Unit IV

Light, Colour, Shading and Hidden Surfaces

Colour models: Properties of Light, CIE chromaticity Diagram, RGB, HSV, CMY.
Illumination Models: Ambient Light, Diffuse reflection, Specular Reflection, and the Phong model, Combined diffuse and Specular reflections with multiple light sources, warn model,
Shading Algorithms: Halftone, Gauraud and Phong Shading.
Hidden Surfaces: Introduction, Back face detection and removal, Algorithms: Depth buffer (z), Depth sorts (Painter), Area subdivision (Warnock)

Text Books:

1. S. Harrington, "Computer Graphics"‖, 2nd Edition, McGraw-Hill Publications, 1987, ISBN 0 – 07 – 100472 – 6.
2. Donald D. Hearn and Baker, "Computer Graphics with OpenGL", 4th Edition, ISBN-13: 9780136053583.
3. D. Rogers, "Procedural Elements for Computer Graphics", 2nd Edition, Tata McGraw-Hill Publication, 2001, ISBN 0 – 07 – 047371 – 4.

Reference Books:

1. J. Foley, V. Dam, S. Feiner, J. Hughes, "Computer Graphics Principles and Practice"‖, 2nd Edition, Pearson Education, 2003, ISBN 81 – 7808 – 038 – 9.
2. D. Rogers, J. Adams, "Mathematical Elements for Computer Graphics"‖, 2nd Edition, Tata McGraw Hill Publication, 2002, ISBN 0 – 07 – 048677 – 8.

preprocessing

[Reference - TB1]

Color Models :-

- is a specification of 3D colour co-ordinate system & a visible subset in the coordinate system within which all colours in a particular Colour range lie.

  e.g RGB colour model is the unit cube subset of the 3D cartesian co-ordinate system.

- The colour model allows to give convenient specification of colours in the specific colour range or gamut.

- There are 3 Hardware oriented colour models: RGB, used for colour CRT monitors, YIQ used for broadcast TV colour system & CMY (cyan, magenta, Yellow) used for some

Colour printing devices.

- These models are not easy to use because they does not relate directly to intuitive colour notions of hue, saturation & brightness.
- Another class of colour model has been developed. These include HSV, HLS & HVC models.

Properties of Light :-

- light source produced by a sun or electric bulb emits all frequencies within the visible range to give white light.
- when this light is incident upon an object, some frequencies are absorbed & some are reflected by object.
- The combination of reflected frequencies decides the colour of object.
- If the lower frequencies are predominant in the reflected frequencies, the object colour is red.
- The dominant frequency decides the colour of the object. Due to this reason, dominant frequency is also called the hue or simply the colour.
- Apart from the frequency, there are two more properties which describe various characteristic of light.

— These are brightness & saturation (purity)

1] The brightness refers to the intensity of the perceived light.

2] The saturation describes the purity of the colour.

3] pastels & pale colours are described as less pure or less saturated.

4] when two properties purity & dominant frequency are used collectively to describe the colour characteristics, referred as Chromaticity.

5] Two different colour light sources with suitably chosen intensities can be used to produce a range of other colour.

— when 2 colours sources are combined to produce white colour, they are referred as complementary colours.

— Red & cyan, green & magenta, blue & yellow are complementary colour pairs.

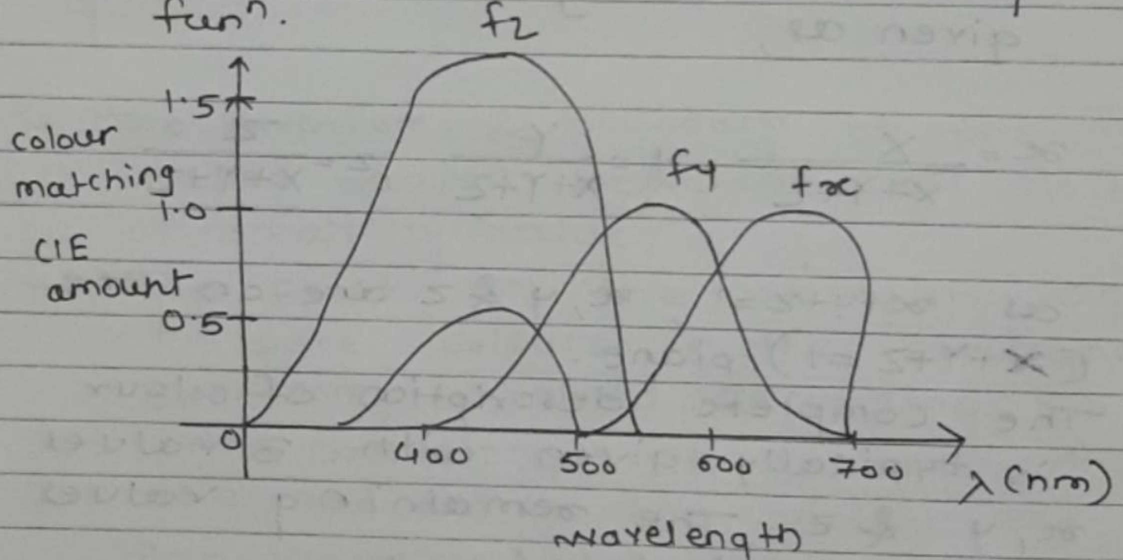
— Colour model use combination of 3 colours to produce wide range of colours, called colour gamut for model.

— The basic colours used to produce colour gamut in particular model are called primary colours.

[Reference – TB2]

CIE Chromaticity Diagram :-

- matching & defining a coloured light with a combination of 3 fixed primary colours is desirable approach to specify colour.
- Commision internationale de I'Elairage (CIE) defined 3 standard primaries called x, y, & z to replace red, green, & blue.
- x, y, & z represents vectors in a 3D additive colour space.
- 3 standard primaries are imaginate colours, they are defined mathmatically with positive colour-matching funⁿ.



- They specify the amount of each primary needed to describe any spectral colour.
- Advantage of using CIE primaries is that they eliminate matching of negative colour values & other problems associated with selecting a set of real primaries.

- Any colour using (λ) using CIE primaries can be expressed as

$$C_\lambda = xX + yY + zZ$$

where x, y, z are the amounts of the standard primaries needed to match C_λ.

- X, Y & Z represents vectors in 3-D additive colour space
with this expression we can define chromaticity values by normalizing against luminance (X+Y+Z).

- The normalizing amounts can be given as,

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z}$$

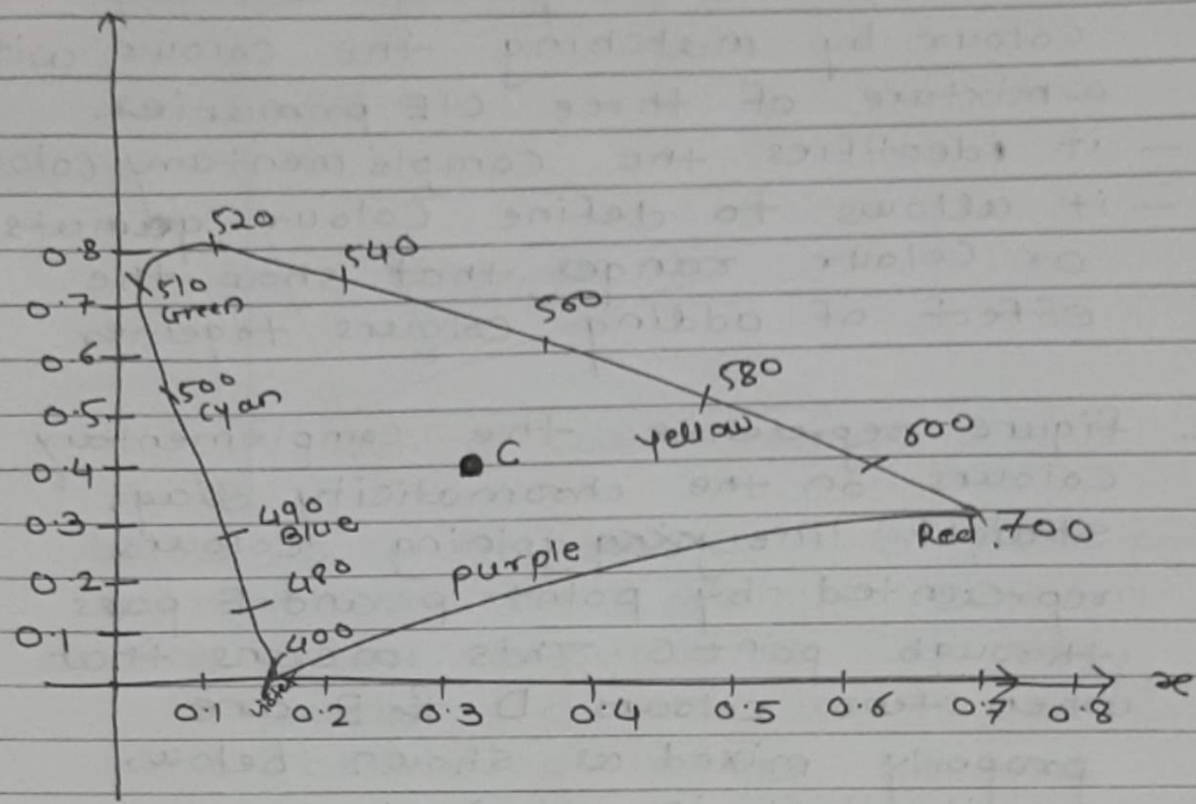
as $x+y+z=1$, x, y & z are on the ($X+Y+Z=1$) plane.

- The complete description of colour is typically given with 3 values x, y & Z. The remaining values can be calculated as

$$z = 1 - x - y, \quad X = \frac{x}{y} Y, \quad Z = \frac{z}{y} Y$$

- chromaticity values depend only on dominant wavelength & saturation & are independent of the amount of luminous energy.
- plotting x & y for all visible colours, we obtain the CIE chromaticity diagram — which is projection on to the (X, Y) plane of

the $(x+y+z=1)$ plane

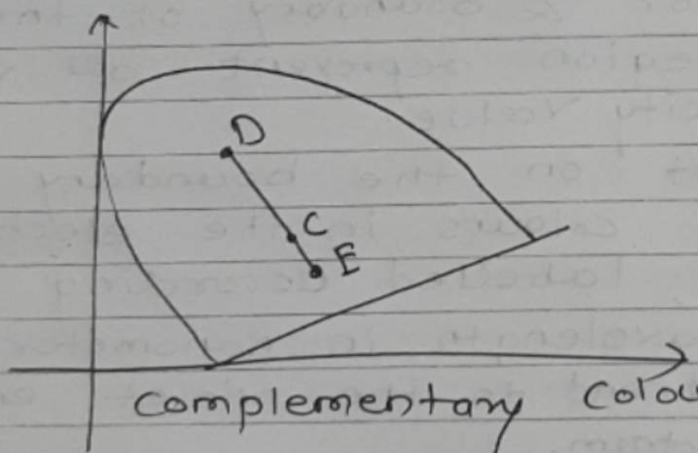


- The interior & boundary of the tongue-shaped region represent all visible chromaticity value.
- The point on the boundary are the pure colours in the electromagnetic spectrum, labelled according to the wavelength in nanometer from the red end to the violet end of the spectrum.
- A standard white light is formally defined by a light source illuminant C, marked by the center dot.
- The line joining the red & violet spectral points is called the purple line, which is not the part of the spectrum.

The CIE chromaticity diagram is useful in many ways:

1. it allows us to measure the dominant wavelength & the purity of any colour by matching the colour with a mixture of three CIE primaries.
- it identifies the complementary colours.
- it allows to define colour gamuts or colour ranges, that show the effect of adding colours together.

- figure represents the complementary colours on the chromaticity diag. Straight line ~~joing~~ joining colours represented by point P and E pass through point C. This means that when two colours D & E are properly mixed as shown below, white light is obtained.

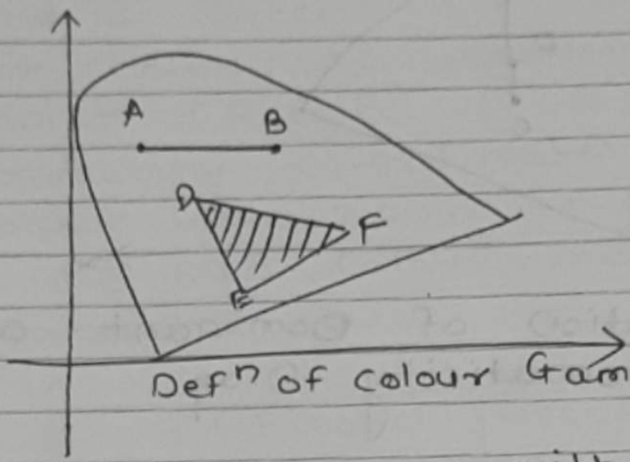


Complementary colours of chromaticity diag.

- Colours D & E are complementary colours & with point C on the chromaticity diag. can identify the complement of colour of known colour.

2. Colour gamuts are represented on the chromaticity diagram as straight line or as polygon. Any two colours say A & B can be added to produce any colour along their connecting line by mixing their

appropriate amounts. The Colour gamuts for 3pt fig.

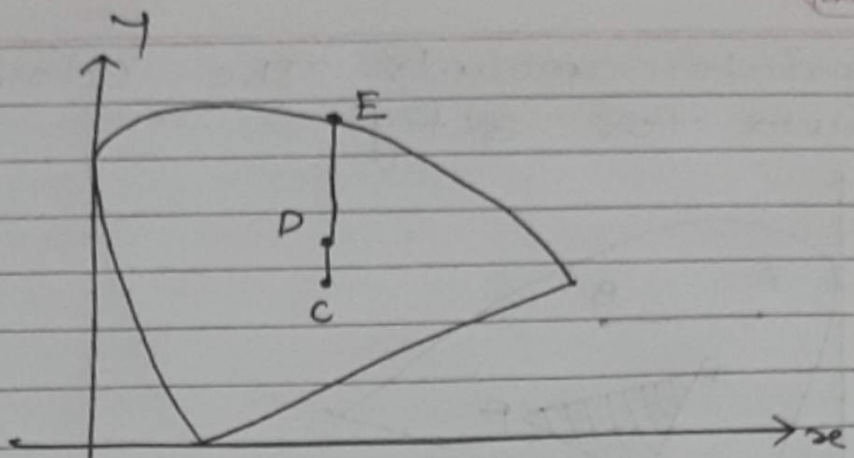


Def^n of colour Gamuts

- below is a triangle with 3 colour points as vertices. the triangle DEF in fig. shows 3 primaries Can only generate colours inside as on the bounding edges of the triangle.

3. chromaticity diag is useful to determine the dominant wavelength of colour.

- for Colour point D is drawn from C through D to intersect the spectral Curve at point E. The colour D an then be represented as a Combination of white light C and the spectral colour E.
  The dominant wavelength of D is p.
  This method for determining dominant wavelength will not work for Colour points that are between C & the purple line because the purple line is not part of Spectrum.



Determination of Dominant wavelength on chromaticity Diag.

RGB Colour Model :-

- Red-Green-Blue RGB model is generally used in comp. graphics.
- it corresponds to Red, Green, Blue intensity settings of a colour monitor.
- we can represents this model with the unit cube defined on R, G & B axes.
- The origin represents black & the vertex with co-ordinates (1,1,1) is white.
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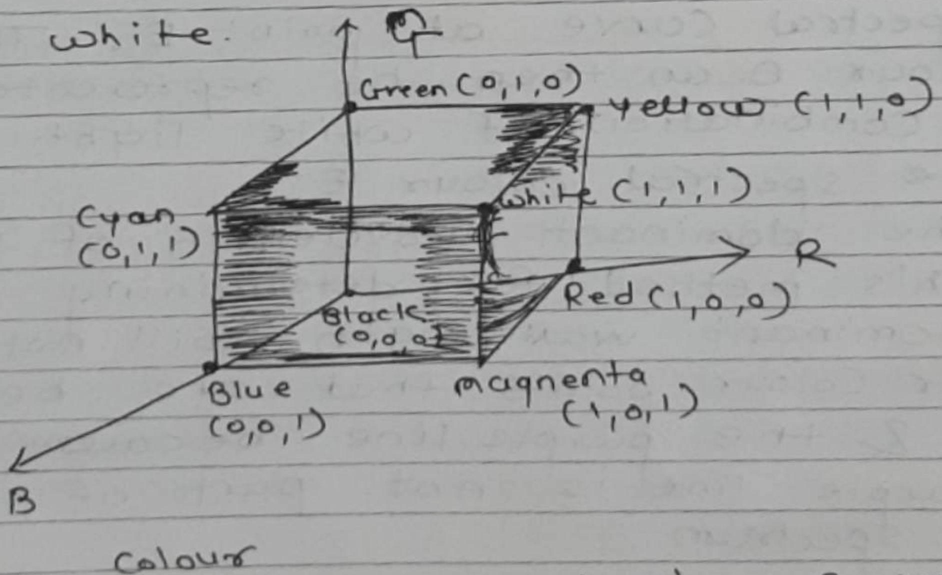


- RGB colour model is an extension of XYZ model. other colours are generated by adding intensities of primary colour like yellow (1,1,0) is a combination of Red & Green.

- each colour is represented by a triplet (R, G, B).
- chromacity co-ordinates for standard colour television. i.e NTSC standard & CIE RGB colour model is represented as

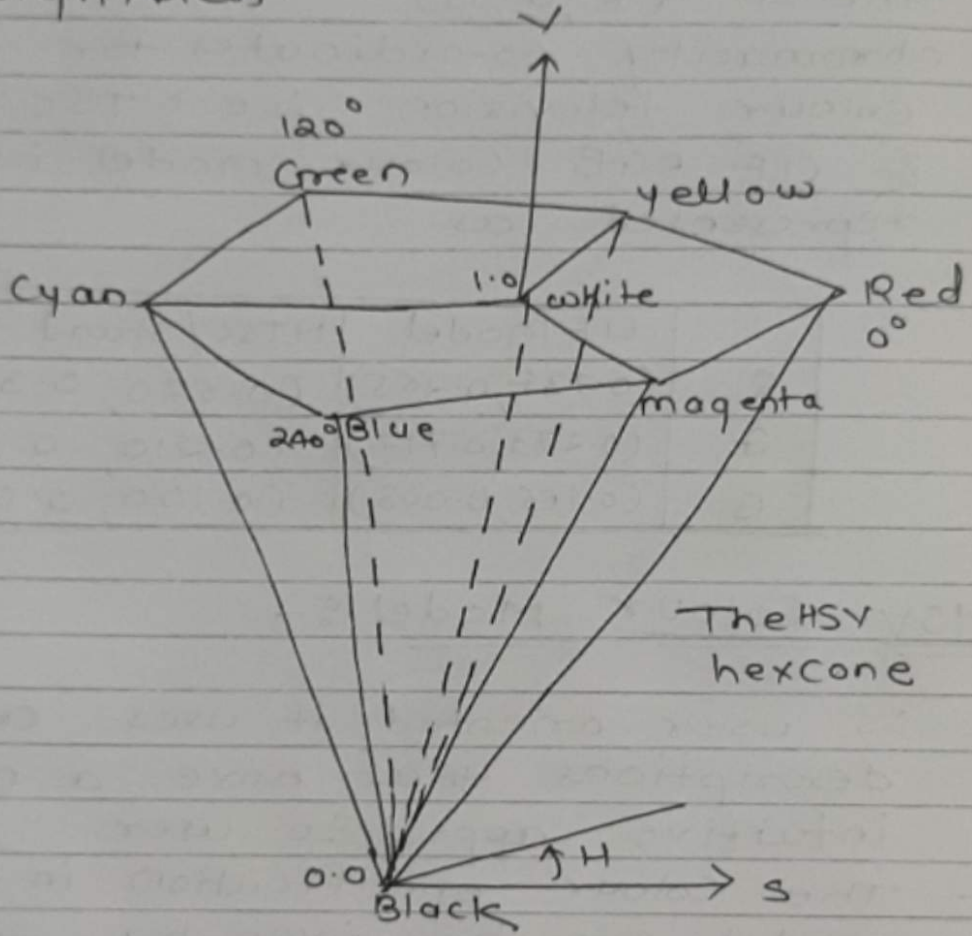
	CIE model	NTSC/Stand Television
R	(0.734, 0.265)	(0.670, 0.330)
G	(0.273, 0.717)	(0.210, 0.710)
B	(0.166, 0.008)	(0.140, 0.080)

HSV Colour Model :-

- is user oriented it uses colour descriptions that have a more intuitive appeal to user.
- The colour specification in HSV model can be given by selecting a spectral colour & the amounts of white & black that are to be added to obtain different shades, tints & tones.
- This model uses 3 colour parameter
  - hue (H)
  - saturation (S)
  - value (V)
- Hue: distinguishes among colours such as green, red, purple & yellow.
- saturation refers to how far colour is from a gray of equal intensity.

e.g.- red is highly saturated whereas pink is relatively saturated.

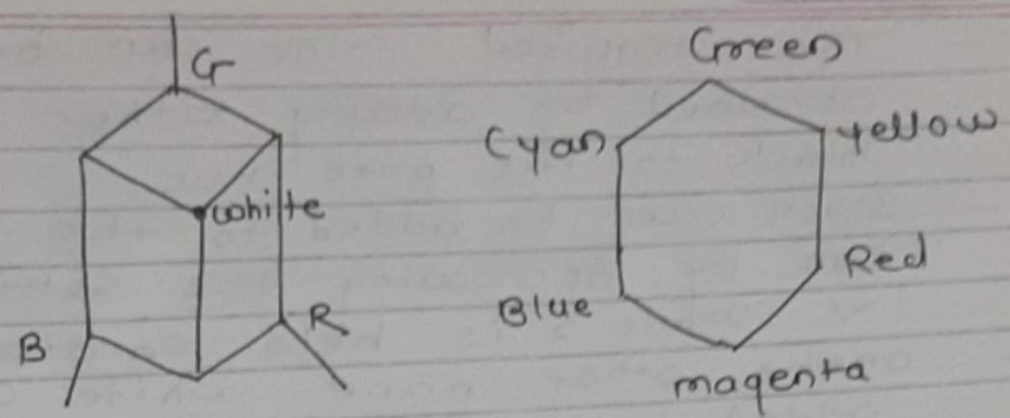
- The value V indicates level of brightness.



- it uses cylindrical co-ordinate system & the subset of the space within which, model is defined as hexcone or six-sided pyramid.

- The top of the hexacone is derived from RGB. if we imagine viewing the cube along the main diagonal from the white vertex to the origin (black).

- fig. shows outline of cube that has the hexagone shapes.



— This boundary of cube is used as top if hexcone & it represents various hue.

— Hue or H is measured by angle around the vertical axis with red at 0°, Green at 120° & so on as in fig of HSV hexacone.

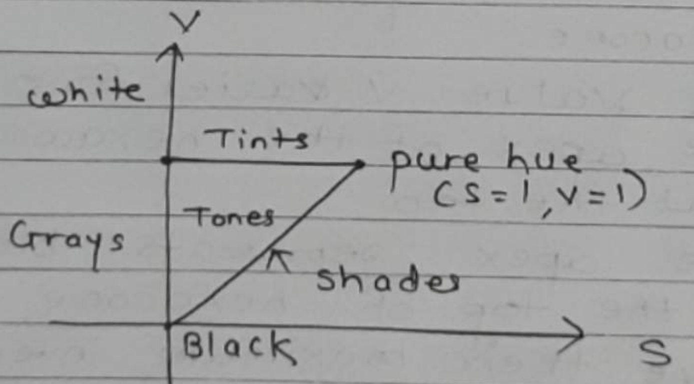
— Complementary colours in the HSV hexacone are 180° apart saturation parameter varies from 0 to 1. its value is the ratio ranging from 0 on the center line (x axis) to 1 on the triangular sides of the hexacone.

— The value V varies from 0 to the apex of the hexacone to 1 at the top.

— The apex represents black.

— At the top of hexacone, colours have their maximum intensity. when V=1 & S=1 we have the pure hues.
e.g, pure red is at H=0, V=1 & S=1, pure green is at H=120, V=1 & S=1
pure blue, H=240, V=1 & S=1 & so on.

- The required color can be obtained by adding either white or black to the pure hue.
- Black can be added to the selected hue by decreasing the setting for V while S is held constant. On the other hand, white can be added to the selected hue by decreasing S while keeping V constant. To add some black & some white we have to decrease both V & S
- The point S=0 & V=1 we have ~~to~~ white colour. The intermediate values of V for S=0 (on the center line) are grey shades. Thus, when S=0, the values of H is irrelevant.
- when S is not zero, H is relevant. At the apex V co-ordinate is 0, At this point the values of H & S are irrelevant.



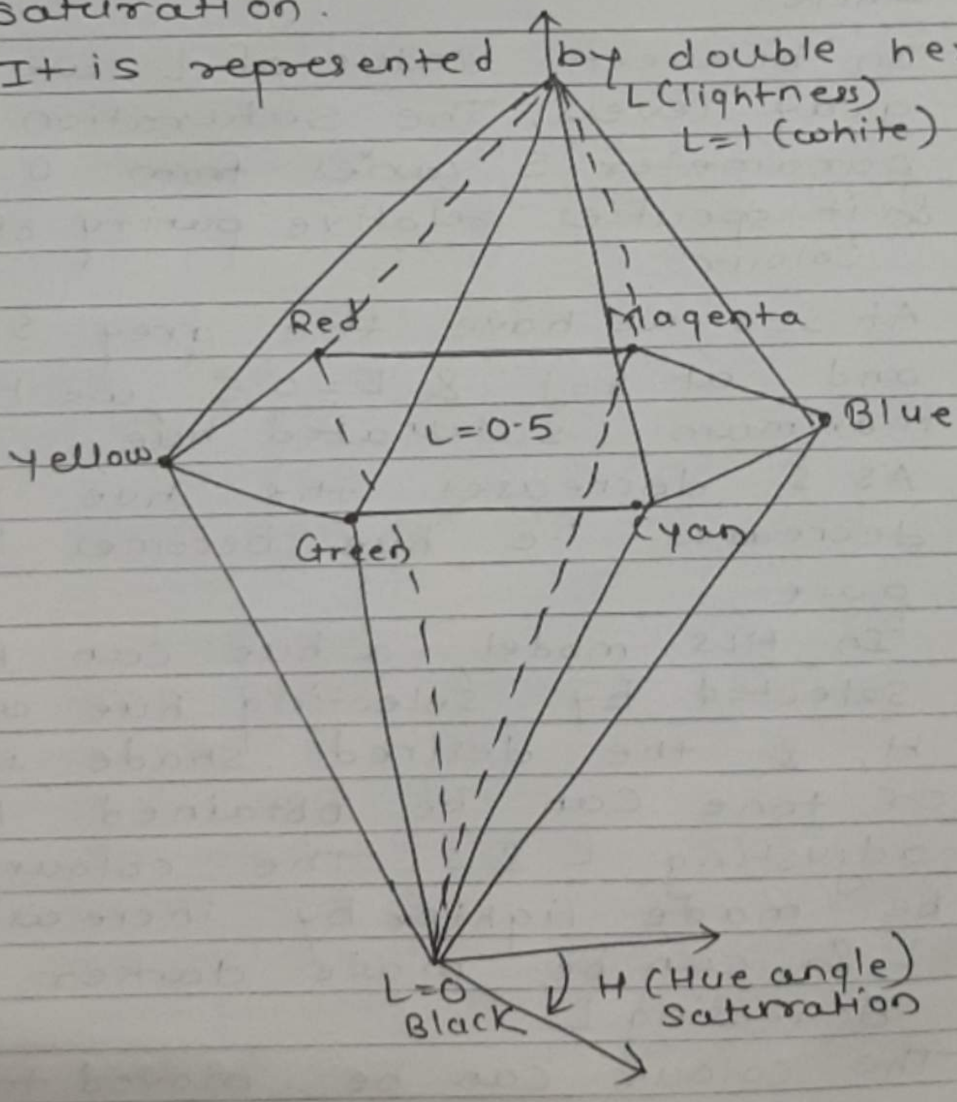
cross sectional panel of HSV showing Tints, Tones, shades.

- This plane represents the colour concepts associated with the term shades, tints & tones
- we can add to black colour to pure hue to produce different shades of the colour.

- white colour to pure hue to produce different tints of the colour.
- Both white & black colours to pure hue to produce tones of colour.

HLS Colour Model :-

- it is based on intuitive colour parameters in the HLS colour model used by Tektronix.
- 3 colour parameters in this model are hue (H), lightness (L) & saturation.
- It is represented by double hexcone



- The hue specifies the angle around the vertical axis of double hexacone
- In this model, $H = 0$, corresponds to blue. The remaining colours are specified around the perimeter of the hexacone in the same order as in HSV model.
- Magneta is at 60° red is at 120° & yellow is located at $H = 180^\circ$.
- Complementary colour are 180°, apart on double hexcone.
- The vertical axis in this model represents the lightness. At $L=0$, we have black & at $L=1$, we have white.
- In between value of L we have gray levels. The saturation parameter S varies from 0 to 1. & it specifies relative purity of Colour.
- At $S=0$ we have the grey scale and at $S=1$ & $L=0.5$ we have maximum saturated hue,
  AS S decreases the hue saturation decreases i.e hue becomes less pure.
- In HLS model, a hue can be selected by selecting hue angle H, & the desired shade, tint or tone can be obtained by adjusting L & S. The colours can be made lighter by increasing L & can be made darker by decreasing L.
- The colour can be moved towards grays by decreasing S.

CMY Colour Model :-

- In this model, cyan, magneta & yellow colours are used as aprimary colour.
- This model is used for describing colour output to hard copy devices.

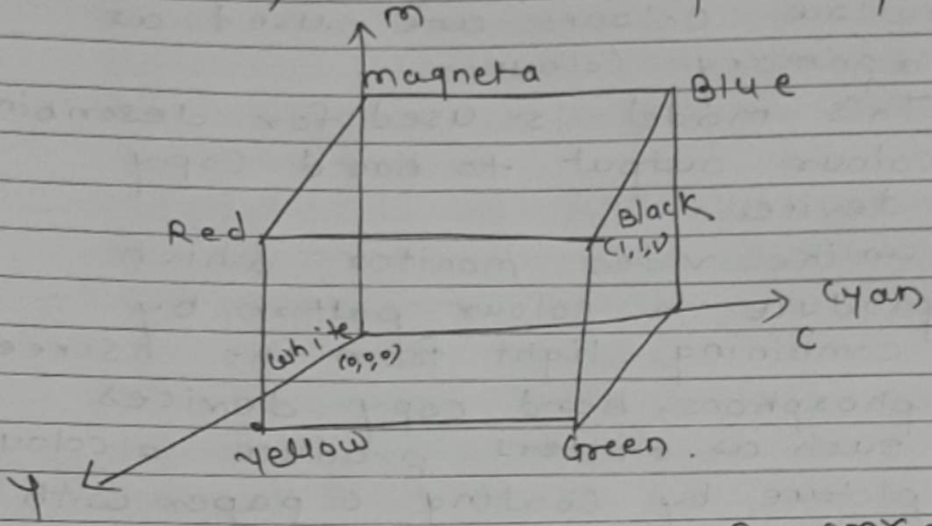
unlike video monitor, which produce a colour pattern by combining light from the screen phosphors, hard copy devices such as plotters produce a colour picture by coating a paper with colour pigments.

- The subset of the Cartesian co-ordinate system for CMY model is the same as that for RGB except that white (full light) instead of black (no light) is at original

Colours are specified by what is removed or subtracted from white light, rather than by what is added to blackness.

- cyan can be formed by adding green & blue light. therefore when white light is reflected from cyan coloured ink, the reflected light does not have red component.
- So red light is absorbed as subtracted by ink. likewise magneta ink subtracts the green components from incident light & yellow subtracts the blue component.

- So cyan, magneta & yellow are said to be complements of red, green, & blue respectively.



Cube representation for CMY model.

- fig shows point (1,1,1) represents black because all components of the incident light are subtracted.
- The point (0,0,0), origin represents white light. The main diagonal represents equal amount of primary colours thus the gray colours.
- A combination of cyan & yellow produces green light because the red & blue components of the incident light are absorbed.
- It is possible to get CMY representation from RGB representation as follows.

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

Applications of colors.

- colors influences perceptions that are not obvious, such as taste of food, for e.g. red or orange pills are generally used as stimulants.
- use in marketing - color psychology is widely used in marketing & branding.
- specific color meaning - diff. colors are perceived to mean diff. things. e.g. tones of red lead to feelings of arousal while blue tones often associated with feelings of relaxations.
- Attracting attention - used as a means to attract consumer attention to product that then influences buying behavior.
- Individual differences - Based on gender, age & culture the use of color is decided.
  e.g children's toys are often categorized as either boys or girls toys solely based on color.
  - younger age groups are often marketed based on diff. color.

Motion Specification -

motion of objects can be controlled by various ways in an animation system various methods as

I] method based on Geometric Infoᵐ :-

- This is straight forward method for motion control. In this method there is direct specification at the motion parameters.
- we explicitly give rotation angle & translation vector.

II] method based on kinetic Infoᵐ :-

- animation sequence can also be constructed using kinematic description with this, we have to specify the animation by giving motion parameters that is position, velocity & acceleration without reference to forces that causes the motion.

III] method based on physical Infoᵐ –

- The description of object behavior under the influence of forces is referred to as physically based modeling.

IV] Procedural motion – in this various elements of model communicate in order to determine their properties. This sort of procedural control is suited to control of animation.

- The procedural interaction among objects can be used to generete motion.

Unit : 04

Shading & Hidden Surfaces

Introduction :- [Reference – TB1]

- we want to display anything on monitor, we are dealing with the intensity of pixels,
- as if we know only two colors black & white.
- color is one of the important properties of light.
- The color of an object depends not only on the object itself. but also on light source illuminating it.

Illumination Models :-

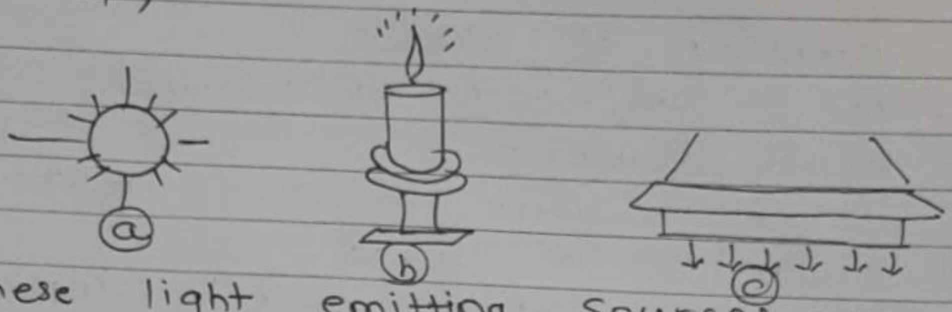
- fundamentally lighting effects are described with models that consider the interaction with object surface.
- This interaction modifies the light in several ways.
  - once light reaches our eyes it gives signals to our perception process to decide what we have seen in actual scene. but visual perception is a complicated process.
- we Concentrate on the location & qualities of the light that falls on the objectes & the way in which object interacts with it.
- A model for the interaction of light with surface is called an illumination model.

light sources :-

- many objects which are available in nature may produce or emit light

These objects are called as light emitting sources.

- The e.g for this could be sun, lamp, star.



- These light emitting sources are further categorized as
  1) point source
  2) distributed light source.

- when the surface of the object which we want to illuminate is bigger than the surface of light emitting source.

1 - then we are calling that light emitting source as point source at fig (b)

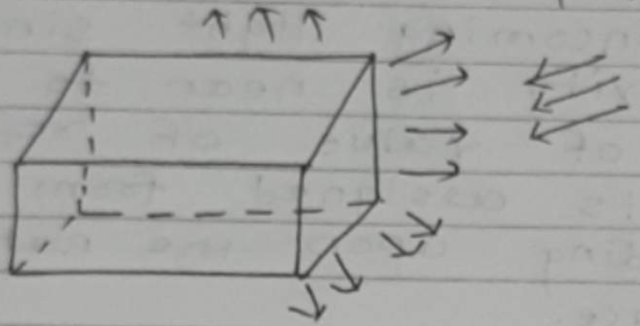
2 - when the surface of light emitting source is greater than the surface of object then we are referring it as distributed light source at fig (c).

* all objects which are not emitting light are grouped under separate category, which is called as light reflecting sources.

Ambient light -

- when we try to produce realistic displays, we must consider this reflected light which is coming from all the directions. su light which is reflected from walls, floor, ceiling, objects in a room.

— it means the surface which is not directly exposed to a light emitting source will still be visible because of light reflecting sources. This light which is reflected from somewhere is called as background light or ambient light.



light reflecting source.

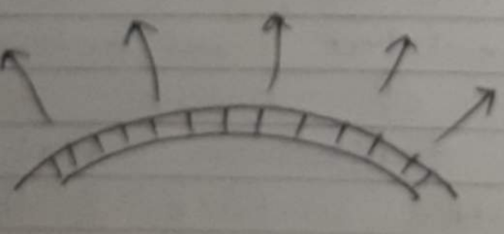
Diffuse Illumination (Reflection) —

— when a light falls on any surface it can be absorbed by the surface, while the rest will be reflected or retransmitted.

— In diffuse reflection, incoming light is not reflected in a single dire^n but is scattered almost in all dire^n.

— The part of incoming light will be absorbed by the surface.

— The light which is not absorbed will be reflected randomly in all direction.



- The ratio of light reflected from the surface to the total incoming light is called the coefficient of reflection or reflectivity (Kd)

- The white surface is having its reflectivity close to 1. hence it reflects almost all incoming light.
- black surface absorbs most of the incoming light since its reflectivity is near to 0.
- range of value of reflectivity (Kd) is assigned from 0 to 1. depending upon the nature of surface.
- Intensity of the diffuse reflection at any point when surface is exposed to ambient light as

$$I = Kd \cdot Ia$$

Ia = intensity of ambient light

Kd = coefficient of reflection.

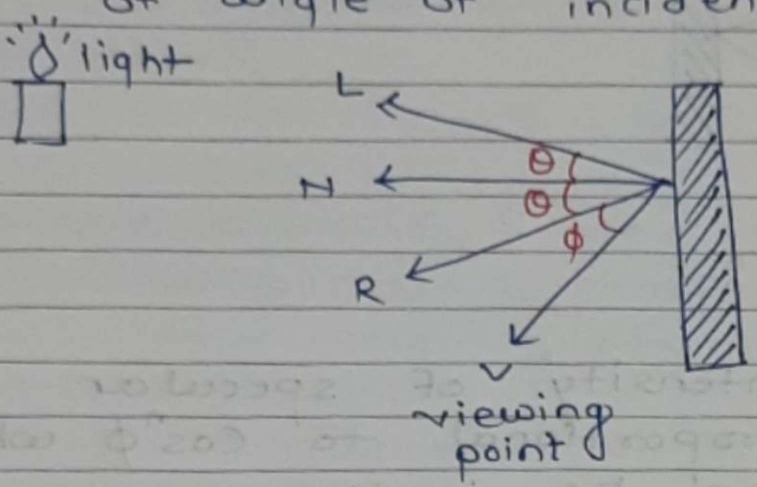
[Reference - TB1]

Specular Reflection & phong Model

- Def^n :- Specular reflection :- is a type of reflection which occurs at the surface of a mirror.

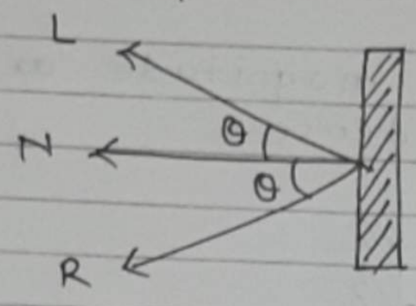
- The light is reflected in a single dire^n, many metals, glass & plastics have a specular reflection which is independent of color.
- In specular reflection, light comes in strikes the surface & then bounces back.

- The angle which the reflected beam makes with the surface normal is called angle of reflection.
- it is same in magnitude as that of angle of incidence.



- The vector 'L' point — direction of light source
- N — surface normal
- vector R — points in the direction of reflected light.
- V - indicates unit vector pointing to the viewer from the surface position.
- Angle ϕ — is viewing angle relative to the specular reflection direction R.
- for an ideal reflector this angle ϕ should be zero.

Shiny Surface - will reflect almost all the incoming light precisely in the dire^n of the reflecti^o^n vector. so it is having narrow reflection range whereas a rough surface has wider reflection range



Phong Model :-

- sets the intensity of specular reflection proportional to $\cos^n \phi$ where angle ϕ, can be in the range of $0°$ to $90°$ i.e $\cos\phi$ in range of 0 to 1. & 'n' determines the type of surface that is to be viewed.
- A large value is assigned to 'n' if the surface is very shiny & 'n' will be small for rough surfaces.
- perfect reflector, like mirror has 'n' as infinite.
- we can approximately model specular intensity variations using specular reflection coefficient $w(\theta)$ for each surface.
- angle of incidence increases $w(\theta)$ also increases when $\theta = 90$ at that time $w(\theta) = 1$ & all the incident light is reflected.

specular reflection model =

$$I_{spec} = w(\theta) \cdot I \cdot \cos^n \phi$$

I = intensity of light source

ϕ = angle betⁿ R & V.

But as V & R are unit vectors in the viewing & specular reflection direⁿ,

$$\cos\phi = V \cdot R$$

— we simplify the eqⁿ by assigning $w(\theta)$ as a constant value (K_s) for the surface

$$\therefore \; I_{spec} = K_s \cdot I \cdot (V \cdot R)^n$$

R is represented in terms of L & N.

Combined Diffuse & specular Reflections with multiple light source.

— we can form a combined model of Diffuse & specular reflection for a single point light source, from a point on an illuminated surface as

$$I = I_{diff} + I_{spec}$$

$$= K_d \cdot I_a + K_d \cdot I_p \cdot (N \cdot L) + K_s \cdot I \cdot (V \cdot R)^n$$

— if we put more than one point light source in a particular scenario

— we obtain the reflection of light at any surface point by summing the contributions from the every individual light source.

- In this scenario the equation becomes as

$$I = k_d \cdot I_a + \sum_{i=1}^{n} I_{pi} \left[k_d \cdot (N \cdot L_i) + k_s \cdot (V \cdot R_i)^n \right]$$

- we need to take care that any pixel intensity is not crossing the maximum limit.
- for this we can apply normalization procedure.
- Here we can set the maximum limit to each term in intensity equation.
- while calculations if any term crosses this limit then we set it to maximum limit.

Warn Model :-

- in this model light source is aimed or pointed in a certain dir^n.
- Depending on the direction of light source the intensity of light varies.
- model suggests a method of controlling light intensity in diff dir^n. which can be used ~~in~~ simulating light effects of a studio.
- In this model, the direction is given by $\cos^n \phi$, where ϕ is angle from the central direction.

- If we need more concentrated light in a central dire^n then we have to keep a larger value for 'n'.
- we may apply multiple light sources also to get additive effect.
- This concept is somewhat similar to phong model. flaps are used to control the intensity of emitted light by a source in diff. dire^n.
- Generally two flaps are there in each dire^n to control the intensity.

[Reference - TBI]

Shading :-

- it is one of the major tool used to create images that are very realistic.
- shaded images can create the impression that the images are real objects & not artificial ones.
- Advantage of using high quality shaded images are that they provide easy, more effective & less costly way of reviewing various alternatives rather than building actual models or prototype.
- shading model are also called as illumination models.
- They are used to calculate the intensity of light at a given point on the surface of object.

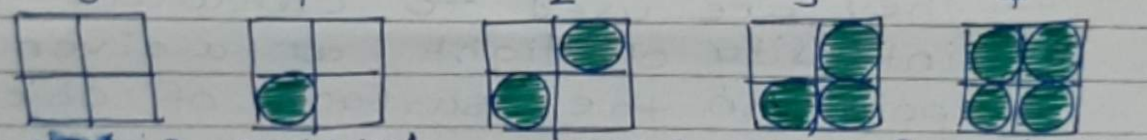
Halftone Shading -

- Many displays & hardcopy devices are bilevel. They can only produce two intensity levels.
- In such displays or hard copy devices, we can create an apparent increase in the no. of available intensities.
- This is achieved by incorporating multiple pixels positions into the display of each intensity value.
- when we view a very small area from a sufficiently large viewing distance, our eyes average fine details within the small area & record only the overall intensity of the area. this

phenomenon of apparent increase in the no. of available intensities by considering combine intensity of multiple pixel is known as halftoning.

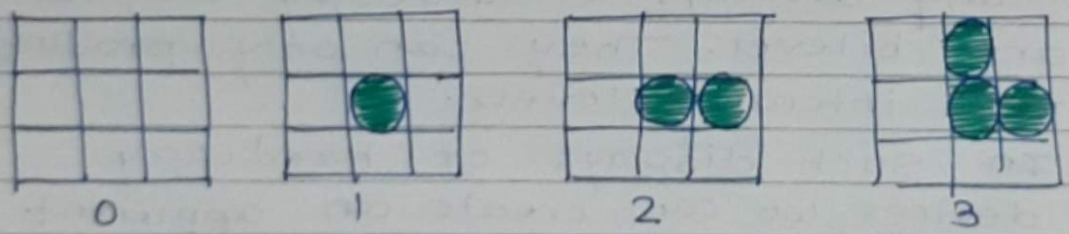
- The halftoning is used in printing black & white photographs in newspapers, magzines & books. The pict produced by halftoning process are called halftones.
- In Comp. Graphics, halftone reproductions are approximated using rectangular pixel regions, say 2x2 pixel or 3x3 pixel.
- These regions are called halftone patterns or pixel patterns.

0 1 2 3 4



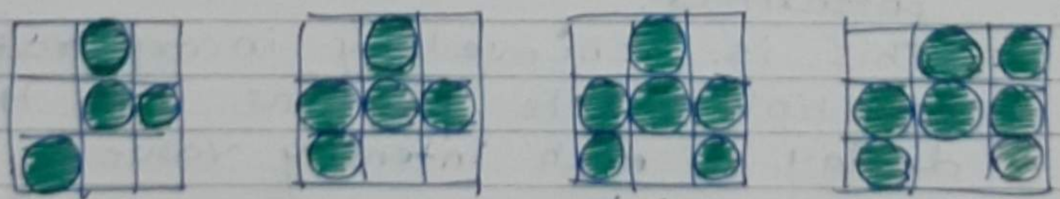
$0 \leq I < 0.2$ $0.2 \leq I < 0.4$ $0.4 \leq I < 0.6$ $0.6 \leq I < 0.8$ $0.8 \leq I < 1.0$

2x2 pixel patterns for creating five intensity levels.



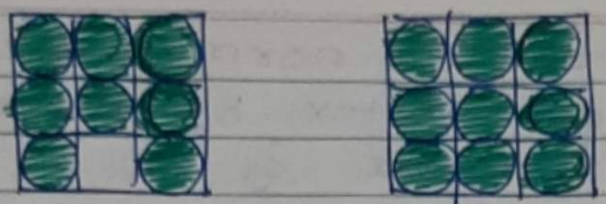
0 1 2 3

$0 \leq I < 0.1$ $0.1 \leq I < 0.2$ $0.2 \leq I < 0.3$ $0.3 \leq I < 0.4$



4 5 6 7

$0.4 \leq I < 0.5$ $0.5 \leq I < 0.6$ $0.6 \leq I < 0.7$ $0.7 \leq I < 0.8$



8 $\quad$ 9

$0.8 \leq I < 0.9$ $\quad$ $0.9 \leq I < 1.0$

3×3 pixel patterns for creating ten intensity levels.

Gauraud shading :- is an interpolation method used in CG to produce continuous shading of surface represented by polygon meshes

- In this method, the intensity interpolation technique developed by Gourand is used.
- The polygon surface is displayed by linearly interpolating intensity values across the surface.
- intensity values for each polygon are matched with the values of adjacent polygons along the common edges.
- This eliminates the intensity discontinuities that can occur in flat shading.

By performing following calculations, we can display polygon surface with Gaurand shading.

1. Determine the average & normal vector at each polygon vertex.
2. Apply an illumination model to easy polygon vertex to determine the vertex intensity.
3. linearly interpole the vertex intensities over the surface of the polygon.

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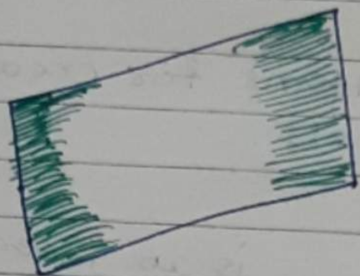
— we can obtain a normal vector at each polygon vertex by averaging the surface normals & all polygons sharing that vertex.



— in fig. there are 3 surface normals N_1, N_2, N_3 for polygon sharing vertex V.

normal vector at vertex V is given as

$$N_v = \frac{N_1 + N_2 + N_3}{|N_1 + N_2 + N_3|}$$

— In general, for any vertex position V, we can obtain the unit vertex normal by equation.

$$N_v = \frac{\sum_{i=1}^{n} N_i}{\left|\sum_{i=1}^{n} N_i\right|}$$

n = is the no. of surface normals of polygons sharing that vertex.

— pseudo-C-Algo. for Gaurand shading
it is a method for linearly interpolating a colour or shade

across a polygon.

- it is very simple & effective method of adding a curved feel to a polygon. that would otherwise appear flat.

- firstly, calculate gradient of shade across the line as usual

Gradient = (Bs-As) / (Bx - Ax)

where

$A_s \rightarrow$ shade at A

$A_x \rightarrow$ x value of A.

- calculate the exact value of the shade at C:

$C_s = A_s + (1 - frac(A_x)) * Gradient$

- you need to be able to render a trip of Gaurand polygon to the screen.

- This involves calculating the shade of each pixel & writing it to the screen. this is simple process.

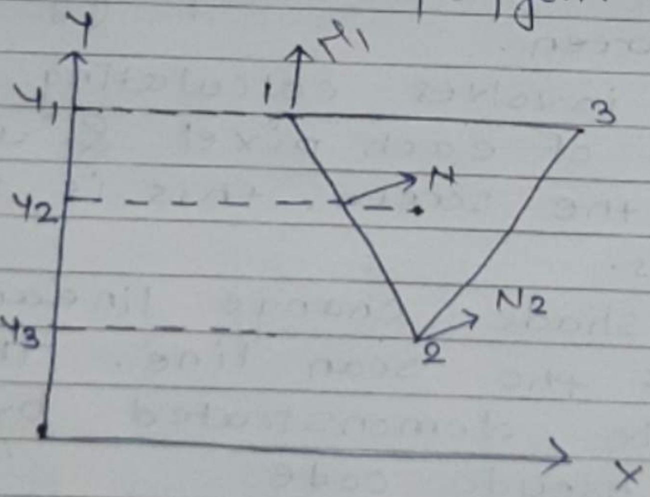
- The shade change linearly across the scan line. The process can be demonstrated by little pseudo code

```
Shade = Cs
Loop x from Cx to Dx
plot pixel at (x, y) with colour shade.
Shade = shade + Gradient
end of x loop.
```

Phong Shading -

- it is also known as normal-vector interopolation shading, interpolates the surface normal vector N, instead of the intensity.
- steps to display polygon surface using phong shading
  1. Determine the average unit normal vector at each polygon vertex.
  2. linearly interpolate the vertex normals over the surface of the polygon.
  3. Apply an illumination model along each scan line to determine projected pixel intensities for the surface points.

- The 1st steps in the phong shading is Same as 1st step in this Gourand Shading.
- In second step the vertex normals are linearly interpolated over the surface of the polygon.



- The normal vector N for scan line intersection point along the edge between vertices 1 & 2 can be obtained by vertically interpolating between edge & end points normals:

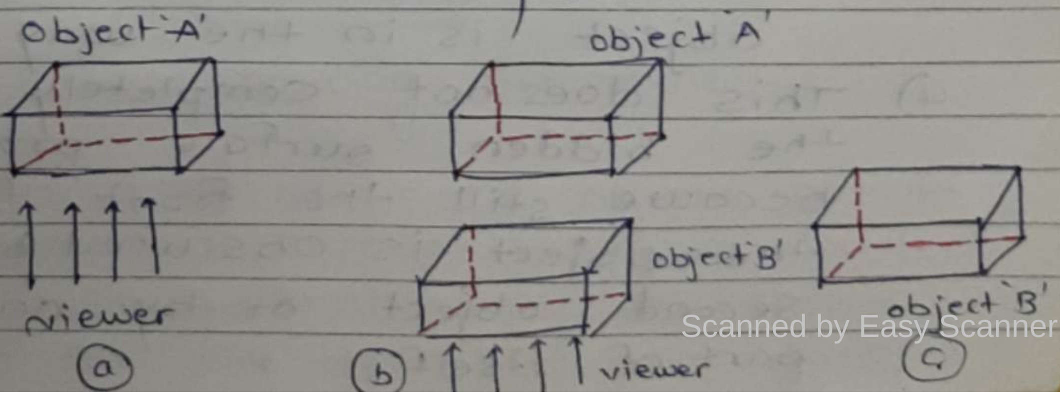
$$N = \frac{y - y_2}{y_1 - y_2} N_1 + \frac{y_1 - y}{y_1 - y_2} N_2$$

- we can use incremental method to evaluate normals between scan lines & along each individual scan line.
- Once the surface normals are evaluated the surface intensity at that point is determined by applying the illumination method.

Hidden Surfaces :-

Introduction —

- if we are looking at some object 'A' & then some object say 'B' comes in between our eye & object 'A' then in that case we are not able to see the object 'A' fully or partially.
- It means object 'B' interrupts the projected path of object 'A'
- In fact some surfaces of this new object 'B' are also not visible because they are eclipsed by object 'B's visible parts.



- The surfaces that are blocked or hidden from view must be removed in order to construct a realistic view of 3D scene.
- Object 'B' should be displayed with only three of the six faces like in fig. c.
- The identification & removing of these surface is called the **hidden surface problem.**
- we have to determine the closest visible surface along each projection line.
-

Back Face Detection & Removal :-

1) Hidden line removal is costly process hence it is advisable to apply easy tests to simplify the problem as much as possible before understanding through analysis.
2) Back face removal is simple test which can be performed to eliminate most of the faces which cannot be seen.
3) This test identifies surfaces which face away from the viewer. The back of the object cannot be visible because bulk of the object is in the way.
4) This does not completely solve the hidden surface problem because still the front face of the object is obscured by a second object or by another part of itself.

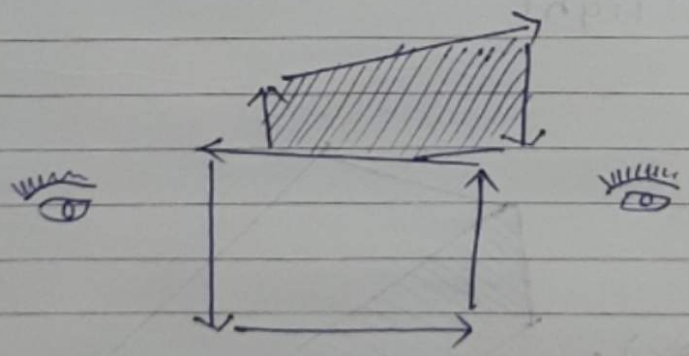
But test can remove roughly half of the surfaces from consideration & thus simplify problem.

5) In this algo only polygon is considered as lines cannot obscure anything & although they might be obscured they are usually found only as edges of surfaces of an object.

6) Because of this, polygons suffice for most drawings, polygon has two surfaces, a front & a black, just as piece of paper does.

7) we might pict our polygons with one side painted light & the other painted dark.

8) How to find which surface is light or dark :- when we are looking at light surface, the polygon will appear to be drawn with counter clockwise open motions & when we are looking at the dark surface the polygon will appear to be drawn with clockwise pen motions

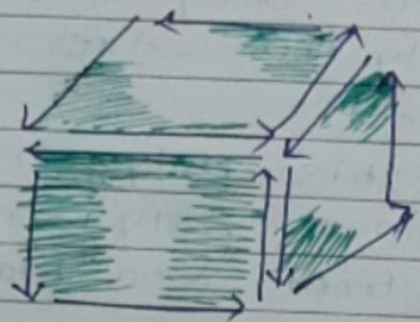


Drawing directions.

9) assume that all solid objects are to be constructed out of polygons in such a way that only the light surfaces are open to air, dark

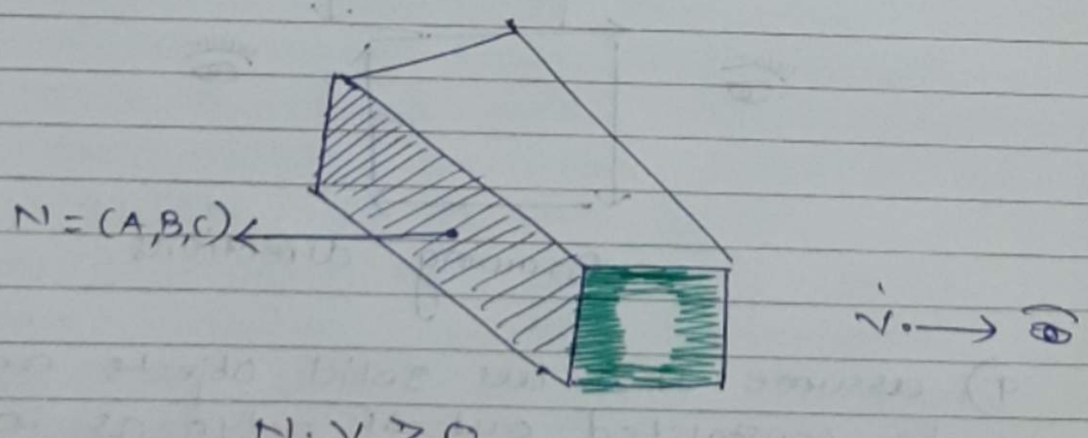
faces meet the material inside the object.

10) This means that when we look at an object face from the outside, it will appear to be drawn counter clockwise



11) If a polygon is visible, the light surface should face towards us & the dark surface should face away from us. if the direction of light face is pointing towards the viewer, the face is visible (a front face) otherwise the face is hidden (a back face) & should be removed.

12) The direction of the light face can be identified by examining the light.

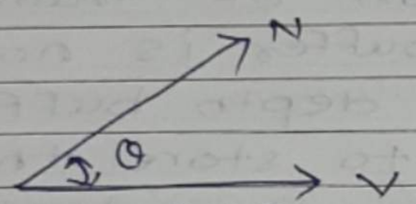


$N \cdot V > 0$

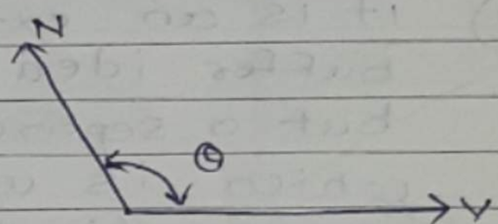
N: Normal vector to the polygon surface with cartesian components (A, B, C)

V : A vector in the viewing direction from the eye or camera position.

- dot product of two vectors gives the product of lengths of the two vectors times the cosine of the angle between them.
- This cosine factor is important to us because if the vectors are in same direction $(0 \leq \theta \leq \pi/2)$ then cosine is positive and the overall dot product is positive.
- if the directions are opposite $(\pi/2 < \theta < \pi)$ then the cosine & the overall dot product is negative.



$\cos\theta > 0$



$\cos\theta < 0$

* Cosine Angles between Two vectors :-

- If the dot product is positive, then the polygon faces towards the viewer otherwise in faces away & should be removed.
- In case, if object description has been converted to projection co-ordinates & our viewing diren is parallel to the viewing Z_v axis then $V = (0, 0, V_z)$ and $V \cdot N = V_z C$
- we only have to consider the sign of C, the z component of the normal vector N.
- if the z component is position then the polygon faces towards the viewer, if negative it faces away.

Algorithms :-

– Depth Buffer (Z - Buffer)

1) This algo is the simplest of all hidden surface removal (HSR) algo.
2) This technique is commonly used to eliminate the hidden surfaces of the object, which are to be displayed.
3) Z-buffer algo is also refered as depth buffer algo.

* 4) This algo examines the visibility of the surface of one point at a particular time.

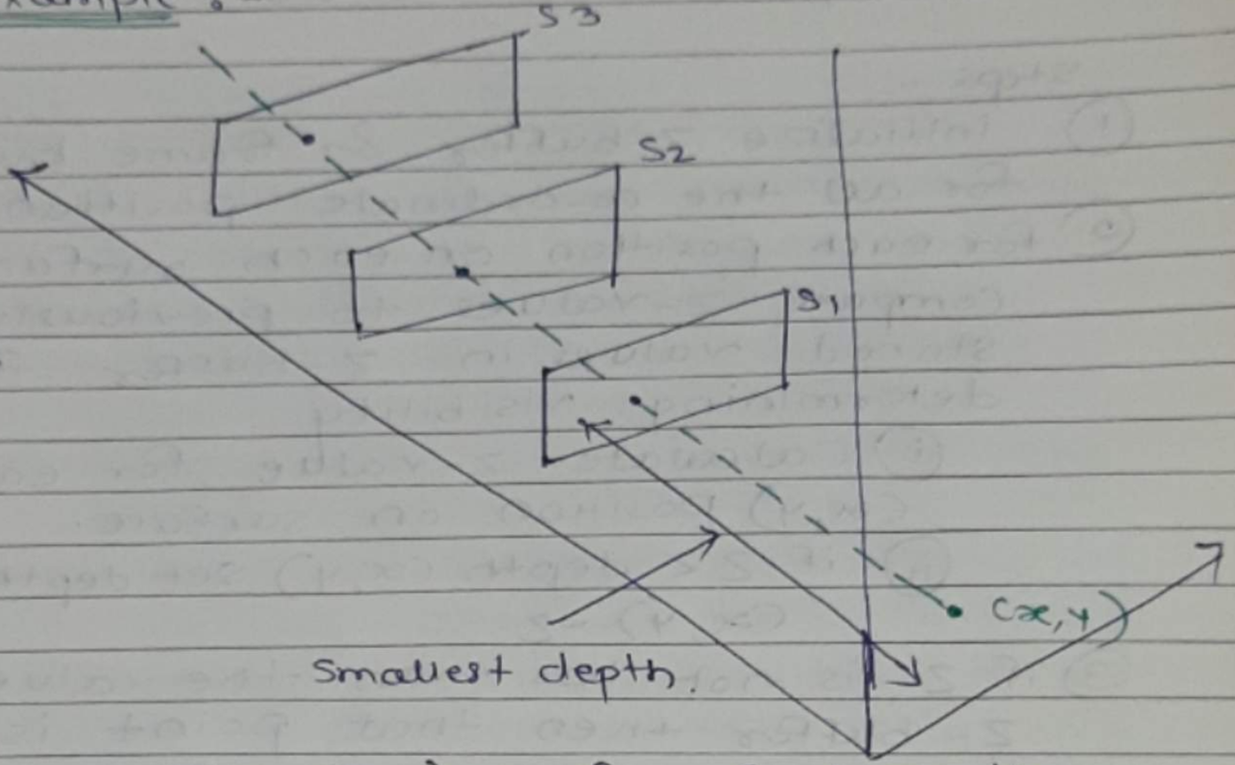
5) it is an extension of frame buffer idea. Z buffer is nothing but a separate depth buffer which is used to store the Z coordinates or the depth of every visible pixel in the image space or video m/m.
6) Thus, two buffers are needed for the implementation of this algo Z buffer (depth buffer) & frame buffer.

working –

1) working of algo is simple.
2) Frame buffer contains the Z-value or depth of new pixel, which is then compared with the depth of that pixel stored in the z-buffer.
3) If the comparison shows that new pixel is infront of the pixel stored in the frame buffer, then the

new pixel is written to the frame buffer & Z-buffer is updated with the new Z-value, otherwise no action is taken.

Example :-



from position (x, y) surface S_1 has the smallest depth value i.e it is the nearest surface from position (x, y) & it is visible at the position.

Algo :-

1) set frame buffer to the background intensity & set the Z-buffer to the minimum Z-value.
2) To calculate Z value or depth at each (x, y) position, scan convert the each in arbitary order. Calculate the depth Z(x, y) at that pixel.
3) The calculated Z-value is then compared with value previously stored in the Z-buffer at that location.
4) if the calculated Z-value is ...

the value stored in the z-buffer.
i.e if z-buffer $(x, y) < z(x, y)$ then replace z buffer (x, y) with $z(x, y)$ otherwise, no action is taken & next pixel is considered.

Steps:-

1. initialize z buffer & frame buffer for all the co-ordinate position (x, y).
2. for each position on each surface, compare z-values to previously stored values in z-buffer for determining visibility
   1. calculate z-value for each (x, y) position on surface.
   2. if $z <$ depth (x, y) set depth $(x, y) = z$.
3. if z is not less than the value of z-buffer then that point is not visible at that position. After the process has been completed for all surfaces, z buffer contains the z values for all visible surfaces.

Advantages:-

1) easy to implement.
2) can be implemented in hardware to overcome the speed prob.
3) algo processes obj one at a time. the total no. of polygons in the pict can be arbitarily large.

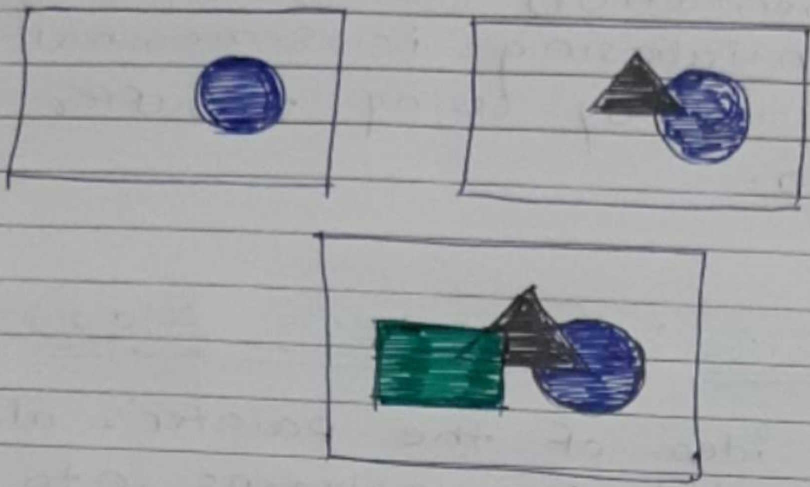
Disadvantage:-

1) requires additional buffer & large m/m.
2) is a time consuming process as it requires comparison for each pixel instead of entire polygon.

3. implementation of transparency & antialiasing is somewhat difficult by using z-buffer algo.

Depth Sorts :- (Painter's Algo)

1) Basic idea of the painter's algo is to paint the polygons into frame buffer in order of decreasing distance from the viewpoint.
2) This process involves following basic funⁿ.
   (a) sorting of polygons in order of decreasing depth.
   (b) Resolving any ambiguities this may cause when polygon's z extents overlap i.e splitting polygons if necessary.
   (c) scan conversion of polygons in order, starting with the polygon of greatest depth.
3) The algo gets its name from the manner in which an oil painting is created. The artist begins with background. then adds the most distant object & then the nearer object & so forth.
4) There is no need to erase portions of background, the artist simply paints on top of them.
5) The new paint covers the old so that only the newest layer of paint is visible.



⑥ using similar technique, we 1st sort the polygons according to their distance from view point. The intensity values for the farthest polygon are then entered into the frame buffer.

⑦ Taking each polygon is succeeding polygon in turn (in decreasing depth order) polygon intensities are painted on the frame buffer over the intensities are painted on the frame buffer over the intensities of the previously processed polygons. This process is continued as long as no overlaps occurs.

⑧ if depth overlap is detected by any point in the sorted list we have to make some additional comparisons to determine whether any of the polygon should be recordered.

⑨ checklist whether any polygon Q does not obscure polygon P by performing following steps:-

ⓐ z-extents of P & Q donot overlap i.e $z_{Q\,max} < z_{P\,min}$.

fig (a)

(b) The y-extends of P & Q do not overlap. (fig b)

(c) The x-extends of P & Q do not overlap.

(d) polygon P lying entirely on the opposite side of Q's plane from the view port. (fig c)

(e) polygon Q lying entirely on the same side of P's plane as the viewport. (fig d)

(f) The projections of the polygons P & Q onto the xy screen do not overlap.

(10) if all these five tests fail, we assume for the moment that P actually obscures Q & therefore test whether Q can be scan-converted before P.

(11) we have to repeat tests 4 & 5 for Q. if these tests also fail then we can say that there is no order in which P & Q can be scan converted correctly & we have to split either P or Q into two polygons.

(12) The idea behind the splitting is that split polygons may not obscure other polygon.

Algorithm :-

1. Sort all polygons in order of decreasing depth.
2. Determine all polygons Q (preceding P) in the polygon list whose z-extends overlap that of P.
3. perform test 2 through 6 for each Q.
    a) if every Q passes the tests, scan convert the polygon P.

(b) if test fails for some Q, swap P & Q in the list & make the indication that Q is swapped. if Q has already been swapped, we the plane containing polygon P to divide polygon Q into two polygons Q_1 & Q_2. Replace Q with Q_1 & Q_2. Repeat step 3.

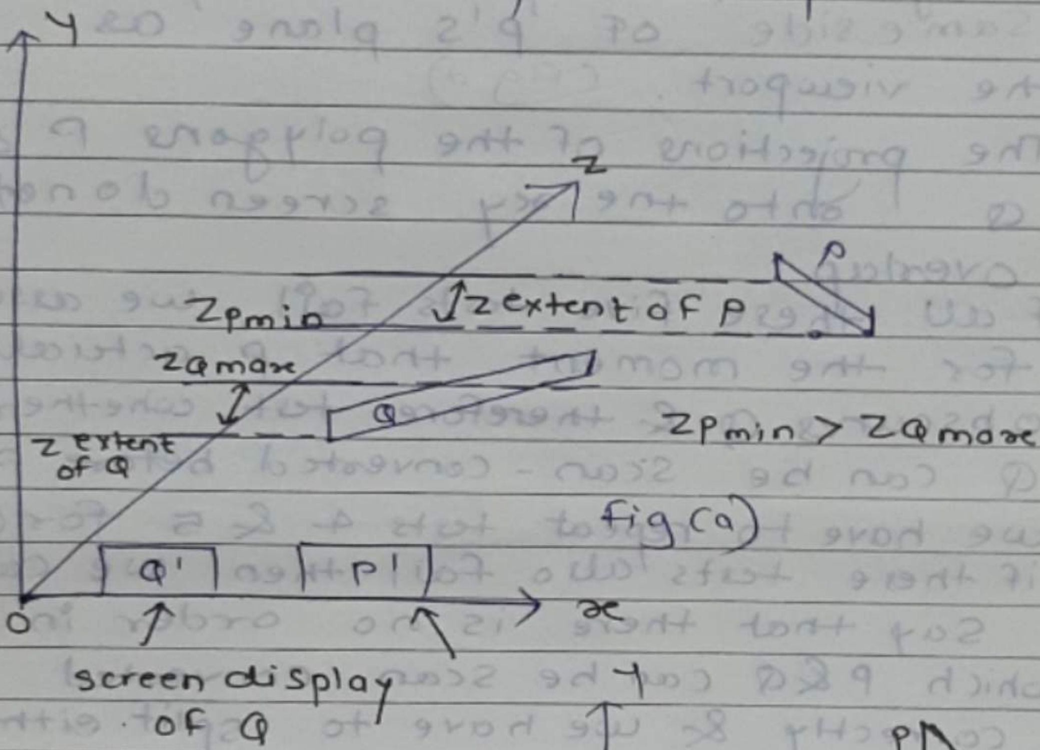


fig (a)

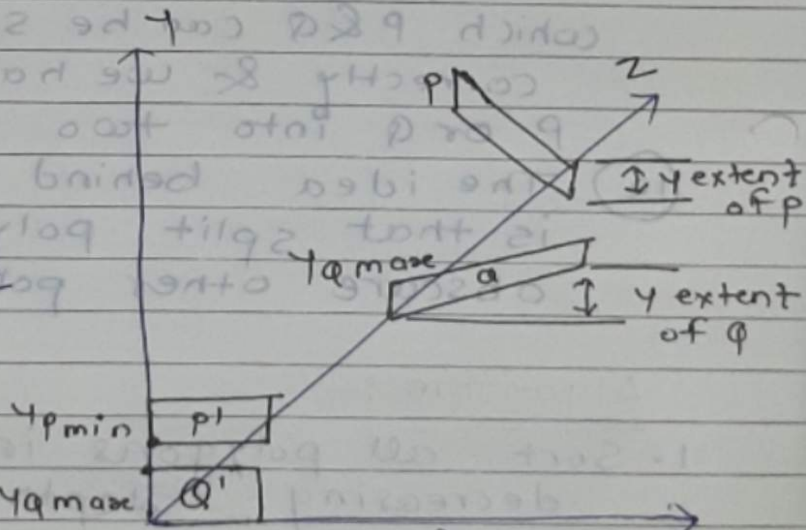
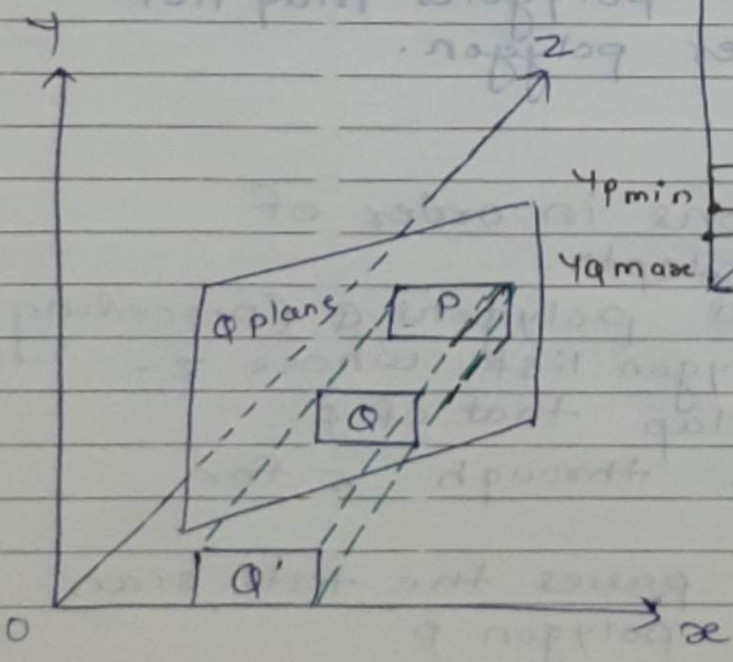


fig (b)



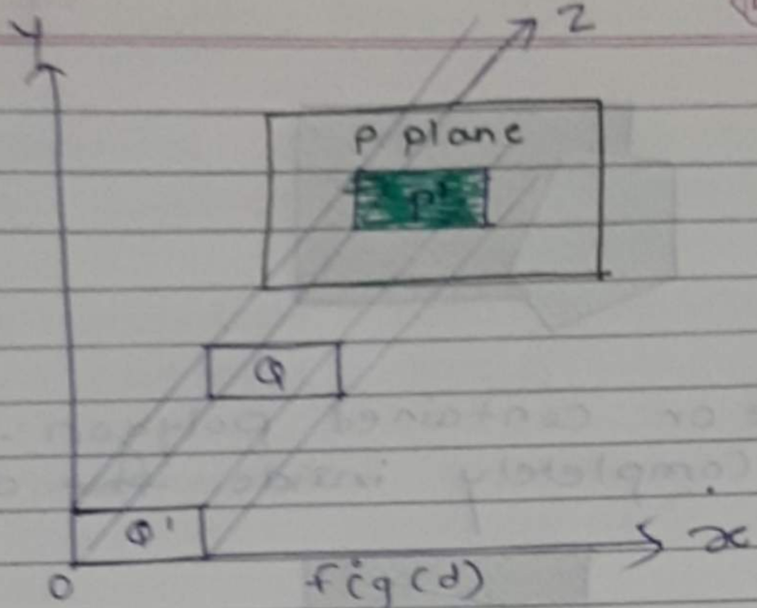
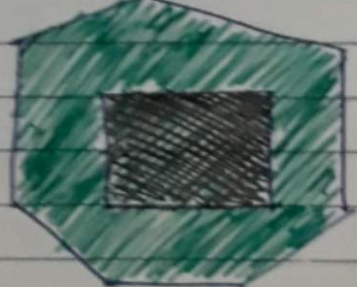


fig (d)

Area Subdivision – (warnock)

1) approach to the hidden surface problem was developed by warnock.
2) area subdivision algo which subdivides each area into four equal squares.
3) at each stage in the recursive – subdivision process, the relationship betn projection of each polygon & area of intrest is checked for four possible ~~approa~~ relationship:

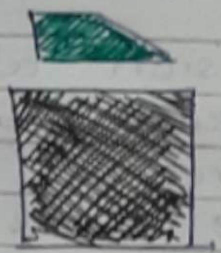
a) surrounding polygon – one that completely encloses the (shaded) area of intrest.



b) Overlapping or Intersecting polygon – one that is partly inside & partly outside the area.

c) Inside or contained polygon :- one that is completely inside the area

d) Outside or Disjoint polygon — one that is completely outside the area.



— after checking four relationship we have to handle each relationship as follows :-

1. if all the polygons are disjoint from the area, then the background colour is displayed in the area.

Z-buffer Algo (Depth Buffer method)

- It compares surface depth at each pixel position on the projection plane.
- This technique was originally proposed by CATMULL 1974
- Z-axis represent Z buffer.

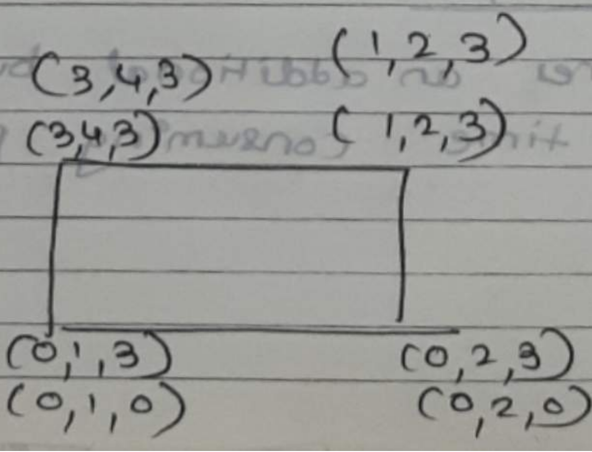
Algo:-

Initialize all depth d(i, j) = ∞ (max depth) ← assume of pixel

corresponding color values → C (i, j) = background color.

```
for (each polygon)
   for (each pixel in polygon's projection)
   {
      find depth Z of polygon at (x,y)
      corresponding to pixel (i,j)
      if (z < d (i,j))
      {
         d (i,j) = z ;  c (i,j) = color ;
      }
   }
```

example :-



each pixel divided.

∞	∞	∞
∞	∞	∞
∞	∞	∞
8	8	8

replace with color value / z value.

3	3	3
3	3	3
3	3	3
3	3	3

tild

3	3	3
2	2	2
1	1	1
0	0	0

Advantages :-

1) easy to implement
2) can be implemented in ~~forward~~ H/w to overcome the speed prob.

Disadvantages.

1) requires an additional buffer
2) it is time consuming process.