# Illumination Model in Computer Graphics

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The series of methods used to depict light in computer graphics scenarios is computer graphics illumination. Although lighting strategies provide versatility in the degree of detail and ongoing functionality, technological requirement and uncertainty often vary widely in terms. To match the requirements of each application, visual designers can choose between a variety of diverse outlets, templates, lighting methods, and impacts.

The intentional use of illumination to produce aesthetic and functional results is illumination or lighting. The utilization of several incandescent lamps, such as fixtures and light fittings, and ambient sunlight by collecting daylight are used in illumination.

To measure the frequency of light that is reflected at a specific location on the surface, the lighting system, also recognized as the Shading model or Illumination model, is used.

There are 3 parameters upon which influence of lightning based:

- **Light Source**

The wavelength of light is the origin that produces light. There are three types of optical outlets. They are-

1. **Point Sources**

Point sources transmit beam of light in all directions from a fixed location, with the luminous source diminishing with duration.

A separate lighting fixture is an instance of a point source.

- **Parallel Sources**

A particular region which is far from the substrate can be called (The sun).

- **Distributed Sources**

Beams arise in a restricted region through (A tube light).
The illumination effect is determined by its location, electromagnetic frequencies and form.

- **Surface**

As light passes, portion of it is transmitted on the substrate and most of it is consumed. The volume of emission and reflection of energy is now determined by the surface morphology. The lightning impact is also determined by the location of the ground and the configurations of all the surrounding surfaces.

- **Observer**

The illumination effect is also influenced by the location and detector frequency intolerances of the observer.

**Illumination Interaction**

Light typically involves several steps in computer graphics. The composition of the object's connections with these elements determines the overall impact of a source of light on an item. The three essential characteristics of illumination (subsequent forms of interaction) are ambient, diffuse, and specular.

- **Ambient Illumination**

Suppose you are positioned on a lane, approaching a glass exterior tower and sun light fall on that tower gazing down from it and reflecting on the item under analysis. It will be Ambient Lighting. In plain terms, the one where the light source is approximate is Ambient Illumination.
The strength of any location on the surface expressed by $I_{amb}$ is:

$$I_{amb} = K_a I_a$$

**Where,**

**$I_a$ = Ambient Light Intensity**
**$K_a$ =Surface ambient reflectivity, value of $K_a$ tends from 0 to 1**

- **Diffuse Illumination**

The subsequent illumination of an artifact by an even wavelength of sunlight reacting with a lamp-light surface is diffuse lighting (or diffuse reflection). It is represented as a feature of the substrate properties of material as well as the direction of incident sunlight, after light hits an item. This communication is the significant contributor to the intensity of the artifact and forms the foundation for its hue.
The mirrored strength of a location on the ground of $I_{diff}$ is:
**$I_{diff} = K_d I_p \cos(?) = K_d I_p (N.L)$**
**Where,**
**$I_p$ = The point of light intensity**
**$K_d$ = The diffuse reflectivity of surface, value $K_d$ tends from 0 to 1**
**N = Normal surface**
**L = The direction of light**

- **Specular Illumination**

The specular illumination portion gives artifacts shine and highlighting. This is different from reflection impact since other artifacts in the world are not apparent in these simulations. Specular illumination instead produces high points on surfaces based on the specular illumination module's strength and the surface's specular refractive index.
The Phong Model is a Specular Replication analytical framework that represents the method for measuring the mirrored strength $I_{spec}$ is:
**$I_{spec} = W(?) I_l \cos^n(?)$**
**Where,**
**$W(?) = K_s$**
**L = Light source direction**
**N = Normal to the surface**
**R = Reflected ray direction**
**V = Observer direction**
**? = Angle between L and R**
**? = Angle between R and V**
**Illumination Models**

In rendered conditions where illumination is estimated depending on the physics of illumination, lighting designs are used to simulate lighting effects. Reflecting ambient lighting as they exist in the modern environment will need more computing power than is feasible for computer graphics without illumination models. The aim of this lighting or illumination design is to calculate the hue of each pixel or the wavelength of daylight mirrored in the image on multiple substrates. There are two primary patterns of illumination, lighting directed towards artifacts and global lighting. They vary as each item is considered independently by object-oriented illumination, while global illumination depicts how daylight communicates between items. Researchers and scientists developing global approaches for lighting to much more precisely mimic how sunlight communicates with its surroundings.

- **Object-oriented illumination**

By projecting a unified source of light to a specific image, object-oriented illumination, also called as local lighting, is described. This methodology is easy to measure, but is also an imperfect estimation of how beam in fact will function in the scenario. A mixture of specular, radiant, and ambient illumination from a single object is also estimated by summarizing it up. The Phong and the Blinn-Phong illumination variants are the 2 distinct regional lighting versions.

1. **Phong illumination model**

The Phong model is one of the more popular scattering patterns. The Phong analysis implies that according to radiant, diffraction, and ambient illumination, the resolution of each dot is the value of the strength. Using the direction of light projecting off an artifact, this method takes into consideration the position of an observer to calculate reflectance light. The angle's coefficient is extracted and elevated to an energy determined by the artist. With this, the developer may determine how big a spotlight they need on an entity; the force is known as the cost of glossiness just because of that. The brightness value is defined by the material's hardness where a reflection will have an infinite value and a quality of one could have the grimmest ground.

- **Blinn-Phong illumination model**

As it utilizes specular energy to illuminate a spotlight on an object based on its shine, the Blinn-Phong illumination model is comparable to the Phong model. As even the Blinn-Phong model utilize the parameter usual to the surface of the object and midway among the beam of light and the observer, the Blinn-Phong distinguishes from the Phong illumination method. In order to obtain accurate specular illumination and decreased computational efficiency, this method is used. The procedure requires less effort since a more active calculation is determining the path of the scattered sunlight vector than measuring the midway coordinate system. Although this is equivalent to the Phong model, it incorporates distinct visual effects, and in able to manufacture a specific mirror effect, the specular reflection coefficient or glossiness might require adjustment.

- **Global Illumination**

Global lighting varies from regional lighting because illumination is measured as it passes across the complete scene. This lighting is centered more strongly on physics and dynamics, with light waves spreading across the picture, scattering, and reflecting forever. There's still some exploratory analysis on global illumination, while more functionality than regional illumination is needed.
Global illumination involves following-

1. **Ray tracing**

Light beams release rays that, via diffusion, distortion, or diffraction, respond to various objects. Any light beam which enters their vision will be seen by a viewer of the picture; a ray that does not enter the viewer goes undetected. By allowing all of the visible light release rays, it is able to estimate this and then measure how each of them interacts with all of the objects in the image. Nevertheless, since most of the incoming light will not enter the viewer and would consume waiting time, this approach is ineffective. By speeding up the process, Ray tracing provides the solution of this problem, transmitting vision beams from the viewer instead and measuring how they communicate before they enter a light beam. While this approach utilizes computing resources more wisely and generates an illumination projection that strongly imitates different sunlight, because of the high concentrations of lighting that enter the eyes of the audience, ray tracing also has heavy computational expenses.

- **Radiosity**

The light emitted by different sensors and the laser beam is taken into consideration by radiation. With exception of ray tracing, which relies on the direction and inclination of the viewer, the illumination of radiation is regardless of the orientation of the object. Radiosity needs more processing capability than ray tracing, but since it only has to be measured once, it can be more effective for fixed illumination scenarios. A movie's surfaces can be split into some kind of significant number of areas; each patch exudes some daylight and impacts the other blotches, so it is essential to fix a wide system of linear equations concurrently in order to achieve the proper radiosity of each area.

- **Photon mapping**

As a two-dominant global lighting optimization that is more effective than raytracing, photon imaging was developed. It is the fundamental concept of measuring, via a number of steps, photons are emitted from a beam of light. The first pass involves the photons being extracted from a beam of illumination and reflecting out of their first item; it then records this graph about where the photons are centered. Each photon that either bounces or is consumed includes both the speed and orientation of the photon graph. The second pass is the representation where the mirrors for multiple substrates are measured. The photon graph is disconnected from the movie's configuration in this phase, ensuring that rendering can be measured independently. It is a good method because it can replicate caustics, and if the perspective or artifacts alter, pre-processing measures do not require to be reiterated.

## Lighting Effects

The lighting effects in an image are the manner in which the sunlight, shadow, allow the image to display. Numerous different illumination effects can be created by a simple flashgun. Whenever the picture is taken toward the sky, the different lighting effects can be seen.
The lighting effects involves the following-

- **Caustics**

Caustics are an illumination consequence of passing via a system of mirrored and diffused light. When pointing at waterways or glass, they emerge as tassels of intense light and are often visible. Caustics can be applied by combining a corrosive texture map only with texture map of the impacted artifacts in three-dimensional graphics. The structure of caustics may either be a visual interface modeled to simulate caustic impact, or a measurement of caustics in live time on an empty image. The latter is more complex and involves the mapping of reverse rays to visualize photons traveling via the three-dimensional rendering framework. Monte Carlo testing is used in a photon analysis lighting method in combination with ray tracing to measure the light intensity emitted by the caustics.

- **Reflection mapping**

Reflection imaging (also recognized as environment imaging) is a technology that involves two-dimensional environment graphs rather than using ray tracing to produce the illusion of reflectivity. Although the presence of reflective artifacts depends on the observers' stimulation parameters, the artifacts, and the conditions around them, graphical equations create reflection curves to decide how artifacts are colored based on these components. Reflections on items can be defined using simplistic, computationally efficient methodologies using two-dimensional environment graphs instead of completely delivering three-dimensional objects to describe environments.

- **Particle system**

To design turbulent, elevated incidents, including such flames, looking to move liquids, detonations, and relocating hair, particle structures utilize catalogs of tiny particles. An electrode distributes molecules that make up the complicated graphics, which provides each particle its characteristics, including color, speed, and lifespan. With the time, based on the impact, these molecules can shift, modify color, or change certain characteristics. Usually, particle systems incorporate complexity to allow the impact practical and non-uniform, including in the potentially generate properties the power source offers each particle.

## Illumination Models:

An illumination Model is a formula in variables associated with the surface properties and light conditions to calculate the intensity of light reflected from a point on a surface.

1. Ambient Light
2. Diffused Light
3. Specularly Reflected Light

### Ambient Light:

An object may be visible even if it is not directly exposed to a light source. That is because some light is always scattered from the nearby illuminated objects and surroundings. This is called **Ambient light**. This light is diffused and non-directional and it is assumed to be incident with uniform intensity on all objects in a scene.

### Diffused Light:

Unlike in the case of ambient lighting where a distributed light source is assumed, intensity profile across surface changes when exposed to point light source. This is because light from the source is incident at a different angle at different points of the surface. The model which represents such diffused reflection is based on Lambert's cosine law and it is given by,

$I_{diff} = I_1 k_d \cos\theta$

## Specularly Reflected Light:

Typical shiny surfaces like polished metal, oily skins, porcelain etc, that are neither diffuse reflector nor ideal reflector like reflect light specularly when exposed to point light source. Such reflection is identified by a highlight or bright spot on the surface when viewed from particular directions. Most interestingly such spots appear to move over the surface with the movement of the viewpoint. This is called **Specularly Reflected Light**.

### *Distance Factor:*

We know that the intensity of light energy falls off as it travels farther from the light source. So, the intensity profile of two identical surfaces, under even lighting conditions, can't be identical if they are at different distances from the light source and/or viewpoint. A factor commonly is known as a distance factor.

### *Color Factor:*

In the illumination models considering only monochromatic lights and surfaces. To model colour light and colored surfaces we can assume there basic components of incident light intensity, namely $I_{RED}$, $I_{GREEN}$ and $I_{BLUE}$ and each of the three coefficient of reflection ($k_a$, $k_d$, $k_s$) as three element ($k_{RED}$, $k_{GREEN}$ and $k_{BLUE}$) vector. This is called as Color Factor. It means for a given surface we can have nine different characteristics reflection coefficients that one-to-one correspondence with similar color lights only.

# Shading:

We have learnt how to calculate the intensity of light reflected from a point in a given lighting and surface condition. Now, we have to use a technique for finding the intensity of a surface as a whole to simulate its appearance under the given lighting condition. This technique is called as **Shading**.

## Constant Shading:

It is the simplest shading model for a polygon surface, it is also known as **flat shading** or **faceted shading**. Instead of applying the illumination model separately at each point of the surface, this model applies the illumination model only once to determine a single intensity value for a polygon. All points over the surface of a polygon are then displayed with the same intensity value. This approach assumes that:

1. All light sources are at infinity implying N.L and attenuation factor are constant across a polygon surface.
2. The viewpoint is at infinity implying V.R is constant across a polygon surface.
3. The graphic object being modelled is a polygonal face isn’t an approximation to a curved surface.

## Interpolated Shading:

**Interpolated Shading** is a kind of trade-off between computational expense and realistic shading quality. To yield more realistic shading with intensity varying from point to point on a surface needs due consideration to change of curvature, the direction of incident light and position of viewpoint from one point on a surface to another.

### *Gouraud Shading:*

The following steps are required to carry out for each polygonal face of the surface mesh for this shading scheme developed by **Gouraud**.

**Step1:** Determine the unit normal vector at each vertex of a polygon. If a vertex is shared by some polygons faces the average of the normals to all the faces at that vertex gives the desired normal vector.

**Step2:** Find the intensities at each vertex by applying illumination models separately using respective vertex normals.

**Step3:** For each scan line, calculate intensities at the intersection of a scan line with an edge by linear interpolation of intensities at the edge endpoints.

**Step4:** Calculate intensities at points along a scan line between the edges by linear interpolation of intensities at the intersections of the scan line with the edges.

*Phong Shading:*

One of the major disadvantages of Gouraud shading is that it avoids finding surface normal at each point on every scan line. As a result, the change in curvature from point to point is overlooked. But **Phong shading** achieves better approximation to the true shape of a surface and thus a better rendering of the surface by determining surface normals at each point using linear interpolation technique. Illumination models are applied at every such point using the normal vector calculated at the respective points and quite obviously the process is computationally expensive.

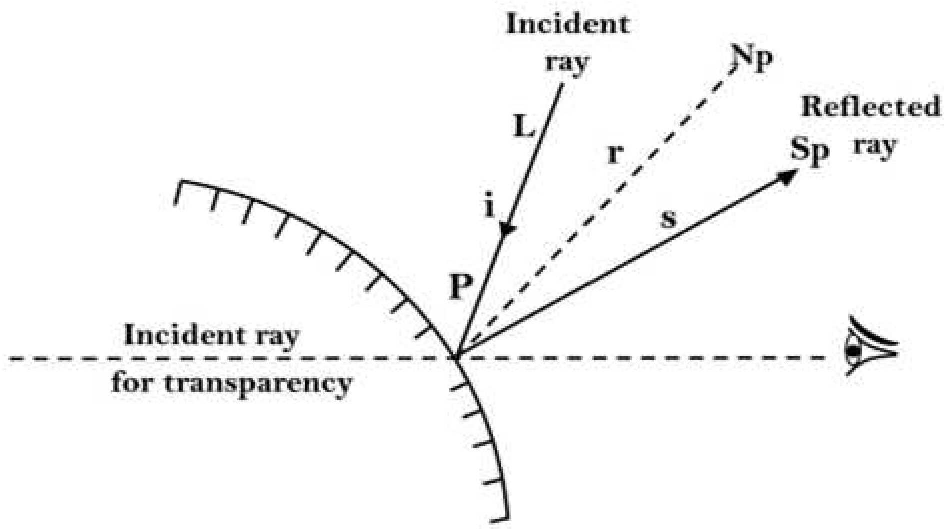
# Introduction of Shading

Shading is referred to as the implementation of the illumination model at the pixel points or polygon surfaces of the graphics objects.

Shading model is used to compute the intensities and colors to display the surface. The shading model has two primary ingredients: properties of the surface and properties of the illumination falling on it. The principal surface property is its reflectance, which determines how much of the incident light is reflected. If a surface has different reflectance for the light of different wavelengths, it will appear to be colored.

An object illumination is also significant in computing intensity. The scene may have to save illumination that is uniform from all direction, called diffuse illumination.

Shading models determine the shade of a point on the surface of an object in terms of a number of attributes. The shading Mode can be decomposed into three parts, a contribution from diffuse illumination, the contribution for one or more specific light sources and a transparency effect. Each of these effects contributes to shading term E which is summed to find the total energy coming from a point on an object. This is the energy a display should generate to present a realistic image of the object. The energy comes not from a point on the surface but a small area around the point.




The simplest form of shading considers only diffuse illumination:

$$E_{pd}=R_p\ I_d$$

where $E_{pd}$ is the energy coming from point P due to diffuse illumination. $I_d$ is the diffuse illumination falling on the entire scene, and $R_p$ is the reflectance coefficient at P which ranges from shading contribution from specific light sources will cause the shade of a surface to vary as to its orientation concerning the light sources changes and will also include specular reflection effects. In the above figure, a point P on a surface, with light arriving at an angle of incidence i, the angle between the surface normal $N_p$ and a ray to the light source. If the energy $I_{ps}$ arriving from the light source is reflected uniformly in all directions, called diffuse reflection, we have

$$E_{ps}=(R_p \cos i)I_{ps}$$

This equation shows the reduction in the intensity of a surface as it's tipped obliquely to the light source. If the angle of incidence i exceeds90°, the surface is hidden from the light source and we must set $E_{ps}$to zero.

# Constant Intensity Shading

A fast and straightforward method for rendering an object with polygon surfaces is constant intensity shading, also called Flat Shading. In this method, a single intensity is calculated for each polygon. All points over the surface of the polygon are then displayed with the same intensity value. Constant Shading can be useful for quickly displaying the general appearances of the curved surface as shown in fig:

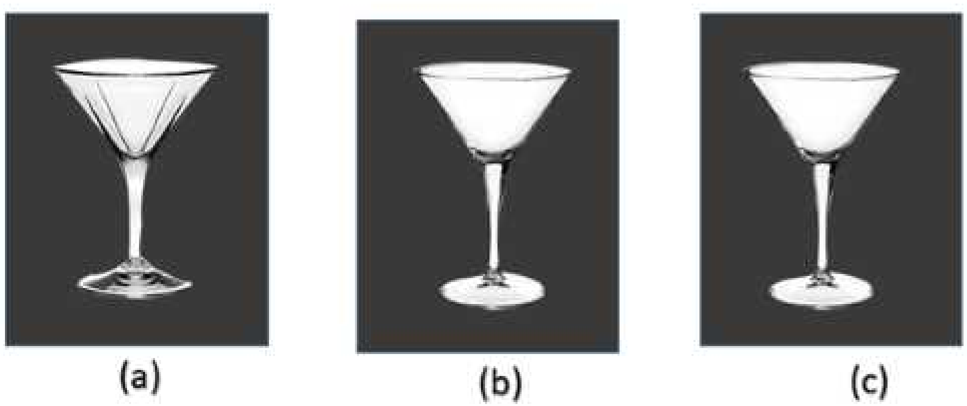



**Fig: A Polygon mesh approximation of an object (a) is rendered with flat shading (b) and With Gouraud shading (c)**

In general, flat shading of polygon facets provides an accurate rendering for an object if all of the following assumptions are valid:-

The object is a polyhedron and is not an approximation of an object with a curved surface.

All light sources illuminating the objects are sufficiently far from the surface so that N. L and the attenuation function are constant over the surface (where N is the unit normal to a surface and L is the unit direction vector to the point light source from a position on the surface).

The viewing position is sufficiently far from the surface so that V. R is constant over the surface (where V is the unit vector pointer to the viewer from the surface position and R represent a unit vector in the direction of ideal specular reflection).

# Gouraud shading

This Intensity-Interpolation scheme, developed by Gouraud and usually referred to as Gouraud Shading, renders a polygon surface by linear interpolating intensity value across the surface. Intensity values for each polygon are coordinate with the value of adjacent polygons along the common edges, thus eliminating the intensity discontinuities that can occur in flat shading.

Each polygon surface is rendered with Gouraud Shading by performing the following calculations:

1. Determining the average unit normal vector at each polygon vertex.
2. Apply an illumination model to each vertex to determine the vertex intensity.
3. Linear interpolate the vertex intensities over the surface of the polygon.

At each polygon vertex, we obtain a normal vector by averaging the surface normals of all polygons staring that vertex as shown in fig:

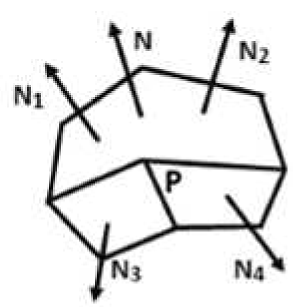



**Fig: The normal vertex at vertex V is calculated as the average of surface normal for each polygon sharing the vertex.**

Thus, for any vertex position V, we acquire the unit vertex normal with the calculation

$$\mathbf{N_V} = \frac{\sum_{k=1}^{n} \mathbf{N_k}}{\left|\sum_{k=1}^{n} \mathbf{N_k}\right|}$$

Once we have the vertex normals, we can determine the intensity at the vertices from a lighting model.

**Following figures demonstrate the next step:** Interpolating intensities along the polygon edges. For each scan line, the intensities at the intersection of the scan line with a polygon edge are linearly interpolated from the intensities at the edge endpoints. **For example:** In fig, the polygon edge with endpoint vertices at position 1 and 2 is intersected by the scanline at point 4. A fast method for obtaining the intensities at point 4 is to interpolate between intensities $I_1$ and $I_2$ using only the vertical displacement of the scan line.

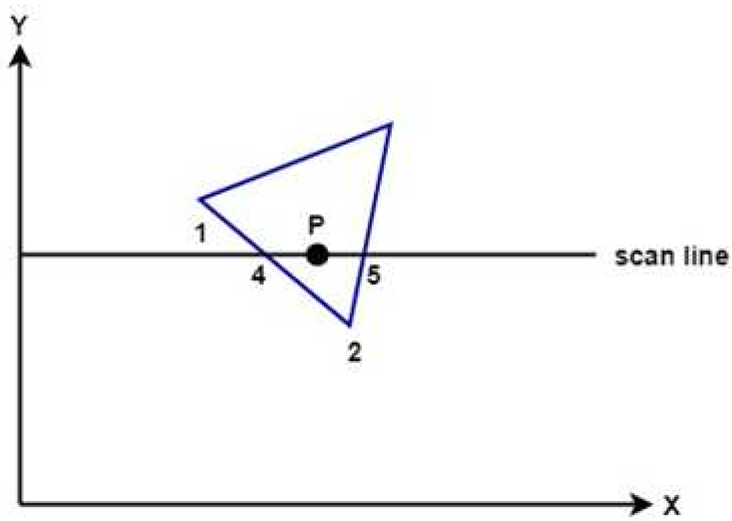



Fig: For Gouraud Shading, the intensity at point 4 is linearly interpolated from the intensities at vertices 1 and 2. The intensity at point 5 is linearly interpolated from intensities at vertices 2 and 3. An interior point P is then assigned an intensity value that is linearly interpolated from intensities at position 4 and 5.

$$\mathbf{I_4} = \frac{y_4 - y_2}{y_1 - y_2}\mathbf{I_1} + \frac{y_1 - y_4}{y_1 - y_2}\mathbf{I_2}$$

Similarly, the intensity at the right intersection of this scan line (point 5) is interpolated from the intensity values at vertices 2 and 3. Once these bounding intensities are established for a scan line, an interior point (such as point P in the previous fig) is interpolated from the bounding intensities at point 4 and 5 as

$$I_P = \frac{x_5 - x_p}{x_5 - x_4} I_4 + \frac{x_p - x_4}{x_5 - x_4} I_5$$

Incremental calculations are used to obtain successive edge intensity values between scan lines and to obtain successive intensities along a scan line as shown in fig:

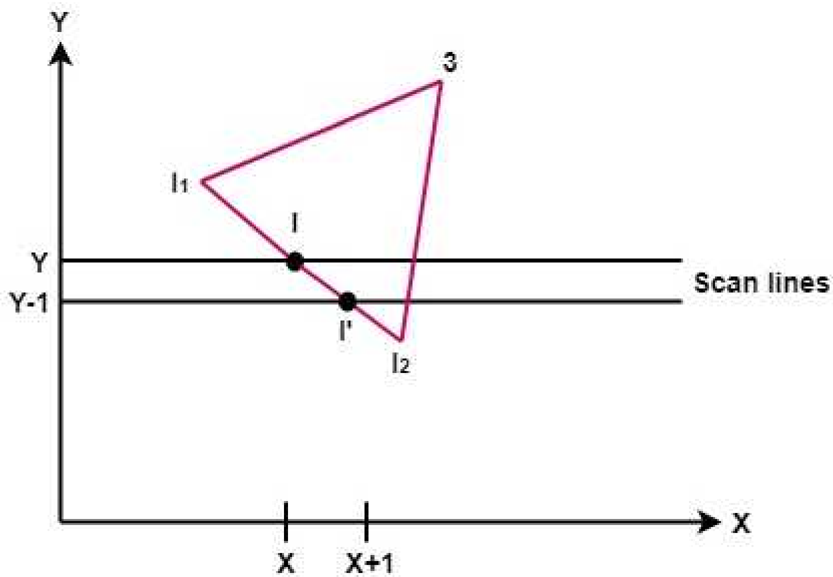



Fig: Incremental Interpolation of intensity value along a polygon edge for successive scan lines.

If the intensity at edge position (x, y) is interpolated as

$$I = \frac{y - y_2}{y_1 - y_2} I_1 + \frac{y_1 - y}{y_1 - y_2} I_2$$

Then we can obtain the intensity along this edge for the next scan line, Y-1 as

$$I' = I + \frac{I_2 - I_1}{y_1 - y_2}$$

Similar calculations are used to obtain intensities at successive horizontal pixel positions along each scan line.

When surfaces are to be rendered in color, the intensities of each color component is calculated at the vertices. Gouraud Shading can be connected with a hidden-surface algorithm to fill in the visible polygons along each scan-line. An example of an object-shaded with the Gouraud method appears in the following figure:

(a) (b) (c)

**Fig: A Polygon mesh approximation of an object (a) is rendered with flat shading (b) and With Gouraud shading (c)**

Gouraud Shading discards the intensity discontinuities associated with the constant-shading model, but it has some other deficiencies. Highlights on the surface are sometimes displayed with anomalous shapes, and the linear intensity interpolation can cause bright or dark intensity streaks, called Match bands, to appear on the surface. These effects can be decreased by dividing the surface into a higher number of polygon faces or by using other methods, such as Phong shading, that requires more calculations.

# Phong Shading

A more accurate method for rendering a polygon surface is to interpolate the normal vector and then apply the illumination model to each surface point. This method developed by Phong Bui Tuong is called Phong Shading or normal vector Interpolation Shading. It displays more realistic highlights on a surface and greatly reduces the Match-band effect.

A polygon surface is rendered using Phong shading by carrying out the following steps:

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 calculate projected pixel intensities for the surface points.

Interpolation of the surface normal along a polynomial edge between two vertices as shown in fig:

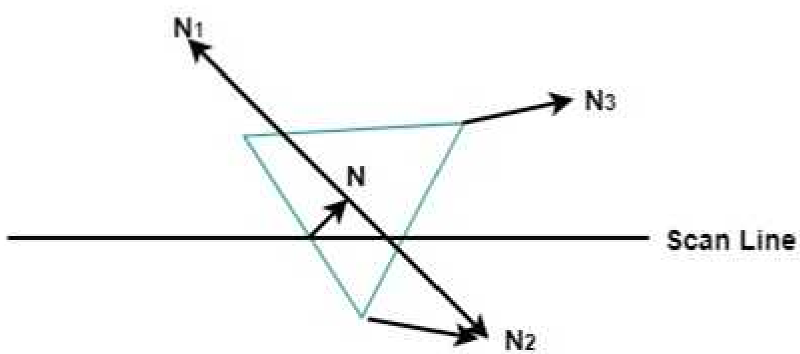



**Fig: Interpolation of surface normals along a polygon edge.**

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

Incremental methods are used to evaluate normals between scan lines and along each scan line. At each pixel position along a scan line, the illumination model is applied to determine the surface intensity at that point.

Intensity calculations using an approximated normal vector at each point along the scan line produce more accurate results than the direct interpolation of intensities, as in Gouraud Shading. The trade-off, however, is that phong shading requires considerably more calculations.