# 3D Graphics Programming Tools

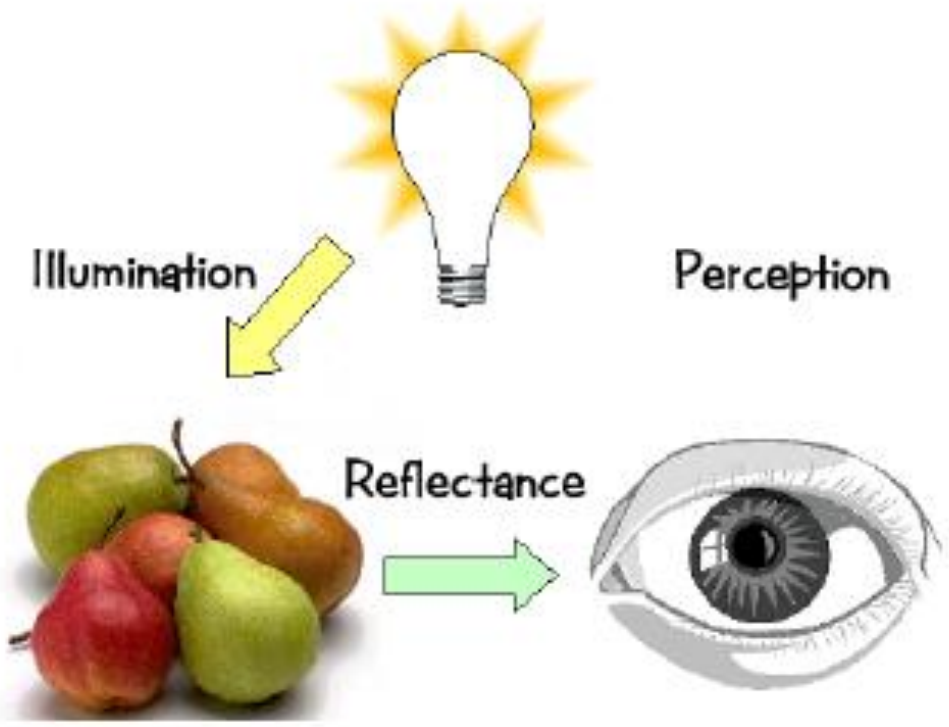
## Colour

# Today's agenda

- Perception of colour
- Colour spaces

# Basics of colour

- To understand how to make realistic images, we need a basic understanding of the physics and physiology of colour vision.



# Lighting versus “Colouring”

# Basics of colour

- Physics
  - Illumination
    - Electromagnetic spectra
  - Reflection
    - Material properties
    - Surface geometry and microgeometry (i.e., polished versus matte versus brushed)
- Perception
  - Physiology and neurophysiology
  - Perceptual psychology

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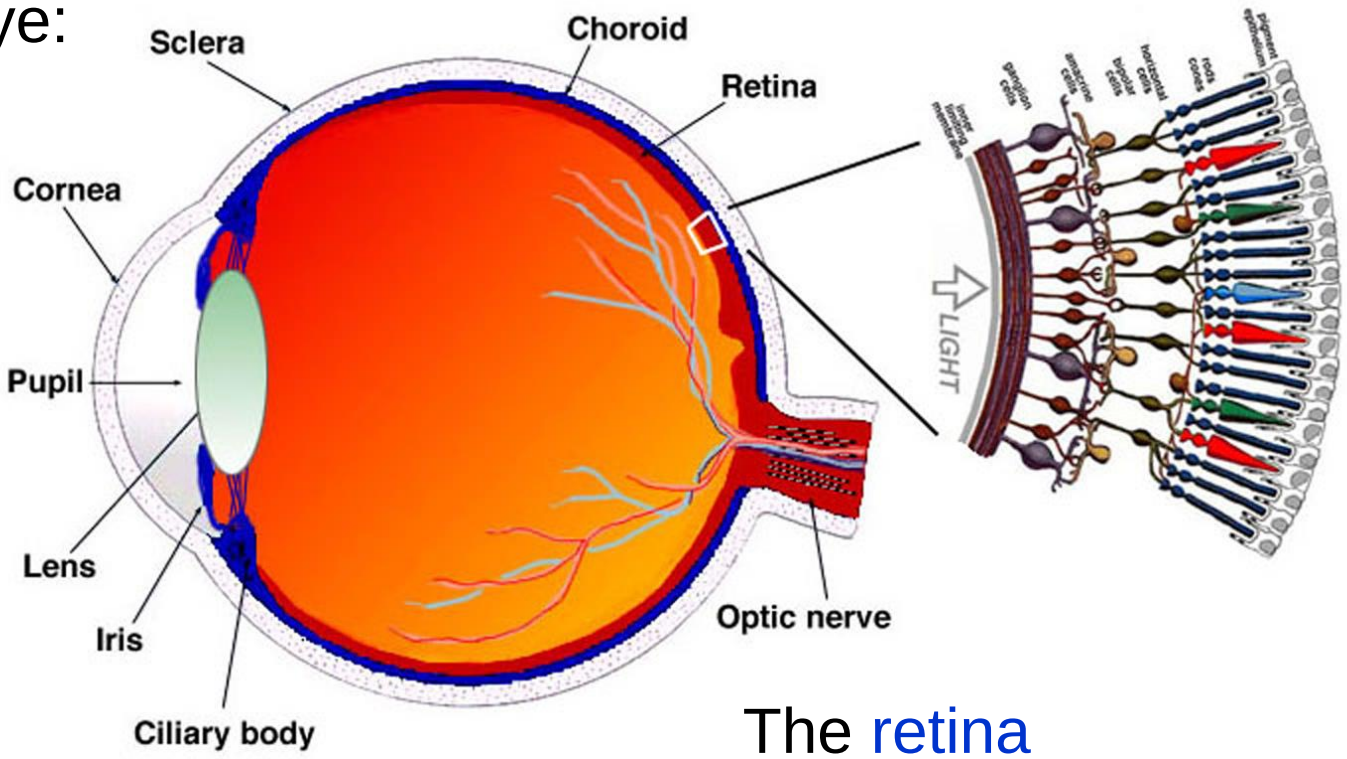
# Physiology of vision

The eye:




The retina

- Rods
- Cones
  - LMS wavelengths ➔ Colour!

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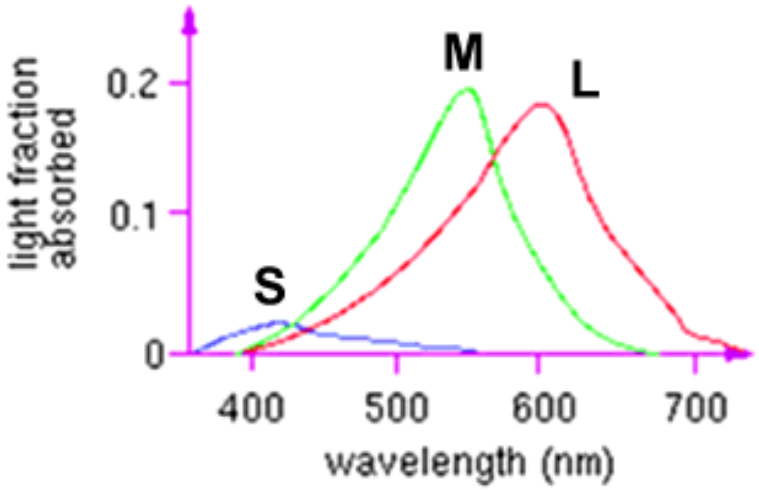
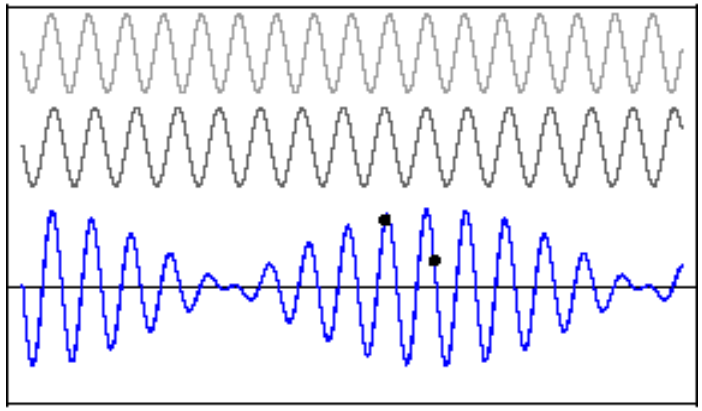
# Physiology of vision: cones

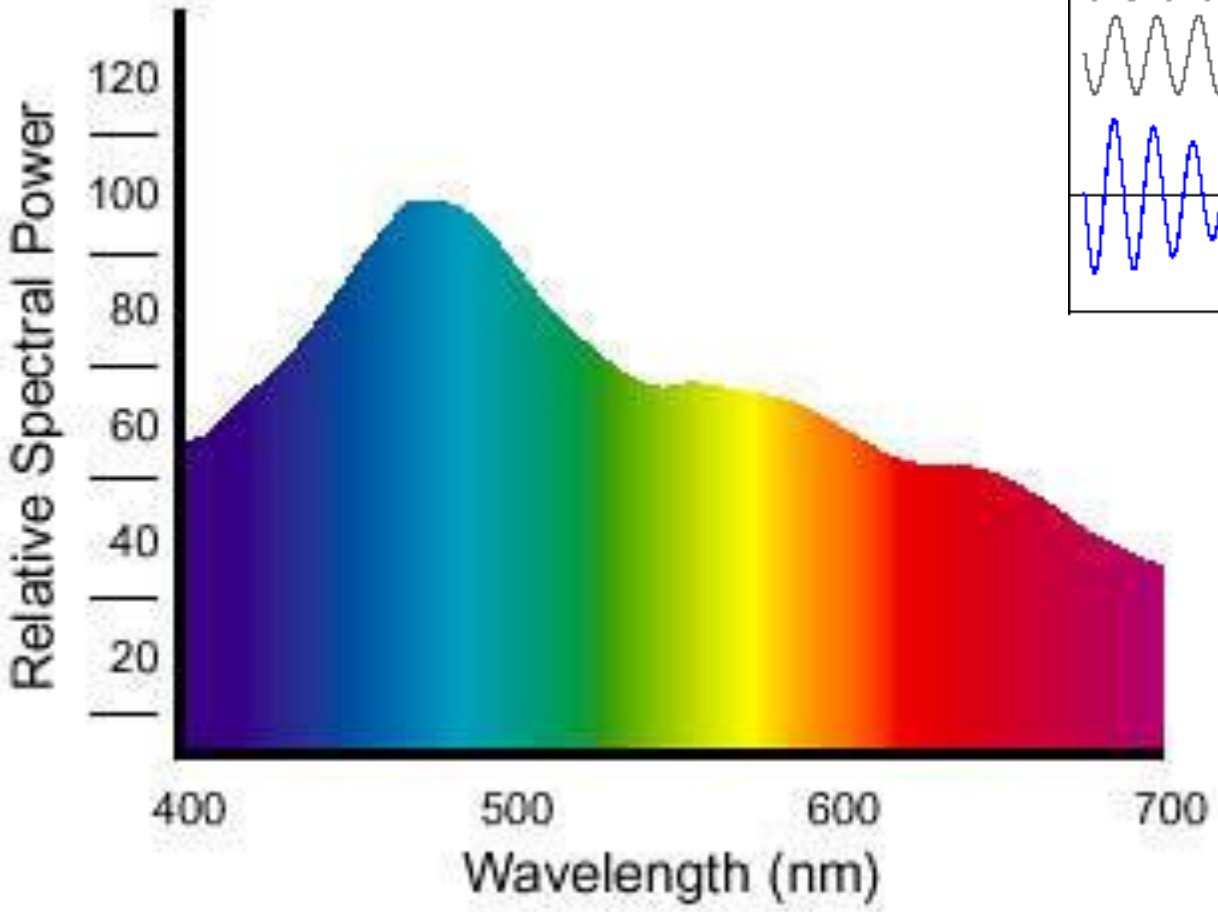
- Cones → three types
  - **L** or **R**, most sensitive to red light (610 nm)
  - **M** or **G**, most sensitive to green light (560 nm)
  - **S** or **B**, most sensitive to blue light (430 nm)




  - Colour blindness results from missing cone type(s)

# Light



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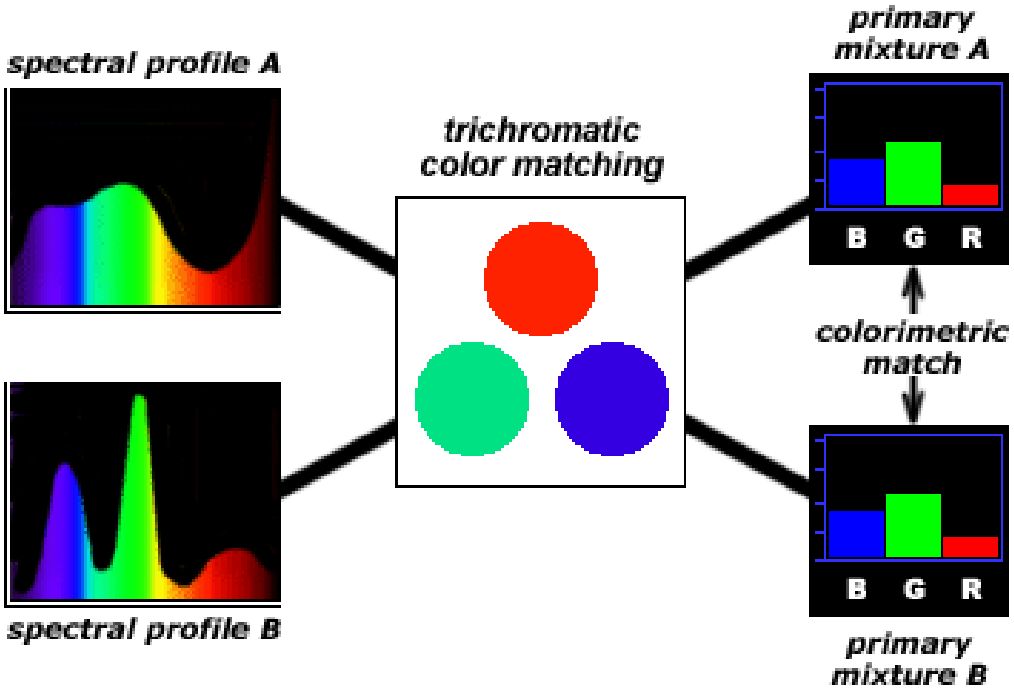
# Perception: metamers

- A given perceptual sensation of colour derives from the stimulus of all three cone types.
- Identical perceptions of colour can thus be caused by very different spectra.

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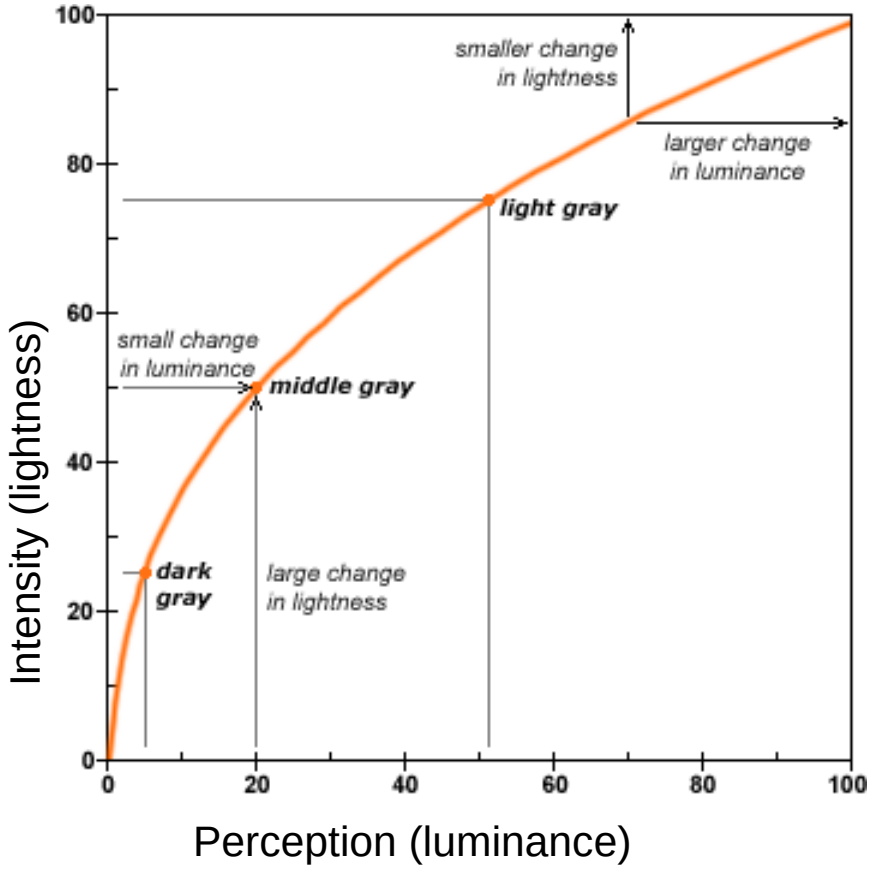
# Perception

- Colour perception is also difficult because:
  - It varies from person to person
  - It is affected by adaptation
  - It is affected by surrounding colours

# Perception: relative intensity

- We are not good at judging absolute intensity
- We perceive relative intensities, not absolute

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# Today's agenda

- Perception of colour
- Colour spaces

# Colour Perception

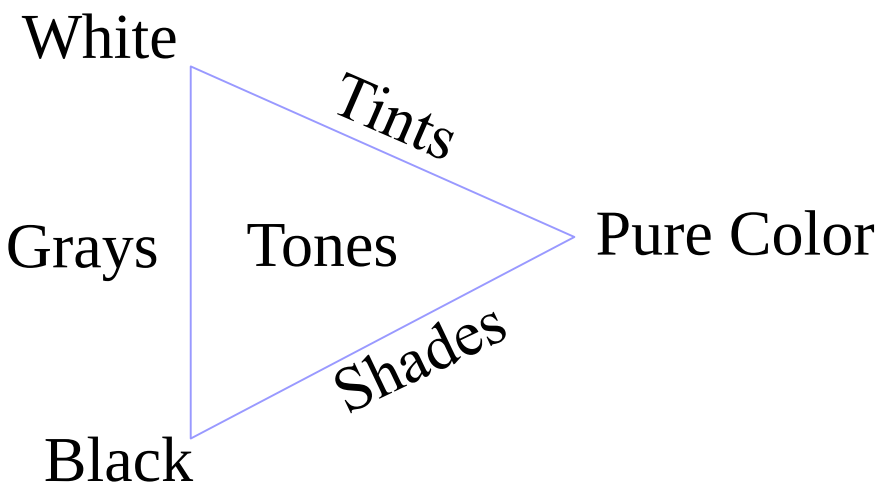
- Colour perception → three quantities
  - *Hue* → Distinguishes between colours like red, green, blue, etc.
  - *Saturation* → How far the color is from a gray of equal intensity
  - *Lightness* → The perceived intensity of a reflecting object

    (Sometimes lightness is called *brightness* if the object is emitting light instead of reflecting it)

In order to use colour precisely in computer graphics, we need to be able to specify and measure colours

# Specify Colour: How do artists do it?

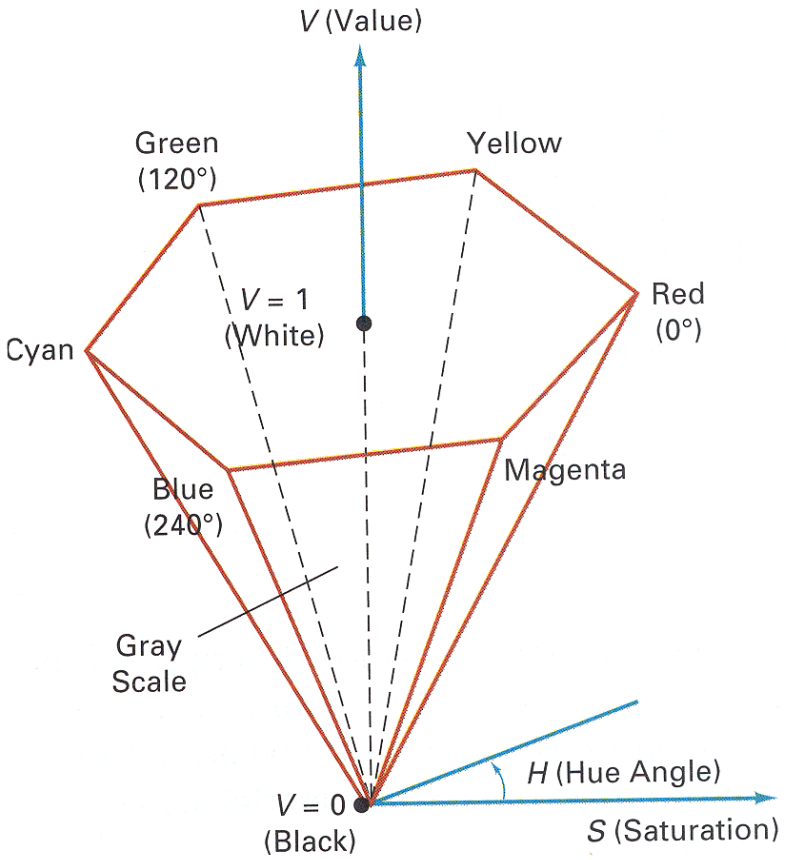
- Artists often specify colour as tints, shades, and tones of saturated (pure) pigments
  - Tint
    - Obtained by adding white to a pure pigment, decreasing saturation
  - *Shade*
    - Obtained by adding black to a pure pigment, decreasing lightness
  - Tone
    - Obtained by adding white and black to a pure pigment



# HSV colour space

- Computer scientists → use an intuitive colour space that corresponds to tint, shade, and tone:
  - Hue
    - The colour we see (red, green, purple)
  - Saturation
    - How far is the colour from gray
      (pink is less saturated than red, sky blue is less saturated than royal blue)
  - Brightness (Luminance)
    - How bright is the color (how bright are the lights illuminating the object)

# HSV colour model




- Hue (H) is the angle around the vertical axis
- Saturation (S) is a value from 0 to 1 indicating how far from the vertical axis the color lies
- Value (V) is the height of the "hexcone"

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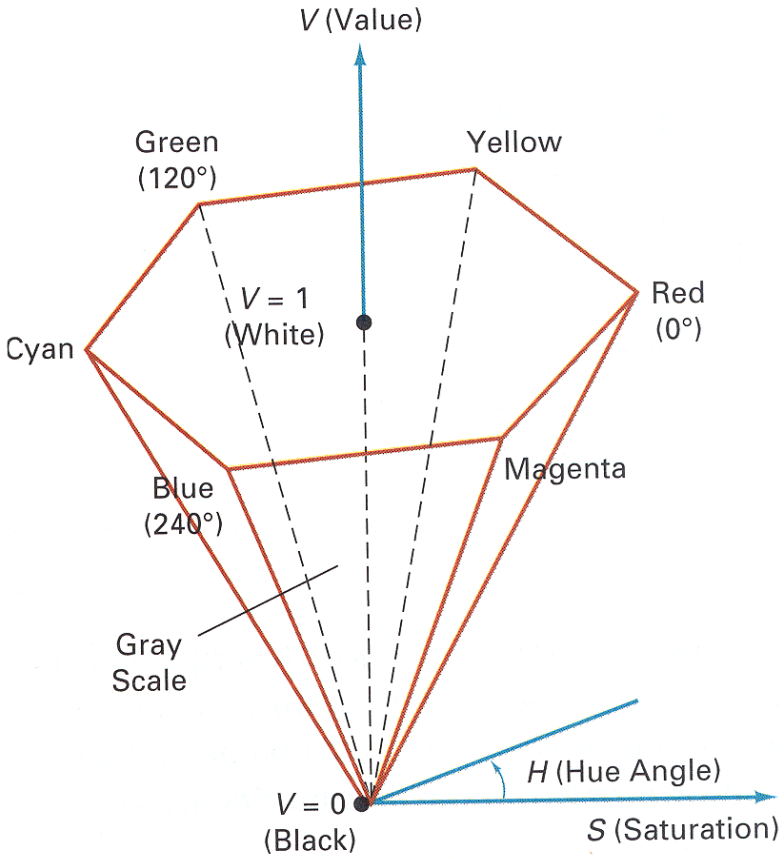
# HSV colour model




| H | S | V | Color |
|---|---|---|---|
| 0 | 1.0 | 1.0 | Red |
| 120 | 1.0 | 1.0 | Green |
| 240 | 1.0 | 1.0 | Blue |
| * | 0.0 | 1.0 | White |
| * | 0.0 | 0.5 | Gray |
| * | * | 0.0 | Black |
| 60 | 1.0 | 1.0 | |
| 270 | 0.5 | 1.0 | |
| 270 | 0.0 | 0.7 | |

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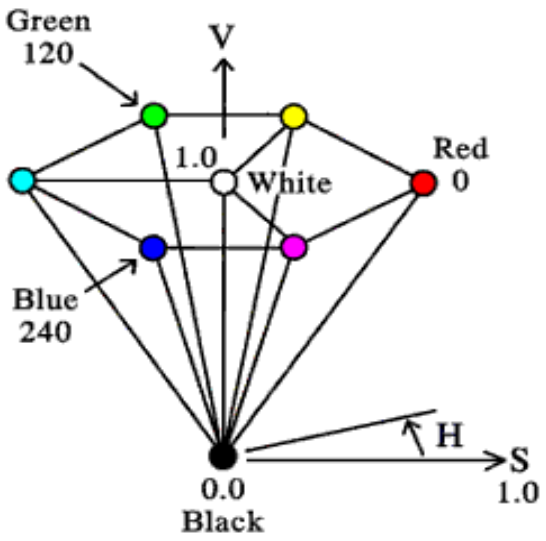
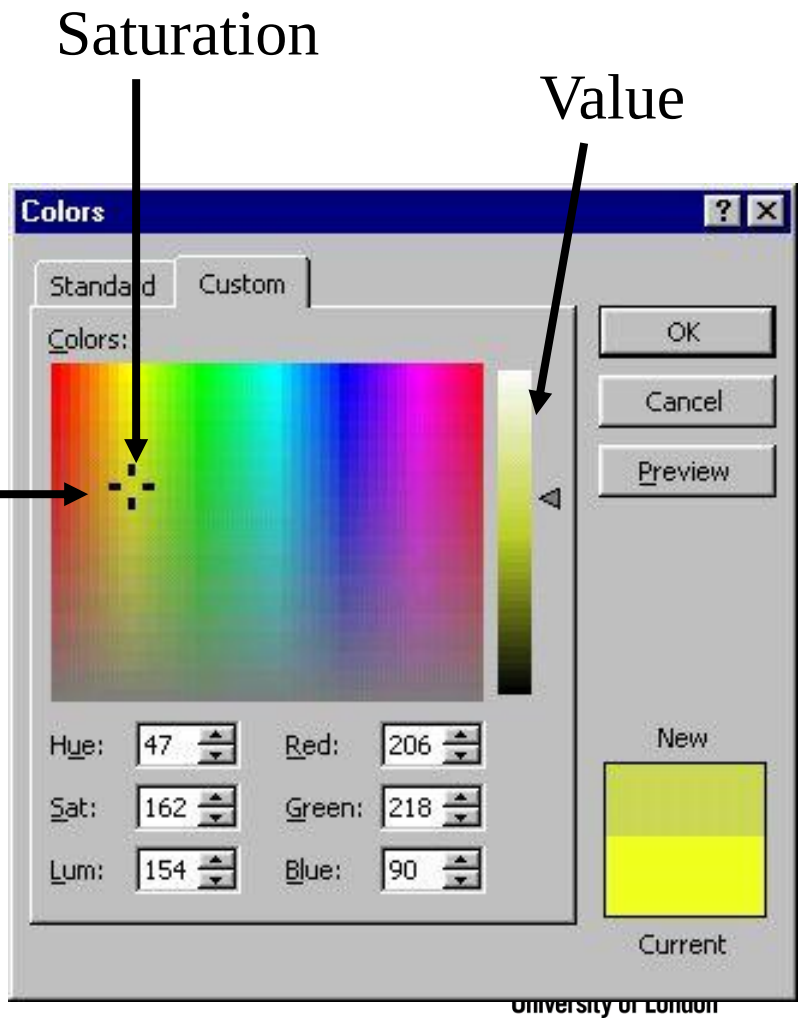
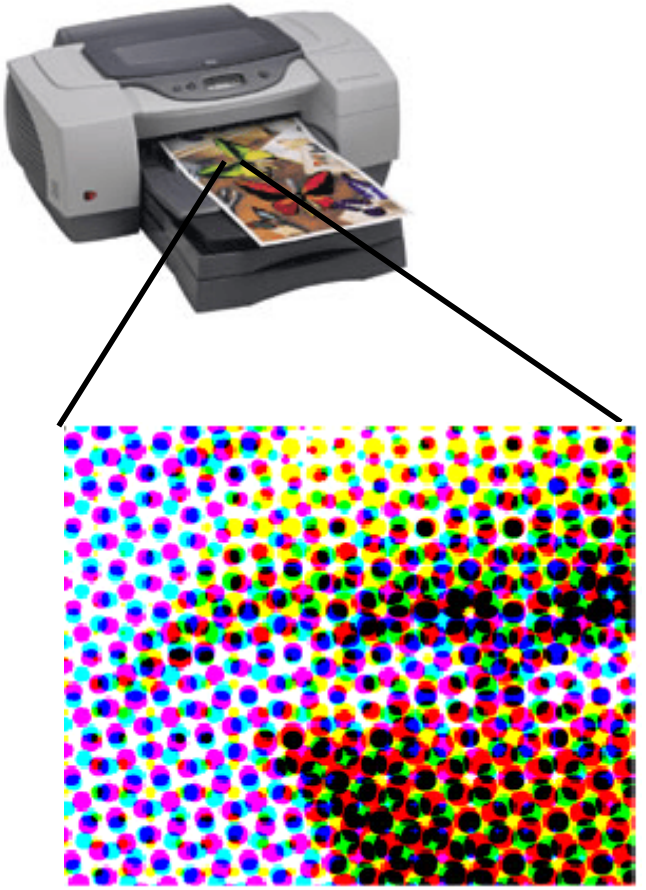
# HSV colour space

- Intuitive colour space
  - H = Hue
  - S = Saturation
  - V = Value (or brightness)



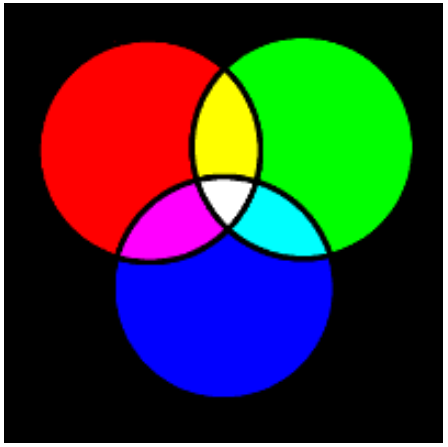



# Computer Display Systems



# Colour Models

Additive (RGB)



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

Subtractive (CMYK)

## The CMYK model

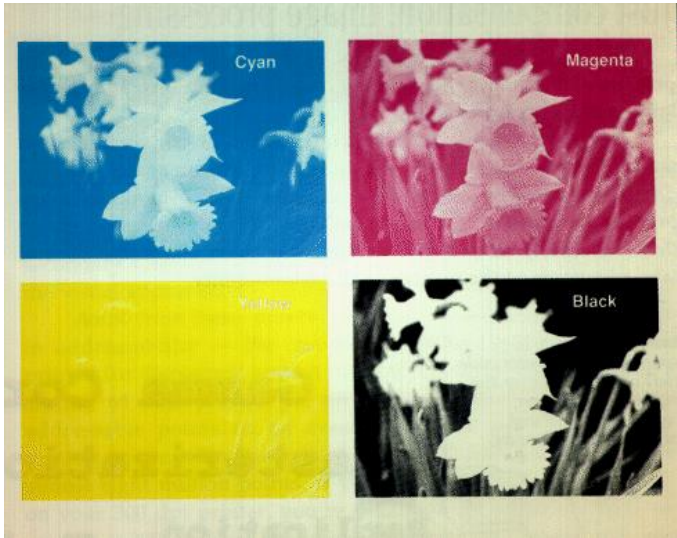
- Cyan, Magenta, Yellow & Black
- Used in printers
- Richer black
- Black ink is cheap

$$K := \min(C, M, Y)$$

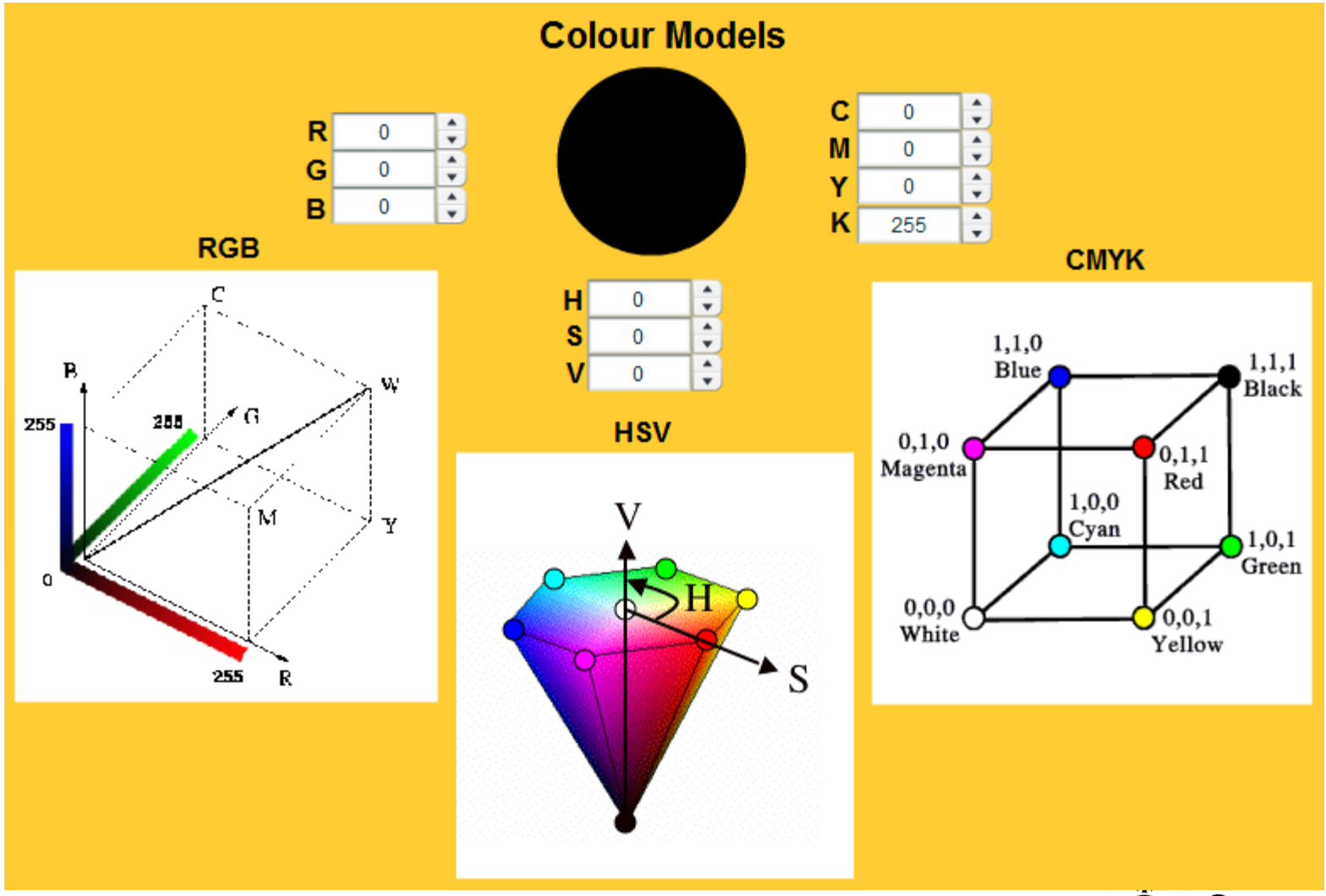
$$C := C - K$$

$$M := M - K$$

$$Y := Y - K$$



# Colour Space Conversion

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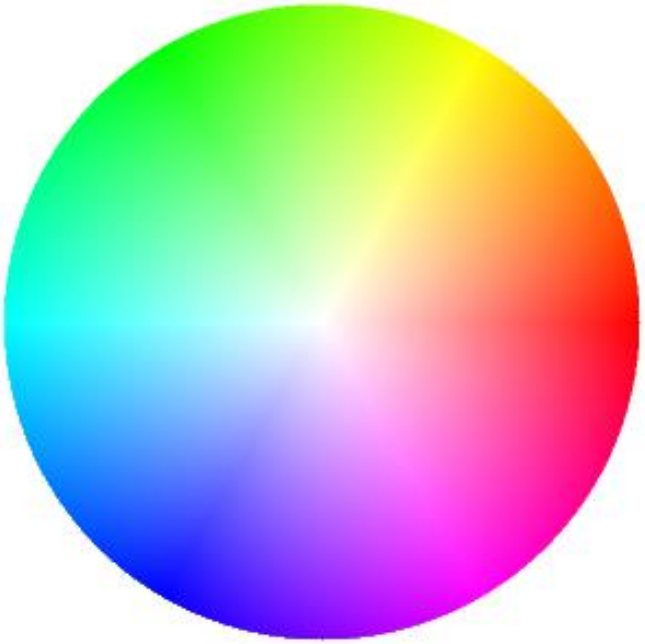
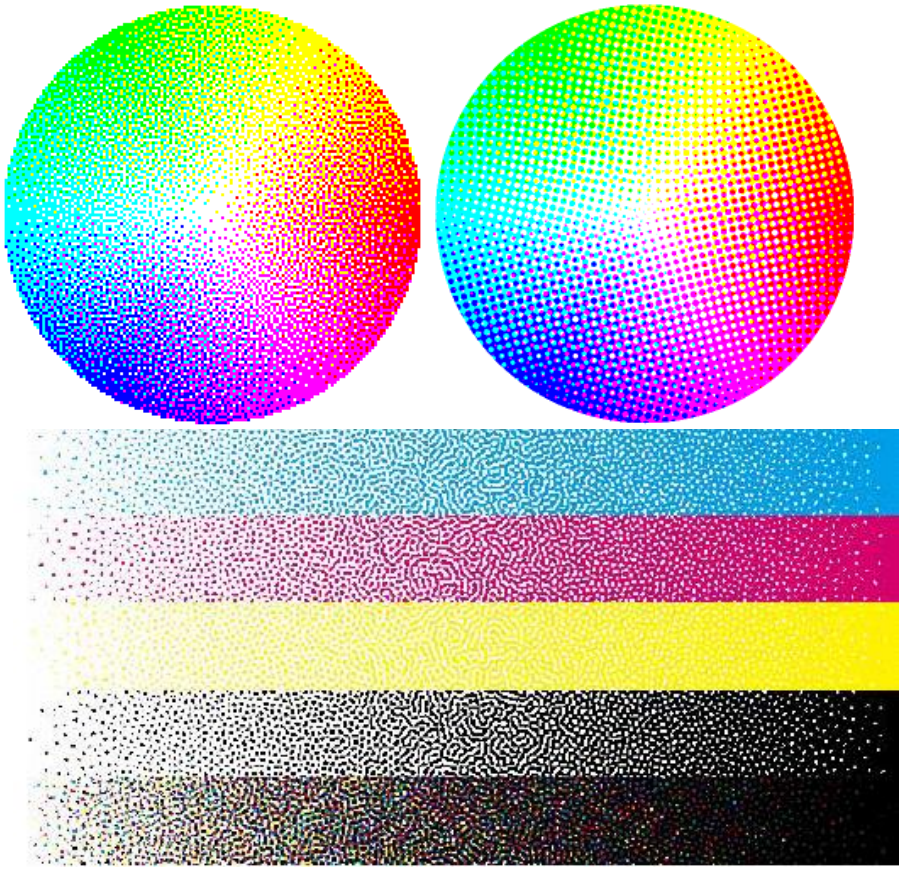
# Continuous Tone and Halftone

To increase the colour resolution by halftone





Continuous tone

Halftone

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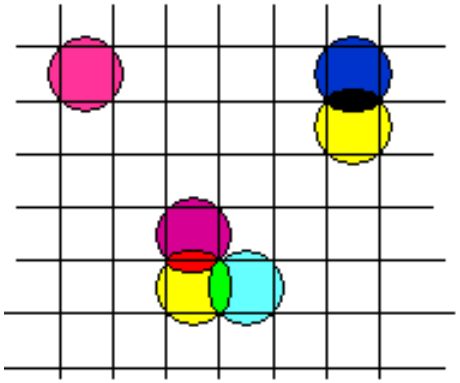
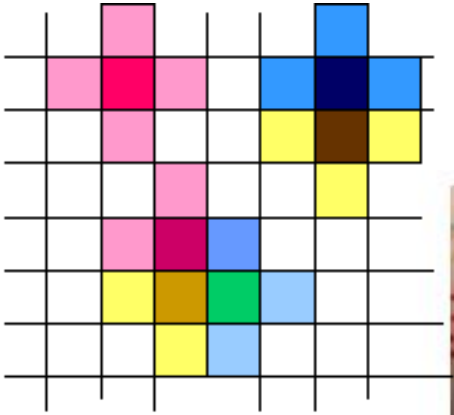
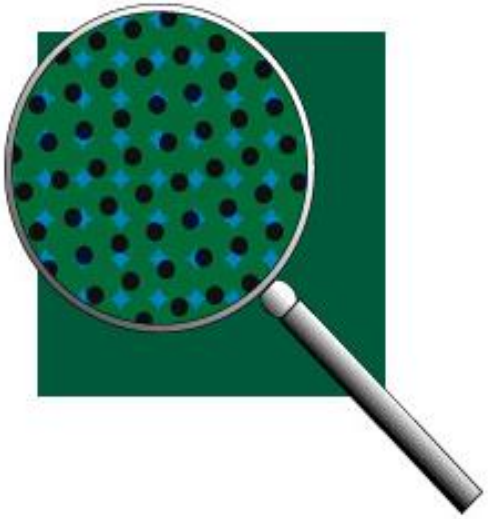
# Colour Halftoning

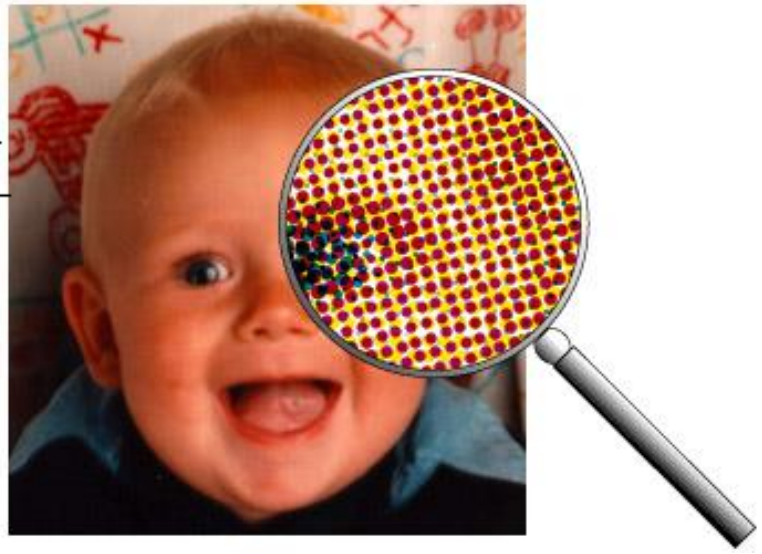
For printing





For display





# What did we learn today?

- Perception of colour
- Colour spaces

# And from now?

- We will stop assigning colours
- We will setup light sources
- We will declare material properties
- We will then calculate the colours

# Solving the lighting problem

- Where are we?
  - We somewhat understand the perception of light (colour)
  - We know how to represent and generate colour using computers
- We now need to understand the interplay of light and objects

# Lighting versus “Colouring”