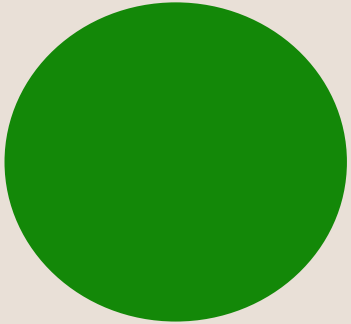
What is Color?

An Introduction to Color Science for Engineers

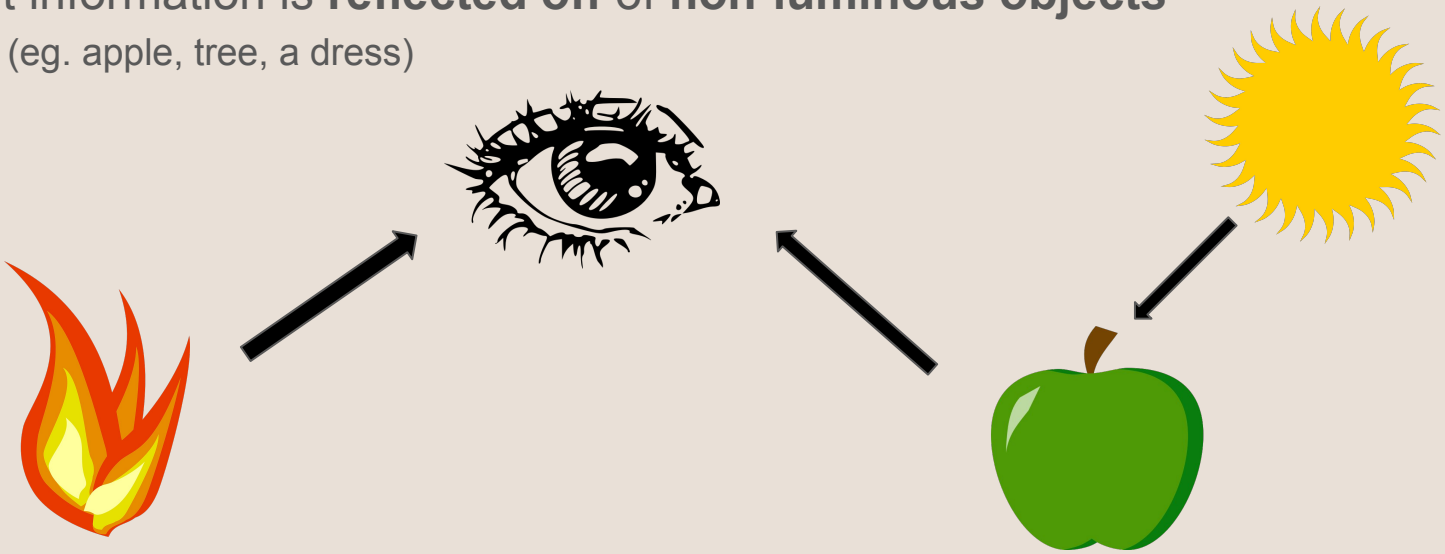
What color is this dress?

How would you describe these contrasting colors?



How do we see color?

- Light information is **radiates off** of **luminous objects**
  - (eg. lamp, sun, flame)
- Light information is **reflected off** of **non-luminous objects**
  - (eg. apple, tree, a dress)



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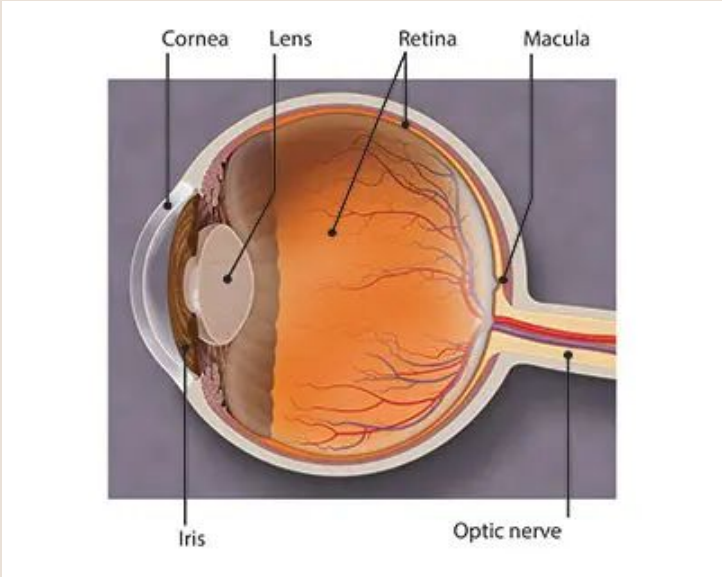
- Light enters our eyes
  - Cell receptors are activated in the retina
  - Electrical signals go off in the brain



[aao.org]

How do we define color?

- As a property of objects as observed in day
  - Brown bear, white onions, silver (AG), gold (AU)
- As a property of light
  - Soft white light of a lamp, red traffic light, red neon open sign

“”DEFINITION. Rays are not coloured but possess the power to produce the sensation of colour”” — Sir Isaac Newton, Opticks

How do we define color? As Engineers?

- Color — An experience from a specific type of light, **the stimulus of light arriving to the retina**, or the response of the brain to create/recognize it.

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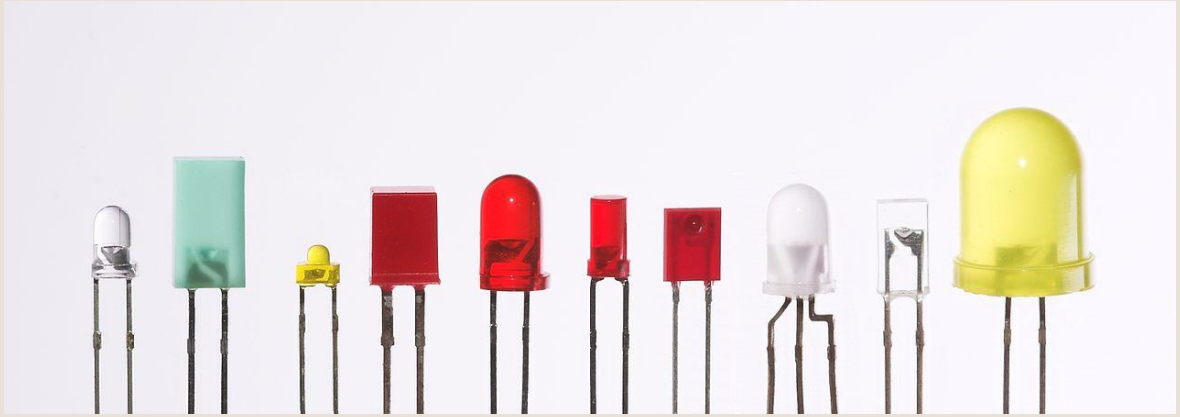

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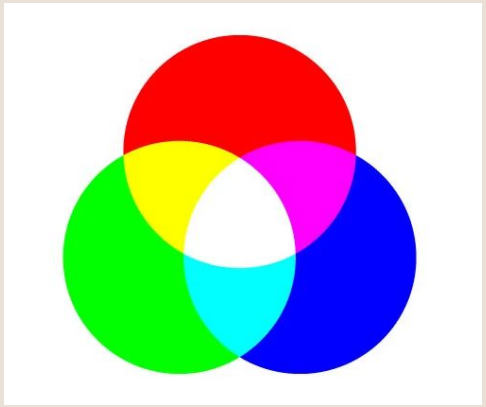
- Coloring — The **process of applying and rearranging colorants** to produce desired colors.
- Primary color — One in a set of colors that are used to **create a color system**.
- Color system — A collection of colors **created by mixing a set of primary colors**, while also accounting for material and audience assumptions.

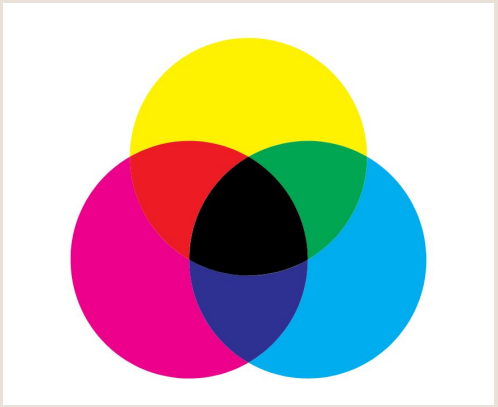
Color Systems & Color Models

RGB
(Red-Green-Blue)



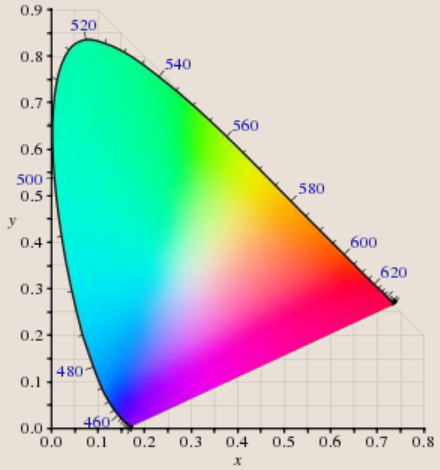
RYB
(Red-Yellow-Blue)

CMYK
(Cyan-Magenta-Yellow-Key)

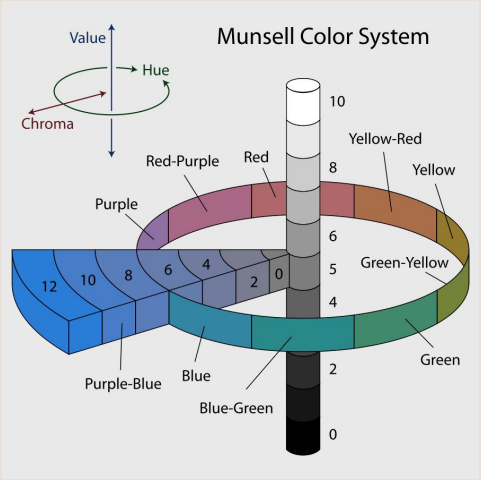


Color Systems & Color Models

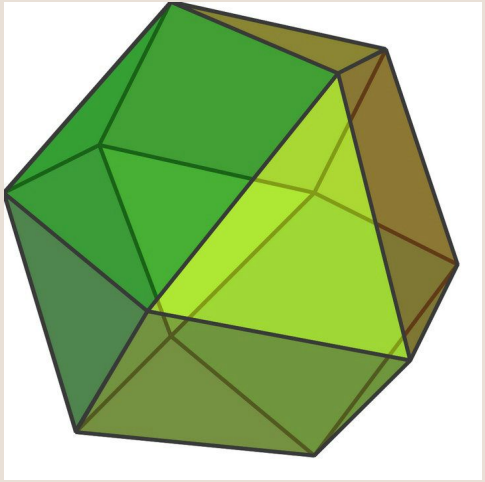
CIE
(International Commission on Illumination, 1931)



Munsell

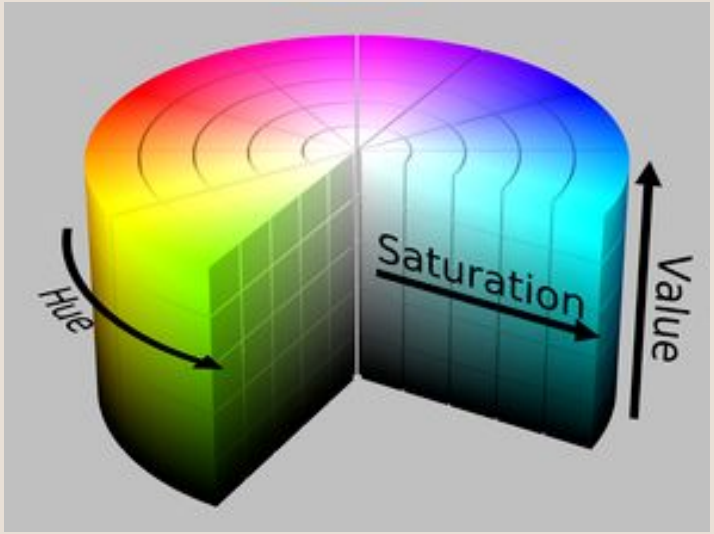


OSA-UCS
(Optical Society of America Uniform Color Space)

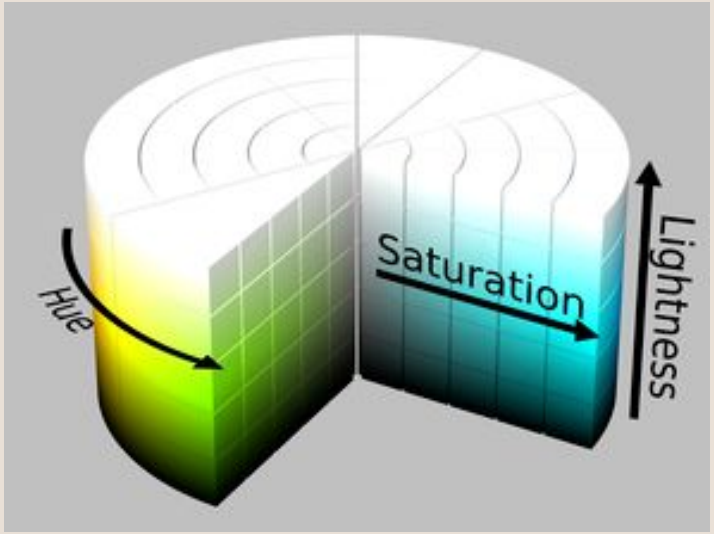


Color System & Color Models

HSV



HSL



Defining Dominant & Secondary Colors

- Palette — A set of colors.
- Dominant Color — One of the most prominent colors in an object.
- Secondary Color — A non-dominant color within the palette of an object.

Methods to Finding Dominant Colors

Color Quantization — the process of simplifying/reducing the number of distinct colors in an image.

1) Sampling the original image for color statistics
2) Choosing a colormap based on the color statistics
3) Mapping the original colors to their nearest neighbors in the colormap
4) Quantizing and redrawing the original image

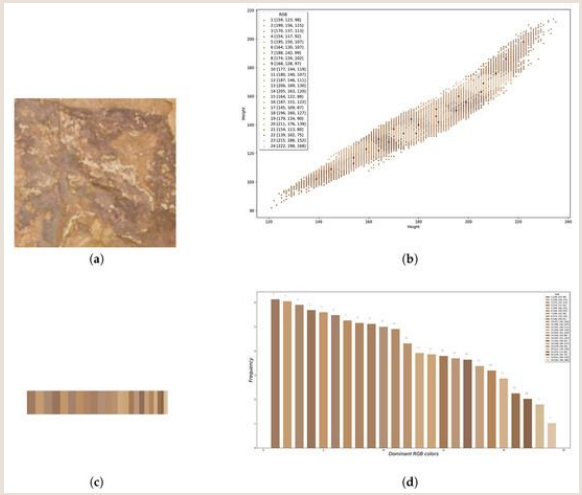
[Heckbert, 1982]

[Heckbert, 1982]

Methods to Finding Dominant Colors

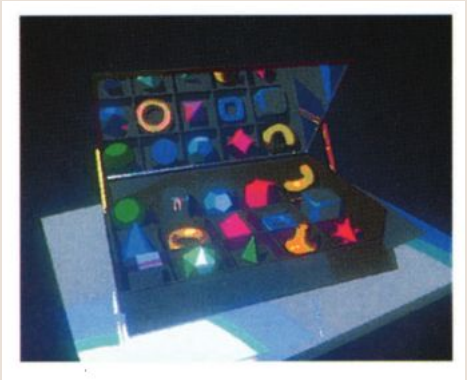
Algorithms

1) Median Cut algorithm
2) K-means algorithm
3) Octrees algorithm



[Molada-Tebar et al, 2020]

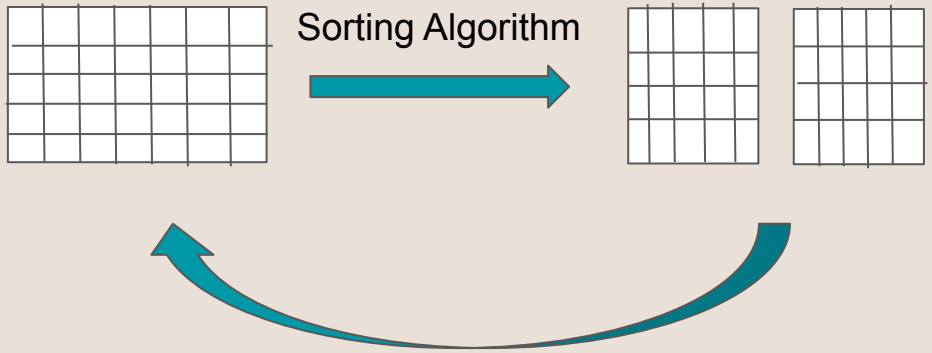
Displayed with 16 million colors [Gervautz & Purgathofer, 1988]



Displayed with 64 colors [Gervautz & Purgathofer, 1988]

Median Cut Implementation Overview

1) Convert an image to some matrix representation
2) Sort the cells by some method
3) Find the median value, split the region into two subsections
4) Repeat steps 2 & 3 for the new subsections. Stop when you have the desired number of distinct colors.
5) Take the average color of each section.

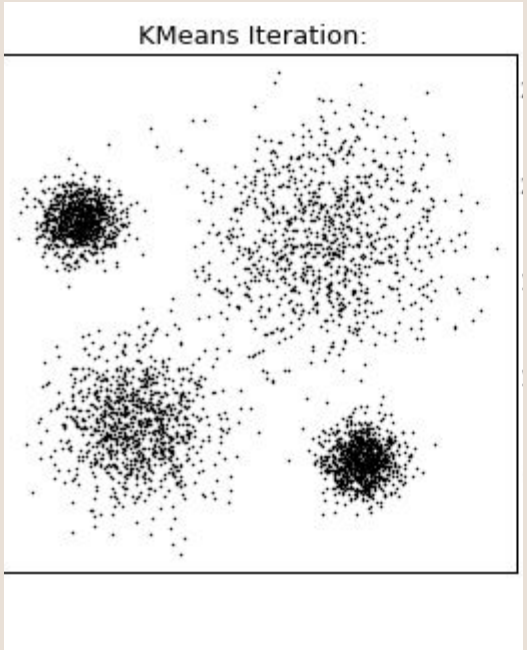


(211, 217, 218)	**(209, 160, 124)**	**(109, 107, 113)**	**(0,24,100)**

(210, 189, 171)	(55, 66, 107)

K-Means Implementation Overview

1) Convert an image to some matrix representation
2) Choose the number of k-clusters (# colors)
3) Select k-random centroids
4) Find the distance between the points and the centroids, associate points with closest centroids
5) Calculate variance between clusters
6) Repeat until best variance found OR max iteration



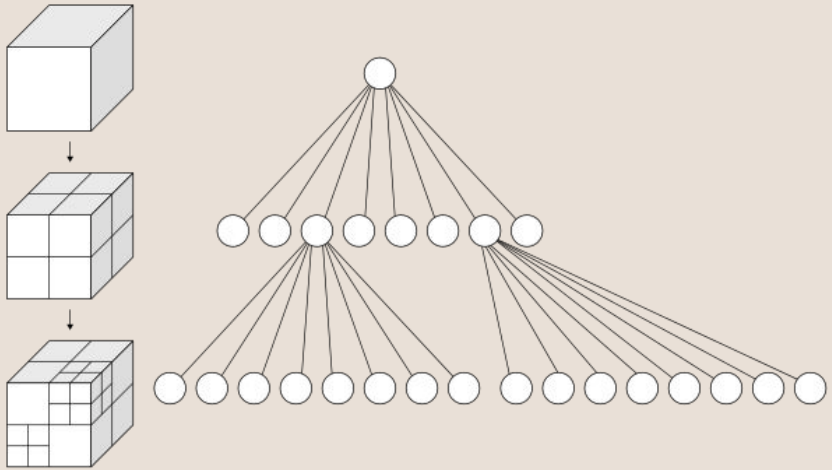
[David Sheehan, 2017]

Octrees Implementation Overview

The principle of the octree algorithm is to sequentially read in the image. Every color is then stored in an octree of depth 8 (every leaf at depth 8 represents a distinct color). A limit of K (in this case K = 256) leaves is placed on the tree. Insertion of a color in the tree can result in two outcomes.

1. If there are less than K leaves the the color is filtered down the tree until either it reaches some leaf node that has an associated representative color or it reaches the leaf node representing its unique color.

2. If there are greater than K leaves in the tree some set of leaves in the tree must be merged (their representative colors averaged) together and a new representative color stored in their parent.



[Matthew Ward, WPI]

Possible Further Reading

- Christian Wengert, Matthijs Douze, & Hervé Jégou. 11/2011. Bag-of-colors for improved image search. MM 2011 - 19th ACM International Conference on Multimedia. https://doi.org/10.1145/2072298.2072034
- David Sheehan. 05/09/2017. Clustering with Scikit with GIFs. dashee87.github.io
- George A. Agoston. Color Theory and Its Application in Art and Design. Berlin; New York, Springer-Verlag, 1987.
- Gervautz & Purgathofer. 1988. A Simple Method for Color Quantization: Octree Quantization. In: Magnenat-Thalmann, N., Thalmann, D. (eds) New Trends in Computer Graphics. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-83492-9_20
- Paul Heckbert. 1982. Color image quantization for frame buffer display. SIGGRAPH Comput. Graph. 16, 3 (July 1982), 297–307. https://doi.org/10.1145/965145.801294