

Chapter 2

Optical Information

Our visual perception depends heavily on three factors: (a) light, (b) its interaction with surface and (c) human visual system that observes the light. In this chapter we would talk about light and its geometrical and optical interaction when interacting with surfaces. This will help us to study the optical information received by our eyes. According to the theory of optics, light consists of small packets of energy called *photons* that behave like particles in some respects and like waves in certain respects. The wavelength of the photons are important for color sensation, but for all other purpose we will be concerned with the particle properties of light.

The photons radiate outward from a *source* – some hot body like sun or a lamp. They travel in straight lines at a speed of 186,000 miles per second speed. When they strike a object, the object is said to be illuminated. Thus, illumination is due to light sources and defines the lighting condition of the environment. A *point light source* is one where the light is radiated from one single point. This kinds of light sources are almost always not found in real-life. However, if a clear light source is far away, it can be considered as a point light source. Point sources produces sharp well defined shadows and strong shading effects on the surface itself. In real life, we usually encounter a *diffused light source*, where the light radiates from a relatively larger region of space. For these kind of sources, both the shadows and the shading effects are blurred and weaker with no sharp edges.

When light hits a surface, the surface reflects, absorbs and transmits light in different proportions. If the light is reflected equally in all directions that gives the surface a matte look. These are called *diffused* or Lambertian surfaces. If the light is reflected more in few directions than others, then the surface looks *specular*. Since the light reaching the viewer from a diffused surface is same at all locations around the surface, such surfaces look same from any view direction. Thus how they look is *view independent*. On the other hand, the light reaching a viewer from a specular surface varies at different view direction. Thus, how they look is *view dependent*.

Most surfaces reflect some light unless they are black that absorbs all light. The light reflected from these surfaces can illuminate some other surface. Then, these surfaces also act like a sources that causes illumination. Thus, such surfaces are called *secondary light sources*. Thus, the light actually gets reflected from many surfaces before it actually gets absorbed. The final effect of all these is that light is reverberating in all directions filling the scene around us with light from all different directions. This is very important for vision. Since different amount of light comes from different direction, we are able to see different shapes and surfaces. Same amount of light from all direction around us would create a gray fog called *Ganzfeld* effect.

The pioneering perception psychologist, J. J. Gibson defined the optical information that is available to the eye by what he called *ambient optic array* (or AOA). This is defined as the structured pattern of light reaching the viewer from all possible directions. It is called ‘ambient’ since the observer is literally surrounded by light from all directions. Figure 2 shows an example of ambient optic array and how it changes as the viewpoint of the viewer is changed. The change in optic array as the viewer moves defines an *optic flow* which is important for different kinds of perception as we will see later in the course.

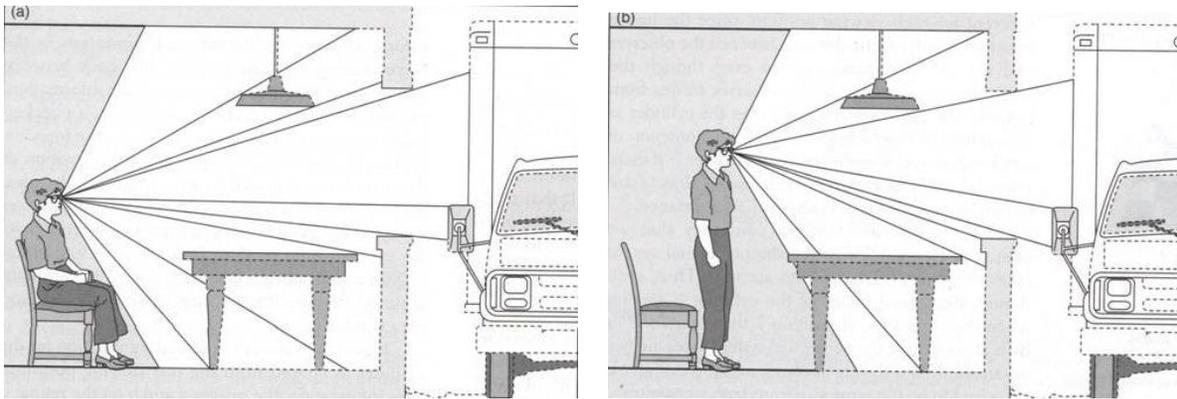


Figure 2.1: The Ambient Optic Array (AOA) is the structured pattern of light reaching the observer’s eye from the environment. The surfaces that are visible to the observer are shown by solid lines and the surfaces that are invisible are shown by dotted lines. (a) The observer is sitting. (b) The AOA changes as the viewpoint changes when the observer stands up.

2.1 Optical Images

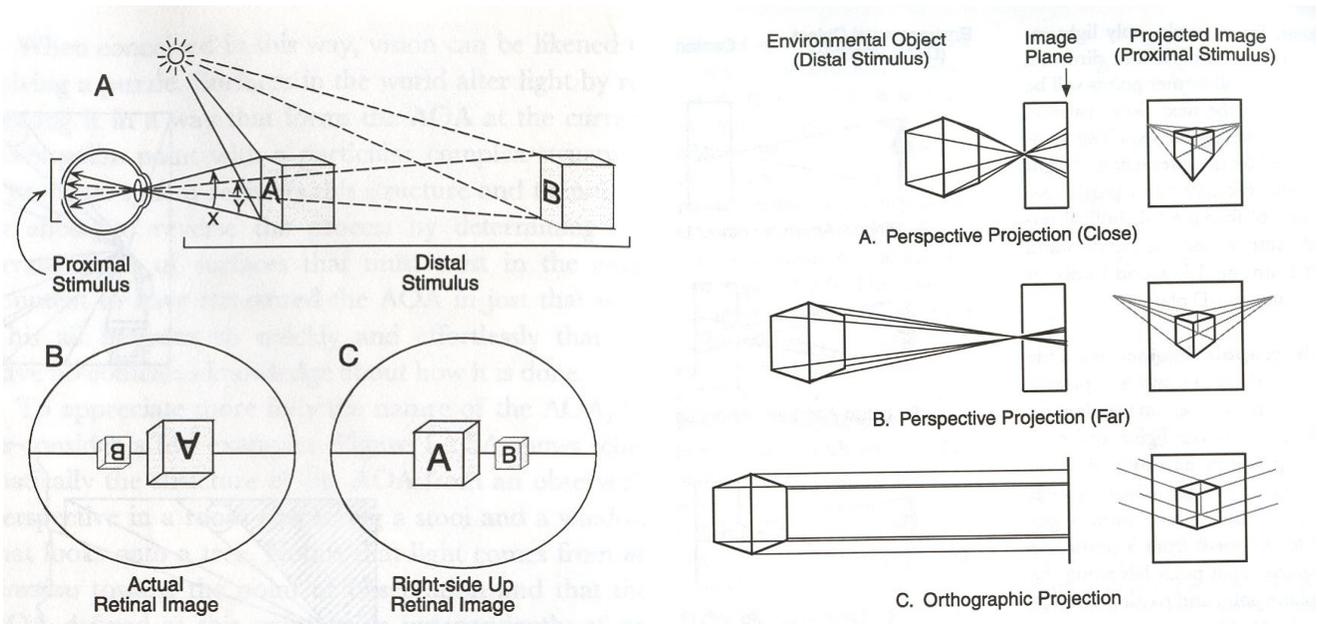


Figure 2.2: Left: Image formation and the size distance relationship. Right: Projective geometry.

In this section, we study the image projected on the retina of the eye to study what kind of information it provides us about the surrounding environment. The 3D world around us is illuminated with light which enter our eye in straight line to form an image on the retina. This situation is illustrated in the Figure 2.1. This forms a two dimensional upside-down image on the retina of the eye. The object of the external world whose image is formed on the eye is called *distal stimulus* (meaning distant from the observer, and the optical image of this object on the retina is called the *proximal stimulus* (meaning close to the observer). The size of an object’s image in the eye is specified by the *visual angle*, the number of degrees subtended by the image from the extremes to the focal point of

the eye. Thus, objects that are closer to the eye subtend higher visual angle and objects that are far away subtend smaller visual angles. The most important point in this image formation lies in understanding that the image of the 3D world is 2D in the retina of the eye. Thus, spatial information is lost while going from three to two dimension of the eye. The depth is lost and that needs to be reconstructed by the human perceptual process. Also, note the light that reaches the eye from any direction comes from the closest object in that direction. Photons from occluded surfaces do not reach the eye. Thus, information about these occluded surfaces also needs to be reconstructed.

The mathematics that guides the formation of 2D images of the 3D world is called *projective geometry*. The first way to form 2D images of 3D world is to use the model of a *pinhole camera*. A pinhole is placed at some distance in front of the image plane. Since light travels in straight lines, the light falling at each point of the image plane of the pinhole camera got there by being reflected from some point in the environment. This gives the basic situation of *perspective geometry*: the process of image formation where light converges towards a single focal point. However, to get a crisp pinhole image the hole must be less than 0.4 mm in size. Because of this small *aperture size*, very little light enters the hole making a low intensity image. If the aperture size is increased to alleviate the situation, the images become blurred. So, a *convex lens* is usually used that collects the light and brings it to focus at the image plane. As we will see later in this chapter, the human eye contains a lens to achieve this virtual pinhole camera model.

This model of perspective projection, though correct, is often complex. So, often visual theorists employ *orthographic projection* where the image is formed by rays travelling parallel to each other and perpendicular to the image plane. The simplified images thus formed ignore depth, but the spatial information is preserved. As an object goes farther and farther away from the eye, the rays from it get closer and closer to parallel. Hence, the images formed by perspective projection come close to the images formed by orthographic projection. Ideally, if the object is at infinity, the images formed by these two are identical. The important difference is that the perspective image of an object at infinity is a point, whereas its orthographic projection results in a spatially extended image. These are illustrated in Figure 2.1.

2.2 The Inverse Problem of Vision

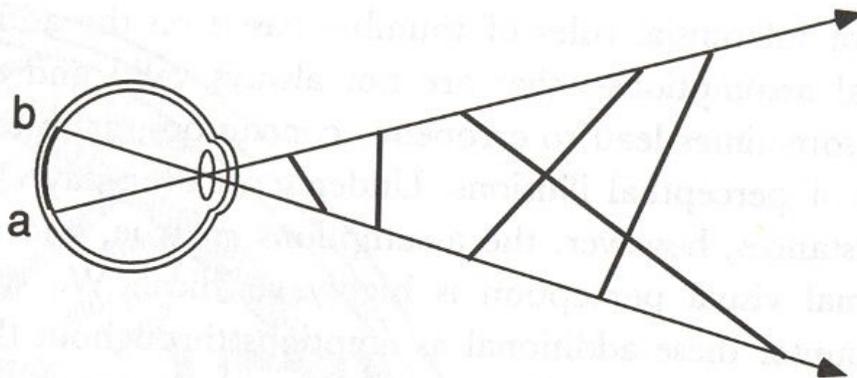


Figure 2.3: An illustration of the inverse projection. The line ab on the retina can be the projection of an infinite set of lines in the environment depending on the actual 3D depths of the points projected at a and b .

The mathematics of projective geometry is well developed and well studied. This forms the basis for the field of *computer graphics*. However, the early stages of visual perception try to solve just the *inverse problem* of

deciphering the 3D world from its 2D images. In projective geometry, the projection of a 3D point in the 2D image *uniquely*. However, more than one point can get projected from the 3D world on to the *same* 2D location. This is illustrated in Figure 2.3. All the points on the ray joining the focal point to an any 3D point can be projected to the same 2D point. Thus, there is not enough information in a 2D image to decide the depth of the point on this ray that is actually imaged.

However, our visual perception seems to do a very good job of solving this inverse problem. As we will see later in this course, this is possible because visual perception makes some assumptions that constrains the underdetermined inverse problem making it solvable. These assumptions are based on highly plausible assumptions in our regular environments. Thus visual perception is a *heuristic process* and can be fooled if these plausible situations do not occur.

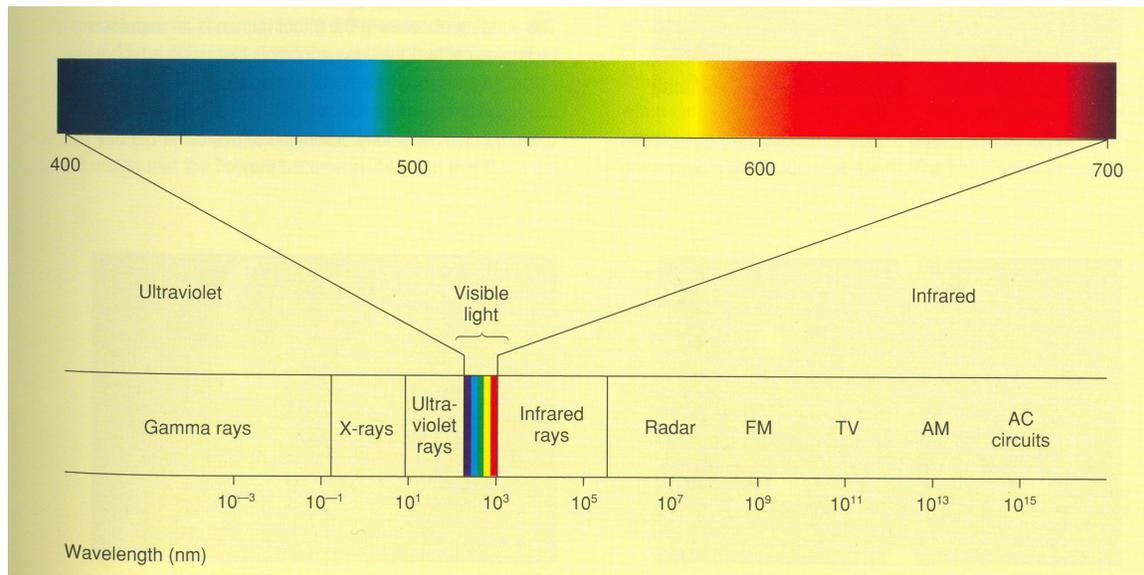


Figure 2.4: The electromagnetic spectrum of light.

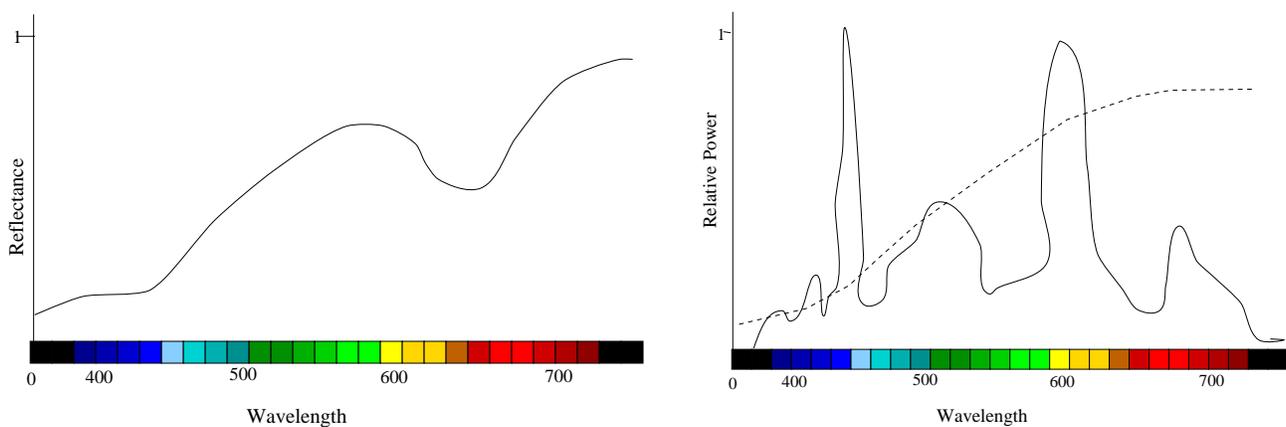


Figure 2.5: Left: Spectrum of light reflected from a red object. Right: Spectrum of a fluorescent (solid line) and a tungsten (dashed line) light sources.

2.3 The Light Spectrum

Till now we were describing the geometric properties of light. Another important property of light, especially for color vision, is its electromagnetic spectrum. The *electromagnetic spectrum* is a continuum of electromagnetic energy produced by electric charges that is radiated as waves. The energy in this spectrum can be described by its *wavelength*. These wavelengths range from extremely short ones (gamma rays with wavelength of 10^{-12} meters) to extremely long ones (radio waves with wavelength of 10^4). Amongst this, the humans can perceive wavelengths of 400 to 700 nanometer (10^{-9}). Thus, this forms the *visible* spectrum of light for human beings as shown in Figure 2.4.

The light that our eye receives has different amounts of different wavelengths and hence forms the sensation of color. Equal amount of light at all wavelengths gives achromatic color. Figure 2.5 shows the spectrum of the light reflected from an object and reaching our eye. Note that this particular object reflects more light in the higher wavelength region and hence is red in color. Similarly the color of any light source can also be defined by its spectrum. Figure 2.5 shows the spectrum for two such light sources. One is the fluorescent light and the other is that of a tungsten lamp. Note that their respective whitish and reddish colors are evident from the spectrum.