Materials and Cameras 8

CS184: Computer Graphics and Imaging

March, 2022

1 Cameras and Lenses

1.1 Terminology

When dealing with cameras and lenses, it is easy to get bogged down by the various terms and mix up how they all relate to one another. Some have direct relationships, while others have inverse relationships, and so on. Let's start by defining the terminology that we commonly use when talking about cameras and lenses.

1. Briefly define each of the following terms in your own words. Where applicable, also draw an accompanying diagram to help explain the concept.

   (a) Focal length

   (b) Field of view

   (c) Exposure

   (d) Shutter speed

   (e) Aperture

   (f) F-stop

   (g) Circle of confusion

   (h) Depth of field

Solution:

(a) Focal length: the distance between the center of a lens and the point at which parallel light rays from infinity at brought into focus

(b) Field of view: the extent of the scene that is visible to the camera's sensor, measured as an angle

(c) Exposure: determines how light or dark an image will appear and is determined by three settings: aperture size, shutter speed, and ISO (gain)

(d) Shutter speed: how quickly the shutter opens and closes for the sensor to capture light; the reciprocal of the how long the shutter is open for during a capture

(e) Aperture: the size of the opening through which light enters the camera and hits the sensor or film

(f) F-stop: the ratio between the focal length and aperture size for a given camera configuration

(g) Circle of confusion: a spot caused by a cone of incoming light rays from a lens that do not come into perfect focus; the less in focus, the larger the circle of confusion

(h) Depth of field: the range of depths that are in focus for a given camera configuration (e.g. the farthest depth in focus - the closest depth in focus)

1.2 Configurations and Effects

1. Assuming focal length is the distance between the sensor and lens, how are focal length and field of view related? For a fixed sensor size, how does increasing focal length affect field of view?

   Solution: Focal length and field of view are inversely related. A shorter focal length results in a wider field of view, while a longer focal length results in a narrow field of view.

2. An image captured with a 50mm focal length is considered to have a "normal" field of view. What about an image taken with a 15mm focal length? How about 150mm focal length? Do these types of images have special names?

   Solution: An image taken with a relatively shorter focal length such as 15mm is called wide angle. An image taken with a relatively longer focal length such as 150mm is called a telephoto.

3. Which of the following camera configurations has the smallest field of view?

   (a) 36mm wide sensor and 50mm focal length lens

(b) 12mm wide sensor and 18mm focal length lens

(c) 24mm wide sensor and 8mm focal length lens

Solution: Recall that the field of view can be computed as an angle:

$$\text{FOV} = 2\text{arctan}(\frac{h}{2f})$$

where h is the sensor size and f is the focal length.

Using this expression, we see that (a) has FOV $2\text{arctan}(\frac{36}{100})$, (b) has FOV $2\text{arctan}(\frac{12}{36})$, and (c) has FOV $2\text{arctan}(\frac{24}{16})$. (c) has the largest FOV at approximately 56.31 degrees, whereas (a) has FOV 19.8 degrees and (b) has FOV 18.43 degrees.

4. How are sensor size and field of view related? What happens to the field of view if I don't move my sensor, but increase its size? What about decreasing its size?

Solution: Sensor size and field of view are directly related to each other. A larger sensor size will result in a larger field of view, and vice-versa.

5. If my F-number is increasing, then what can I deduce about the size of my aperture and/or my focal length?

Solution: F-number is defined as the ratio of focal length to aperture size. Thus, if my F-number is increasing, then either my focal length is increasing relative to my aperture size. This could happen if I increase my focal length while holding aperture size constant or if I decrease my aperture size while holding my focal length constant.

6. To help reduce motion blur when I capture photos, I can increase the shutter speed of my camera (which reduces the amount of time the sensor is exposed to light). What are the tradeoffs of doing so? What can I do to mitigate the tradeoffs?

Solution: Recall that exposure is the product of exposure time and irradiance. Increasing shutter speed reduces exposure time, so our overall exposure value is lower. This means that our images will become darker in exchange for reducing the effects of motion blur. To counteract this, we can attempt to boost the amount of irradiance falling on the sensor by increasing the size of our aperture by a proportional amount.

7. How are depth of field and aperture size related? What happens to the depth of field

if I reduce the size of my aperture? What else happens if I reduce the size of my aperture?

Solution: Depth of field and aperture size are inversely related. A smaller aperture size will result in a larger depth of field (a larger range of depths in the image will be in focus). Conversely, a larger aperture size will result in a smaller depth of field. However, as we saw above, aperture size is directly proportional to exposure, so reducing the aperture size will increase depth of field at the tradeoff of having a darker image.

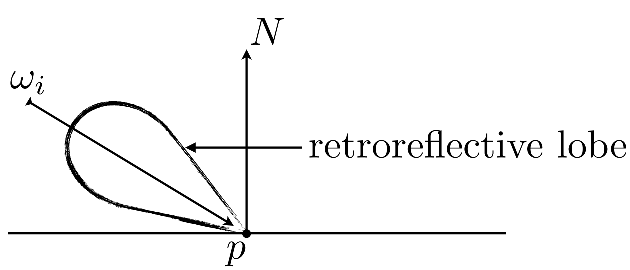
8. Briefly explain why photographers must choose between depth of field and motion blur for moving objects.

Solution: To gain better depth of field, photographers must reduce the size of their aperture when taking photos. However, this means that less light will reach the sensor. In order to maintain roughly the same amount of exposure that the sensor gets, photographers then need to also decrease their shutter speed, which could introduce motion blur into their photos. The opposite tradeoff also holds true.

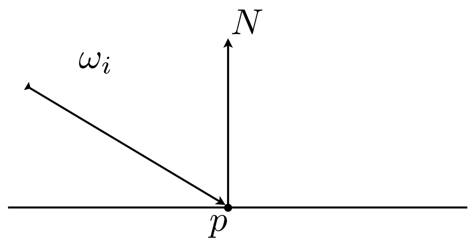
2 BRDF Material

For surfaces with the BRDFs described below, consider a single incident ray of light as shown from direction ω_i to a surface point p with indicated surface normal vector N. Please sketch on these drawings the reflected distribution of light at point p. The first is done as an example for you.

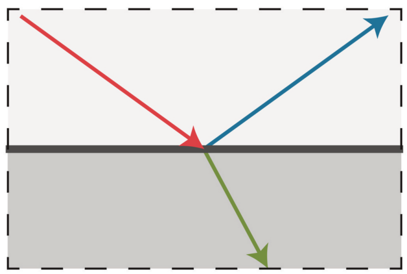
Example: BRDF: glossy retroflection.



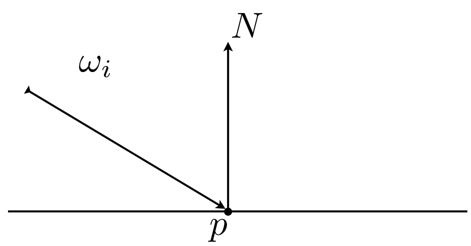
1. BRDF: a material with both specular reflection and specular refractive transmission, such as glass.



Solution:



2. BRDF: a material with both diffuse and glossy specular components, such as sand-blasted aluminum.



Solution: