MCA101 : COMPUTER GRAPHICS

COLOR REPRESENTATION

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OUTLINE

WHAT ARE COLOURS

Colour is the visual perception based on the electromagnetic spectrum. Though color is not an inherent property of matter, color perception is related to an object's light absorption, reflection, emission spectra, and interference — Wikipedia

FIGURE: Image Courtesy: Wikipedia

RGB COLOURS

Perception of color originates from different light wavelength or spectral sensitivity in cone cell types, which is then processed by the brain. For most humans, colors are perceived in the visible light spectrum with three types of cone cells (trichromacy)

— *Wikipedia*

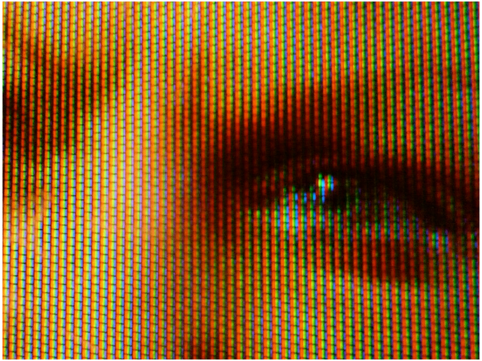


FIGURE: Image Courtesy: Wikipedia

VISIBLE SPECTRUM

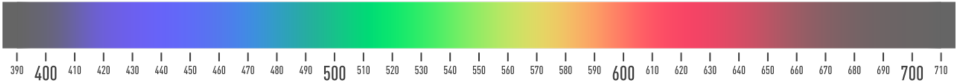


FIGURE: Visible Spectrum. Courtesy: Wikipedia

RGB/A REPRESENTATION

A colour in machine representation is

- a 3-vector for RGB, i.e.
  - $\mathbf{c} \in \mathbb{R}^3_{[0,1]}$ in floating-point representation;
  - $\mathbf{c} \in \mathbb{Z}^3_{[0,255]}$ in 8-bit fixed-point representation.
- a 4-vector for RGBA, i.e.
  - $\mathbf{c} \in \mathbb{R}^4_{[0,1]}$ in floating-point representation;
  - $\mathbf{c} \in \mathbb{Z}^4_{[0,255]}$ in 8-bit fixed-point representation.

OUTLINE

AN IMAGE AS COMPOSITION OF PIXELS

- An image is represented in pixels;
- Conceptually, an image may be thought of split into a rectangular grid of height H and width W;
- Each cell of such a grid, is called a pixel. A pixel is the smallest unit of area patch in an image and contains a uniform colour throughout;
- $H \times W$ is called the resolution of such an image.

AN IMAGE AS A BOUNDED SPACE

- An optical camera sensor receives coloured signals within the spatial opening from its shutter;
- The sensor registers the signals as energy/ intensity corresponding to each of the R,G,B frequencies of visible spectrum.
- The signals are physically continuous in space.
- In practice, samples are discrete in space.
- The space is 2-dimensional and bound on top, bottom, left and right.
- Hence an image may also be interpreted as a quantised and bounded spatial signal.

IMAGE CHANNELS

- Each of R, G, B, A etc. are known as channels.
- If a camera may sample more frequencies, including ultra- and infra-optical spectrum, the resulting image is called a hyper-spectral image.
- The RGB image has 3-channels
- The RGBA image has 4-channels
- A hyper-spectral image may have many channels, say C channels.

IMAGE IN FLOATING-POINT REPRESENTATION

A floating-point may be 16-bit, 32-bit or 64-bit per channel, generally used internally within graphic frameworks like OpenGL/ WebGL etc.

An image with resolution $H \times W$,
containing C channels
is represented as $\mathbf{x} \in \mathbb{R}_{[0,1]}^{C \times H \times W}$.

An RGB image with resolution $H \times W$,
is represented as $\mathbf{x} \in \mathbb{R}_{[0,1]}^{3 \times H \times W}$.

An RGBA image with resolution $H \times W$,
is represented as $\mathbf{x} \in \mathbb{R}_{[0,1]}^{4 \times H \times W}$.

Image in 8-bit fixed-point

A fixed-point may be 8-bit, 16-bit, 32-bit or 64-bit per channel, generally 8-bit is most commonly used.

An image with resolution $H \times W$, containing C channels is represented as $\mathbf{x} \in \mathbb{Z}_{[0,255]}^{C \times H \times W}$.

An RGB image with resolution $H \times W$, is represented as $\mathbf{x} \in \mathbb{Z}_{[0,255]}^{3 \times H \times W}$.

An RGBA image with resolution $H \times W$, is represented as $\mathbf{x} \in \mathbb{Z}_{[0,255]}^{4 \times H \times W}$.

QUESTION

1. How is a grayscale image with resolution $H \times W$ with floating-point representation described mathematically?
2. How is a grayscale image with resolution $H \times W$ with 8-bit fixed-point representation described mathematically?
3. How is a grayscale image with resolution $H \times W$ with 16-bit fixed-point representation described mathematically?

QUESTION

1. What is the minimum size (in bytes) required to store an uncompressed RGB image in FHD resolution. Assume the image header to be H bytes.
2. What is the minimum size (in bytes) required to store an uncompressed RGBA image in FHD resolution. Assume the image header to be H bytes.

OUTLINE

COLOUR TABLES

In order to improve storage efficiency of images,

- Included colours are listed, the count $n < 256$ generally. This is called a colour table.
- For each pixel, the colour is approximated and assigned to be one of the colours in the table, and the colour index is stored instead of the complete colour information.
- This reduces the storage requirement by order of magnitude.
- The only additional storage requirement is that of the colour table, $n \times 3$ bytes

For example,

- RGB image requires $8 \times 3 = 24$ bits per pixel; whereas
- Colour table with upto 2 colours would require only 1-bit per pixel;
- Colour table with 3-4 colours would require only 2-bit per pixel;
- Colour table with 5-8 colours would require only 3-bit per pixel;

STORAGE EFFICIENCY

Num Bits	Max Num Colours
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	256

QUESTION

What is the minimum size (in bytes) of storage required to store an image with colour table with 100 RGB-colours? Assume the image header to be H bytes.

OUTLINE

HSL AND HSV

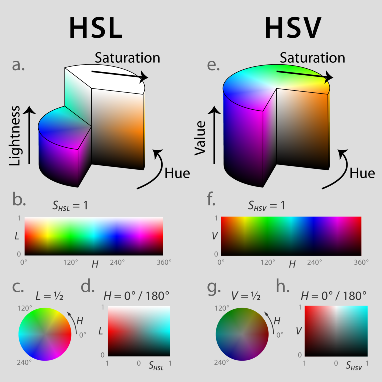


FIGURE: Image Courtesy: Wikipedia

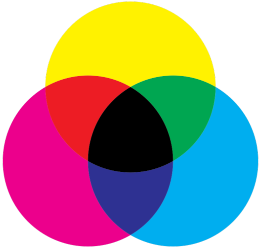
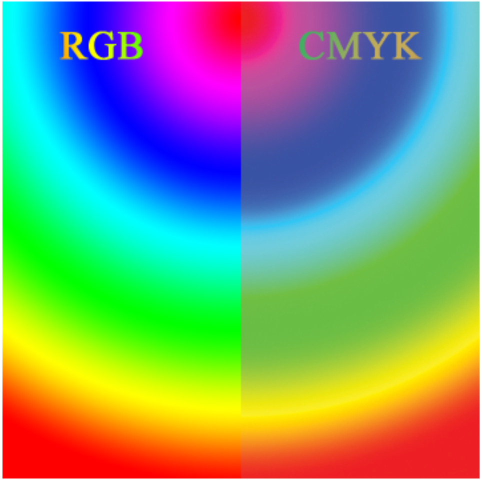


FIGURE: When subtractive CMY inks are combined at full strength, pairwise combinations are red, green, and blue. Combining all three gives an imperfect black colour.

FIGURE: Color printing typically uses ink of four colours: cyan, magenta, yellow, and black.

RGB VS CMYK



A comparison of CMYK and RGB color models. This image demonstrates the difference between how colors will look on a computer monitor (RGB) compared to how they might reproduce in a particular CMYK print process.

Image Courtesy: Wikipedia

COLOUR MIXING: ADDITIVE VS SUBTRACTIVE

ADDITIVE COLOUR MIXING

Three overlapping light bulbs in a vacuum, adding together to create white.

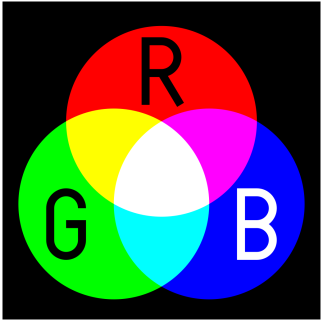


FIGURE: Image Courtesy: Wikipedia

SUBTRACTIVE COLOUR MIXING

Three splotches of paint on white paper, subtracting together to turn the paper black.

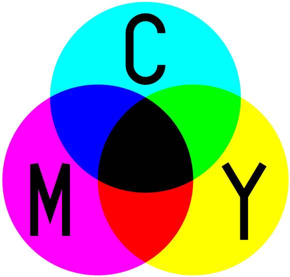


FIGURE: Image Courtesy: Wikipedia

OTHER COLOUR SPACES

1. Munsell (Munsell Colour System)
2. Pantone (Pantone Matching System)
3. Colour Fan Decks (by Paint Manufacturers)
4. Y,u,v Colour Space
5. L,a,b Colour Space

(Read More)

OUTLINE

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Point on straight line segment connecting vectors $\mathbf{a}, \mathbf{b}$, may be given parameterised by $t \in \mathbb{R}_{[0,1]}$ as,

$$\begin{aligned} f(t) &= (1-t)\mathbf{a} + t\,\mathbf{b} \\ &= \mathbf{a} + t(\mathbf{b} - \mathbf{a}) \end{aligned}$$

$$\begin{aligned} t = 0 &\iff f(t) = \mathbf{a} \\ t = 1 &\iff f(t) = \mathbf{b} \end{aligned}$$

Question

Given two points $\mathbf{a}, \mathbf{b} \in \mathbb{R}^2$, find the point on straight line connecting them, and in between, so that it is twice as far away from $\mathbf{b}$ as it is from $\mathbf{a}$.

Solution

Point on straight line connecting $\mathbf{a}$, $\mathbf{b}$, and in between, may be given parameterised by $t \in \mathbb{R}_{[0,1]}$ as,

$$f(t) = (1 - t)\mathbf{a} + t\,\mathbf{b}$$

Here if the Euclidean distance $\Delta_E(\mathbf{a}, \mathbf{b}) = 1$ unit, then $\Delta_E(\mathbf{a}, f(t)) = 1 - t$ units, and $\Delta_E(f(t), \mathbf{b}) = t$ units. Hence,

$$t = \frac{2}{3} \qquad \because t = 2(1 - t)$$

$$\mathbf{p} = f(t = \frac{2}{3}) = \frac{1}{3}\mathbf{a} + \frac{2}{3}\mathbf{b}$$

Question

Given two RGB colours $\mathbf{a}, \mathbf{b} \in \mathbb{R}^3$, find the colour $\mathbf{c}$, so that it is twice as far away from $\mathbf{b}$ as it is from $\mathbf{a}$.

Solution

Point on hypothetical straight line in RGB colour space connecting $\mathbf{a}$, $\mathbf{b}$, and in between, may be given parameterised by $t \in \mathbb{R}_{[0,1]}$ as,

$$f(t) = (1 - t)\mathbf{a} + t\mathbf{b}$$

Here if the Euclidean distance $\Delta_E(\mathbf{a}, \mathbf{b}) = 1$ unit, then $\Delta_E(\mathbf{a}, f(t)) = 1 - t$ units, and $\Delta_E(f(t), \mathbf{b}) = t$ units. Hence,

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OUTLINE

BARYCENTRIC COORDINATES

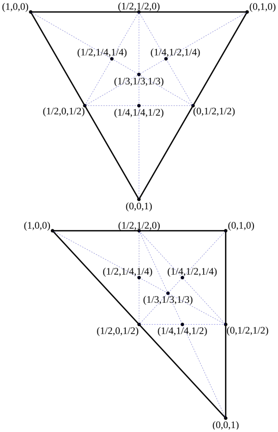

FIGURE: Image Courtesy: Wikipedia

With respect to the vertices **a**, **b** and **c**, the points inside the triangle may be represented as $(\lambda_a, \lambda_b, \lambda_c)$, where $\lambda_a + \lambda_b + \lambda_c = 1$.

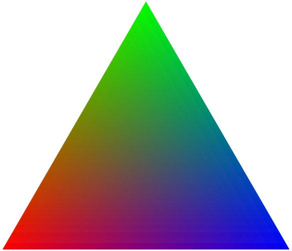

FIGURE: Barycentric coordinates are used for blending three colors over a triangular region evenly in computer graphics. Image Courtesy: Wikipedia

With respect to the vertices **a**, **b** and **c**, the points inside the triangle may be represented as $(\lambda_a, \lambda_b, \lambda_c)$, where $\lambda_a + \lambda_b + \lambda_c = 1$.