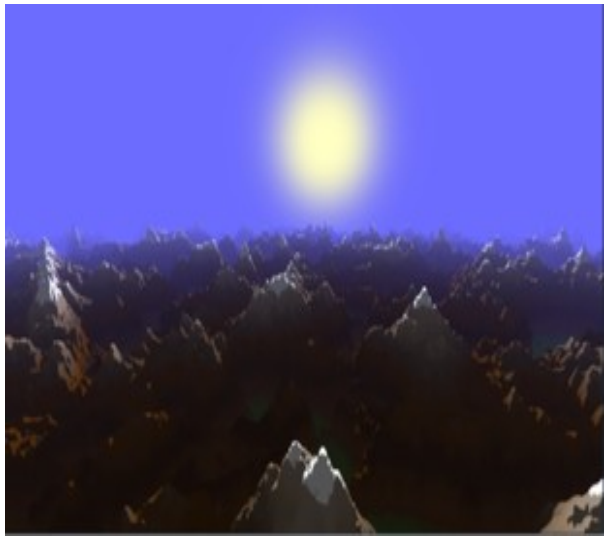
CHAPTER 4 LIGHTING

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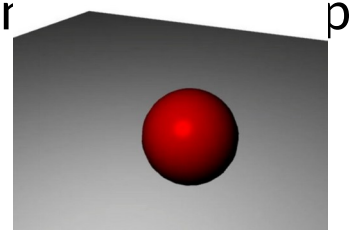
Computer graphics lighting

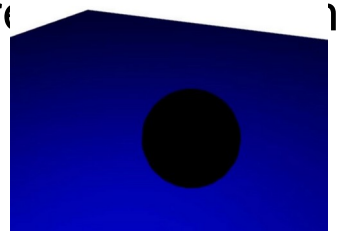
- **Computer graphics lighting** is the collection of techniques used to simulate light in computer graphics scenes.
- While lighting techniques offer flexibility in the level of detail and functionality available, they also operate at different levels of computational demand and complexity .
- A directional light source illuminating a terrain.



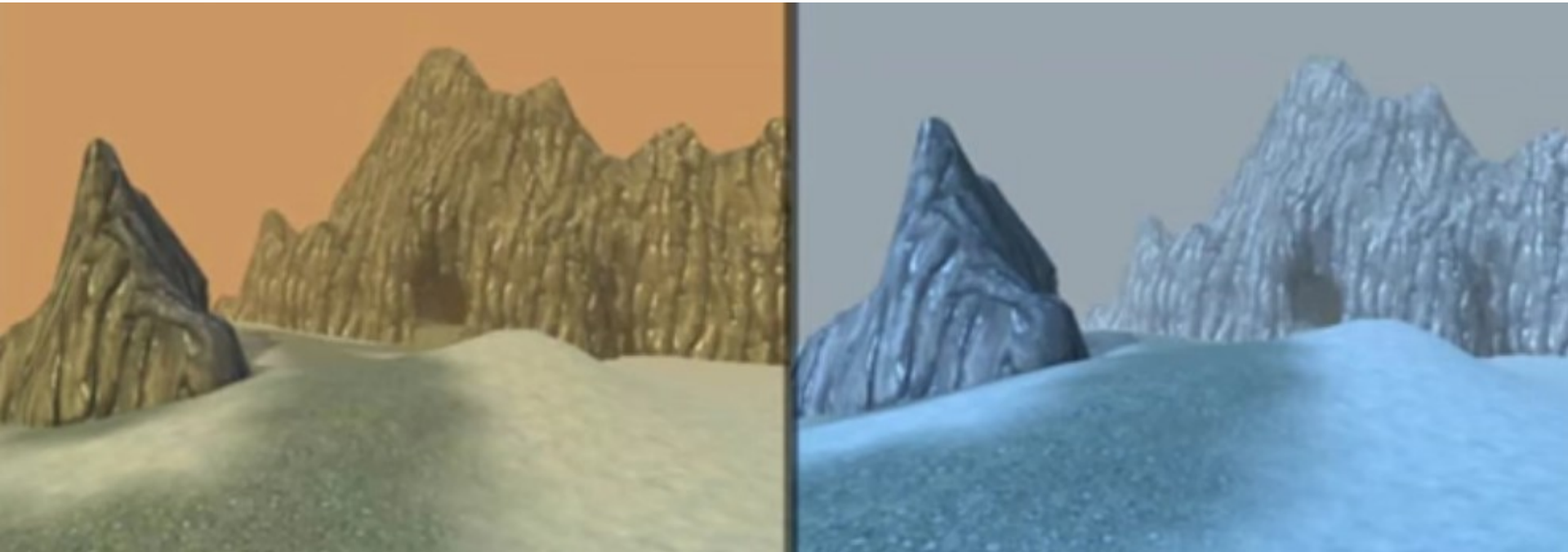
How lighting works in games

- There are many ways to present colours with numbers.
- Using RGB is the simplest form of representation to understand.
- Numbers can be assigned from 0 to 255 to red, green and blue to make colours.
- (0,0,0) is Black, (255,255,255) is white and mixed in between like (18,0,20) is purple, the mixture of all different colours.
- If the white light is shined on a red ball, the ball absorbs all the red light and reflects all the other colours. This is one of basic rules of optics.
- If we shine blue or green light on a red ball it doesn't absorb any of the light. Because there is no red to absorb. So it reflects all of it making appear black.
- This is important to think about in games. Since tinting light can completely char[illegible]pher[illegible]ment.



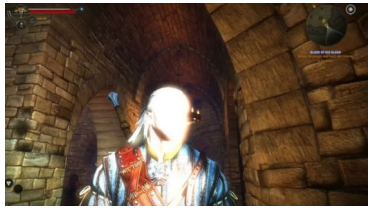


- For example red tint is necessary for desert environment and blue tint is necessary for cold environment to emphasize that atmosphere.



- Next the intensity and filtering of the light has to be considered.
- When making a game with sun as the prime light source, is it quietly illuminating the world below or is it a blind in firy angel comet.
- It can depend whether it should be dramatic or realistic.
- It should be ensured that there is not too much or too little. If it is not so, then it may interfere players experience.
- Besides sunlight there could be indoor light, candles, flash light and so on. But there should be some level realism in stylistic games.










Lambertian equation

- Lambertian simple equation calculates the intensity () of the light reflected by an object.
- = C.I.N.L.cosϴ
- C=color
- I=intensity of light source
- N=normal vector
- L=light vector
- Cosϴ=angle between N and L
- It is the colour times the intensity of the light source times the direction of the light source both applied by the normal vector of an object and the cosine of the angle between them.

Shading and coloring- Cel shading

- **Cel shading** or **toon shading** is a type of non-photorealistic rendering designed to make 3-D computer graphics appear to be flat by using less shading color instead of a shade gradient or tints and shades.
- The cel-shading process starts with a typical 3D model.
- Where cel-shading differs from conventional rendering is in its non-photorealistic illumination model.
- Conventional smooth lighting values are calculated for each pixel and then quantized to a small number of discrete shades to create the characteristic "flat look", where the shadows and highlights appear as blocks of color rather than being smoothly mixed in a gradient.

What are shaders?

- Shaders are the set of instructions to the GPU which is executed all at once for every pixel on the screen.
- A shader is given an input pixel at certain position (x,y) and it returns the new colour(R,G,B) shader transformation for that pixel.
- For example, a shader for all pixels look at RGB value and add some value to blue value to all pixels, this adds **blue tint** to the entire image.
- A gradient can be created by instructing the shader to increase the blue value as the x coordinate of a pixel increases so that less blue is on left and more blue towards right.





Wireframe method

- The term "cel-shading" is popularly used to refer to the application of this "ink" outlining process in animation and games, although originally the term referred to the flat shading technique regardless of whether the outline was applied.
- The Utah teapot rendered using cel shading:

1. The back faces are drawn with thick lines
2. The object faces are drawn using a single color
3. Shading is applied

- Steps 2 and 3 can be combined using multitexturing (part of texture mapping).



Edge-detection method

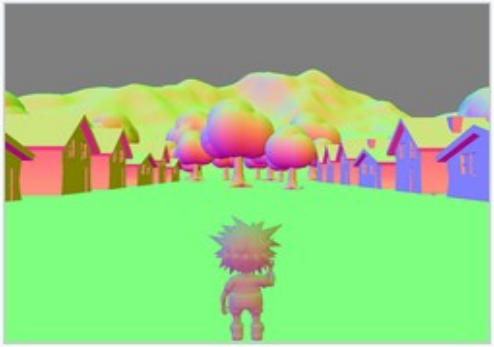
2D image processing outlining technique



First, the scene is rendered with cel shading to a screen-sized color texture.



Then depth-information of the scene is rendered to a screen-sized texture.



World-space surface normals are rendered as a screen-sized texture.

And then...

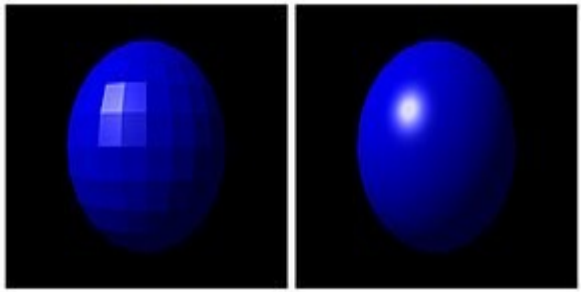


A Sobel filter or similar edge-detection filter is applied to the normal and depth textures to generate an edge texture. Texels on detected edges are black, while all other texels are white.

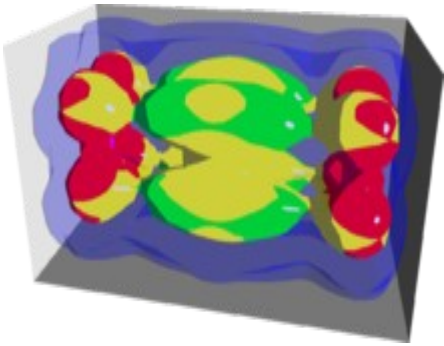


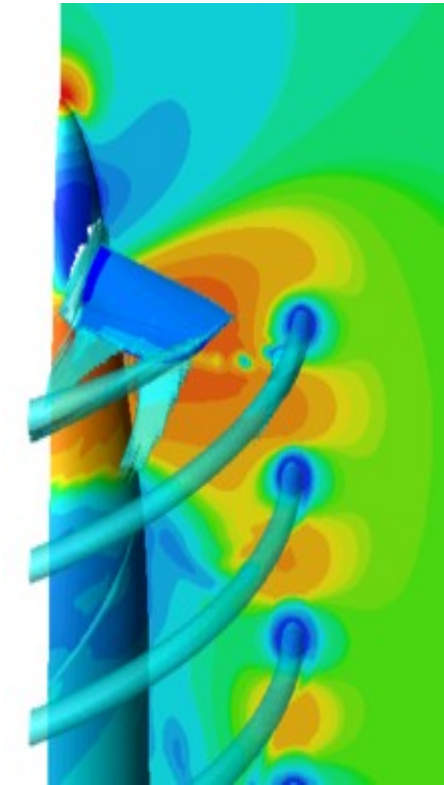
Finally, the edge texture and the color texture are composited to produce the final rendered image.

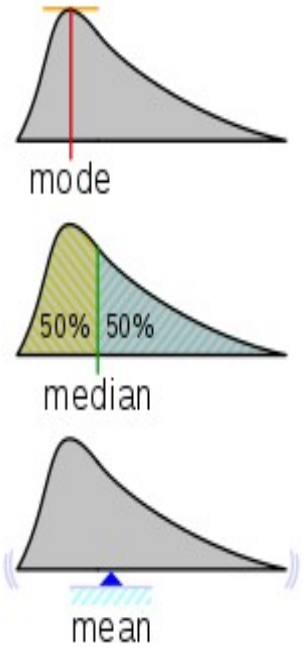
- Shaders are most commonly used to produce lit and shadowed areas in the rendering of 3D models.
- Phong shading (right) is an improvement on Gouraud shading, and was one of the first computer shading models ever developed after the basic flat shader (left), greatly enhancing the appearance of curved surfaces in renders.



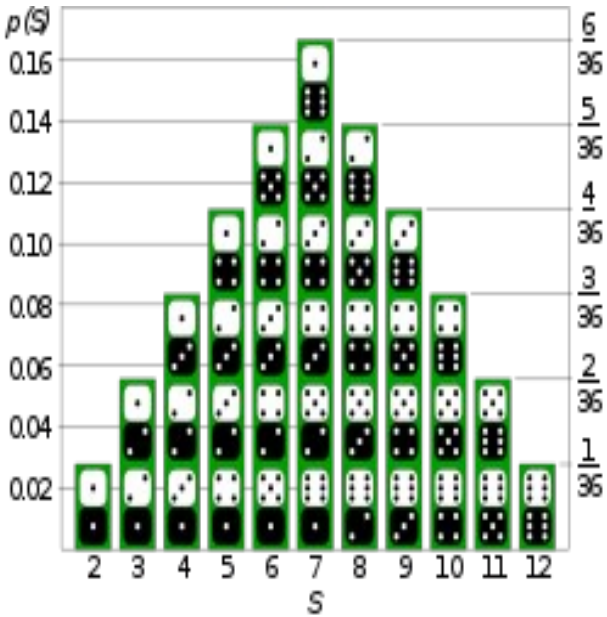
- Cel-shaded rendering of two **isosurfaces** of the **probability density** of a **particle in a box** in top figure.
- An **isosurface** is a three-dimensional analog of an isoline.
- It is a surface that represents points of a constant value within a volume of space; in other words, it is a level set of a continuous function whose domain is 3D-space.
- Isosurface of vorticity trailed from a propeller blade.
- Note that this is an isosurface plotted with a colormapped slice in bottom figure.
- **Vorticity** is a pseudovector field that describes the local spinning motion of a continuum near some point, as would be seen by an observer located at that point and traveling along with the flow.







- A **probability density function** (**PDF**), or **density** of a **continuous random variable**, is a function whose value at any given sample (or point) in the **sample space** (the set of possible values taken by the random variable) can be interpreted as providing a *relative likelihood* that the value of the random variable would equal that sample.
- Geometric visualisation of the mode, median and mean of an arbitrary probability density function
- A **sample space** is usually denoted using set notation, and the possible ordered outcomes are listed as elements in the set.
- The probabilities of rolling several numbers using two dice example is seen in bottom figure.

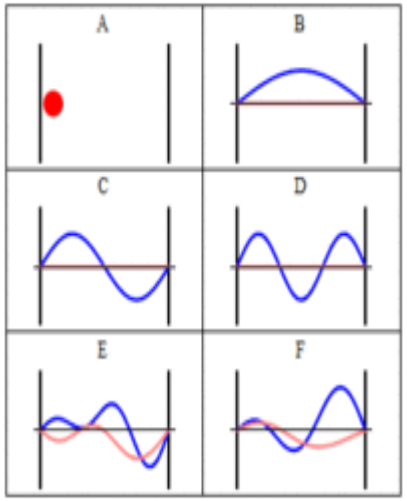


A random variable X has a continuous probability distribution if there is a function $f : \mathbb{R} \to [0, \infty)$ such that for each interval $I \subset \mathbb{R}$ the probability of X belonging to I is given by the integral of f over I For example, if $I = [a, b]$, then we would have:

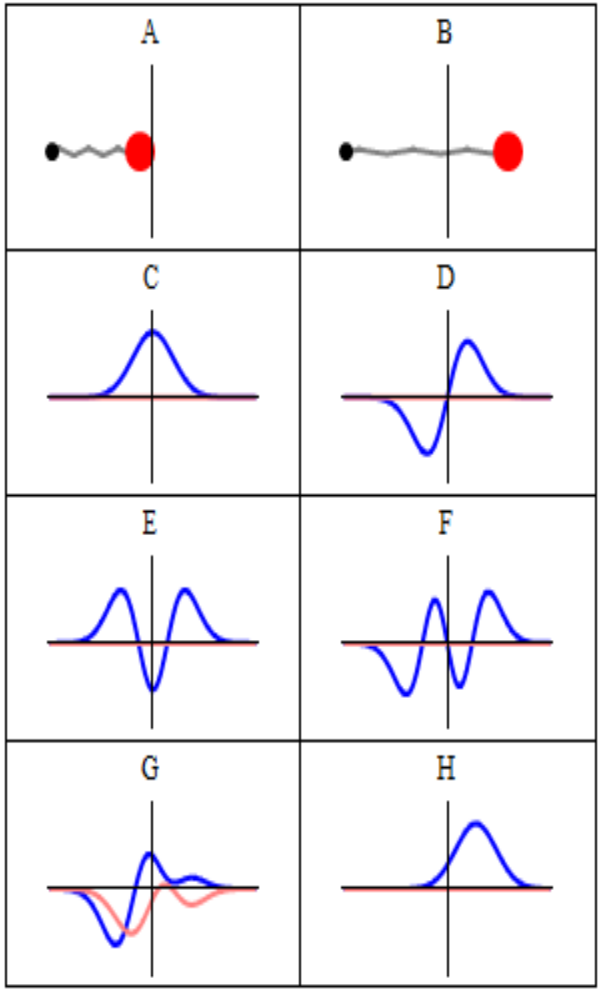
$$\mathrm{P}[a \leq X \leq b] = \int_a^b f(x)\,dx$$

In particular, the probability for X to take any single value a (that is, $a \leq X \leq a$) is zero, because an integral with coinciding upper and lower limits is always equal to zero. A variable that satisfies the above is called **continuous random variable**.

- The **particle in a box** model (also known as the **infinite potential well** or the **infinite square well**) describes a particle free to move in a small space surrounded by impenetrable barriers.
- Some trajectories of a particle in a box according to Newton's laws of classical mechanics (A), and according to the Schrödinger equation of quantum mechanics (B–F).
- In (B–F), the horizontal axis is position, and the vertical axis is the real part (blue) and imaginary part (red) of the wavefunction.
- The states (B,C,D) are energy eigenstates, but (E,F) are not.

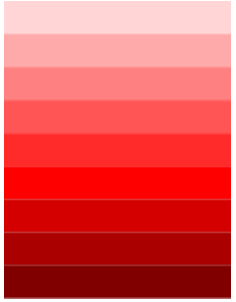


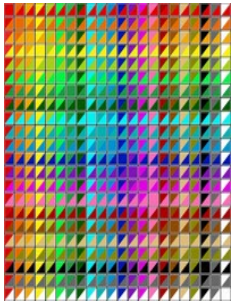
- A **stationary state** is a quantum state with all observables independent of time.
- It is an eigenvector of the Hamiltonian.
- This corresponds to a state with a single definite energy (instead of a quantum superposition of different energies).
- A harmonic oscillator in classical mechanics (A–B) and quantum mechanics (C–H).
- In (A–B), a ball, attached to a spring, oscillates back and forth.
- (C–H) are six solutions to the Schrödinger Equation for this situation.
- The horizontal axis is position, the vertical axis is the real part (blue) or imaginary part (red) of the wavefunction.
- (C,D,E,F), but not (G,H), are **stationary states**, or standing waves. The standing-wave oscillation frequency, times Planck's constant, is the energy of the state.



- A **color gradient** specifies a range of position-dependent colors, usually used to fill a region.
- For example, many window managers allow the screen background to be specified as a gradient.
- The colors produced by a gradient vary continuously with position, producing smooth color transitions.
- A color gradient is also known as a **color ramp** or a **color progression**. In assigning colors to a set of values, a gradient is a continuous colormap, a type of color scheme.
- A linear, or axial, color gradient example is seen in the figure.
- A **window manager** is system software that controls the placement and appearance of windows within a windowing system in a graphical user interface

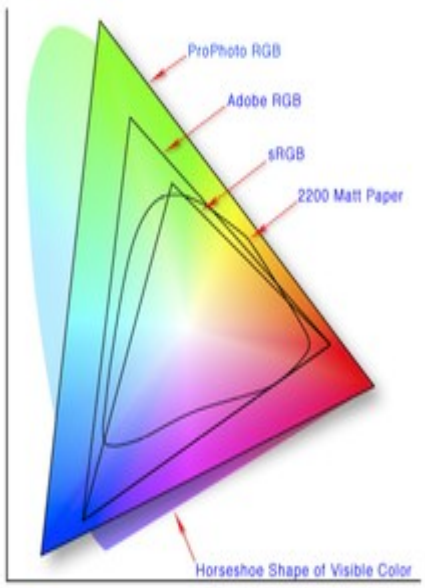


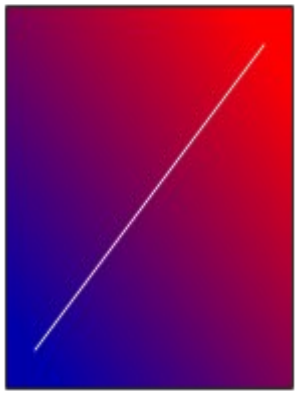




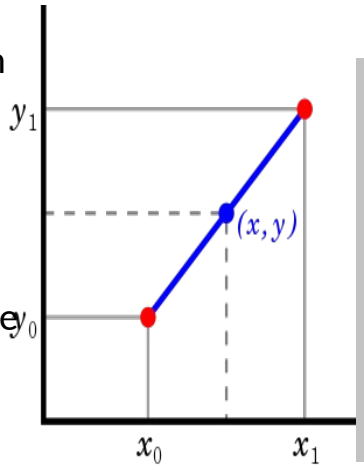
- Example of monochromatic color is in first figure.
- **Monochromatic colors** are all the colors (tints, tones, and shades) of a single hue.
- **Hue** is one of the main properties (called color appearance parameters) of a color, defined technically in the CIECAM02 model as "the degree to which a stimulus can be described as similar to or different from stimuli that are described as red, orange, yellow, green, blue, purple," which in certain theories of color vision are called unique hues.
- Monochromatic color schemes are derived from a single base hue, and extended using its shades, tones and tints (that is, a hue modified by the addition of black, gray (black + white) and white.
- As a result, the energy is more subtle and peaceful due to a lack of contrast of hue.
- Contrasting color combinations such as blue and red create visual vibrations when placed next to each other, while analogous colors such orange and red blend together in second figure.

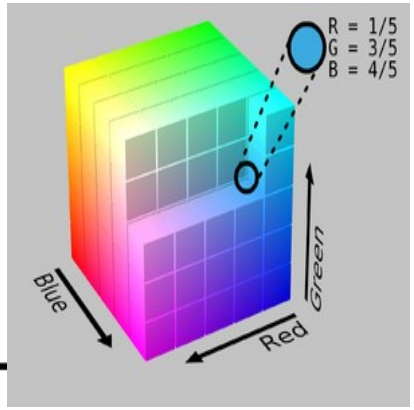
- Color gradient is a set of colors arranged in a **linear order** (ordered)
- Linear order is a binary relation on some set X. A continuous colormap is a curve through a **colorspace**. A **color space** is a specific organization of colors.
- A comparison of the chromaticities enclosed by some color spaces in first figure. An axial color gradient, with a white line segment connecting the two points in second figure.
- An axial color gradient (sometimes also called a linear color gradient) is specified by two points, and a color at each point. The colors along the line through those points are calculated using linear interpolation, then extended perpendicular to that line.
- In digital imaging systems, colors are typically interpolated in an RGB color space, often using gamma compressed RGB color values, as opposed to linear. CSS and SVG both support linear gradients.





- Given the two red points, the blue line is the linear interpolant between the points, and the value *y* at *x* may be found by linear interpolation in first figure.
- An **RGB color space** is any additive color space based on the RGB color model.
- RGB-Cube example is seen in second figure.
- The effect of gamma correction on an image: The original image was taken to varying powers, showing that powers larger than 1 make the shadows darker, while powers smaller than 1 make dark regions lighter.





Gamma correction, or often simply **gamma**, is a nonlinear operation used to encode and decode luminance or tristimulus values in video or still image systems. Gamma correction is, in the simplest cases, defined by the following power-law expression:

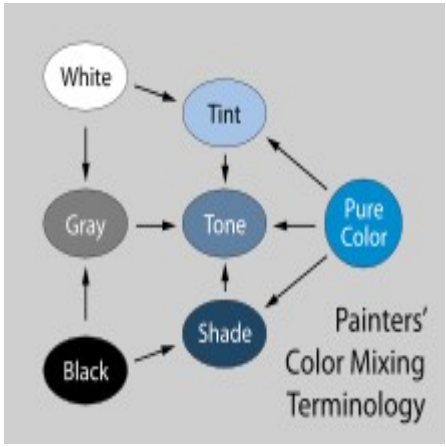
$$V_{\text{out}} = AV_{\text{in}}^{\gamma},$$

where the non-negative real input value V_{in} is raised to the power γ and multiplied by the constant *A* to get the output value V_{out}. In the common case of *A* = 1, inputs and outputs are typically in the range 0–1.

A gamma value $\gamma < 1$ is sometimes called an *encoding gamma*, and the process of encoding with this compressive power-law nonlinearity is called **gamma compression**; conversely a gamma value $\gamma > 1$ is called a *decoding gamma*, and the application of the expansive power-law nonlinearity is called **gamma expansion**.

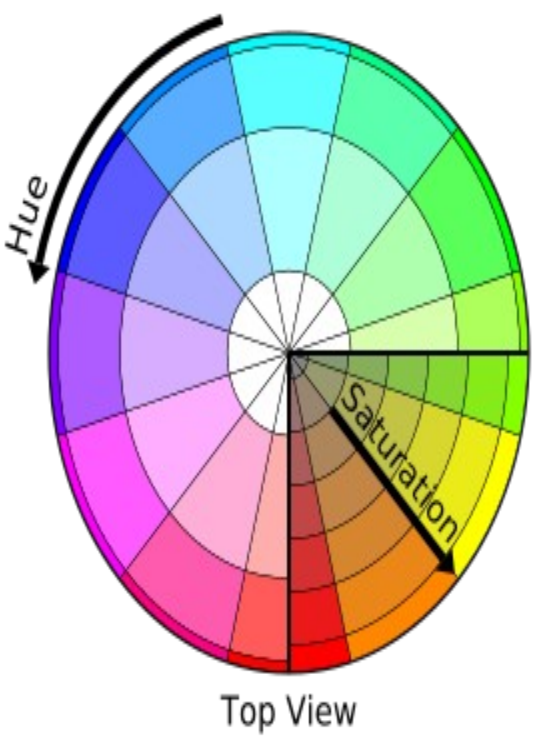


- A **tint** is a mixture of a color with white, which reduces darkness, while a **shade** is a mixture with black, which increases darkness.
- Both processes affect the resulting color mixture's relative saturation.
- A **tone** is produced either by mixing a color with grey, or by both tinting and shading.
- Mixing a color with any neutral color (including black, gray, and white) reduces the chroma, or colorfulness, while the hue (the relative mixture of red, yellow, green, etc. depending on the colorspace) remains unchanged.
- Some tints and shades of blue is shown.

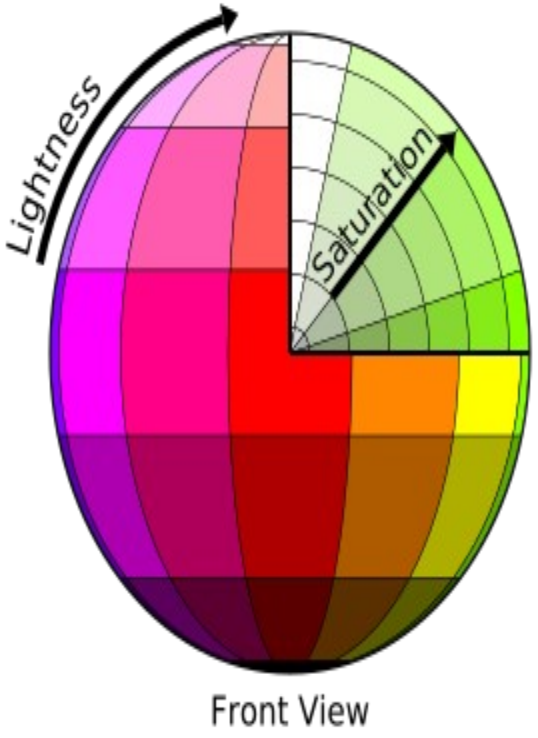




- An extension of the color wheel: the color sphere. Colors nearest the center or the poles are most *achromatic*.
- Colors of the same lightness and saturation, but of different hue, are called *nuances*.
- Colors of the same hue and saturation, but of different lightness, are called *tints* and *shades*.
- Colors of the same hue and lightness, but of different saturation, are called *tones*.



Top View



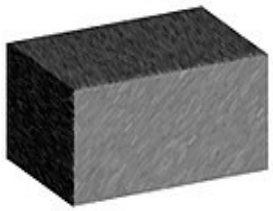
Front View

Surface shading algorithms

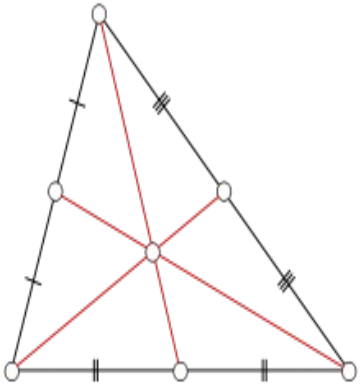
- Popular surface shading algorithms in 3D computer graphics include:
- Flat shading: a technique that shades each polygon of an object based on the polygon's "normal" and the position and intensity of a light source
- Gouraud shading: a fast and resource-conscious vertex shading technique used to simulate smoothly shaded surfaces
- Phong shading: used to simulate specular highlights and smooth shaded surfaces

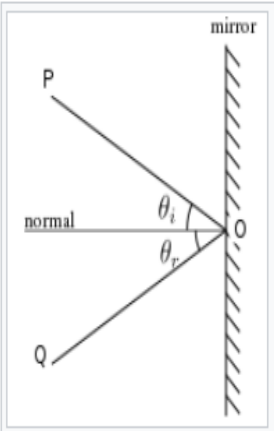
Flat shading

- Here, the lighting is evaluated only once for each polygon (usually for the first vertex in the polygon, but sometimes for the **centroid** for triangle meshes), based on the polygon's surface normal and on the assumption that all polygons are flat.
- The computed color is used for the whole polygon, making the corners look sharp.
- This is usually used when more advanced shading techniques are too computationally expensive.
- Specular highlights are rendered poorly with flat shading: If there happens to be a large specular component at the representative vertex, that brightness is drawn uniformly over the entire face.
- If a **specular** highlight doesn't fall on the representative point, it is missed entirely.
- Consequently, the specular reflection component is usually not included in flat shading computation.



- The **centroid** or geometric center of a plane figure is the arithmetic mean position of all the points in the figure.
- Informally, it is the point at which a cutout of the shape could be perfectly balanced on the tip of a pin.
- The definition extends to any object in n-dimensional space: its centroid is the mean position of all the points in all of the coordinate directions.
- **Specular** reflection, or regular reflection, is the mirror-like reflection of waves, such as light, from a surface.





Coplanar condition of specular reflection, in which $\theta_i = \theta_r$.

Smooth shading-Gouraud shading

Smooth shading

- In contrast to flat shading where the colors change discontinuously at polygon borders, with smooth shading the color changes from pixel to pixel, resulting in a smooth color transition between two adjacent polygons.
- Usually, values are first calculated in the vertices and bilinear interpolation is used to calculate the values of pixels between the vertices of the polygons.
- Types of smooth shading include Gouraud shading and Phong shading.

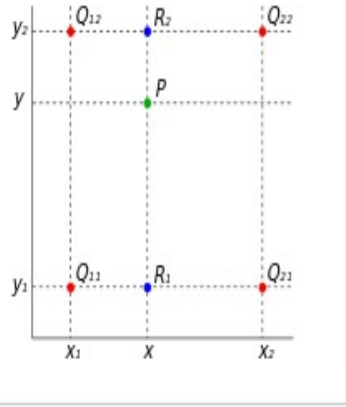
Gouraud shading

- Determine the normal at each polygon vertex.
- Apply an **illumination** model to each vertex to calculate the light intensity from the vertex normal.
- Interpolate the vertex intensities using **bilinear** interpolation over the surface polygon.

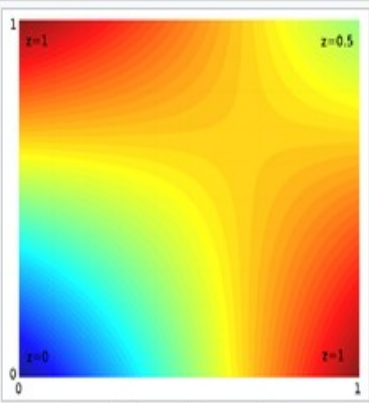
Problems:

- Due to lighting being computed only at vertices, the inaccuracies (especially of specular highlights on large triangles) can become too apparent.
- T-junctions with adjoining polygons can sometimes result in visual anomalies.
- In general, T-junctions should be avoided.

- The **illumination** models listed here attempt to model the perceived brightness of a surface or a component of the brightness in a way that looks realistic. Some take physical aspects into consideration, like for example the Fresnel equations, microfacets, the rendering equation and subsurface scattering.
- **Bilinear interpolation** is an extension of linear interpolation for interpolating functions of two variables (e.g., x and y) on a rectilinear 2D grid.
- Bilinear interpolation is performed using linear interpolation first in one direction, and then again in the other direction. Although each step is linear in the sampled values and in the position, the interpolation as a whole is not linear but rather quadratic in the sample location.
- Bilinear interpolation is one of the basic resampling techniques in computer vision and image processing, where it is also called bilinear filtering or bilinear texture mapping.



The four red dots show the data points and the green dot is the point at which we want to interpolate.



Example of bilinear interpolation on the unit square with the *z* values 0, 1, 1 and 0.5 as indicated. Interpolated values in between represented by color.