cs676: Lecture 5: Light and Color

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Note: This lecture note includes figures from lecture slides by Steve Seitz, Derek Hoiem, James Hays, Jitendra Malik, Kristen Grauman

1 Introduction

In the previous class we discussed the geometric issues for image formation. Now we look at photometric issues related to image formation. An image is obtained based on two things, the amount of light incident at the camera (the intensity) and the wavelength of light (denoting the color). In this note, we analyse these quantities in some detail.

2 Radiance

Light is obtained from an illumination source and reflected from an object. The reflected light is incident on the camera and captured through the lens onto the image plane. The amount of light that is incident depends on the reflection model. This is illustrated in figure 1

The way a pixel gets its value is based on the incident light that is reflected from a surface. This is shown in figure 2

There are two main models for reflection, diffuse reflection and specular reflection.

In diffuse reflection, the incident light is uniformly diffused into all directions. This model is called Lambertian model [1] Dull, matte surfaces such as chalk exhibit diffuse reflection. These surfaces appear equally bright from all viewing angles because they reflect light with equal intensity in all directions. The brightness depends only on the angle θ between the light source direction and the surface normal. If the light source is incident on the surface with angle θ then the amount of surface covered by a beam of light that has an infinitesimally small area dA is $dA/\cos\theta$. Therefore the amount of light energy that falls on the surface is proportional to θ.

For the viewer, the amount of light reflected from a unit differential area dA towards the viewer is proportional to $\cos\alpha$, where α is the angle between the surface normal and the viewer. However, the surface area seen is inversely proportional to $\cos\alpha$, therefore the terms cancel and the amount of light seen is independent of the viewer's direction and is only proportional to $\cos\theta$

The diffuse illumination equation is then

$$I = I_p k_d \cos\theta \tag{1}$$

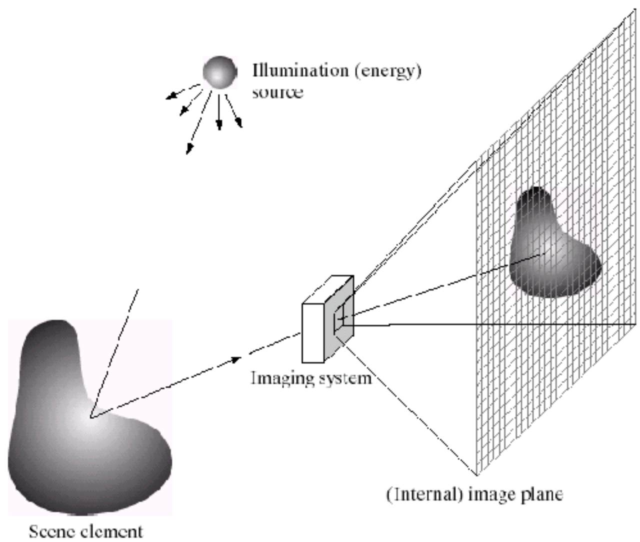

Fig. 1. Imaging of a scene

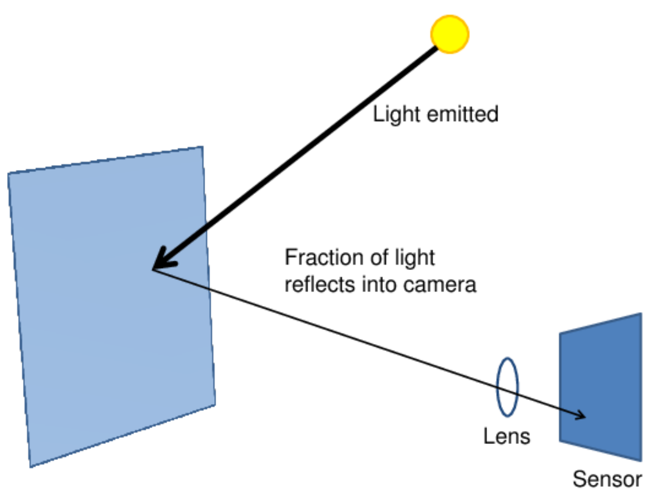

Fig. 2. How does a pixel get its value?

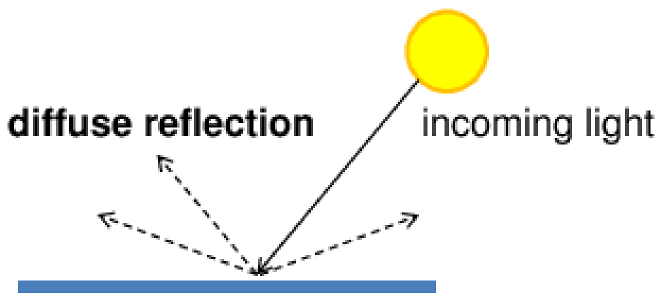

Fig. 3. Diffuse Reflection

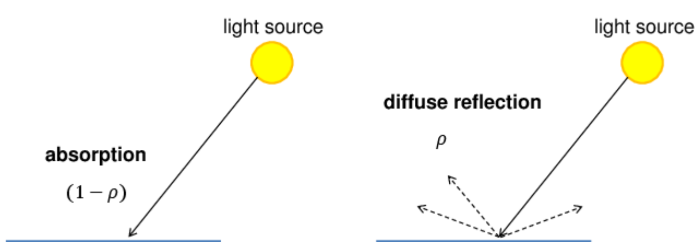

Fig. 4. Lambertian Reflection

where I_p is the point light source's intensity, the material's diffuse reflection coefficient is between 0 and 1.

Assuming normalized vectors this can be given by

$$I = I_p k_d (\bar{N} \cdot \bar{L}) \tag{2}$$

In specular reflection, the incident light is reflected in a direction opposite to the angle of incidence. This reflection model is called the Phong model [1]. In this model, the amount of light specularly reflected is given by

$$I = k_s \left(\bar{R} \cdot \bar{V}\right)^n \tag{3}$$

where $\bar{R}$ is the reflection vector that is symmetric about the normal of the surface with the incident illumination vector. $\bar{V}$ is the vector in the direction of the viewer or camera. k_s is the specular reflection coefficient and n denotes the specular reflection fall-off. The more specular a surface is, higher is the fall-off and the n is then higher.

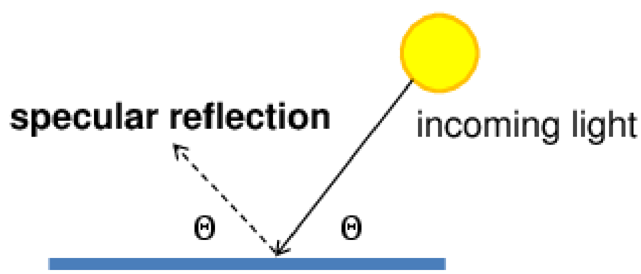

Fig. 5. Specular

In the real world, the reflection model is more diverse. The complete model is termed a Bidirectional reflectance distribution function (BRDF). This is a 4 dimensional function that relates incoming light to the outgoing light. It measures the ratio of the outgoing radiance of the light I_r to the incoming irradiance of light E_i.

The incoming irradiance of light is given by

$$E_i = I_i (\bar{N} \cdot \bar{L}) d\omega_i \tag{4}$$

Here $d\omega_i$ is the solid angle subtended by the incoming radiance. In principle this measures the total flux incident on the surface per unit area and is measured by measuring the flux that is incoming over a conical section that measures the incoming light.

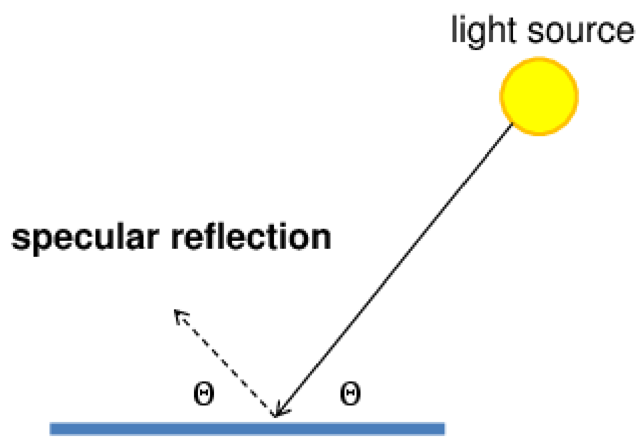

Fig. 6. Specular

The BRDF is then given by

$$\rho = \frac{I_r}{E_i} \tag{5}$$

This is measured over the hemisphere over the surface.

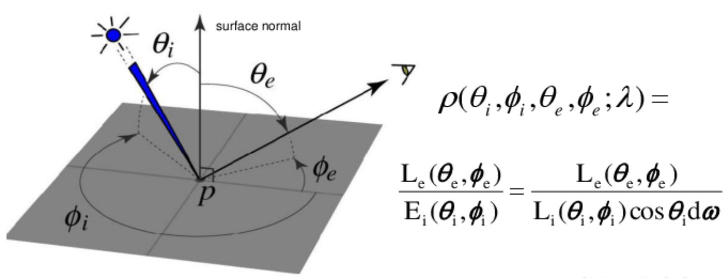

Fig. 7. Bidirectional Reflectance Distribution function

So far we have considered reflection. Other possibilities for light interaction with surface are refraction, transparency, fluoresence, phosporescence, subsurface scattering, total internal reflection.

If the light interacts with a medium having refraction index n_1, into a medium having refractive index n_2, then it bends based on the angle given by Snell's law, i.e.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} \tag{6}$$

Similarly we have the phenomenon such as transparency, where light passes through a medium. We obtain fluoresence and phosporescence when light is emitted by an object. If light is incident at an object boundary and the angle of incidence is greater than a critical angle then total internal reflection occurs, i.e. the light is reflected internally.

Another case that occurs is subsurface scattering as shown in figure 10. In this phenomenon, the light travels into the surface and scatters within the surface and is emitted through some other point after travelling through the subsurface. This is applicable for materials like human skin and milk

For the purposes of the course, we will be interested more in reflection rather than the other interactions of light.

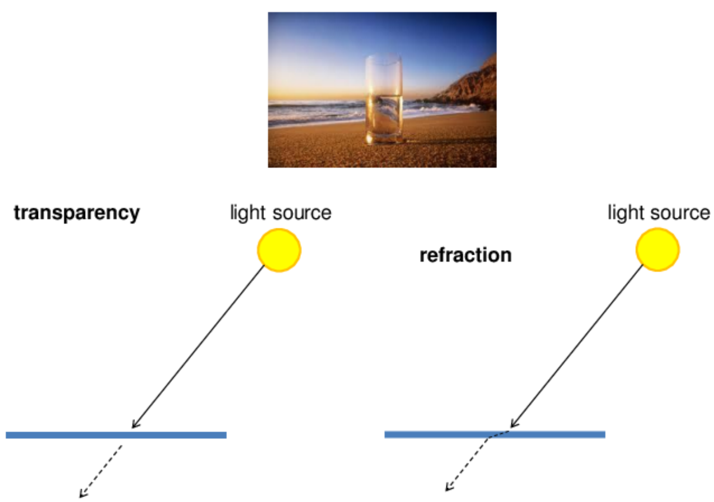

Fig. 8. Refraction and Transparency

The reflection of light is used for recreating depth through techniques such as photometric stereo. In this method, the object and camera are stationary. But, light source is moved. The different observations obtained as a result can be used for estimating depth of an object.

We need to consider the behaviour of light also for other tasks such as tracking or recognition in order to robustly track or recognize entities.

Similarly, we have so far considered the the illumination sources to be point light sources. However, there are other sources such as directional sources of light and ambient light sources Together, the light sources, the surface reflectance

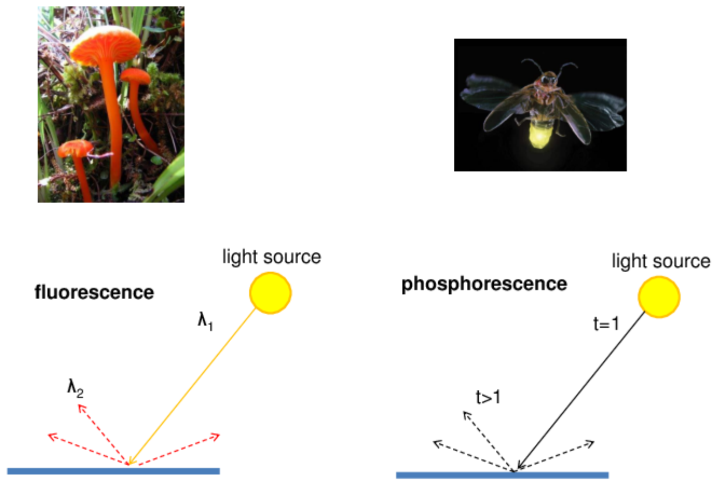

Fig. 9. Fluoresence and Phosporesence

model of the surfaces determine the amount of light being incident on the image plane.

3 Color

Once, the light is incident on the image plane, the color of the light is determined by the wavelength and the sensitivity of the imaging elements to particular wavelengths of light. The light is composed of a broad spectrum of wavelengths as shown in figure 11. The particular wavelength determines the color and the intensity determines its value. We show examples of different wavelengths of light emitted by different light sources in figure 12. In figure 13 we show the reflected light wavelengths by different materials.

The color of the light is affected both by the spectral radiance of the illuminant and by the spectral reflectance of the surface.

One question that arises is if light is a broad spectrum of many different wavelengths why the preponderance towards the colors red, green and blue. This is explained on the basis that humans have specific color receptors that are sensitive to these colors as shown in figure 16.

In order to represent the color there exist various color spaces. The CIE color space is one such standardized color space, where the color is generated by linear combination of 3 primary colors. Similarly we have RGB color space. These are linear color space. However, the arrangement of color in these spaces are not so intuitive. So, we therefore have other color spaces such as HSV color space that are more intuitive in terms of arrangement of colors. Other color spaces include

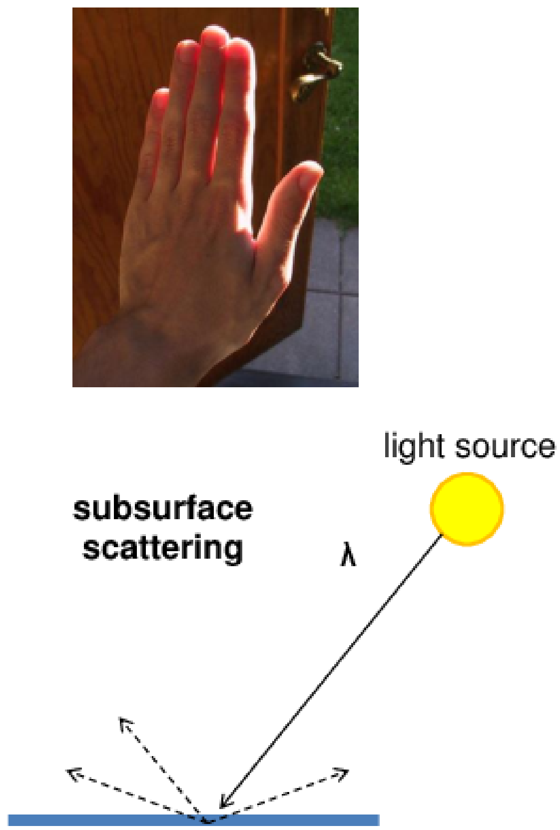

Fig. 10. Subsurface scattering

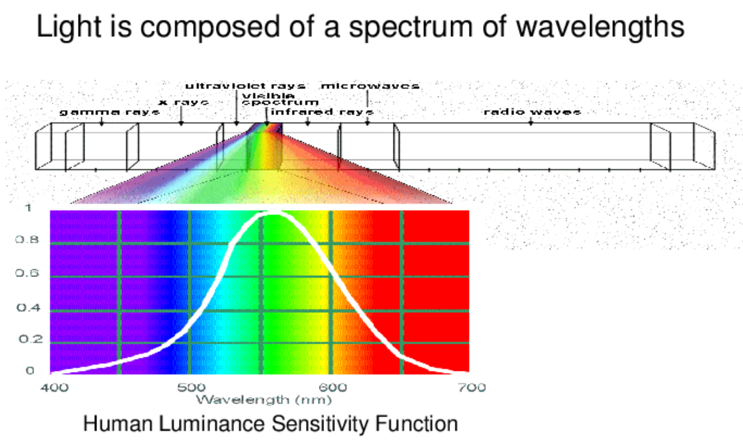

Fig. 11. Color spectrum

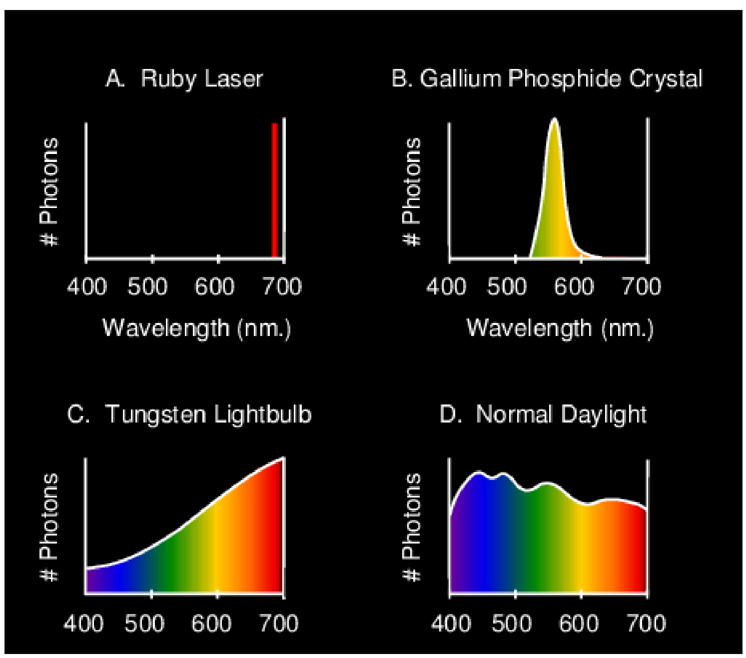

Fig. 12. Wavelengths corresponding to specific colors for different sources of light

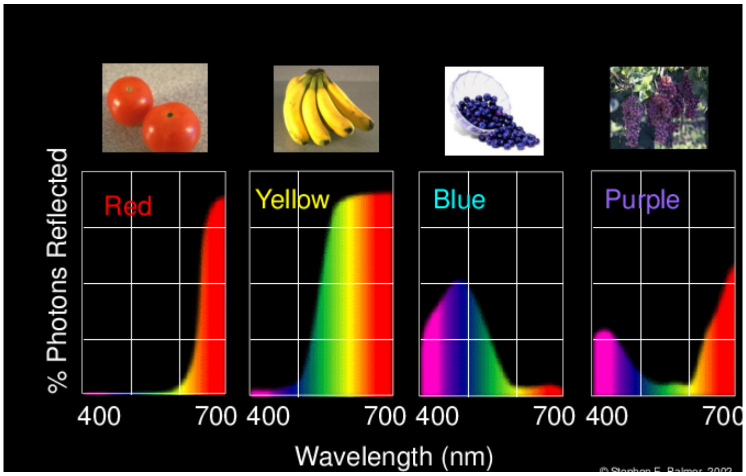

Fig. 13. Wavelengths corresponding to different reflection properties

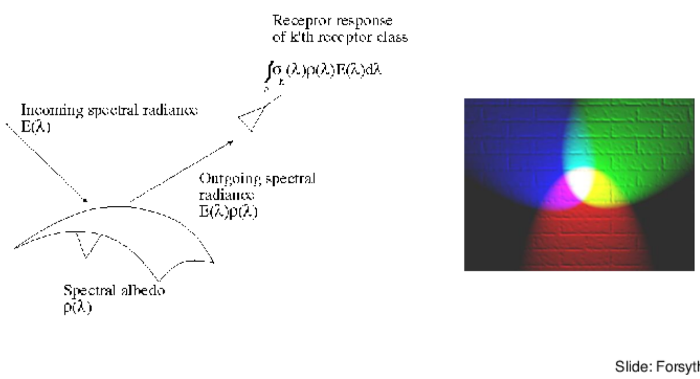

Fig. 14. Dependence of color on illumination

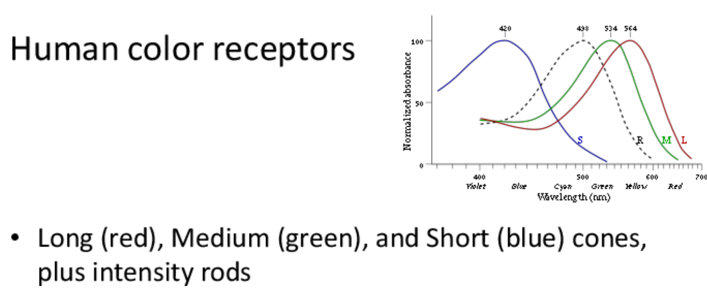

Fig. 15. Human receptors

spaces like YCbCr that are used in image and video compression where the Y channel corresponds to the gray scale image and Cb and Cr channels have the color values that are stored in half the resolution of the gray scale image.

References

1. Foley, J.D., van Dam, A., Feiner, S.K., Hughes, J.F.: Computer Graphics: Principles and Practice (2Nd Ed.). Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA (1990)

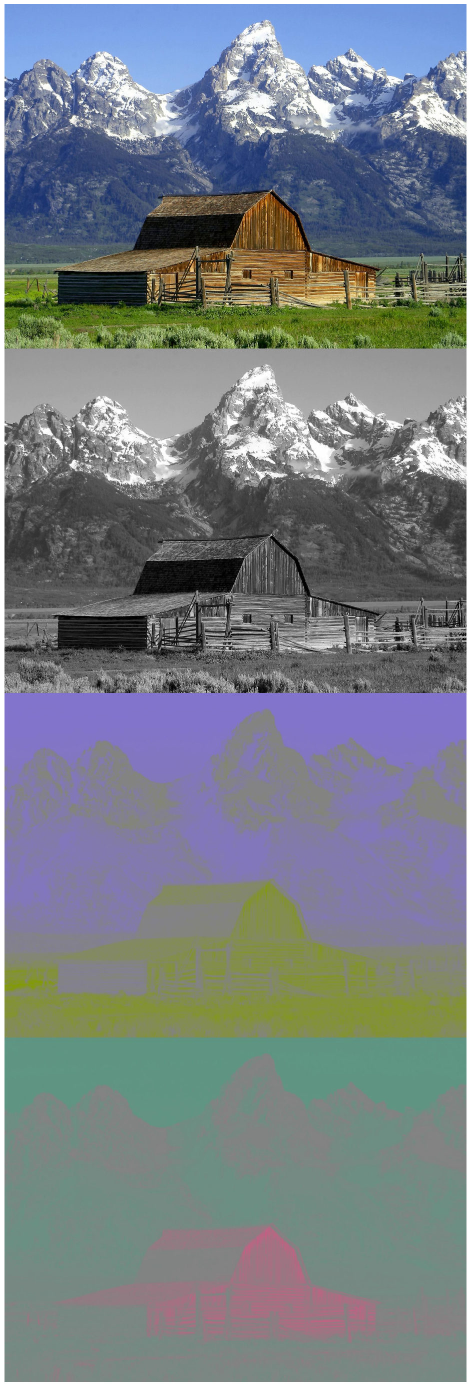

Fig. 16. Example decomposition of image in YCbCr color space