A ray-tracing renderer inspired by Roger Deakins' vintage photography.

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2 Background

"What a cool shot! Roger Deakins, you madman!" - An Internet critic's praise of Roger Deakins

Roger Deakins is regarded as a legend by those in the film and the cinematography community. Many of his films embody, to the letter, the oft-quoted Hollywood dictum that "Every Frame [should be] a Painting." Even if you are not a film aficionado, chances are you have seen at least one film that has been lensed by him, whether it be the 1990s classic *The Shawshank Redemption*, the Academy-Award winning historical drama *1917*, or the luxuriously-colorful, yet cerebral James Bond film *Skyfall*. From a perspective of cinematography, my personal favorite of Roger Deakins's films is *The Assassination of Jesse James by The Coward Robert Ford*. Several of the sequences in the film are impeccably lit, but one of the most memorable features of the film are the dream-like transition shots that were created using specialized lenses called "Deakinizers."[Dominik, 2007]

In the words of Deakins himself in *American Cinematographer*: " . . .[The movie] is shot using a specially constructed lens, which involved mounting the front element of a Kiowa wide-angle lens onto a standard Planar prime. The effect is to somewhat mimic the look of an old box camera and there were a

Figure 1: A dream-like transition shot from *The Assassination of Jesse James by the Coward Robert Ford* showing the passage of time. Note the two sources of blur in the image: one due to the actual image geometry, and one due to the loss of color sharpness.

Figure 2: Another screenshot of those dream-like transition shot from the film. This image also has a loss of sharpness in the image, as well as some vignetting around the image.

number of reference images we used to develop this look." Deakins created these shots after his collaborator, the director Andrew Dominik "had a whole lot of still photographers, but also images clipped from magazines, stills from *Days of Heaven*, and even Polaroids taken on location that looked interested [sic] or unusual."[ASC, 2007] Thus, these so-called Deakinizer lens creates "imperfections" in time.

The interview further describes the physical basis of the Deakinizer lens: Deakins went to Otto Nemenz [a company that specializes in the maintenance of motion picture and digital cinema cameras, lenses and accessories] with a normal 50mm lens and a small single optical element that he would hold in front of it to emulate the look he wanted to achieve. Afterwards, Dan Lopez and Steve Hamerski at Otto Nemenz took a wide-angle Kinoptic Lens and very simply removed an element, creating color diffraction and optical vignetting around the edges. This new camera created a dreamy and soft effect in its shots in which there was clarity at the center and the lines at the edges were blurry and smeared.

A Deakinizer lens can thus be broken down into the following three photographic effects:

- Tilt-shift lens: Since the Deakinizer can be tilted on the horizontal x-axis, and shifted along the vertical z-axis, it is possible to create different vanishing lines in the image.
- Optical vignetting: Since the Deakinizer lens that Lopez and Hammerski made was done by removing a lens element, some of the light that is focused into the camera–particularly around the edges–is darker. This phenomenon is referred to as vignetting and it follows a cosine-fourth power law.
- Color diffraction: A Deakinizer lens also produces slight color diffraction due to the light rays diffracting as they hit the edge of the lens barrel.

The following post will describe an implementation of the preceding three effects in an attempt to creating our own "dream-like transition" shots in our ray-tracer. We shall start with the following base image:

Figure 3: A ray-traced image that simulates some basic camera effects including depth-of-field. This ray tracer also makes use of skyboxes, which are directly and indirectly traced onto geometry.

It should be noted that this is a software based ray tracer, many of whose ideas and principles are taken from the book series *Ray Tracing in One Weekend*, an excellent introduction to the algorithm of ray tracing.[OneWeekend]

3 Tilt-Shift Lens

This is perhaps the most simple, and trivial of the three phenomena to implement. We simply add a "tilt" and "shift" parameter to our camera class. Those parameters are merely added as offsets when the "getRay" function is called on the camera. To implement tilt-shift blur a "base" parameter for the tilt and shift was added as well, and interpolation was performed between each. (This can be thought of as motion blur of the camera.)

This particular ray tracer simply performs the calculation by randomly sampling from all possible tilt-shift offsets to generate the blur. One may conceptualize this implemention of code as a way of simulating motion blur, except instead of moving the objects, the camera itself is moved.

Figure 4: The original image with a tilt-shift effect visible in the proximity of the geometry, and some of the details of the skybox.

4 Optical Vignetting

As mentioned in the "Background" section, optical vignetting darkens the edges of an image. Mathematically, the light falloff is proportional to the fourth power of the cosine of the angle at which light impinges the image plane. Mathematically this is stated as: $I = \frac{L\pi l^2 cos^4\theta}{Z^2}$,where I represents the irradiance, L the incoming radiance, l is the radiance of the lens, and Z is the distance from the lens to the image plane.[Reiss, 1945] In our camera code, we simply include a function that returns a correction factor to mimic vignetting. Note well, vignetting is very strong for fish-eye lenses due to the incredibly wide field of view, but not pronounced at all for telephoto lenses. Therefore, when we generate our final overall image, we will try to select camera parameters that mimic the same parameters that Deakins used for his shots.

Figure 5: A render of the original image with optical vignetting. The darkening due to this implementation of vignetting is much stronger than the one used by Deakins for the film, but the parameters can be tweaked to soften the overall effect. The reason why this render has such a particularly strong effect in comparison to some older photographs is that older film had smaller ratio of image dimension to aperture size, while this camera's image dimension to aperture size ratio is much greater. We would this have to increase the aperture size (and thus alter the focal length and other camera-related properties.)

5 Color Diffraction

This is by far the most complex of the three phenomena implemented, and discussed in this paper. The first thing that must be done is to sample across the spectrum of possible colors. To that end, we created a Monochromatic Ray class, that gives each ray a wavelength and intensity. There is also a helper function to convert a chromatic wavelength into its appropriate RGB value.

There are many treatments of diffraction. In this paper, we shall only be concerned with far-field diffraction, (Fraunhoffer). Near-field effects, (Fresnel) are ignored, since the only diffraction that we are interested in is the diffraction occuring at the lens aperture, which is a significant distance away from the image plane.

To sample from these "diffraction rays" we relegate some of our sampling rays to diffraction rays, a relatively large number of the samples are still devoted to non-diffracted rays. If a ray is selected to be a "diffraction ray" we select a ray of random color, and calculate its intensity using the Fraunhoffer diffraction formula:[Hecht, 2017]

$I = I_0(\frac{sin\beta}{\beta})^2$

where $\beta = \frac{\pi D sin\theta}{\lambda}$,

Note, this is the formula for first-order peaks, higher-order terms are ignored since their contributions to the overall color of a pixel are neglible. In treating diffraction effects where such terms are more significant, one may seek to implement the higher order Fresnel terms.

The overall effect is to make the image more "diffraction-limited" or what is often described as being "grainier" to laymen.

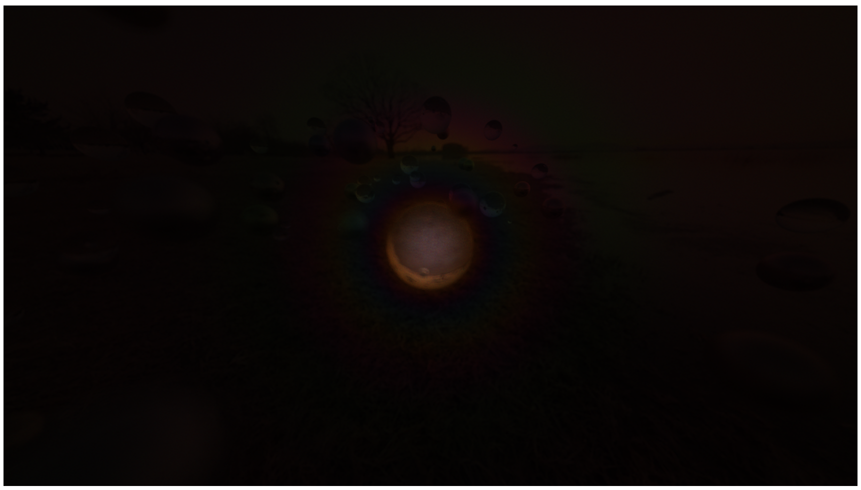

Figure 6: A render of the original scene but with only diffraction rays. When diffraction rays are combined with non-diffracting rays, sharpness is lost in the overall image.

6 Putting it All Together

This final render connects all the dots: tilt-shift blur, optical vignetting, and color diffraction. Each parameter may be tweaked by the artist to make the effect more pronounced. Perhaps, much like Deakins wished, the optical vignetting phenomenon can be tweaked so that it isn't as pronounced in the final render.

There are two immediate problems to consider when choosing to sample diffraction rays versus non-diffraction rays. It seems that because the intensity of diffraction is much smaller than the intensity of non-diffracting rays, then one should some number of rays proportional to this value; but careful! this may result in portions of the spectrum being undersampled (this is akin to not using Russian Roulette sampling), introducing biased results into the overall render.

The other problem has to do with tone mapping. Many renderers, including this one, coupled a ray's intensity with each sampled ray. But this probably should be decoupled so that each ray's intensity (and thus contribution to the

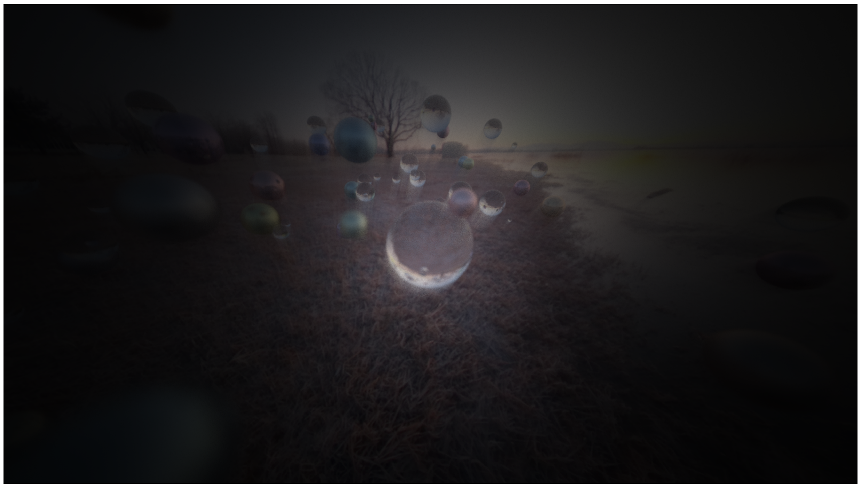

Figure 7: A render of the scene combining the tilt-shift effect, optical vignetting, and Fraunhoffer diffraction. The overall effect is to create a dream-like quality, in which an image is only fuzzily recalled, but not perfectly remembered.

overall image's radiance) should be controllable by the programmer so that tone mapping can be determined by the artist.

Further information on both of these problems can be found in:[Möller, 2019].

References

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