Mansoura University
Faculty of Computers and Information
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COMPUTER GRAPHICS

Grade: 2ND YEAR (GENERAL –BIO)

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Chapter 2
Color theory

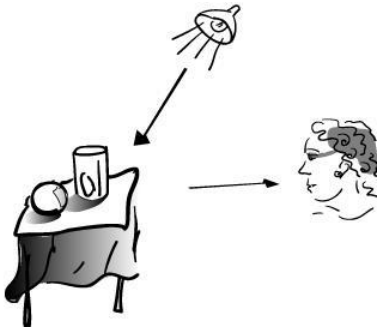
COLOR

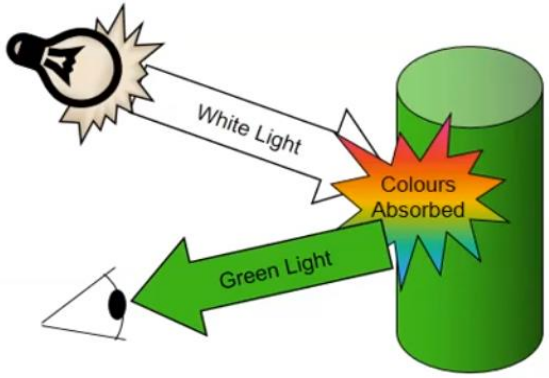
- ***Color*** is an attribute of objects (like *texture, shape, smoothness,* etc.).
- Any method for explaining the properties or behavior of color within some particular context is called ***a color model***
- A **color model** is an abstract mathematical model describing the way colors can be represented as tuples of numbers, typically as three or four values or color components. When this model is associated with a precise description of how the components are to be interpreted (viewing conditions, etc.), the resulting set of colors is called "color space".

- No **single** model can explain all aspects of color, so we make use of different models to help describe different color characteristics.

WHY IS COLOR DIFFICULT AND IMPORTANT?

- Color importance:
  - Color is an excellent descriptor: Suitable for object Identification and Extraction.
  - Discrimination: Humans can distinguish thousands of color shades and intensities but few shades of gray levels.

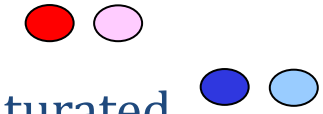




- Color of an object depends not only on the object itself, but also on the light sources illuminating it, the color of surrounding area, and on the human visual system (the eye/brain mechanism)
- Some objects reflect light (wall, desk, paper), while others transmit light (cellophane, glass)

Color Terms

1. ***Hue*** distinguishes among colors (e.g., red, green, purple, and yellow)
2. ***Saturation*** refers to how pure the color is, how much **gray** is mixed with it
   - red saturated; pink unsaturated
   - royal blue saturated; sky blue unsaturated
   - Pastels are less saturated, hence less vivid and less intense



3. ***Lightness****:* perceived achromatic intensity of reflecting object
4. ***Brightness****:* perceived intensity of a self-luminous object, such as a light bulb, the sun, or an LCD screen

Color Mixture

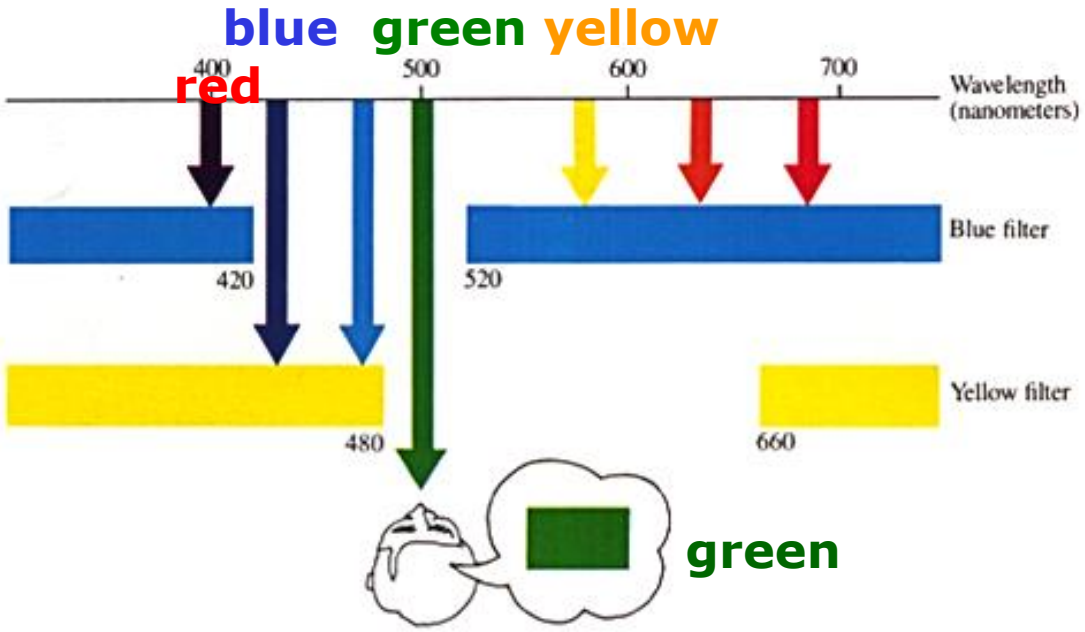
- The effect of (A) passing light through several filters (subtractive mixture), and (B) throwing different lights upon the same spot (additive mixture)

A

B

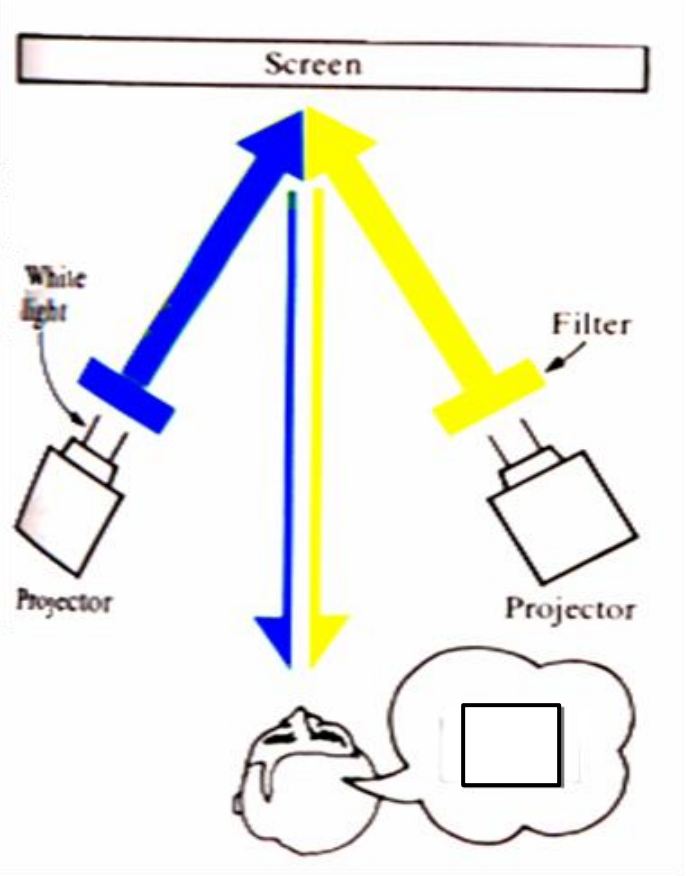
1-Subtractive Mixture الطباعة بالأحبار

- *Subtractive mixture* occurs when mixing paints, dyes, inks, etc. that act as a filters between the viewer and the light source / reflective surface.
- In subtractive mixing, the light passed by two filters (or reflected by two mixed pigments) are wavelengths that are passed by the two filters



2-Additive Mixture للشاشات

- *Additive mixture* occurs when color is created by mixing visible light emitted from light sources
  - Used for computer monitors, televisions, etc.
- Light passed by two filters (or reflected by two pigments) impinges upon same region of retina
- On the diagram: pure blue and yellow (green+red) filtered light on same portion of the screen, reflected upon same retinal region, produce white/gray



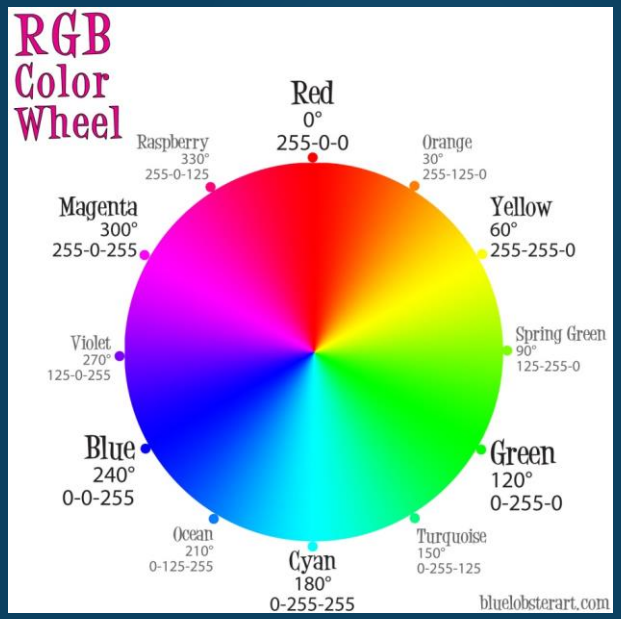
COLOR MODELS

- Color Model (Color Space, Color System)
  - Specify colors in a standard way
  - A coordinate system that each color is represented by a single point.
- Most used models:
  - RGB model (Monitor/TV)
  - CYM model (3-color Printers)
  - CYMK model (4-color Printers)
  - HSI model (Color Image Processing and Description)

Color Models

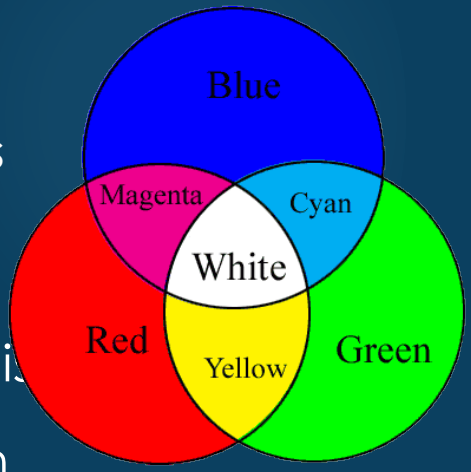
1- RGB

2- CMYK



1-Color Models - RGB

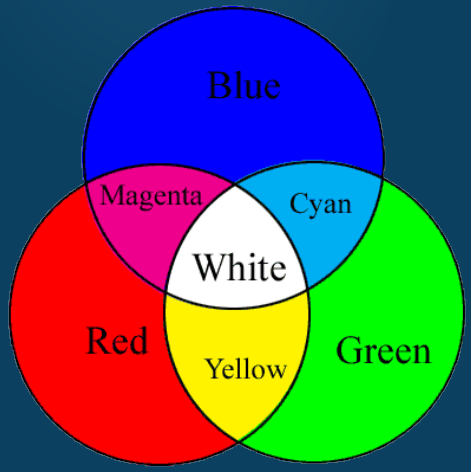
- Additive Color: RGB
  - Describes colors that emanate from glowing bodies such as lights, TV, and computer monitors
  - In additive color models, mixing two colors results in a brighter color
- **Additive Colors** are created by mixing spectral light in varying combinations. The most common examples of this are television screens and computer monitors, which produce colored pixels by firing red, green, and blue electron guns at phosphors on the television or monitor screen.



Color Models - RGB

Eyad Alshareef

- Overlapping colors from 3 projectors produces new colors
  - Red + green -> yellow
  - Green + blue -> cyan
  - Red + blue -> magenta



Color Models - RGB

- **RGB color space** or **RGB color system**, constructs all the colors from the combination of the **R**ed, **G**reen and **B**lue colors.
- The red, green and blue use 8 bits each, which have integer values from 0 to 255. This makes 256*256*256=16777216 possible colors.

Color	HTML / CSS Name	Hex Code #RRGGBB	Decimal Code (R,G,B)
	Black	#000000	(0,0,0)
	White	#FFFFFF	(255,255,255)
	Red	#FF0000	(255,0,0)
	Lime	#00FF00	(0,255,0)
	Blue	#0000FF	(0,0,255)
	Yellow	#FFFF00	(255,255,0)
	Cyan / Aqua	#00FFFF	(0,255,255)
	Magenta / Fuchsia	#FF00FF	(255,0,255)

Color Models - RGB

Eyad Alshareef

- The color systems used by scientists and artists are entirely different.
  - An artist will mix blue and yellow paint to get a shade of green.
  - A scientist will mix green and red light to create yellow. The printed page in a magazine is yet another system.

Color Models - RGB

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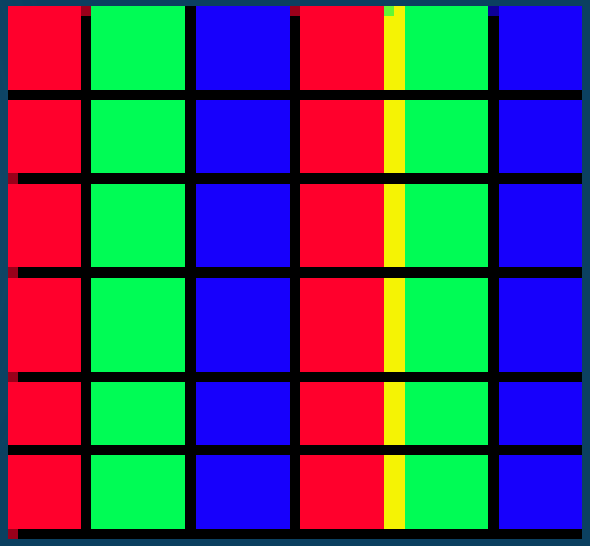
- This color model is used in computer monitors, television sets, and theater. If you put your eye up against your television screen you might something like

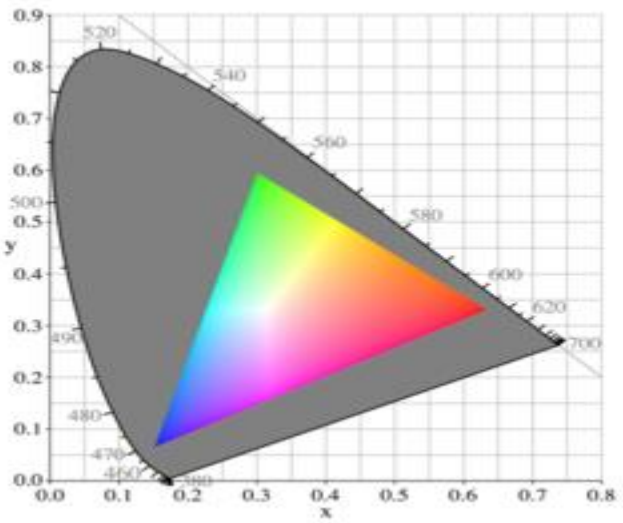


COMPLEMENTARY HUES – ADDITIVE MIXTURE

Complementary hues: Any hue will approach gray if additively mixed with it's opposite hue on the color circle. Such hue pairs are complementary. Of particular importance are the pairs that contain four unique hues: red-green, blue-yellow "complementary hues"

- Note that combining two complementary hues can never equal gray. For example, adding green to red will give you a yellowish gray, which is more *neutral* than the initial red

COLOR GAMUT
مجال الألوان المتاح في الجهاز



The gray area represents the entire chromatic range. The colored triangle represents the color display.

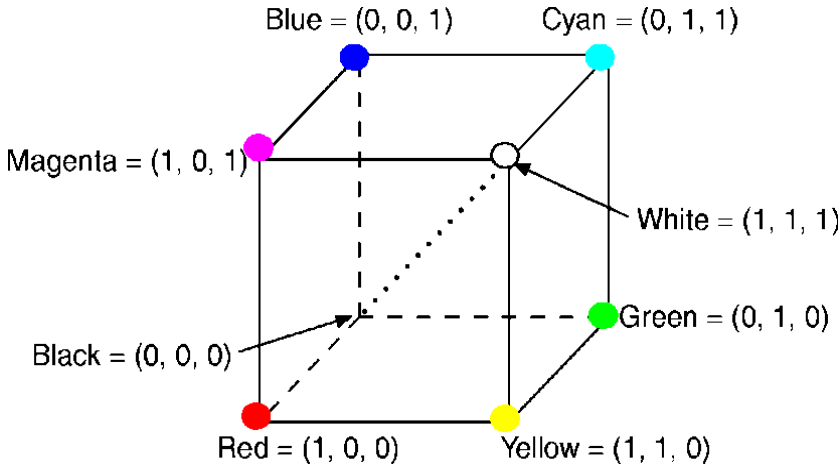
Definition of GAMUT

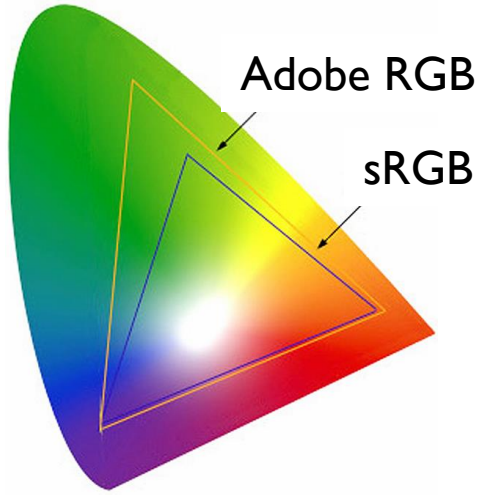
1. The subset of colors which can be accurately represented within a given color space or by an certain output device and ink combination.

2. The complete set of colors found within an image at a given time. Converting a digitized image to a different color space, or printing it to a given medium generally alters its gamut.

THE RGB COLOR MODEL

- RGB primaries are additive (RGBA)
- The RGB cube (Grays are on the dotted main diagonal)
- Main diagonal => gray levels
  - black is (0, 0, 0)
  - white is (1, 1, 1)
- RGB color gamuts
  - differs from one display to another
  - differs by company too:
    - Adobe RGB - larger space
      - Currently the standard for digital photography
    - sRGB (HP/Microsoft) - fewer colors, but allocated bit depth better and more than enough for most on-screen and Web uses
      - Most monitors now cover 100% of sRGB space





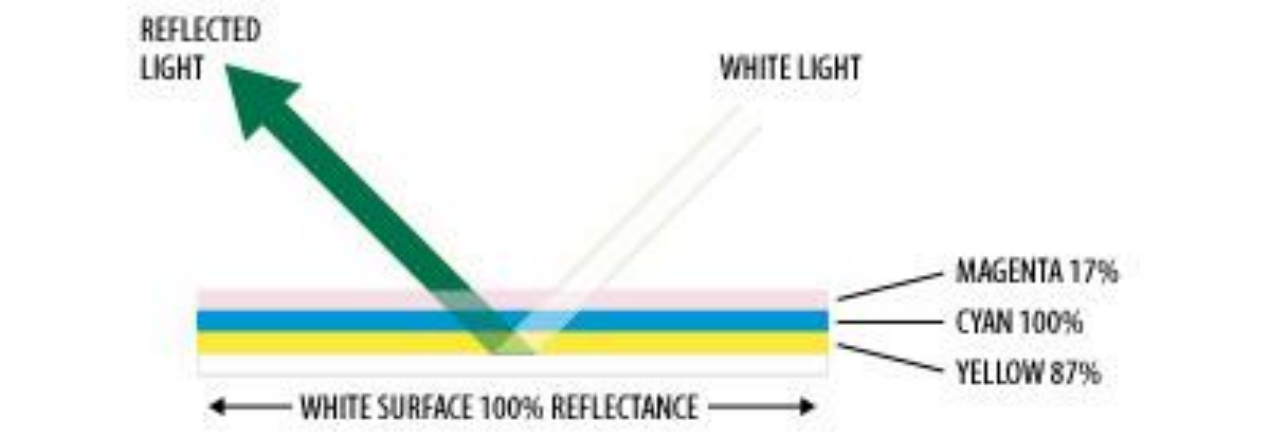
2-Color Models - CMYK

Eyad Alshareef

- Subtractive Color : CMYK
  - Most object reflect light
  - Mixing two colors creates a darker one
- Similar to paint and printer's ink
- Primary colors are cyan, magenta, yellow, which are complements of red, green and blue, respectively
- Where 3 inks overlap, there is black (gray)

Color Models - CMYK

- Subtractive colors are seen when pigments صبغات in an object absorb certain wavelengths of white light while reflecting the rest.



Color Models - CMYK

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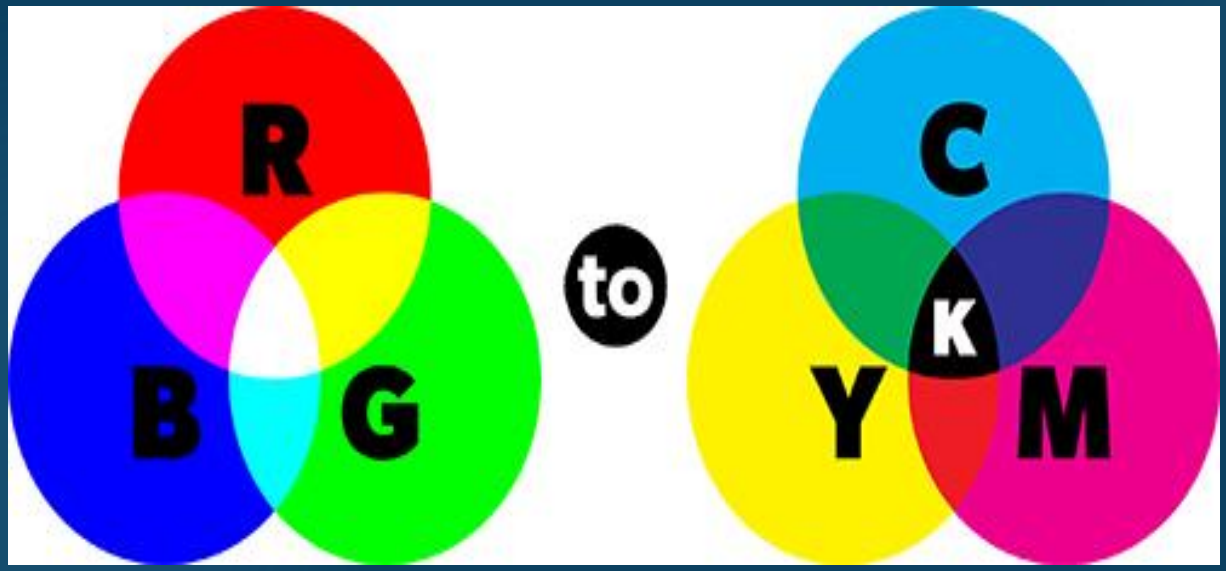
- **CMYK is a *subtractive, reflected light* color system.** All colors start with white "paper", to which different color "inks" are added to absorb (subtract) light that is reflected.
- In theory, CMY are all you need to create black (applying all 3 colors at 100%). Alas, that usually results in a muddy, brownish black, so the addition of K (black) is added to the printing process. It also makes it easier to print black text

Color Models - CMYK

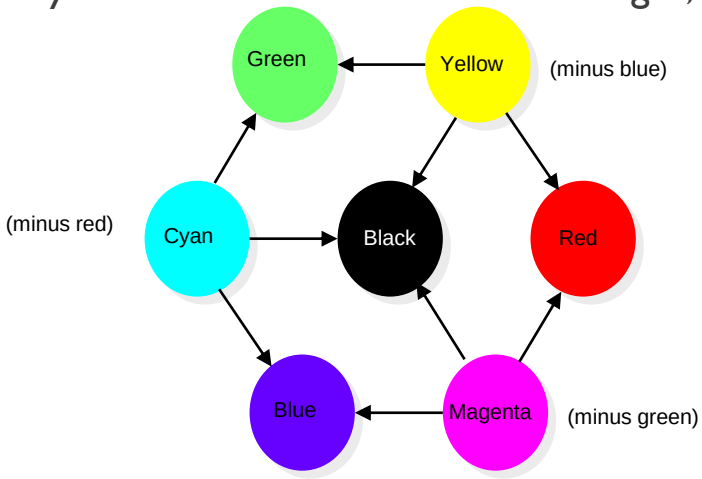
Eyad Alshareef



THE CMY(K) COLOR MODEL

- Used in electrostatic and in ink-jet plotters that deposit pigment on paper
- Cyan, magenta, and yellow are complements of red, green, and blue
- Subtractive primaries: colors are determined by what is subtracted from white light, rather than by what is added to blackness
  - white is at origin, black at (1, 1, 1):

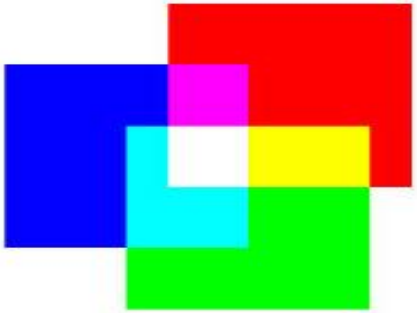
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



subtractive primaries (cyan, magenta, yellow) and their mixtures

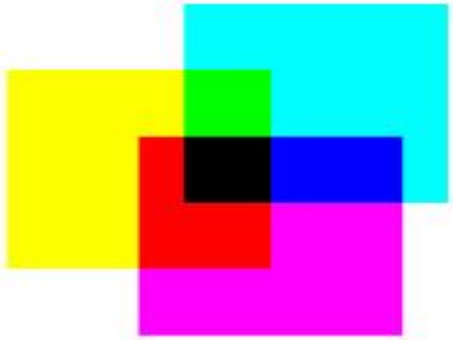
RGB AND CMYK

RGB and CMYK are two different color spaces. The RGB color space uses light in colors of red, green, and blue to create the visible spectrum. Our eyes see color in terms of reflected light, so the observed world is closer to RGB than CMYK. That is why native RGB devices that use light to create color, such as film recorders, scanners, and cameras can reproduce color fairly accurately.



RGB. Three colors of light, red, green and blue make white light. Cyan, magenta and yellow are also combinations of RGB.

The intensity of light also changes the color.



CMYK. Three inks, cyan, magenta and yellow make black. In practice this black lacks intensity, so a separate black (K) is usually added. Red, green and blue are made from CMYK.

CMY AND CMYK COLOR MODELS

- **CMY:** Secondary colors of light, or primary colors of pigments are used.
- Used to generate hardcopy output (Printer and Copier).
- Some facts:
  - Printer papers are white (reflect all colors)
  - Printers use ink (Transparent)

- K (Blac**k**) is practical problem of C+M+Y≠Black (Muddy Brown) وذلك بسبب مشكلة في جودة الاحبار الكيميائية. Add a fraction of Black color

Color Models - CMYK

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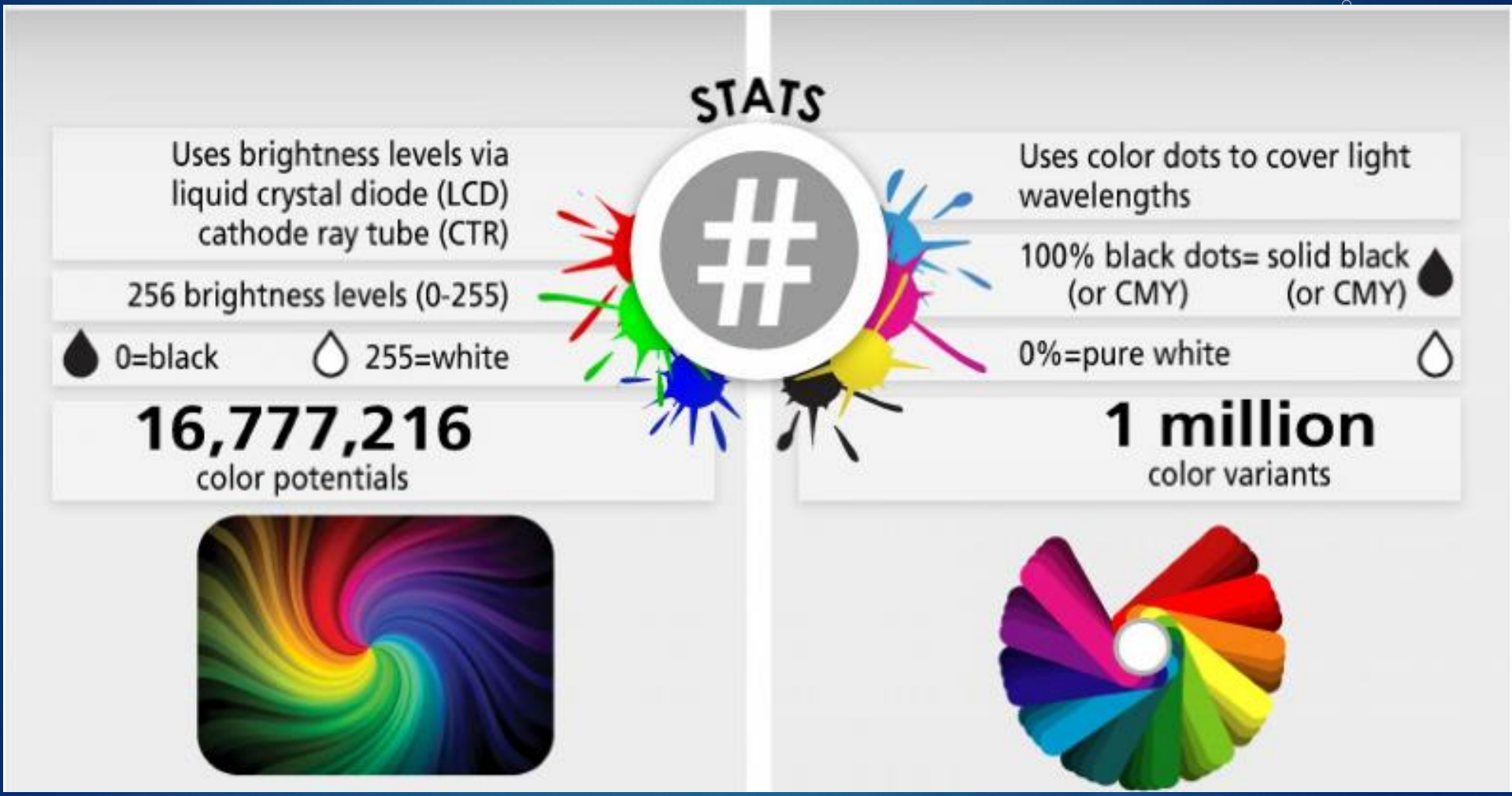
- Below is an example of a photo originally produced in RGB colors converted to CMYK colors as displayed on a computer monitor. Notice how the colors are much more vibrant on the RGB picture.

Color Models – RGB vs. CMYK



3-RGB AND HSV/HSI/HSL COLOR SPACE CONVERSION

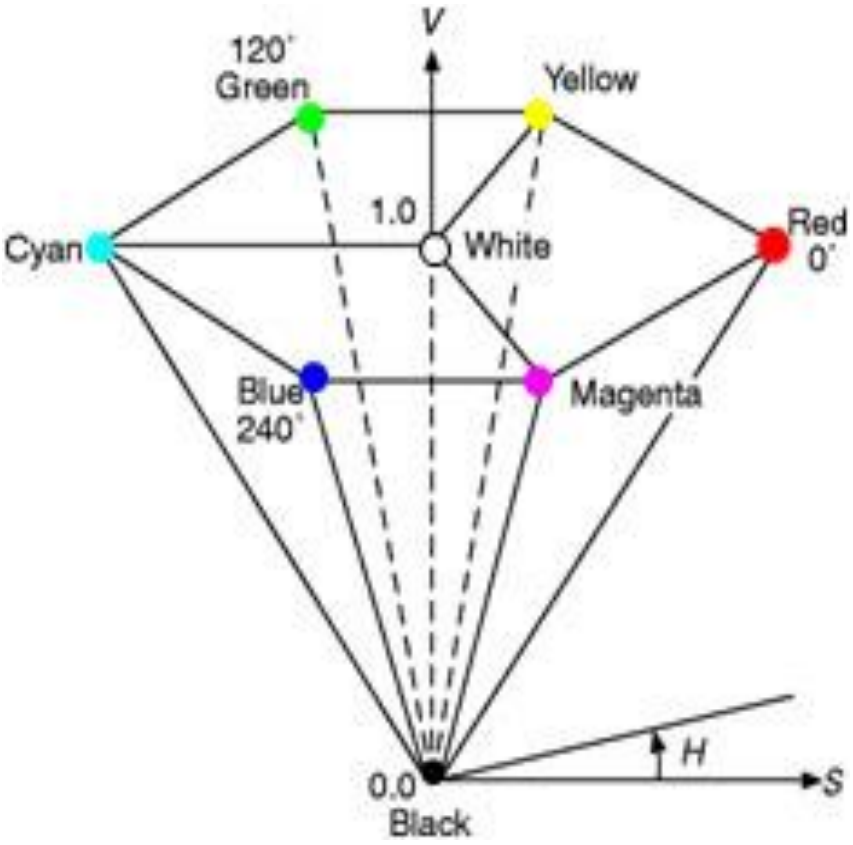
- Human description of color is not RGB or CMY**K**

مثلاً: أحمر غامق، أخضر فاتح

- So, other models are required like: HSV/HSI/HSL
- HSV (hue-saturation-value), HSI (hue-saturation-intensity) and HSL (hue-saturation-lightness) are the three most common cylindrical-coordinate representations of points in an RGB color model.
- The HSV/HSI/HSL representations rearrange the geometry of RGB in an attempt to be more intuitive and perceptually relevant.
- The representations HSV, HSI and HSL are very similar, but not completely identical.

THE HSV COLOR MODEL-I

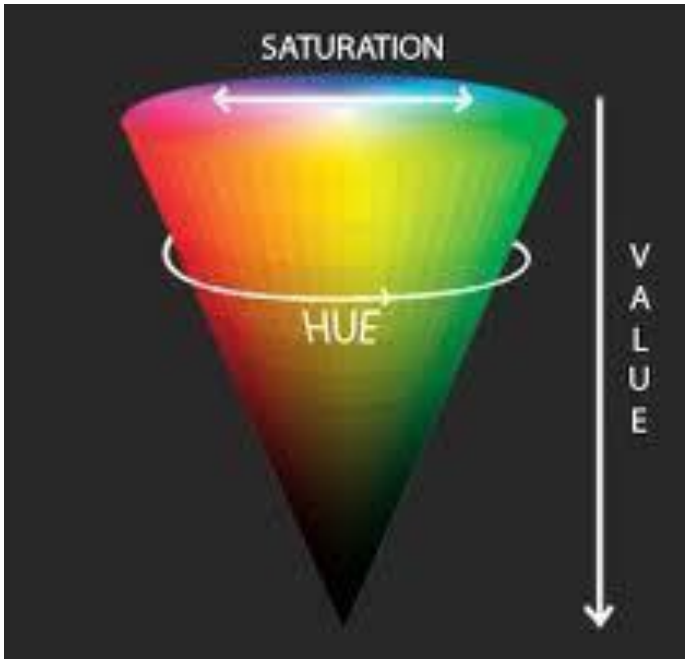
- **Hue**
- In HSV, hue represents color. In this model, hue is an angle from 0 degrees to 360 degrees.



Angle	Color
0-60	Red
60-120	Yellow
120-180	Green
180-240	Cyan
240-300	Blue
300-360	Magenta

THE HSV COLOR MODEL-2

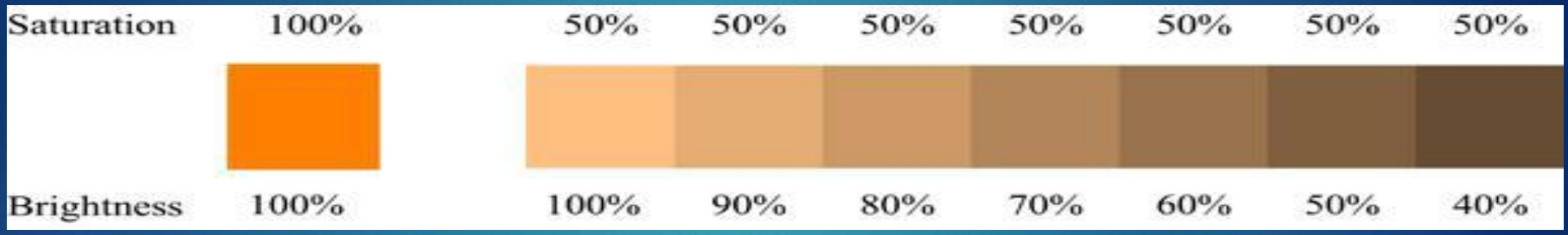
- **Saturation**
- Saturation indicates the range of grey in the color space. It ranges from 0 to 100%. Sometimes the value is calculated from 0 to 1. When the value is '0,' the color is grey and when the value is '1,' the color is a primary color. A faded color is due to a lower saturation level, which means the color contains more grey.
- **Value**
- Value is the brightness of the color and varies with color saturation. It ranges from 0 to 100%. When the value is '0' the color space will be totally black. With the increase in the value, the color space brightness up and shows various colors.



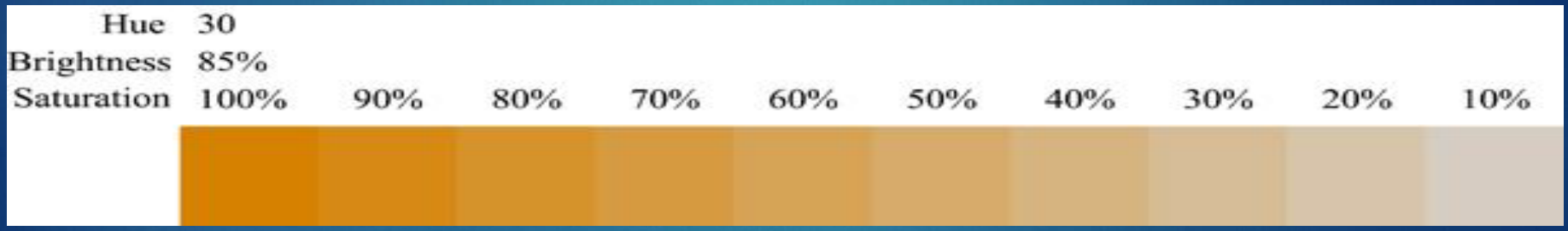
https://www.tech-faq.com/hsv.html

Color Models

- **Varying Brightness**



- **Varying Saturation**



Suggested Rule for Creating **Color Palettes** using HSV

- Color **Palettes** is all selected colors to be used in scene.
- **Suggested rule (***not strict, you can ignore it sometimes***):** https://gamedevelopment.tutsplus.com/articles/picking-a-color-palette-for-your-games-artwork--gamedev-1174

```
IF hues do not equal each other
THEN set saturations to match each other
AND set brightnesses to match each other
```

```
ELSE IF saturations do not equal each other
THEN set hues to match each other
AND set brightnesses to match each other
```

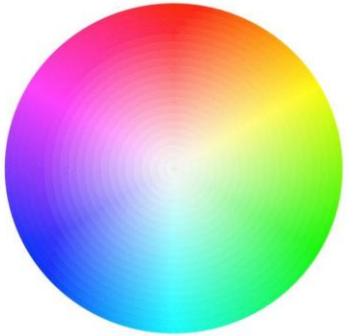
```
ELSE IF brightnesses do not equal each other
THEN set hues to equal each other
AND set saturations to equal each other
```

AN INTRODUCTION TO COLOR THEORY AND COLOR PALETTES

- User interface (UI) designers have the challenging task of incorporating color into their interface in a way that poignantly communicates a brand's visual identity.
- While it might seem like a website's color palette is a matter of the client's personal taste, in reality, UI designers rely on a framework called color theory: a multilayered set of guidelines that informs the use of color in design.
- Color theory is a framework that informs the use of color in art and design, guides the curation of color palettes, and facilitates the effective communication of a design message on both an aesthetic and a psychological level.
- Modern color theory is largely based on Isaac Newton's color wheel, which he created all the way back in 1666. The basic color wheel displays three categories of color; primary colors, secondary colors, and tertiary colors.

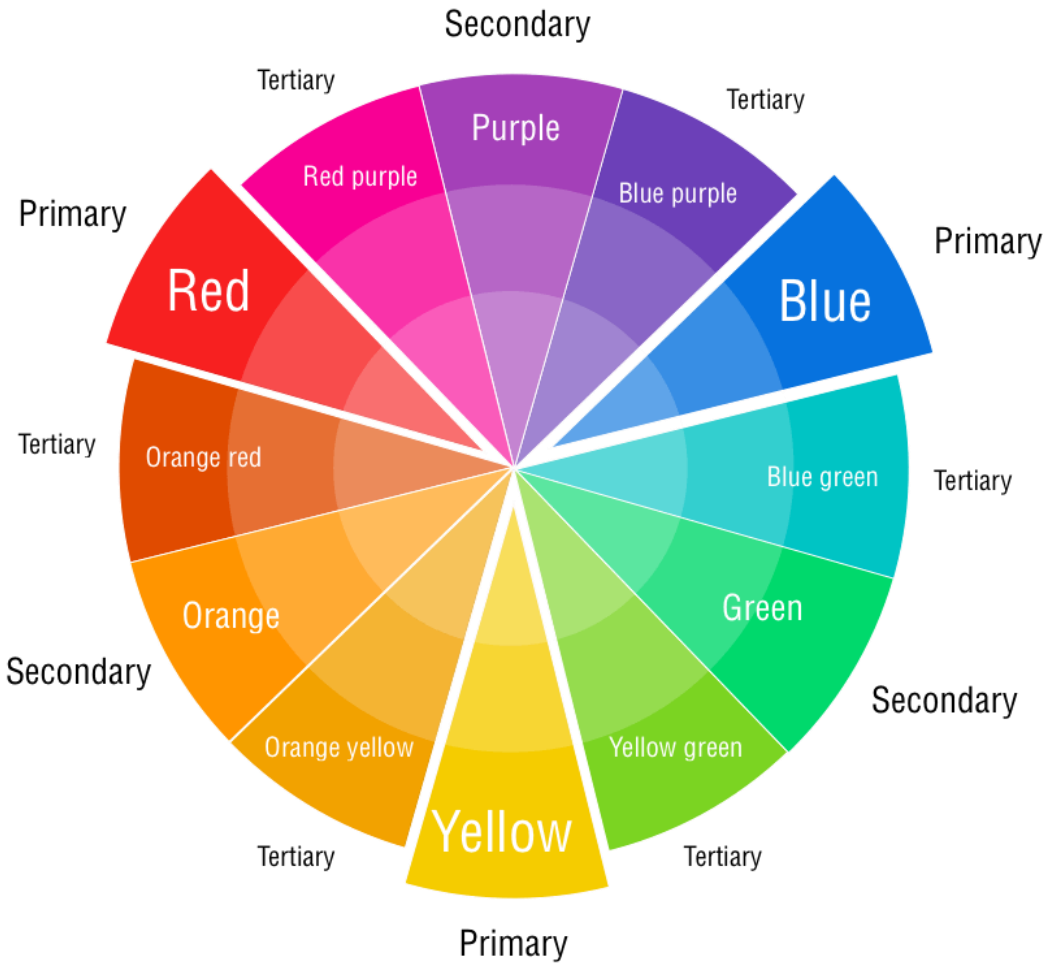
COLOR WHEEL

- An artist creates a color painting by mixing color pigments صبغة with white and black pigments to form the various shades in the scene.
-



You can use a color wheel to find color harmonies by using the rules of color combinations. Color combinations determine the relative positions of different colors in order to find colors that create a pleasing effect.

- Based on Color Wheel:



SHADES, TINTS AND TONES

- **Shade**

A shade is created by adding black to a base hue, darkening the color. This creates a deeper, richer color. Shades can be quite dramatic and can be overpowering.

- **Tint**

A tint is created by adding white to a base hue, lightening the color. This can make a color less intense, and is useful when balancing more vivid color combinations.

- **Tones**

A tone is created by combining black and white—or grey—with a base hue. Like tints, tones are subtler versions of the original color. Tones are less likely to look pastel, and can reveal complexities not apparent in the base color.

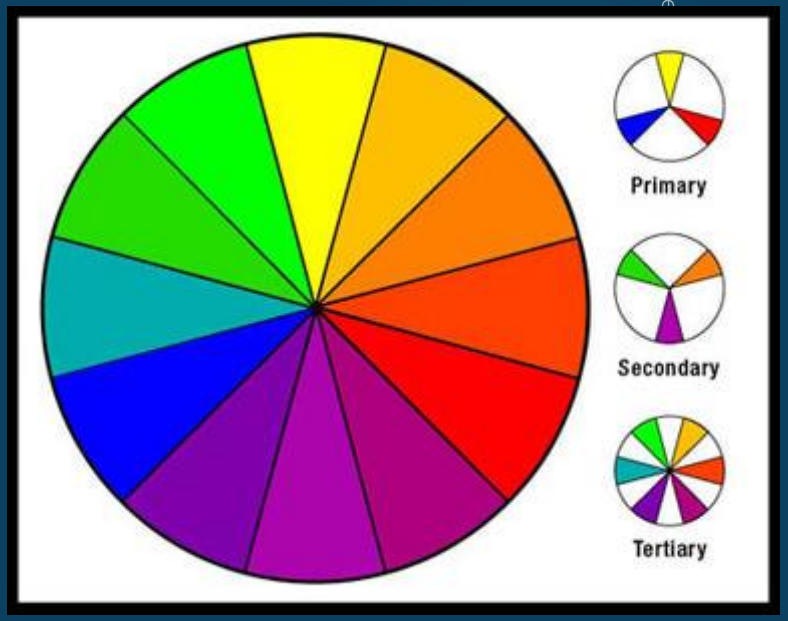
https://www.canva.com/colors/color-wheel/

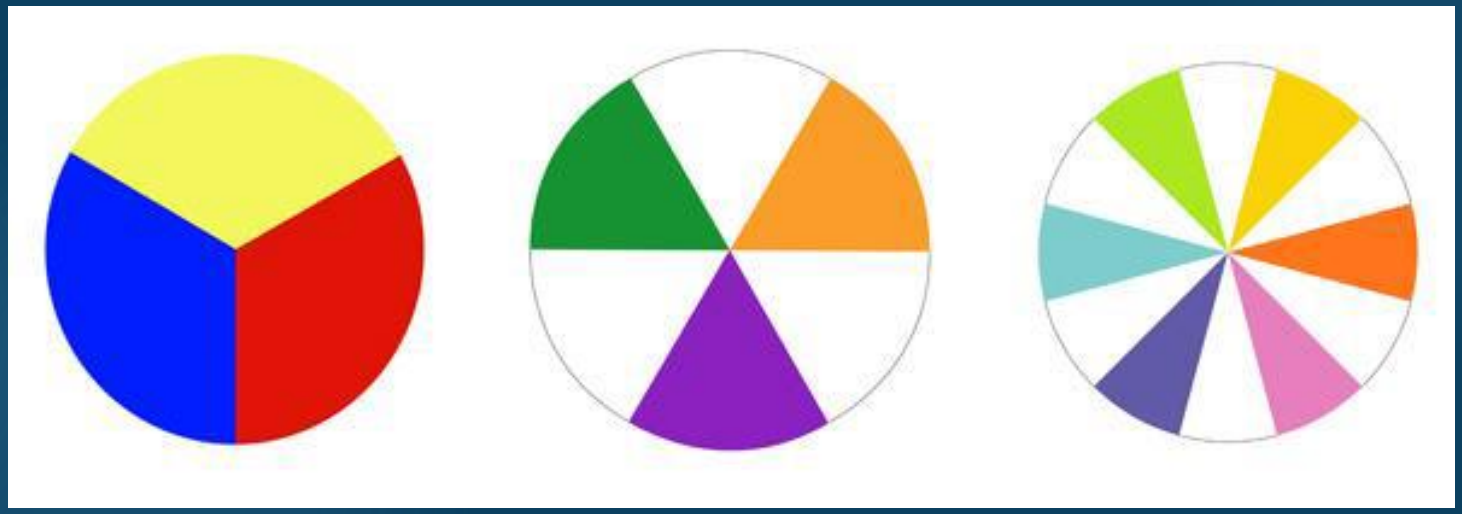
Color Harmony Schemes

- **Primary colors: ألوان أساسية**
  red, yellow and blue

- **Secondary colors:**
  ألوان فرعية
  obtained by mixing two primary colors - orange violet, green

- **Tertiary colors:**
  ألوان ثانوية
  obtained by mixing equal amounts of a primary and secondary color - red-violet, blue-violet, blue-green, yellow-green, yellow-orange, red-orange





- Primary Colors

Secondary colors

Tertiary Colors

COLOR TEMPERATURE

- Even if you're a design beginner, you've likely heard the terms "warm, cool and neutral" terms. This is referred to as color temperature, and it's an essential consideration when it comes to color theory:
- **Warm colors** contain **shades** of **yellow** and **red**;
- **cool colors have a blue, green, or purple tint**;
- **Neutral colors** include **brown, gray, black, and white**.

- The temperature of a color has a significant impact on our emotional response to it. Within the psychology of colors, for example, warm colors show excitement, optimism, and creativity, whereas cool colors symbolize peace, calmness, and harmony.

Color Harmony Schemes

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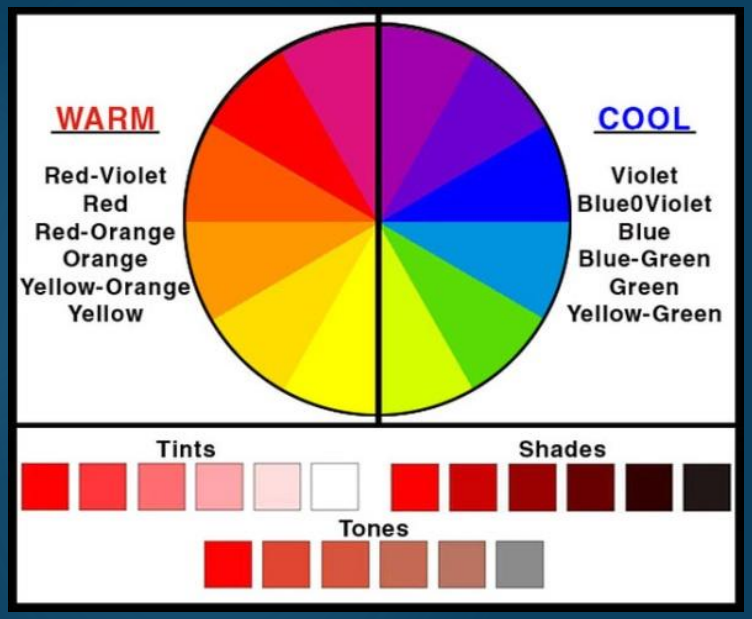
- Warm (yellow, orange, red) or cool (blue, green) colors



Color Harmony (Color Schemes)

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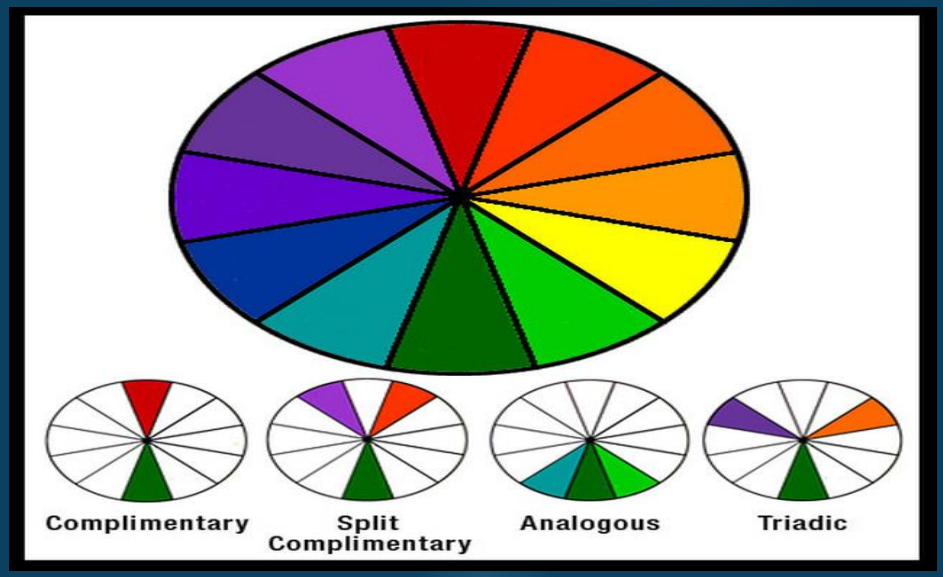
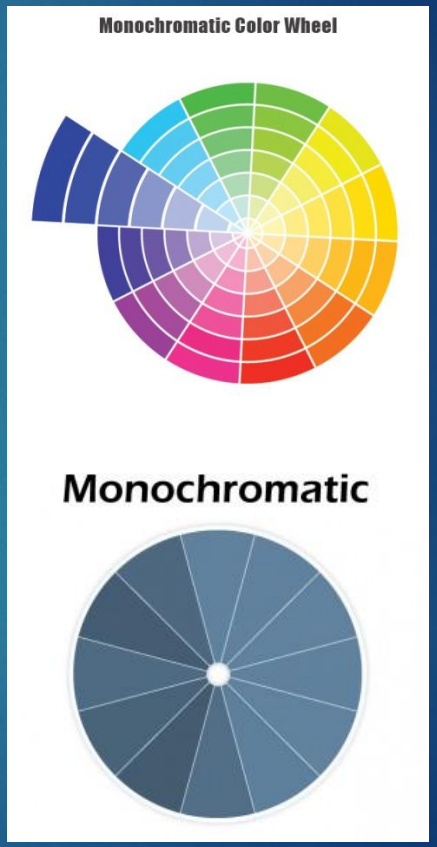
- Certain combinations of colors tend to be pleasing. They arise from the color harmony schemes
- examples:
  - Monochromatic
  - Complementary
  - Analogous
  - Triadic

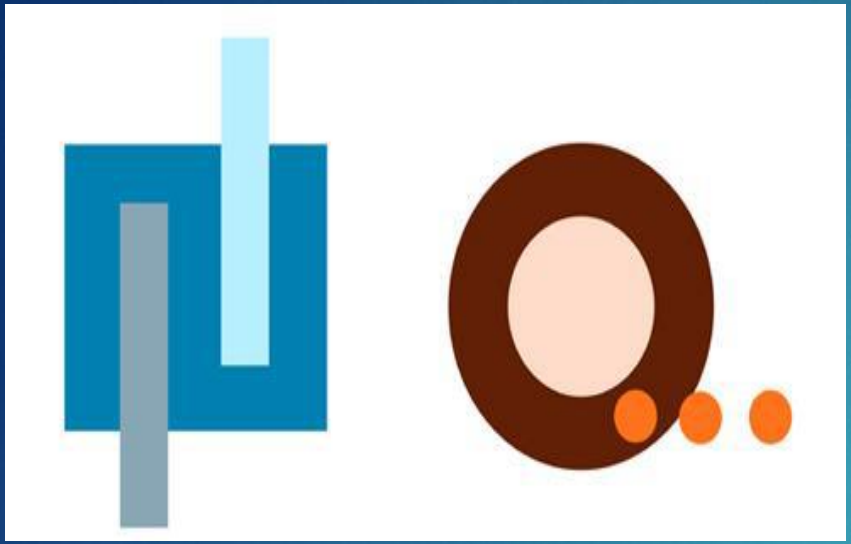


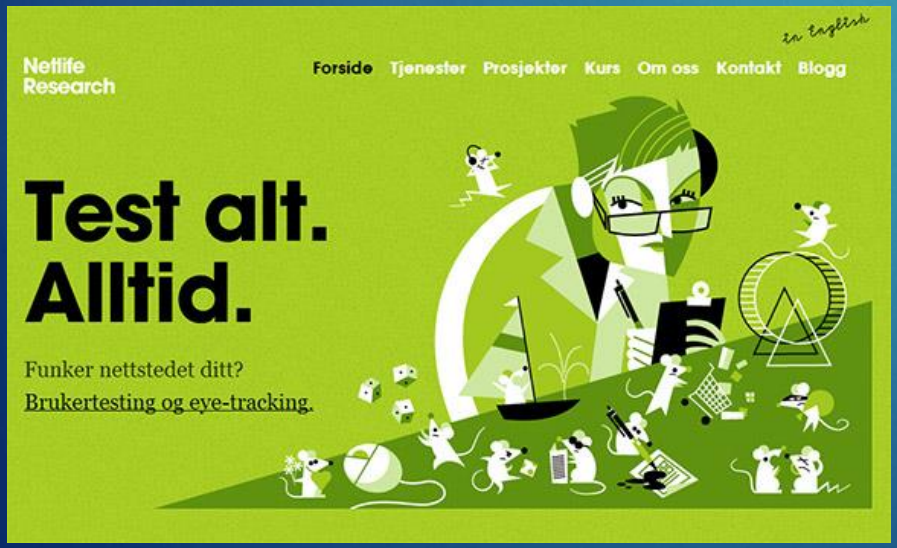
Harmony Schemes- 1-**Monochromatic**

- all colors have hues that are the same or within a few degrees of one another
- colors vary in saturation or brightness, but hue is consistent
- enhances cohesiveness to overall layout of web page



Monochromatic Examples





Harmony Schemes- 2-**Complementary**

- uses a pair of complementary hues, which appear opposite one another on a color wheel
- one color is dominant, the other is an accent
- use the dominant hue to fill the large areas

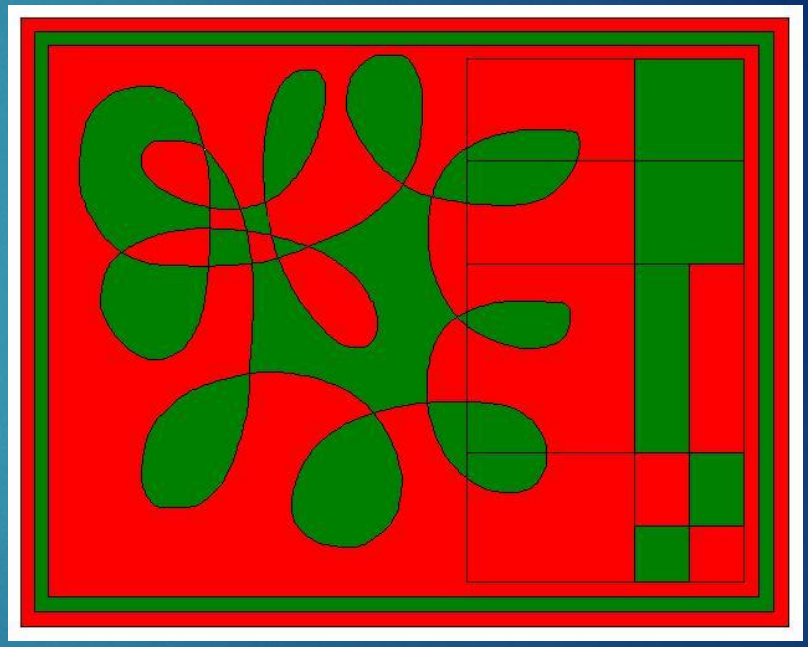
Using the Wheel

Complementary Colors are the colors opposite from one another on the wheel.

These colors provide the **most** visual contrast.

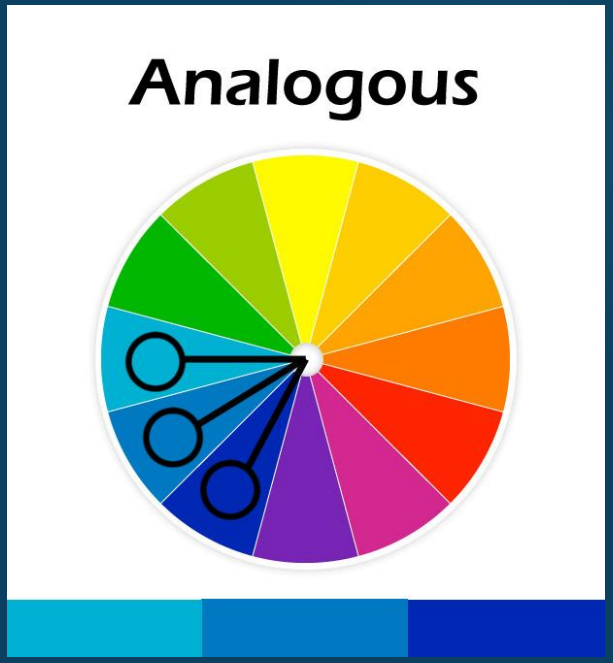
Contrast is the noticeable level of difference between two colors.

Complementary examples



Harmony Schemes- 3-**Analogous**

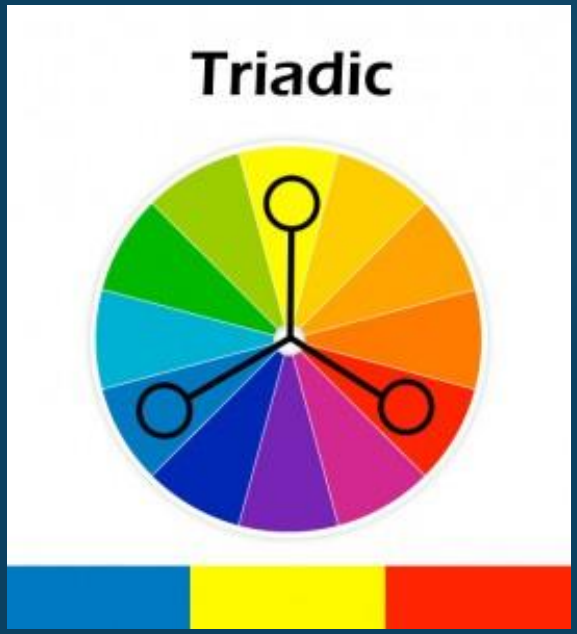
- three colors which lie close together on a color wheel
- often echo the colors found in nature
- pleasing combinations (such as orange, yellow, green)
- more interesting if the colors do not have the same brightness and saturation



Analogous examples

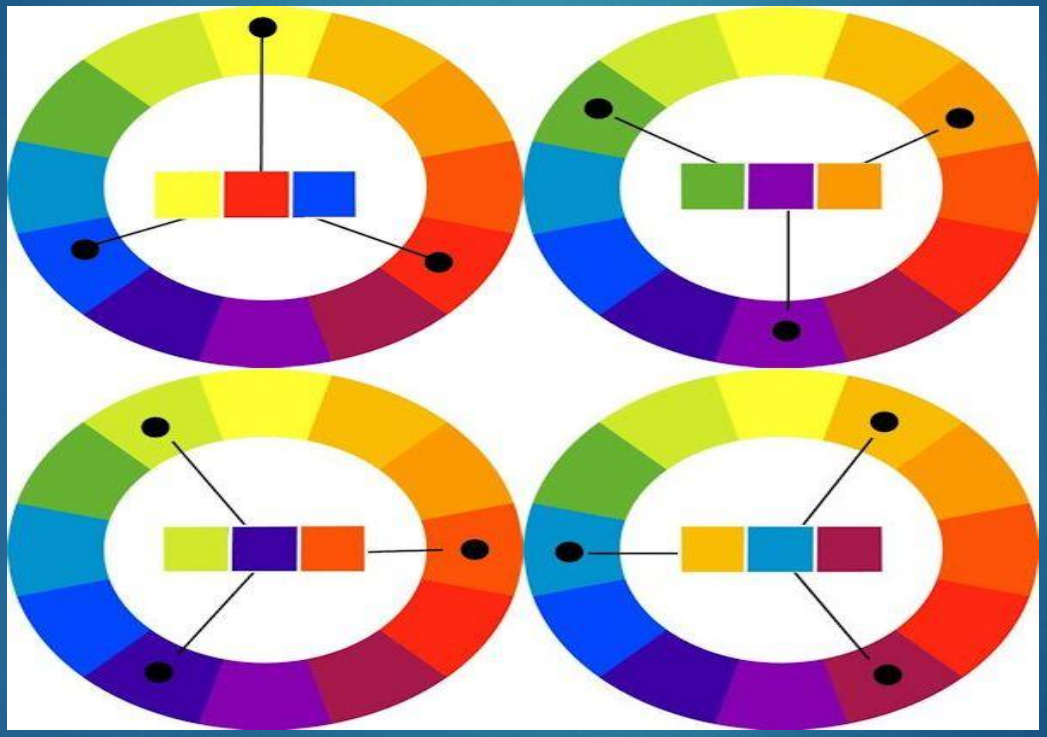
Harmony Schemes- 4-**Triadic**

- Any 3 colors, spaced equally around a color wheel
- Color hues form a triad
- Offers wide variety of choice and can create excitement
- Can be overpowering unless colors chosen vary in brightness and saturation, or the number of text and background are limited



Triadic examples

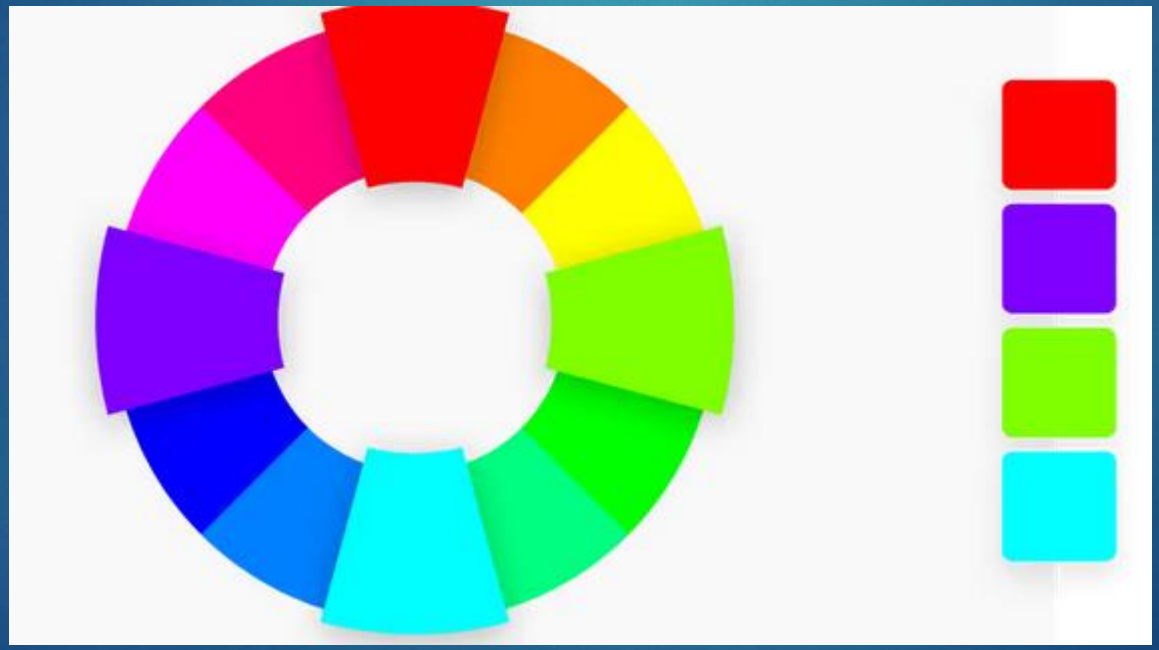
Eyad Alshareef



Triadic examples

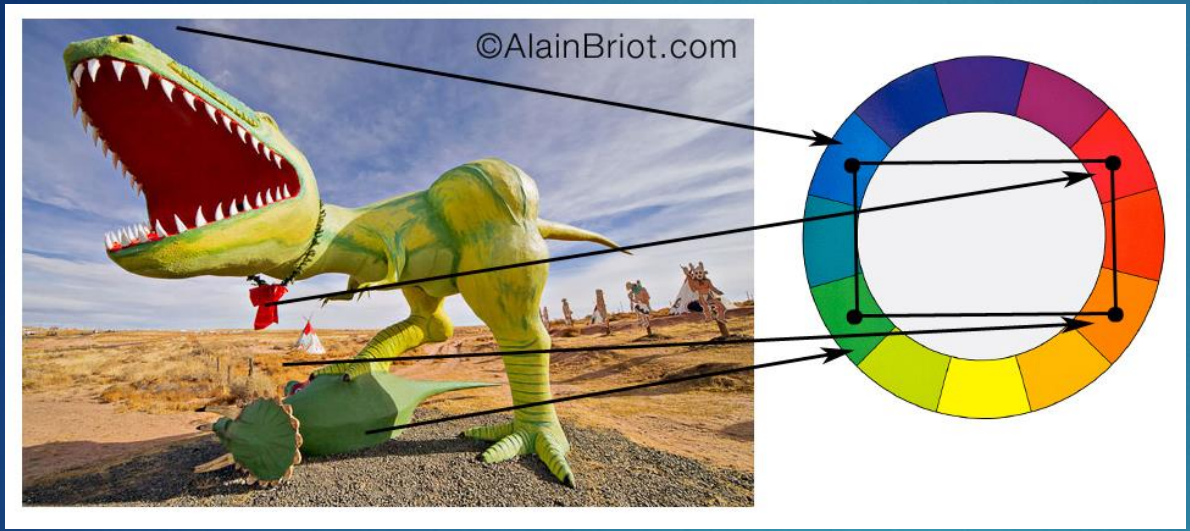
Harmony Schemes-
5- **Tetradic** رباعي

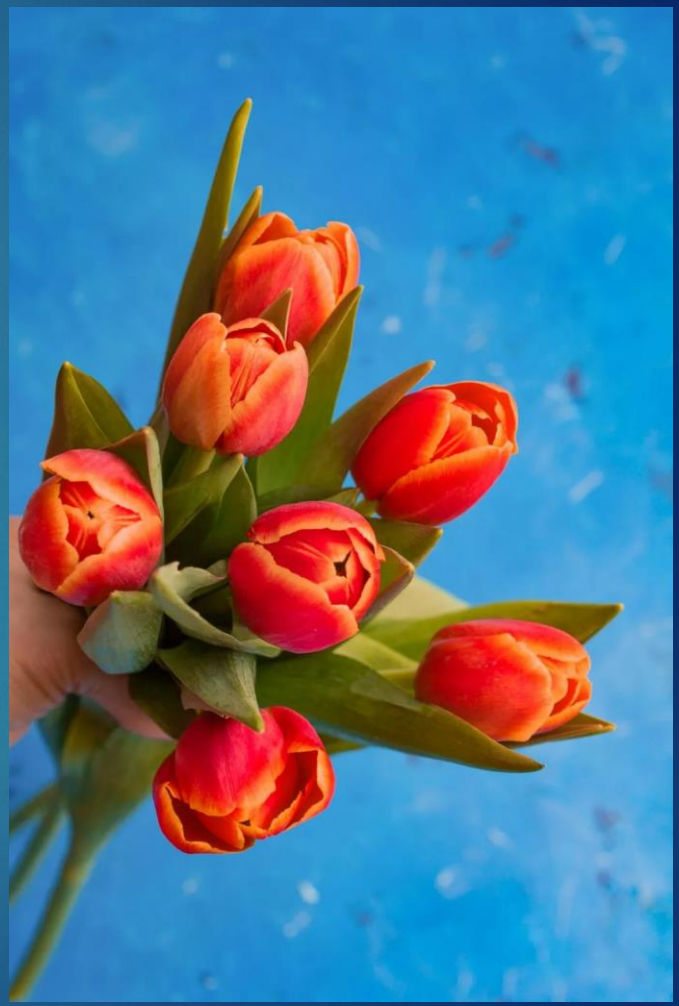
- Four colors that are evenly spaced on the color wheel. Tetradic color schemes are bold and work best if you let one color be dominant الغالب, and use the others as accents مساعدين . The more colors you have in your palette, the more difficult it is to balance,



https://www.canva.com/colors/color-wheel/

Tetradic رباعي examples

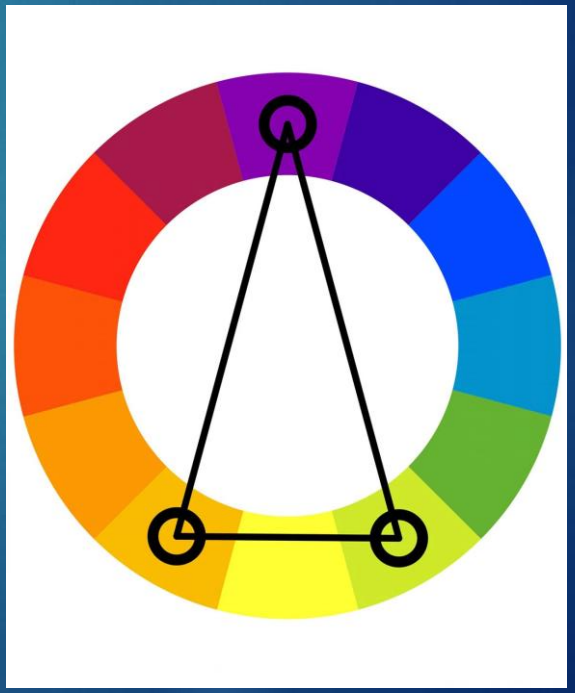




https://www.canva.com/colors/color-wheel/

Harmony Schemes-
6- **Split complementary**

- When figuring out split-complementary colors, you want to start out with a base color. From there, you combine it with two colors that sit directly adjacent to its complementary color without choosing the complementary color itself.



https://www.canva.com/colors/color-wheel/

Example for Split-Complementary

https://uxplanet.org/how-to-use-a-split-complementary-color-scheme-in-design-a6c3f1e22644

Color in Text and Background guidelines

Eyad Alshareef

1. Text should be readable مقروء
2. Contrast between text and background is important
3. Dark text on light background is best or one with high brightness and low saturation
4. Avoid combinations that differ only in their blue component (yellow on white)
5. Avoid red-green, red-blue, magenta-green combinations which cause vibration and eye fatigue.

Palette Flashing Problem
زغللة أثناء الانتقال بين صورتين

Eyad Alshareef

- Palette Flashing occurs when you use a series of images each with its own color palette. When the new image replaces the older one a flash occurs on the screen - a serious problem in multimedia
- Solution
  - use a single palette for all project images or
  - fade each image to white or black before showing the next image since white and black are present in most palettes

AN INTRODUCTION TO COLOR THEORY AND COLOR PALETTES

- **Primary colors**
  are colors you can't create by combining two or more other colors. The primary colors are red, blue, and yellow.
- The **secondary colors**
  are orange, purple, and green—in other words, colors that can be created by mixing any **two of the three primary colors**.
- **Tertiary colors**
  are created by mixing a primary color with a secondary color. The tertiary colors are magenta, vermillion, violet, teal, amber, and chartreuse.

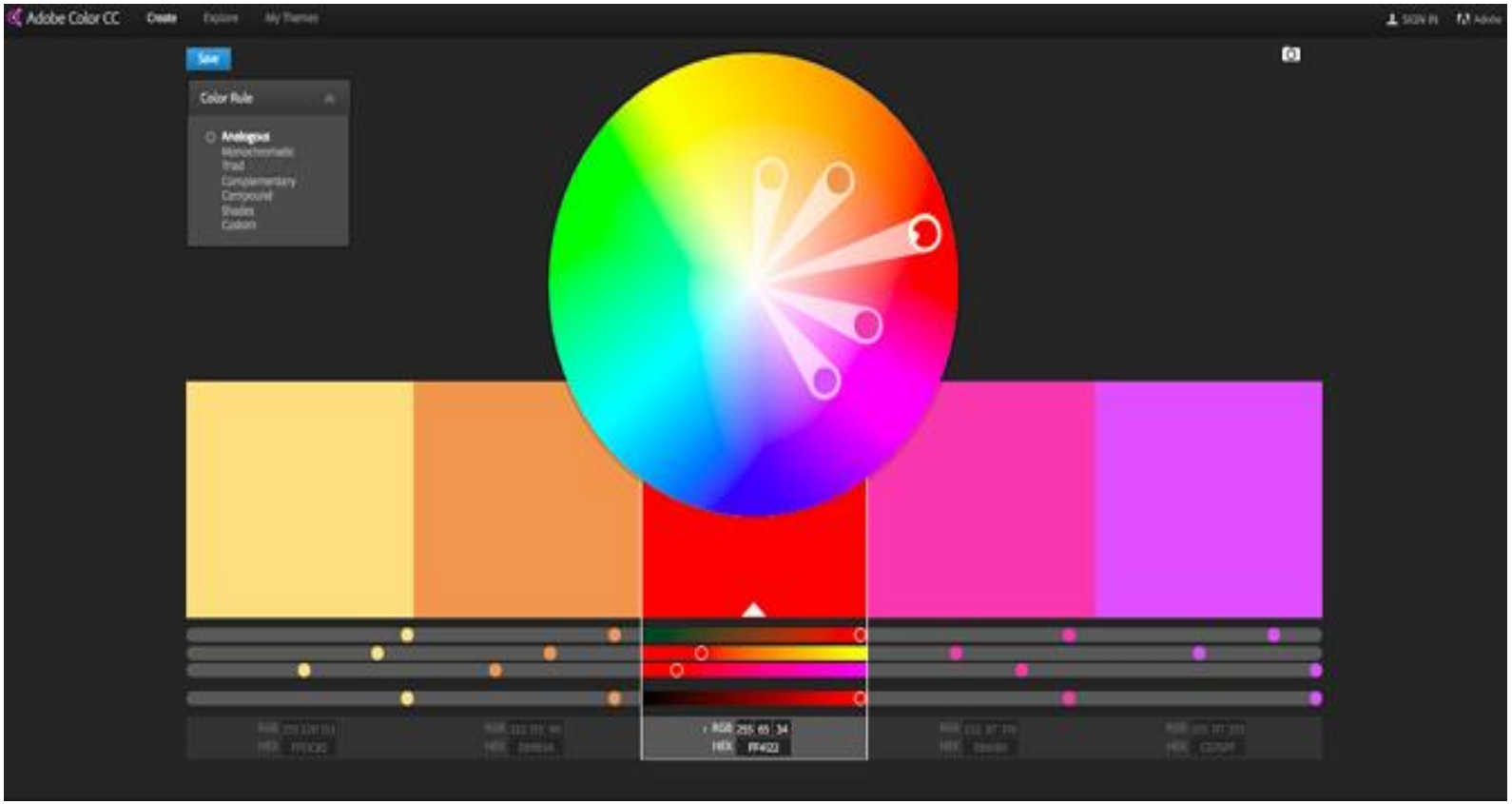
10 best color palette generators

- Coolors
- Adobe Color
- Paletton
- Colormind
- Color Hunt
- Canva
- Khroma
- ColorSpace
- Colorkuler
- Designinspiration

https://www.shopify.com/partners/blog/69878531-the-ultimate-list-of-online-colour-palette-generators-for-web-design

COLOR TOOLS

- **Adobe Color**



Thanks