Rendering Skewed Plane of Sharp Focus and Associated Depth of Field

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1 Introduction

Depth of field is the region of a scene that is in focus in an image. This is measured relative to a *plane-of-sharp focus.* When using a physical camera, this plane is perpendicular to the optical axis of the camera lens, unless the camera is a *view camera.* This special camera enables many effects, including skewing the plane-of-sharp focus and associated depth of field.

Using a view camera, the photographer can position and orient the lens plane and film plane independently; in fact, the film plane need not be perpendicular to the optical axis of the lens. This enables the photographer to control two unique types of effects: *perspective correction*, and *arbitrary orientation of the plane-of-sharp-focus* anywhere in the viewing volume.

Perspective correction is vital for architecture photography, where it is desirable to maintain parallel vertical lines even when the view direction is angled up from the horizontal, as is the case, for example, in photographing a tall building from ground level. Vertical lines converge when they are not parallel to the film plane. This effect is not discussed in this sketch.

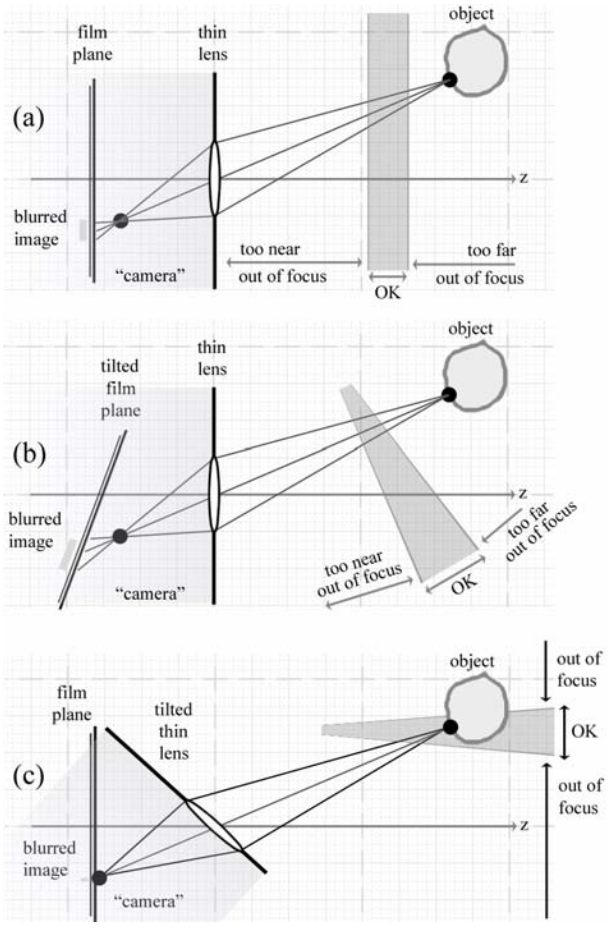

Figure 1: (a) Depth of field as it is generally presented.
(b)(c) The depth of field effect when the lens or film planes are tilted.

The ability to orient the plane-of-sharp-focus seems to be unknown in computer graphics. Whenever *depth of field* has been rendered, it is always aligned with the viewing direction. Previous algorithms for rendering images with depth of field did not recognize that it can be possible for the volume of space that is "in focus" to be at *any* orientation with respect to the viewing direction (see Fig. 1). The effect is possible with a physical camera in the case of a view camera.

2 Optics: *Scheimpflug and Hinge rules*

There are two geometric rules, called the *Scheimpflug and Hinge rules*, that relate the plane-of-sharp-focus to the lens plane and film plane. The first rule states that the plane-of-sharp-focus must intersect both the film plane and lens plane, at a single line. The second rule states that both the plane that is parallel to the film intersecting the center of the lens and the plane parallel to the lens located one focal length in front of the lens along its optical axis will also intersect the-plane-of-sharpest-focus along a single line.

These two rules in concert determine how to locate the plane-of-sharpest-focus given an arbitrary lens plane and film plane. Conversely, these rules can be invoked to determine the orientations of the lens plane and film plane that are required to achieve a particular plane-of-sharpest-focus.

3 Simulation

We incorporated *skewed depth of field* effects into a program using an OpenGL accumulation-buffer approach. An image with defocus is rendered by blending together several images projected through a set of sample points on the lens. Each sample point uses a different transformation matrix derived from the geometry.

The screenshot below is from our system simulating a view camera. The user interactively tilts or swings the lens or film planes (lower panel), with the result shown in the upper right. Although the camera is pointed *down*, the entire front face of the tower remains in focus whereas the brown building is not in focus.