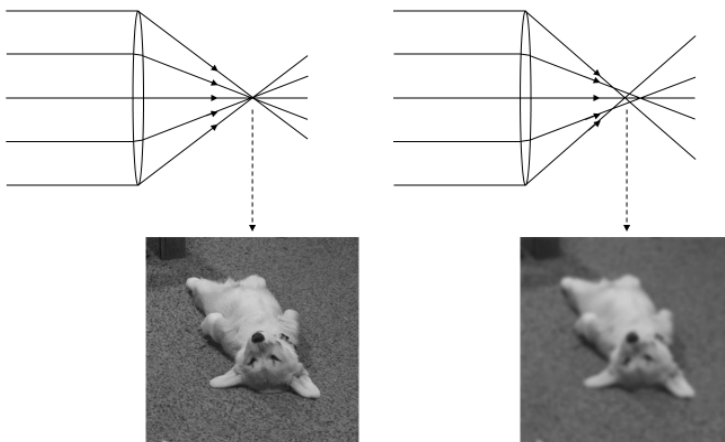


4.5 Forming the Perfect Image Is a Tall Order

Ideally we would like an image formed by the optics to be an exact copy of the scene in every imaginable way. To replicate the scene, we would need to record the three-dimensional aspects of the scene with the proper color and brightness. Then, there is the changing nature of the scene over time that would need to be recorded as well. We can imagine a future where we could walk through an image of a scene and think that we were walking through the actual scene, but for now we will discuss the limitations of the digital cameras that we use today.

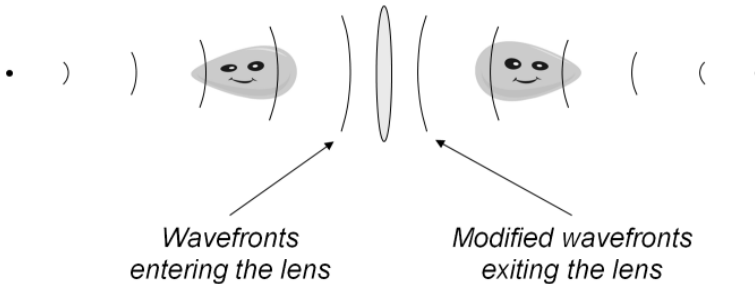
Optical engineers work hard to design lenses and mirrors that bring all of the light together in just the right way to achieve a highly detailed copy of a scene. Unfortunately, this is harder than it seems. This is why lenses sufficient to form reasonably good images were not produced until the 16th century. The way light comes together to form an image is very sensitive to the shape of the lens or mirror, and very small changes can lead to noticeable differences in the quality of the image. These deviations from the ideal optical system are called aberrations, and optical designers take great pains to minimize them. They do so by adding more optical elements and creating optics with more complex shapes.



We see blurring in our pictures if light isn't brought together in just the right way.

The main effect of aberrations is the blurring of an image, as we have all seen when the image isn't focused properly. To get an idea of this sensitivity, if the lens in your digital camera misses the location where the light should come together by a distance of about ten hair widths or more, you will likely see a noticeable blurring in the image.

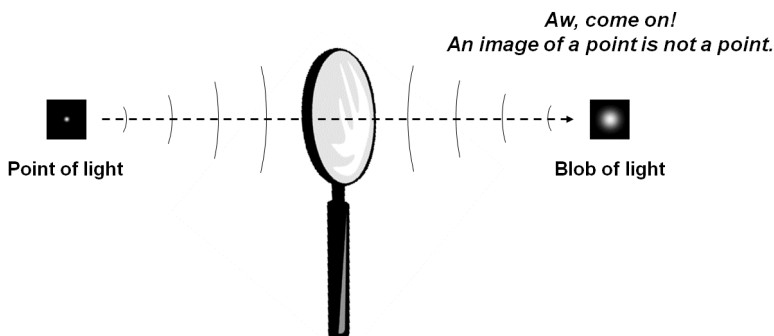
How can we measure how well our camera optics is pulling the light together? A simple way is to see how well it can record an image of a simple point of light. After all, if the camera can faithfully reproduce a tiny point of light in a scene, it can reproduce any detail in the scene on the scale of that tiny point. Using the ray-tracing approach that we've used so far gives the impression that all we need to do is properly bring all of the light coming through the optics together at the focal point, and voilà, we will have a high-detail image! Unfortunately, the ray-tracing approach does not take into account that light is an electromagnetic wave. We must consider the wave properties of light through the optics to understand how well the light is pulled together. Physical optics is the study of the wave nature of light and shows us how a lens or mirror changes the wavefronts of the light as they move through a camera.



Physical optics shows us how a lens modifies the wavefronts of light to create an image.

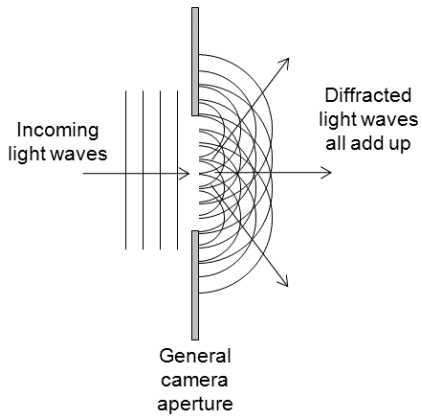
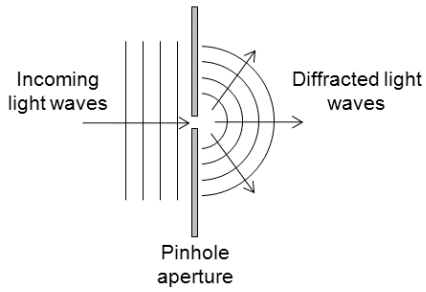
Even with the highest-quality optics, the wave nature of light will prevent us from making a point-for-point copy of the scene, so the goal of imaging a perfect point is already lost. Why is the

dream dashed so soon? Because as light travels, it spreads out, and the camera aperture can never be large enough to capture all of the light necessary to image a perfect point. We need the optics to form an image, but we can't make the size of the optics infinitely large (remember, this isn't Hollywood). When the light hits the edge of the camera aperture, it diffracts or spreads out from that edge, causing a point of light to go from skinny to fat. This means that a point of light in the scene spreads out into a blob by the time it is imaged in the camera. As we will see later, there are other factors in the camera that also cause a point of light to spread out by the time it is recorded in the image. This spreading of the point is described by the point spread function (PSF) of the camera.



A point of light is not actually imaged as a point because of the wave nature of light and the limited size of light-collecting optics.

So, how do we calculate what the light will look like after it enters a camera aperture? Given a camera design, how do we know what the PSF will look like? What differences in the PSF are important? These are important questions because we want to make the PSF as small as possible so that a point of light in the scene will look as much as possible like a point of light in the image. But when is the PSF good enough? Mathematics for calculating the PSF and its effect on an image can be fairly difficult, but fortunately our work can be simplified by looking at image formation in a different light (pun intended, again!).



What pattern does the light make out here?



It's not simply a shadow of the aperture!

Light diffracts after passing through a camera aperture, further complicating the effort to understand the quality of the image.