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Depth of field and the vanishing fence

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Abstract

Students are amazed when I show them a zoo photo of an animal behind a fence and then a zoomed-in photo where the fence has disappeared. They ask 'Where did the fence go?' This paper will explore this magical phenomenon which draws from concepts in photography (angle of view, depth of field) and physics (convex lenses, focal length, real images). An accompanying video demonstrates how the fence vanishes as one zooms in on the zoo animal (Ruiz 2018 *Video: Where is the Fence?* http://mjtruiz.com/ped/fence/).

Background

Examples of teaching photography to physics majors [1] and non-science majors [2] have been fairly common for the past few decades. Student assignments ‘to photograph a natural or contrived phenomenon’ have also been used to narrow ‘the gap between physics and students’ [3]. Students can use digital cameras to take photos and videos of the ‘vanishing fence phenomenon’ described in this paper. The challenge is to capture a subject behind a fence so that the subject is in focus, while the fence is so out of focus that it disappears in the photo or video. However, it is difficult to achieve the effect with a smartphone because the cameras are so small. One needs a camera capable of a relatively large aperture.

The vanishing fence act

See figure 1 for two stills of African lions from a video taken at Henry Doorly Zoo and Aquarium, located in Omaha, Nebraska, USA. Figure 1(a) is a wide-angle still of the lion behind a fence, while figure 1(b) is narrow-angle still of the same scene. To dramatically illustrate angle of view in class I make an angle by extending my arms so that the entire class is within the angle that spans from my left hand to my right hand. I explain that capturing the entire class on a photo is a wide-angle view. Then I bring my extended arms together to form a small angle such that only the face of one student is included. I explain that for a portrait shot taken from a distance we have a narrow angle of view. The lens that gives a wide angle of view is called a wide-angle lens, while the lens providing for a narrow angle of view is called a telephoto lens. A zoom lens allows the photographer or videographer to change the angle of view smoothly. Note that the fence in the telephoto still of figure 1(b) is so out of focus that it has almost vanished.

After visiting the African lions at the Omaha zoo, we walk a distance to check out the bongos, large antelopes that dwell in African forests. Look at the stills of the bongos in figures 2(a) and 2(b). The fence was much closer to the videographer compared to the situation with the lions. The fence in the latter case has vanished for the zoomed-in still of the bongo, figure 2(b). In the next section we use physics to explain this magical disappearance act.

(a)

(b)

Figure 1. (a) (upper photo) is a still of two lions extracted from a video before the videographer zoomed in. Both the lions and the fence are clearly visible in tolerable focus. Figure (b) is a zoomed-in still. The fence is now considerably out of focus to the point that it has almost vanished.

(a)

(b)

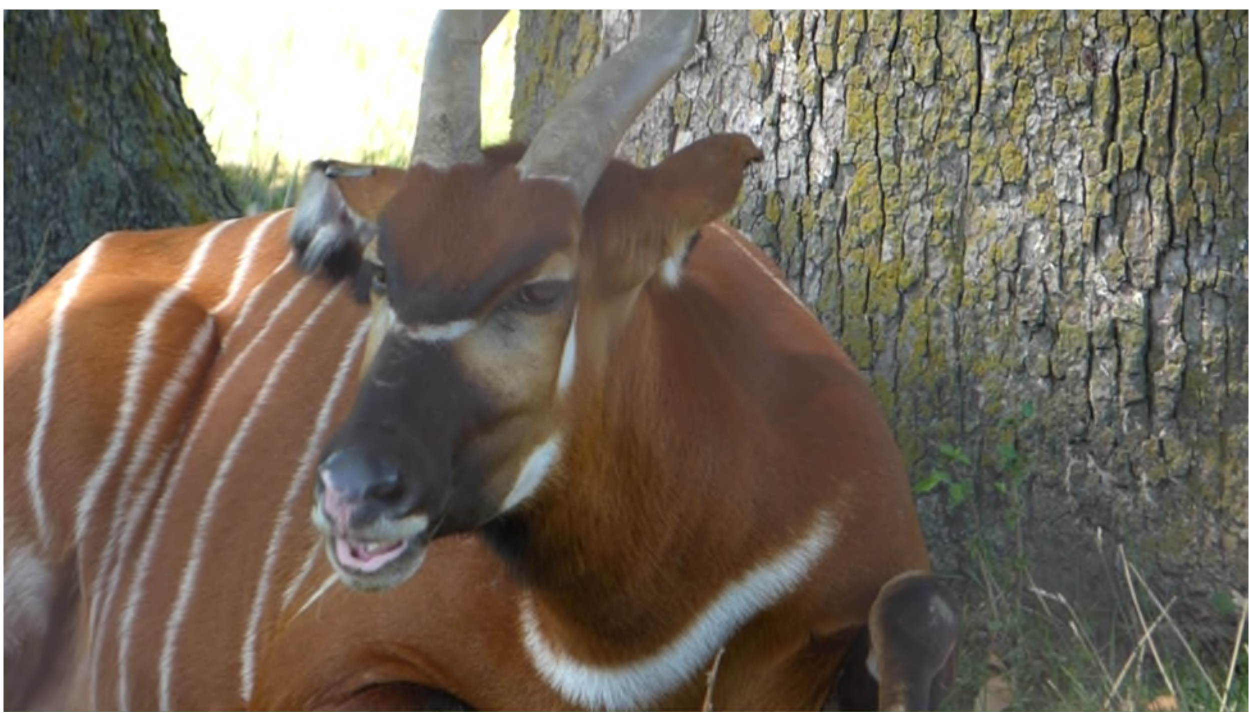

Figure 2. (a) (upper photo) is a still of two bongos extracted from a video before the videographer zoomed in. The bongos and fence are both visible. Figure (b) is a zoomed-in still, where the fence has vanished since it is so much out of focus.

The vanishing fence act explained

We employ ray diagrams to analyze the stills of the previous section. Students are introduced to ray diagrams in introductory physics [4]. They learn how to sketch light rays and images formed by plane mirrors, spherical mirrors, and lenses. An article in this journal shows how such ray diagrams can be made using PowerPoint [5]. The camera utilizes a convex lens to produce a real image on a light sensor. Therefore, our task is to sketch real images formed by a convex lens in a camera.

Examine the ray diagrams of figures 3(a) and 3(b). Each subject location to the left of the lens, such as the lion (animal) or fence, has a unique real-image location to the right of the lens. When the videographer focuses on the lion, the real image of the lion is on the light sensor at the video plane of focus. The light from the fence is intercepted by the light sensor before it has a chance to form a sharp image. If the blurriness of the fence is so slight that it is not perceived, we say that both subjects are in tolerable focus, as seen in figure 1(a). The depth of field refers to the distance from the closest subject to the farthest subject such that all subjects within this range are in tolerable focus. The corresponding range of real images to the right of the lens is referred to as the depth of focus. When the videographer zooms in on the lion, the fence becomes more and more blurred at the video plane of focus.

For the short focal length in figure 3(b), both images are smaller when compared to their respective counterparts in figure 3(a). Therefore, more subject area can fit in the field of view for the photo or video. Photographers say that the angle of view is large since more of the scene can be captured. Therefore, the short focal-length lens is our wide-angle lens. On the other hand, for the long focal length in figure 3(a), the images are relatively larger. Therefore, less overall scenery can fit on the photo or video. Such a long focal-length lens has a narrow angle of view and is our telephoto lens. Think ‘telescope’ for telephoto since the subjects appear larger.

Ask your students which of the two lenses has the greater depth of field, the wide-angle lens or the telephoto. The answer is the wide-angle lens since the real images for different subject distances appear relatively closer to each other. When the videographer focuses on the lion, the fence is in tolerable focus (figure 1(a)) since its real-image location is not far from the real image of the lion. However, for the telephoto lens there is more separation distance between the locations of the real images for the animal and fence (see figure 3(a) compared to 3(b)). The fence is no longer in tolerable focus (figure 1(b)). The depth of field for the telephoto lens is smaller, which is what we want. If the fence is considerably outside the depth of field, its image is so spread out that it vanishes (figure 2(b)).

(a)

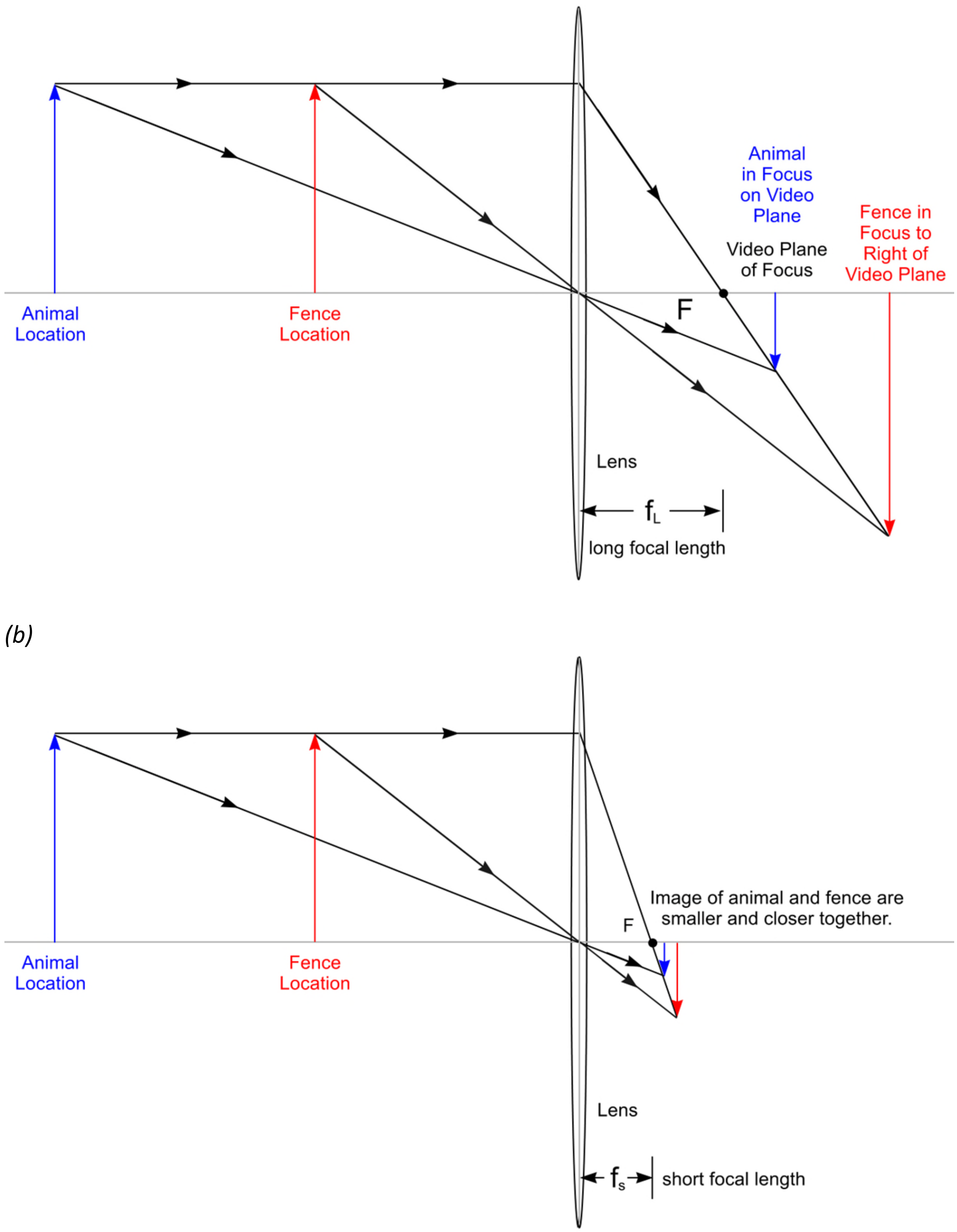

Figure 3. (a) Animal and fence subjects and their corresponding real images for a long focal-length lens. (b) The same subjects with their real images formed by a short focal-length lens. The images for the short focal length (figure b) are smaller and closer to each other.

Figure 4 illustrates the vanishing of the fence. A point from the bongo (animal) is imaged at the video plane of focus since the videographer has zoomed in on the animal. The point from the bongo is in sharp focus at the light sensor (video plane). The point from the fence is imaged to the right of the video plane of focus. For a long focal-length lens, the separation between the respective images is greater, as seen by comparing figures 3(a) and 3(b). The light rays coming from the point on the fence are intercepted by the light sensor at the video plane of focus before they have a chance to converge and form a sharp image farther to the right. The point from the fence is sufficiently spread out on the light sensor so that it vanishes.

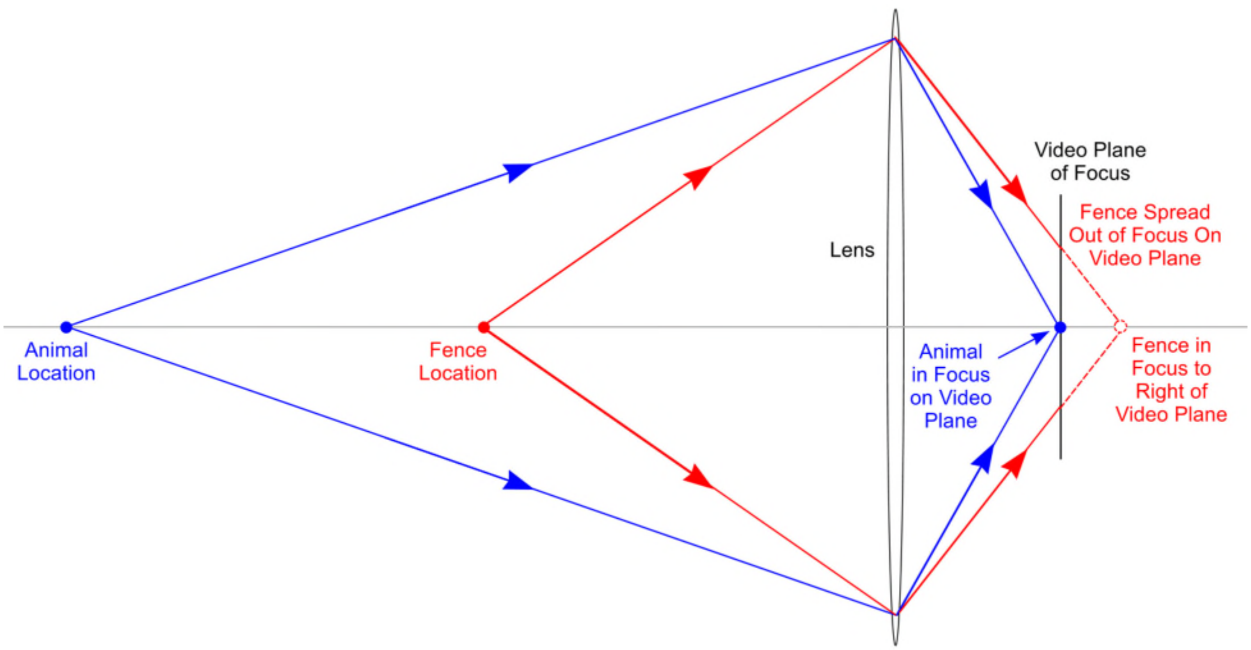

Figure 4. A point from the animal subject is focused as a point in the video plane of focus since the videographer has zoomed in on the animal. A point from the fence is spread out on the video plane as its point of focus lies beyond and to the right of the video plane of focus.

Students may still ask how one can capture light that is blocked by the fence when viewed by a human. The answer is subtle and found in figure 4. Since the metallic regions of the fence sections are very thin, light from a point directly behind the fence can reach the outer portions of the lens by passing above and below the fence. See the blue rays in figure 4, which rays reach the outer portions of the lens. The lens then focuses this light on the video sensor. Meanwhile, light from the fence is too spread out on the sensor to be seen. Therefore, due to the physics of lens focusing, light from directly behind the fence is captured.

Note that the aperture in figure 4 is relatively large. If the aperture were smaller, only the rays closer to the optic axis would get through the lens. These rays are not spread out as much and would improve the focus of the fence. Students are encouraged to use cameras where the aperture can be set as large as possible. Unfortunately, today's mobile phones with built-in small cameras are limited to relatively small aperture sizes. *[Author’s Comment Post Publication: The small aperture on a smartphone is actually a good thing since in the usual case we want the accompanying larger depth of field to get overall sharper photos.]*

A video is included [6] where we start with a wide angle and then gradually change to a very narrow angle of view. The zoom lens is set at the short focal-length extreme at first. Gradually increasing the focal length to the telephoto realm appears to bring the lion or bongo closer. As the subject gets larger and larger, we see less area of the subject and the depth of field decreases significantly. For the bongo, this decrease in depth of field causes the fence to vanish (figure 2(b)).

Conclusion

Students desiring to take photos or video of animals at a zoo should not be discouraged if there is a fence between them and their subjects. If there is considerable distance between the subject and the fence, there is a possibility that they can make the fence disappear with their understanding of physics. Their chances are even better if the fence is closer to them compared to the subject. By zooming in on the distant subject, the nearby fence becomes out of focus since the real-image location of the fence lies beyond the plane of focus for the subject. If the fence is sufficiently out of focus at the camera sensor, the fence vanishes.

Though this paper provides detailed analysis of the physics and introduces terminology from photography, the lesson can be shortened considerably. As long as students understand that when taking a picture, one has to focus on the subject to get a sharp image, they can do experimental work in the field taking their own photos. The aim is to photograph subjects behind fences such that the fences do not appear on the photographs. Though I am a physics teacher and photographer with an understanding of depth of field, I am still always amazed as I zoom in on a zoo subject and see the fence between me and the subject vanish before my very eyes. Be sure to watch the short video included with this paper to witness this magic for yourself [6].

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[Author's Comment Post Publication: I retired from UNCA after the Spring 2021 semester, completing 43 academic years at UNCA (1978-2021).]