 6 million cones distributed in the retina
One type of photosensitive pigment, leads to achromatic vision	**Three types of photosensitive pigment in humans, leads to colour vision**

Adapted from
Kandel, E. R.; Schwartz, J.H.; Jessell, T.M. (2000).*Principles of Neural Science* (4th ed.). New York: McGraw-Hill. pp. 507–513. ISBN 0-8385-7701-6.

Biological Background

- Humans have three different types of cones (L, M, S) being sensitive to different wavelength ranges:
  - Long → red
  - Medium → green
  - Short → blue.
- The sensitivity characteristics are almost identical for all humans.
- Any colour produces 3 types of responses in our visual system -- one for each type of cone.



Normalised spectral sensitivity of the three cone types in the human eye.
Author: M. Mainberger (2008).

Biological Background

- Colours are no objective physical reality.
- Colour perception is a biologically useful interpretation of the physically existing wave length spectrum.
- We can now turn to a mathematical representation of colour.

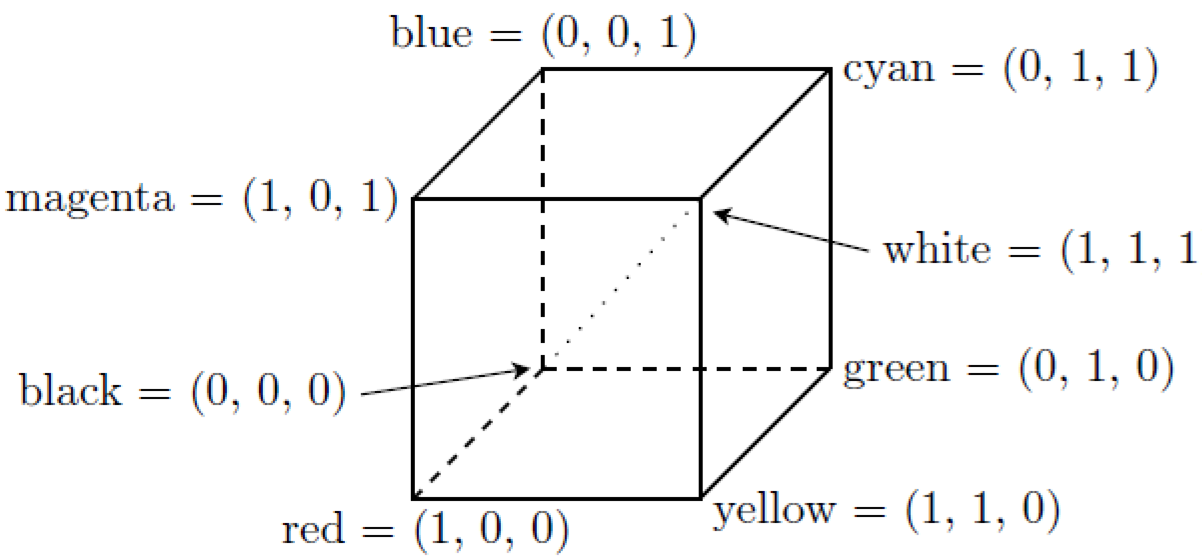
Technical Colour Spaces

The RGB Colour Space

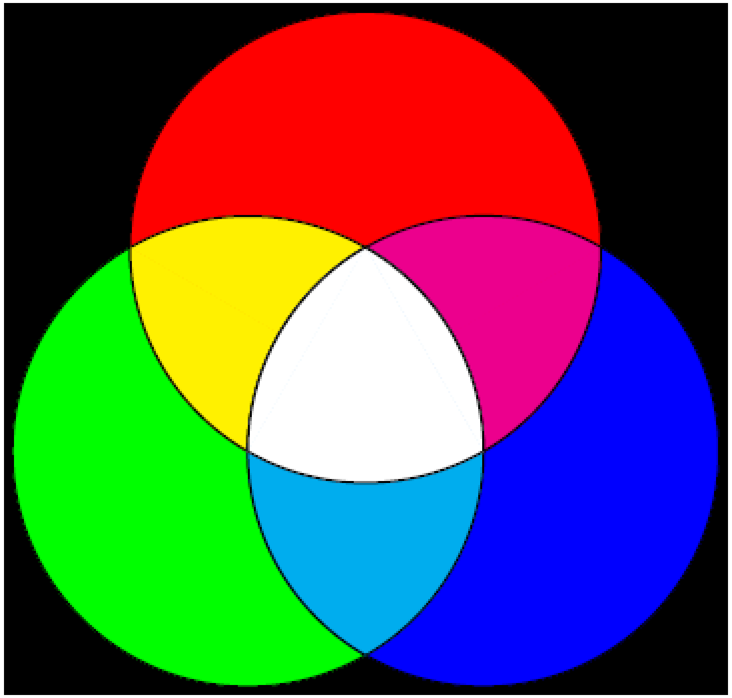
- Additive Model
- Primary colour basis
  - red (R = (1, 0, 0))
  - green (G = (0, 1, 0))
  - blue (B = (0, 0, 1))
- All colors are generated as linear combinations of these 3 primary colours.
  - This yields the so-called RGB Cube

Technical Colour Spaces

- Every colour has a complementary colour such that adding them gives white.
- The complementary colour is at the opposite side of the cube.



Technical Colour Spaces



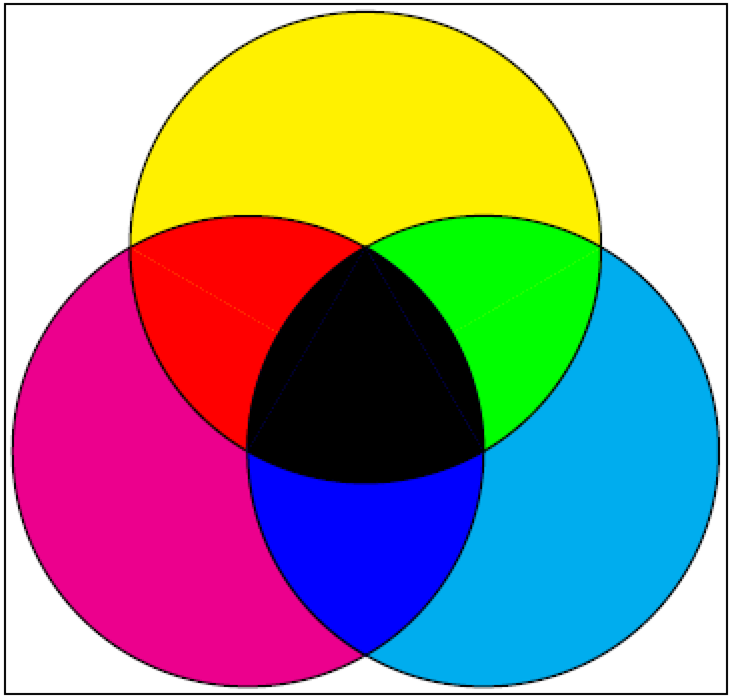
Colours can be blended by linear combinations of the primary colors in the RGB space. Computer screens use this kind of **additive** colour blending.

Technical Colour Spaces

The CMY Color Space

- Used by printers and copiers that place colour pigments on white paper.
- In contrast to the additive RGB model, the CMY model is subtractive.
  - Colour impressions are determined by the colour that is subtracted (absorbed into the white paper) from white light.
- Complementary to RGB
  - Basis: cyan (C=(1,0,0)), magenta (M=(0,1,0)), and yellow (Y=(0,0,1))
- In the RGB model, an equal combination of the primary colours R, G, B gives white.
- In the CMY model, an equal combination of the primary colours C, M, Y creates … ?
  - black.

Technical Colour Spaces



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

Colours can be blended by linear combinations of the primary colors in the CMY space.
Printers use this kind of **subtractive** colour blending.

Technical Colour Spaces

The CMYK Colour Space

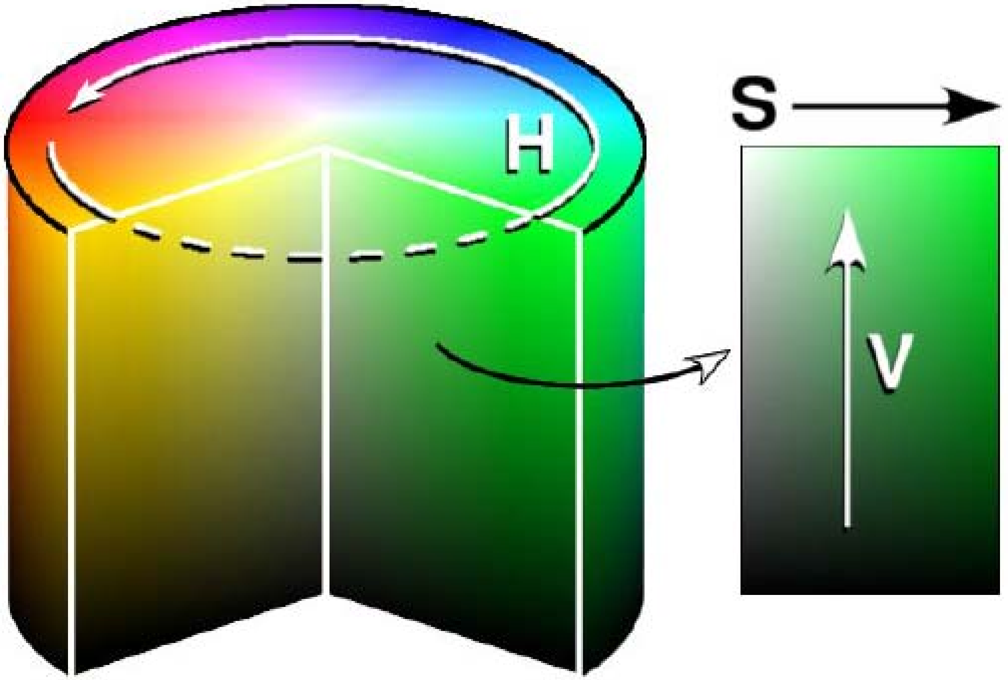
- Extension of CMY to include black (K) as fourth colour
- Useful for colour printers that print large amounts of text in black
- Conversion formula for CMY to CMYK

$$
\begin{aligned}
K &\leftarrow \min(C, M, Y) \\
C &\leftarrow C - K \\
M &\leftarrow M - K \\
Y &\leftarrow Y - K
\end{aligned}
$$

Amount of C, M and Y will be reduced by K.

Technical Colour Spaces

- **The HSV Colour Space**



The HSV colour space uses a cylindrical polar coordinate system with hue, saturation and value as coordinates. Source: `http://de.wikipedia.org/wiki/HSV-Farbraum`.

Technical Colour Spaces

<u>The HSV Colour Space</u>

- Based on a cylindrical polar coordinate system with hue, saturation and value as coordinates
- Hue (H)
  - polar angle in the horizontal plane
  - red: 0; green: 120; blue: 240
- saturation (S)
  - radius in the horizontal plane
  - gives distance of the colour to the next grey tone
- value (V)
  - vertical axis in the coordinate system
  - defines how dark or bright a colour is

Technical Colour Spaces

HSV can offer advantages when illumination changes appear

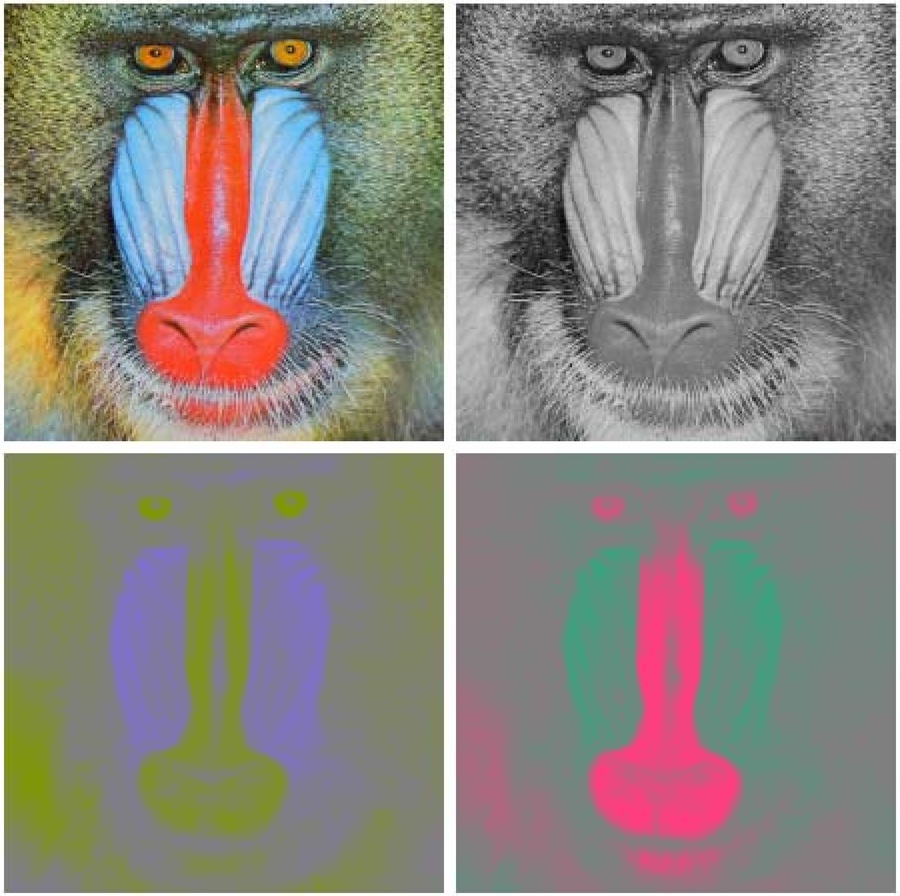
- Typical changes
  - global multiplicative changes: global illumination changes
  - local multiplicative changes: shadow, shading
  - local additive changes: specular highlights
- The H and S channels are photometric invariants:
  - H is invariant under all these three changes.
  - S is invariant under global and local multiplicative changes.
  - V is not invariant under any of these changes.

Technical Colour Spaces

The YCbCr Colour Space

- Used in video and digital photography systems
  - digital PAL and NTSC television,
  - JPEG and MPEG compression
- separates the colour image into
  - a luma component Y that is basically a greyscale version of the colour image
  - a chroma component Cb that measures deviation from grey in blue–yellow direction
  - a chroma component Cr that measures deviation from grey in red–cyan direction

Technical Colour Spaces



Top left: Original image, 512×512 pixels. **Top right:** The luma channel Y contains the luminance information with lots of details. **Bottom left:** Blue-yellow chroma channel Cb. **Bottom right:** Red-cyan chroma channel Cr. Author: M. Mainberger (2009).

Color Spaces and Image Compression

- The luma channel Y should be stored in high resolution, while the chroma channels Cb and Cr can be subsampled without significant visual deterioration.
- This is exploited in the JPEG compression standard.
- **Assignment 1**

Summary

- Visible light consists of electromagnetic waves in the range from 380 to 750 nanometers.
- Illuminated real objects emit a mixture of different wave lengths.
- Human colour perception is based on three types of cones that are sensitive in different frequency bands.
- An additive blending of the three primary colours red, green and blue is used for creating other colours.
- This is realised in the RGB colour space which is a very frequently used additive colour space for digital cameras and monitors.

Summary

- The CMY and CMYK spaces are subtractive colour spaces for printers and copiers.
- The HSV colour space represents colours in a cylindrical polar coordinate system.
  - This can be useful when illumination changes appear.
- The YCbCr representation separates luma from chroma information.
  - One can subsample the chroma channels without severe visual degradation.
  - Useful for image compression.