THE CONCEPT OF INFINITY IN VIEW CAMERA PHOTOGRAPHY

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1. Introduction

The term 'infinity' is ubiquitous in photography, but many photographers aren't quite sure what it means. This article is an attempt to explain how the term arose and how it is used in photography, particularly in view camera photography.

Frequently, people ask where they should focus to be focused 'at infinity', thinking of it as some specific distance, albeit very large. But, nothing in a scene can literally be at infinity, although, paradoxically, it is possible, at least in principle, to focus at infinity.

Before trying to explain that, let me say something about the three dimensional space which contains the subject matter of our photographs. The model of space we carry in our heads is based on what helped our hunter-gatherer ancestors to survive. It bears little resemblance to what modern physics and astronomy tell us about the geometric structure of the real physical universe. For one thing, we see a flat Earth, whereas we know our planet is a globe. For another, we think of images being formed, on film or in our heads, instantaneously, whereas we know that light travels at a finite speed. Modern astronomy tells us that the universe is expanding and remote galaxies move away from us at ever increasing speeds. We will never see anything for which the recession speed exceeds the speed of light, and much of the light we can see was emitted billions of years ago. Finally, quantum theory presents us with a physical reality at the level of the very small, in which objects behave both like particles and waves[1], which is beyond our ability to visualize.

Fortunately, the model of geometry, created by Euclid some 2300 years ago, is a pretty good guide to the practical world of everyday affairs, including to a large extent photography. But there is one important difference. In Euclidean geometry, the distance between two points is independent of where the points are located, while the distance between the images of such points in a camera does depend on where they are located—the further away the points, the closer their images, But none of this has anything to do with distant galaxies.

2. Vanishing Points, and Points at Infinity

Photography arose as an attempt to fix the image of the camera obscura, one of many aids artists used to draw accurately in perspective, staring in the Renaissance. The idea of a vanishing point in perspective drawing is what led to the concept of a point at infinity.

Photographers are familiar with the example of a pair of railroad tracks on a flat plain receding into the distance. The tracks appear visually to converge to a

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[1]This duality shows up in photography, where we treat light as consisting of photons when doing geometric optics and waves when worrying about diffraction.

point on the horizon, but there is no such point. Like the mythic pot of gold at the end of the rainbow, it recedes from you as you approach it. Although it has no physical reality, we can still envision it as existing in an extension of our geometry 'at infinity'. Moreover, in a camera, it takes on an actual physical reality.

Consider the images of the rails in the camera's film plane.[2] With a view camera, we can see those images lines on the ground glass, and they actually do converge to a point, which is called a *vanishing point*. Note that any pair of parallel lines will have a vanishing point, and in fact, all lines parallel to the same line will have the same vanishing point. See Figure 1. The picture has been rotated 180 degrees

FIGURE 1. Parallel Lines converging to vanishing points

from what you would see on the ground glass, so it is right side up. I've indicated two vanishing points for different families of parallel lines, one to the left, and the other to the right. A vanishing point may or may not be within the frame. In this example, you can see each family of parallel lines converging towards its vanishing point, but those points are outside the frame.

In Figure 1, the vanishing points are on the horizon, but generally, any point in the (extended) image plane is a potential vanishing point for a family of parallel lines in view from the camera. For example, for a road going up a hill, the vanishing point would be in the sky. Similarly, the sides of a road on a downhill slope will converge to a vanishing point under the ground.

But we need to say just a little more about what we mean by 'in view'. The lens in a conventional camera will point in a certain direction, and its potential view is everything in front of the camera. If you change the direction the camera points, you change what is potentially in view. For a view camera, it is a bit more complicated because the lens plane and the film plane can be reoriented with respect to one another. For our purposes, we may think of the lens as a single point and ignore for the moment which way the lens plane, and with it the lens axis, is oriented. That point establishes a center of perspective or viewpoint. Its position is the single most important choice the photographer makes. Questions of focus aside—imagine the camera is a pinhole camera—everything else is determined by the position of the film plane, i.e., the ground glass. As obvious as it is, let me point out one important feature of the the film plane: it has two sides, and the lens is on one side of it. Only points in space on the same side as the lens may

[2]Increasingly in the future, instead of film, we may have an electronic device recording a digital image, but the principle is the same.

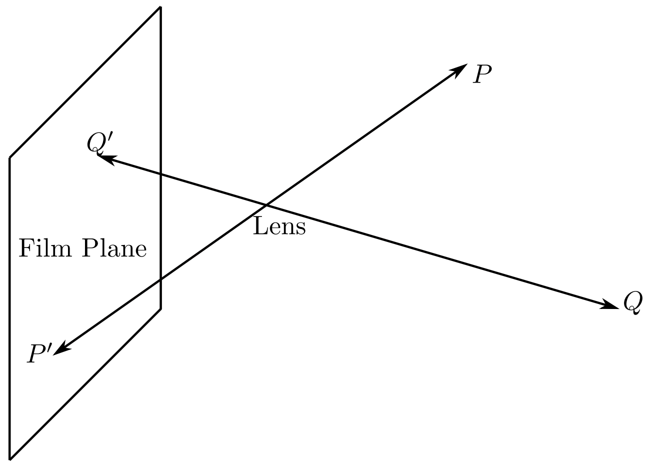

Figure 2. Subject and image points

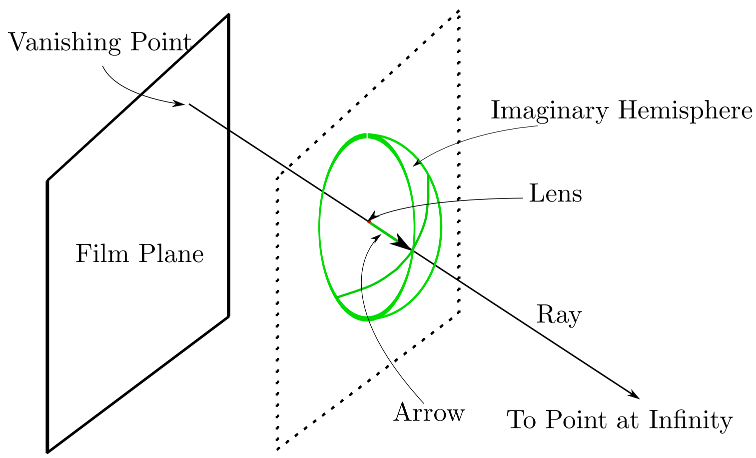

Figure 3. Vanishing points, rays, and points at infinity

yield images in the film plane, and not all of those are potential candidates. As indicated in Figure 2, the ray from the subject point to the lens, continued beyond the lens must intersect the film plane. Of course, the camera enclosure, including the lens plane, will further restrict what can be seen in the film plane, as will optical restrictions on what can come to focus there, but we ignore that for the moment.

One way to picture this is indicated in Figure 3. With each possible vanishing point in the (extended) film plane, we associate a ray through the lens. The ray is specified by an arrow of length one. (The ends of these arrows form an imaginary hemisphere, as indicated in green the diagram.) Any line in the scene which is parallel to that ray will be imaged as a line passing through the vanishing point, and corresponding to that vanishing point, we may think of such lines as converging to a common point at infinity in the scene.

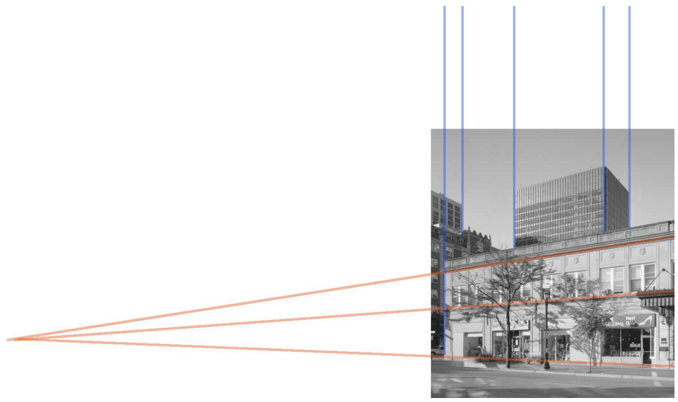

FIGURE 4. Vanishing points in image, one at infinity

There is one case that is of special interest. Suppose the arrow is parallel to the film plane. Then the corresponding family of parallel lines is also parallel to the film plane, and their images in the film plane are parallel. So there appears to be no vanishing point for those lines. This is the situation in architectural photography when the rear standard has been kept vertical so that the vertical sides of a building won't converge. (See Figure 4 which shows one set of lines converging to a vanishing point to the left, and another set of vertical parallel lines.) In cases like this, rather than give up on the idea of a vanishing point, it makes sense to say in that the vanishing point in the film plane is also at infinity.[3] To see why this makes sense, consider what happens if we don't quite get the back vertical and it is tilted slightly up. The vanishing point for the vertical sides of the building will be somewhere very high, certainly out of the frame. As we adjust the back to get it vertical, that vanishing point will move higher and higher, so it make sense to think of it as approaching infinity when the back is perfectly vertical.[4]

3. Focal Planes, Rear and Front

So far, we have not used the ability of the lens to focus the image, so lets turn to that. Geometric optics is the subject that tells us to a high degree of accuracy how images are formed by lenses. It tells us that each point in the scene comes to focus at a specific point inside the camera. If the film plane passes through that point, the image in that plane is exactly in focus. Otherwise, there will be a blur in the film plane, called a circle of confusion, and if that circle of confusion is small enough, an observer can't distinguish it from a point. Thus, wherever we place the

[3]There is a subtle difficulty with this notion, which I will return to later.

[4]Some might argue that we don't really have to worry about vanishing points at infinity since the back will never be perfectly vertical, nor will it ever be perfectly parallel to the sides of the building. So the vanishing point will always be at some finite distance, albeit very high . Note, however, that the height of the vanishing point increases rapidly as the back gets closer and closer to the vertical. There is no single height which we can think of being essentially at infinity

film plane, there will be a region in the scene, called the depth of field, which we consider adequately in focus.

Let's see how that affects the concept of points at infinity. There is a plane,

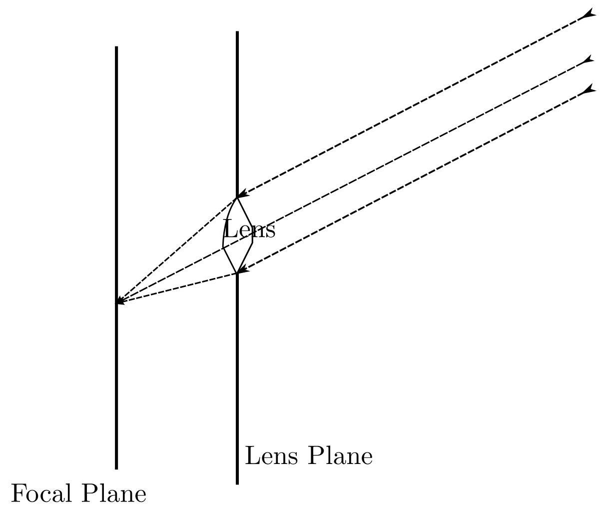

FIGURE 5. Focal Plane

called the focal plane, which is parallel to the lens plane and at distance from it equal to the focal length of the lens. The theory tells us that any set of parallel rays entering the lens, will come to focus at a point in that plane. See Figure 5. Correspondingly, we may think of that point as being the vanishing point associated with a point in the scene, at infinity, where all those rays 'start'. Any subject point at great distance from the lens, will come to focus at a point slightly in back of the focal plane, but it may be so close that we can't tell the difference. So in that sense, from the perspective of what happens behind the lens, we may think of any distant subject point as being virtually at infinity.

The plane in front of the camera, parallel to the lens plane, at distance equal to the focal length, is called the front focal plane. It has a property analogous to that of the focal plane. Rays starting from a point in the front focal plane, emerge from the other side of the lens as parallel rays, so they never come to focus anywhere inside the the camera, no matter how large it may be. Rays starting at a point just in front of the front focal plane, will emerge almost parallel to one one another, and they will come to focus, in principle, at a point at very great distance (not within any camera you can imagine). So, it makes sense to think of the image of a point in the front focal plane as being at infinity in the image space.

If we try to get even closer than the front focal plane, then we can't produce any image at all.[5] The region between the two focal planes, can be thought of as being 'beyond infinity' in the sense that such points can be neither real subject points nor real image points.

[5]Sometimes the image of such a point is called a virtual image. If you put a magnifier closer to the subject than its focal length, then it produces such a virtual image, but it has to be converted into a real image by some optics, such as that in your eye, to be recorded.

Generally speaking, for finite points, geometric optics tells us that points lying in a plane in the scene come to focus at a plane on the other side of the lens. View camera photographers are familiar with Scheimpflug's rule which tells us that the the subject plane in the scene, the lens plane, and the image plane intersect in a common line.[6] If we extend this to the focal plane, that leads us to an interesting conclusion. We should consider the set of all points in the scene at infinity as also forming a *plane* with image the focal plane. We call that plane *the plane at infinity*. Similarly, the set of all images of points in the front focal plane should also be viewed as forming a plane at infinity. Moreover—at this point you may not be surprised to find out—they should be considered to be the *same* plane.

The above discussion illustrates how the formation of images distorts Euclidean geometry. An 'imaginary' plane at infinity in the scene, which we can never reach in reality, becomes a real physical plane behind the lens, the focal plane. On the other hand, a real plane in the scene, the front focal plane, which is the absolute limit of how close a point in the scene can be to the lens, produces an image plane, at infinity, which we can never reach. In addition, the relation between subject points and object points does not respect the ordinary Euclidean notion of distance. No point at finite distance from the camera can literally be at infinity. No matter how far it is from the lens, the remaining distance to infinity is still infinite. On the other hand, as noted above, its image may be so close to the focal plane that we can't see any difference. Also, points in the far background, which are very far apart may have images which are extremely close together. And similarly, points in the foreground which come to focus far apart on the ground glass may in fact be fairly close in the scene.[7] This enormous distortion of geometry is not obvious to us when we look at a photograph, because the human visual system has evolved so that two dimensional representations of three dimensional space make sense to us. Without that, a photograph would be incomprehensible. But our eyes and brains are not perfectly adapted for this, so looking at a photograph is still quite a bit different than looking at the scene from which it was made, something every photographer should be aware of.

4. Hinge Line and Tilt Horizon

Let me finish by discussing two additional concepts useful in view camera photography, which relate to things happening at infinity: the hinge line and the tilt horizon. Imagine a plane through the lens parallel to the film plane. I call that the reference plane. That would be the original position of the lens plane before any tilts or swings. The exact subject plane after a tilt or swing, or any combination thereof, intersects the reference plane in the hinge line. See Figure 6

The hinge line is controlled completely by the tilt angle, but as you focus by moving the rear standard along the rail parallel to itself, the exact subject plane swivels about the hinge line, which stays fixed. (Whenever you have a situation with a bunch of mutually dependent variables, you may find it difficult to see what is going on. So anything that stays fixed will be important.) Moreover, the depth of field region has the form (approximately) of a wedge, bounded above and below

[6]Notice that the Scheimpflug line, since it lies between the focal planes, contains neither real subject points nor real image point.

[7]This is usually captured by the notion or magnification or scale of reproduction, which can vary from 1:1 or even larger in the extreme foreground to close to zero in the remote background.

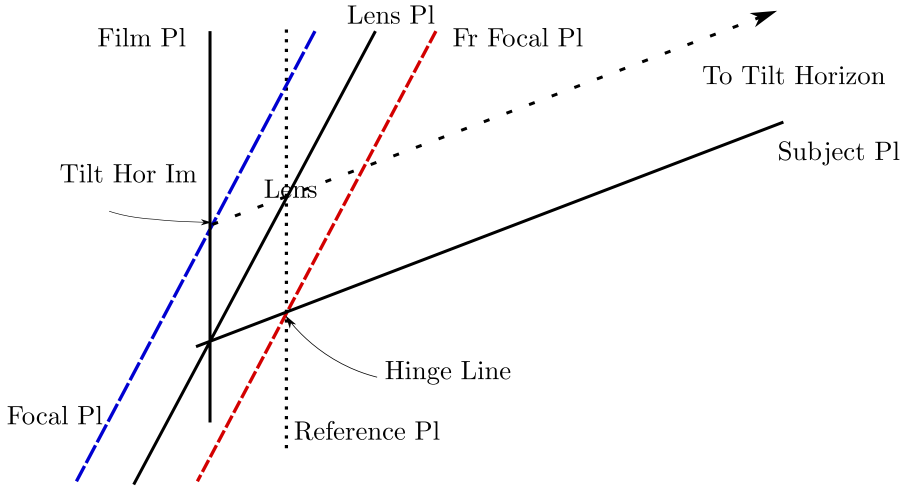

Figure 6. Hinge line, tilt horizon, and image of tilt horizon

by two planes, with the exact subject plane between them, and the entire wedge swivels about the hinge line as you focus by moving the rear standard.

But the hinge line has another property, which seems less known. It is also the intersection of the exact subject plane with the front focal plane. In particular, it is the unique line in the exact subject plane with image at infinity.[8]

Finally, let's look at the intersection of the plane at infinity with the exact subject plane. I call that the tilt horizon. All lines parallel to the exact subject plane pass through it, and its image in the film plane consists of all vanishing points for such lines. Moreover, all points in the exact subject plane which are sufficiently far away come to focus very close to that line. If the frame is positioned properly, it on the ground glass, and that can help you figure out how much to tilt.

There is a lot more than can be said about points at infinity. Any serious investigation of view camera geometry makes use of points at infinity, and it is difficult or impossible to do any serious calculations without taking that into account. I could go on for many pages elaborating on neat things that can be done if you understand infinity in the context of the view camera, but I may already have stretched the patience of most readers, so I will stop here.

Appendix A. A Subtlety

Look at Figure 3 again. Each arrow is associated with a single vanishing point in the film plane and a corresponding single point at infinity in the scene. But there appear to be some exceptions. Namely, the arrows parallel to the film come in pairs, pointing in opposite directions. But, for each such pair, there is only one family of parallel lines parallel to the film plane. In that case, we decided to put the vanishing point at infinity in the film plane. Figure 7 shows an example with such lines, and it shows the two arrows pointing in opposite directions. So, it appears that there should be two vanishing points, in this case, one at each 'end'.

[8]That image line is where the film plane intersects the plane at infinity, and it also stays fixed as you focus by moving the rear standard parallel to itself.

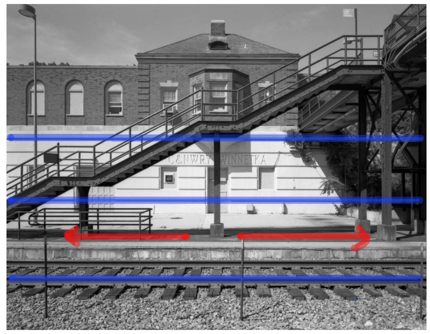

Figure 7. Lines Parallel to film plane, vanishing point at infinity

This presents something of a quandary. Why should the lines parallel to the film plane be different from all the others? If we were to turn the camera slightly to one side or the other, the parallel lines in the picture would converge to a single finite vanishing point in the scene, in one case far to the left and it the other case far to the right. Why should such a small shift change two vanishing points into one?

The solution adopted long ago by geometers was to say that, despite appearances, there is only one vanishing point at infinity for a family of parallel lines parallel to the film plane. It is hard to square this idea with our normal notions of distances and continuity in geometry. On the other hand, we have already seen, our notions of when points are close together or far apart is distorted by the process of forming an image. So it may be not entirely surprising that we have to bend our intuition a bit in this case for the sake of consistency.

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