WHAT IS LIGHT?

- Light is defined as an electromagnetic radiation. The visible light that we see is only a tiny fraction of the electromagnetic spectrum, extending from very low frequency radio waves through microwaves, infrared, visible and ultraviolet light to x-rays and ultra-energetic gamma rays.
- Our eyes respond to visible light, identifying rest of the spectrum needs an arsenal of technical tools ranging from radio receivers to impressive counters.
- Light is radiant energy. When light is absorbed by a physical object, its energy is converted into some other form.
- Visible light causes an electric current to flow in a photographic light meter then its radiant energy is transferred to the electrons as kinetic energy. Radiant energy (denoted as Q) is measured in joules.

RADIOMETRY

- Radiometry is the science of measuring radiant energy transfers. Radiometric quantities have physical meaning and can be directly measured using proper equipment such as spectral photometers.
- Radiometry is the science of measuring light in any portion of the electromagnetic spectrum. In practice, the term is typically limited to the measurement of infrared, visible and ultraviolet light using optical instruments. There are two aspects of radiometry: theory and practice.
- The practice includes the scientific instruments and materials used in measuring light, including radiation thermocouples, bolometers, photodiodes, photosensitive dyes and emulsions, vacuum phototubes, charged-coupled devices and a plethora of others.

Uses of Radiometry:

Following are the application areas based on Radiometry:

- **Public:** Camera, Photography, TV.
- **Biomedical:** Optical instrumentation, Medical imaginary.
- **Industry**: Photovoltaic, Lightning, Security, Non-destructive testing.
- **Spatial:** Planetary or deep space observation, Satellite design.
- **Defense:** Identification, Navigation.

PHOTOMETRY

- Photometry is the science of measuring visible light in units that are biased according to the sensitivity of the human eye. It is different from radiometry, which is the science of measurement of radiant energy (including light) in terms of absolute power.

- Photometry is a branch of science concerning light in terms of color apparent by the viewer from the physical inspiration of imposing photons into the eye and the combined response with the brain.
- The purpose of photometry is to measure light in a way that takes the sensitivity of human visual system into account.
- Photometry is essential for evaluation of light sources and objects used for lighting, signaling, displays, and other applications where light is envisioned to be seen by humans. It is a quantitative science based on a statistical model of the human visual responses to light that is, our perception of light under wisely precise conditions.

WHAT IS COLOR?

- It is defined as an quality of an object or substance with respects to light reflected by an object, usually determined visually by measurement of hue, saturation and brightness of the reflected of light.
- It is also defined as an quality of visual insight consisting of any arrangement of chromatic and achromatic content this attribute can be described by chromatic color names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic color names such as white, gray, black, etc., and qualified by bright dim, light, dark, etc., or by combination of such names.
- Light is a mixture of radiations having different wavelength where different wavelength implies different colors.

COLOR: COLORIMETRY

Science related to the perception of colors is known as Colorimetry.

The Science of Colorimetry is used to quantify the response of the human visual system and match human color perception for applications in a variety of industries.

- Display Manufacturing: - Quality control for industrial production lines and incoming inspection of display glass. Display calibration for LED, LCD, Plasma, projection, CRT displays.
- Broadcasting: - Measuring and standardizing video walls for color accuracy, uniformity of brightness and white balance.
- Graphic Design and Computer Animation: - Professionals who rely on color accuracy and precision color measurement benefit from understanding Colorimetry

Color: Color perception is naturally independent. The objective capacities of the color of a source object is alleged by a standard human observer that also can be measured. Various standard human observers are defined in the disciple of Colorimetry. According to standard model, the perceived color of a given spot can be reduced to a threedimensional value. The three dimensions of color can be described as color of brightness, hue and purity or saturation.

Chromaticity: A two-dimensional explanation of color has the mixture of hue and purity, neglecting the third dimension of brightness. The luminance (brightness) and chromaticity of a spot on a display, taken together, provide a complete depiction of its color.

COLOR SPACES

- A range of colors that can be created by the primary colors of pigment and theses colors then define a specific color space.
- It is a way to represent colors, usually used in relation to computers or graphics boards. Color includes levels of grey. Number of bits specifies color space. 1 bit color is black and white combination. Grey scale pattern refers 2 bits to generate black, dark grey, light grey, white colors.
- Color space, also known as the color model (or color system), is an abstract mathematical model which simply describes the range of colors as tuples of numbers, typically as 3 or 4 values or color components (e.g. RGB). It is an elaboration of the co-ordinate system and sub-space. Each color in the system is represented by a single dot.

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. This section describes ways in which human color vision can be modeled. There are three different color models that describes the different perceived characteristics of color are RGB model, CMY model, HSV or HLS Model.

RGB Color model:

- The RGB color model is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors.

The name of the model comes from the initials of the three additive primary colors, red, green, and blue.

- The main purpose of the RGB color model is for the sensing, representation, and display of images in electronic systems, such as televisions and computers, though it has also been used in a conventional photography. Before the electronic age, the RGB color model already had a solid theory behind it, based on the human perception of colors.
- In the RGB color model, we use red, green, and blue as the three primary colors. We do not actually specify what wavelengths these primary colors correspond to, so this will be different for the different types of output media, for example, different monitors, films, videotapes, and slides.

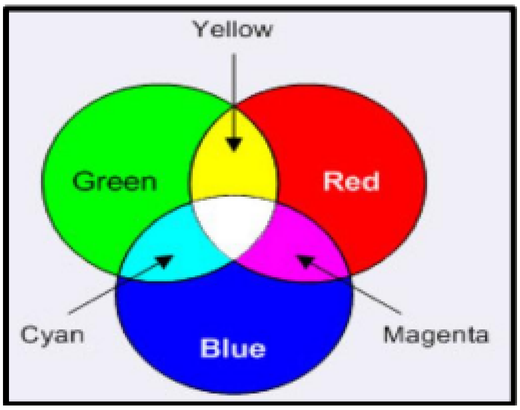


Fig 9.3: RGB color model

CHROMATIC ADAPTATION

The surroundings in which viewer objects and images has a larger effect on how we perceive those objects/ the range of viewing environment (i.e., by mean of light) is very large, from sunlight too moonlight or from candle light to luminous light. The lightning condition is not only involving a very high range of light but also varies greatly in the range of color which emits light.

A human visual system accommodates these change in the environment through a process called as adaptation.

There are three types of adaptation: -

- Light adaptation
- Dark adaptation
- Chromatic adaptation

Light Adaptation:

1) It refers to the change occurs when we move from very dark to very light environment i.e., dark -> light

2) When this happens we are dazzled at first by the light but soon we adapt to the new situation and then we begin to distinguish objects in our environment.

Dark Adaptation:

1) It refers to the change occurs when we move from very light to very dark environment i.e., light -> dark

2) When this happens we see very little at first but after some time the details of an objects starts appearing in front of us.

3) Time needed to adapt objects in dark adaptation is much longer than that of light adaptation.

Chromatic Adaptation:

1) It refers to the human's ability to adjust and largely ignore differences in the color of the illumination. Although, we are able to largely ignore the changes in the viewing environment but we are unable to do it completely. For example, color appears much more colorful in a sunny day as compare to a cloudy day.

2) Chromatic adaptation is the ability of the human visual system to discount the color of a light source and to approximately preserve the appearance of an object. For example, a white piece of paper appears to be white when viewed under sky light and tungsten light (light under a light bulb). However, the measured tri-stimulus values are quite different for the two viewing conditions

3) Chromatic adaptation is the biological equivalent of a white balancing operation that is available on most of the modern cameras. It allows white objects to appear white for a large number of lightning conditions.

COLOR APPEARANCE

Colorimetry allows us to precisely require and communicate color in device independent manner and chromatic adaptation allows us to predict color matches across changes in illumination but these tools are still inadequate to define how color actually look like.

A Color appearance Model provides mathematical formulae to transform Physical measurements of the stimulus and viewing environment into Correlates of perceptual attributes of color (eg. lightness, Chroma, hue, etc.).

There are different parameters used for color appearance which are given as follows: - HUE - Brightness - Lightness - Colorfulness - Chroma - Saturation

HUE: It is an Attribute of a visual sensation according to which an area appears to be similar to one of the perceived colors i.e. pure color: red, yellow, green, and blue, or to a combination of two of them. Hue is a more technical definition of our color perception which can be used to communicate color ideas.

Brightness: It is an Attribute of a visual sensation according to which an area appears to emit more or less light. It is referred to as the absolute level of the perception.

Lightness: It is a representation of variation in the perception of a color or color space's brightness. It is referred to as relative brightness normalized for changes in the illumination and viewing conditions. Lightness defines a range from dark (0%) to fully illuminate (100%). Any original hue has the average lightness level of 50%. Lightness is the range from fully shaded to fully tinted. We can lighten or darken a color by changing its lightness value

Colorfulness: It is an attribute of a visual sensation according to which the perceived color of an area seems to be more or less chromatic (e. multiple color variations).

Chroma: Chroma is a component of a color model. There's a blue yellow and a red-green chroma component.

Saturation: Saturation is used to determine certain color and measured as percentage value. Saturation defines a range from pure color (100%) to gray (%) at a constant lightness level.

Q. Explain the concept of BRDF in brief.

What Is BRDF?

- When light encounters objects in the scene, it interacts with the surfaces by being reflected, refracted, or absorbed. If we make the simplifying assumption that light striking a surface location will reflect at the same location, then the interaction between the light and the surface can be described using a six-dimensional function called the bidirectional reflectance distribution function, or BRDF.
- At a high level, the BRDF describes how "bright" a surface will look from a particular direction and it also describes how much light is reflected.
- BRDF must capture following view and light dependent nature of reflected light Viewer/light position dependency (incoming/outgoing rays of light)

  Example - Shiny plastic teapot with point light illustrated in Fig. 6.3.1.

Fig. 6.3.1 : Shiny plastic teapot with point light on it

1. Different wavelengths (colors) of light may be absorbed, reflected, transmitted differently
2. Positional variance - light interacts differently with different regions of a surface, e.g. wood

BRDF is defined mathematically as, the ratio of the quantity of reflected light in direction w_o, to the amount of light that reaches the surface from direction w_i. given by,

$$BRDF = \frac{L_o}{E_i}$$

L_o is surface Radiance and E_i is irradiance

Properties of the BRDF

Q. Explain different properties of BRDF.

1. **Domain**

   For a particular surface point x, the BRDF is a four-dimensional function: two dimensions to specify the incoming direction, and two dimensions to specify the outgoing direction. Furthermore, if the BRDF is allowed to vary spatially over an object's surface, this leads to an additional two dimensions.

2. **Range**

   The BRDF can take on any positive value.

3. **Reciprocity**

   The value of the BRDF remains unchanged if the incident and outgoing directions are swapped. Reciprocity means that surface reflection is invariant to the direction of light flow, i.e. the reflected radiance remains unchanged if the light and camera positions are swapped. This property is essential for many global illumination algorithms and allows light to be traced either in the forward or backward direction.

4. **Energy conservation**

   Due to energy conservation, a surface cannot reflect more light than it receives.

Q. Briefly explain Grassmann's law in detail.

- As we know that human have different cone types, the experimental color matching laws states that any color stimulus (i.e., a particular color impression perceived by the viewer) can be matched completely with an additive mixture

of three appropriately modulated color sources. Mainly used by televisions and monitors which produce many different colors by adding mixture of red, green and blue light for each pixel. This procedure is known as trichromatic generalization.

- Hermann Grassmann was the first to describe the algebraic rules for match colors, which is known as Grassmann's law of additive color matching and are given below.
  - Symmetry law
  - Transitive law
  - Proportionality law
  - Additivity law

Symmetry law

It states that if color stimulus M matches color stimulus N, then N matches M.

i.e., if M = then N = M

Transitive law

It states that, if color stimulus M matches N and N matches O, then M matches O. i.e., if

M = N and N = O then M = O

Proportionality law

- It states that, if color stimulus M matches N then aM matches aN, where "a" is a positive scalar factor. i.e., if M = N then aM = aN

Additivity law

- It states that, if color stimulus M matches N, O matches P and M + O matches N + P, then M + P matches N + O
  i.e., if M = N, O = P and M + O = N + P
  then, M + P = N + O
- The additivity law forms the basis for color matching and colorimetry as a whole.

any portion of electro...

BRDF [Bidirectional Reflectant Distribution function]

$= \frac{\text{radiance}}{\text{irradiance}}$

Radiance : quantity of light reflected in a direction

Irradiance : quantity of light arrived from a direction

Four properties of BRDF

1. Domain : For a particular surface point x, the BRDF is a 4 dimension function
   2 dimension for specifying incoming direction
   2 dimension for specifying outgoing direction
2. Range : Can take any positive value
3. Reciprocity : Value remain unchanged if the incident and outgoing direction are swapped

Teacher's Signature:..................

4. Energy Conservation : Due to energy conservation, a Surface cannot reflect more light than it received.

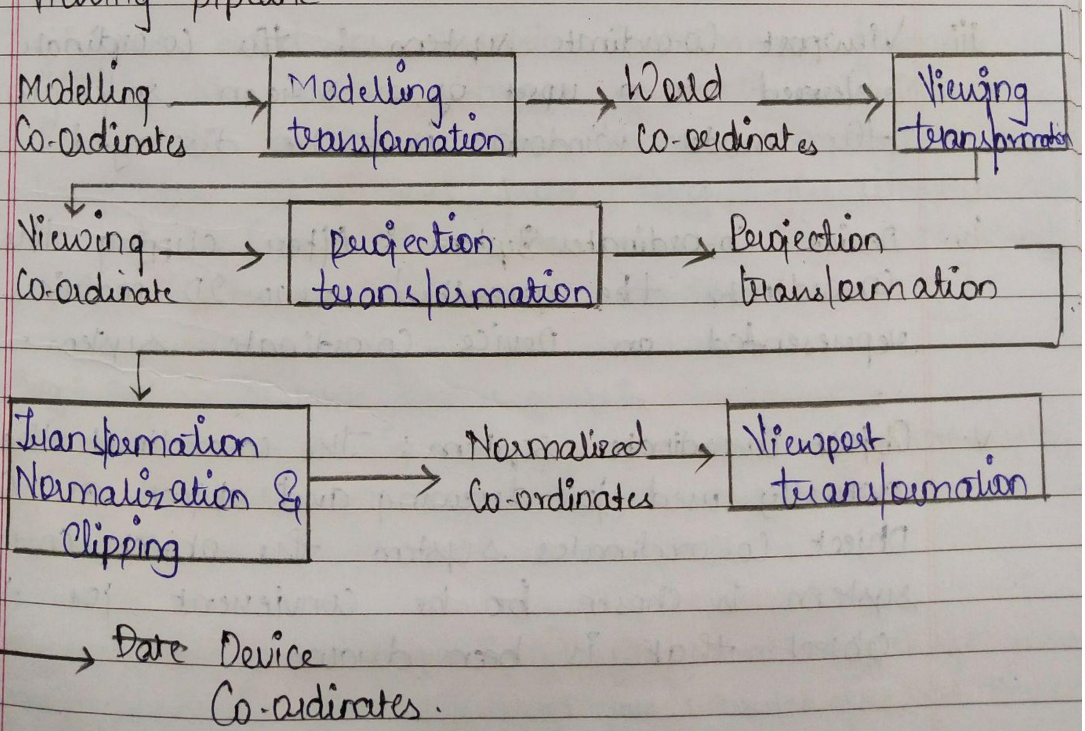
* Viewing in 3D

3D object must be projected onto the flat viewing surface of the output devices

* Stages in 3D viewing.

Modelling Transformation
Viewing transformation
Projection Transformation
Normalization transformation & clipping
Viewport transformation.

* Viewing pipeline



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* Co-ordinates System : A co-ordinates system is used to represent a point, it contains a references point [origin] and three linearly independent vectors.

Different types of co-ordinates system.

i. World co-ordinates system : The system in which a complete object is represented is known as world co-ordinate system.

ii. Screen co-ordinate system : the co-ordinate system of a screen is a cartaion co-ordinate system the origin [0,0] is at the top left of the screen positive x increases toward the right and positive y increases towards the bottom co-ordinate system of a screen.

iii. Viewport co-ordinate system : the co-ordinate system refered to a upset of a screen space where the model window is to be displayed.

iv. Device co-ordinates system : After clipping the final co-ordinates the generated two 2D matrices is represended on Device co-ordinate system.

v. Object co-ordinate system : The co-ordinat that you actually used for drawing and object are called Object co-ordinates system. the object co-ordinate system is chosen to be convienent for the object that is been drawn

10/12/22

Grassmann law :

Herman Grassmann was the first to discribe the algebraic rules for march colors, which is known as Grassman law of additive color matching.

1. Symmetry law :

It states that if color stimulus M matches color stimulus N then N matches M

ie if $M = N$,

then $N = M$

2. Transitive law :

if $M = N$ & $N = O$

then $M = O$

3. Additive law :

if $M = N$, $O = P$

$M + O = N + P$

then, $M + P = N + O$

4. Proportionality law :

if $M = N$ (where 'a' is scalar factor)

then $aM = aN$

color stimulus → The light entering the eye

color → It is the quality of object with respect to light reflected by object.