Questions

1. Suppose you are taking a picture with a camera and you wanted to keep the exposure constant but increase the depth of field. What are your options?

2. Consider the motion blur example of the billiard balls, shown in slide 21. This image was constructed by rendering many images at closely sampled times and then taking their average. This mimics what happens when a camera takes a picture – the shutter is open for a finite duration and the images that arrive at the sensor are integrated over time.

   Describe the motion that occurs in this image. What is ordering in which balls are hit ? The interesting part of the image is why some balls are smoothly motion blurred whereas others are blurred but not smoothly. Explain that effect.

3. One interesting motion blur effect that is used in photography is to rotate the camera continously to follow the path of a translating object. This camera rotation can roughly cancel the image motion of the object, which enables the object to appear sharp in the image. It also causes the background to be blurred. This effect is often used in car advertising.

   Suppose you have a very bright light (e.g. light bulb) in the scene which is overexposed in a single image (i.e. the intensity saturates at 255). How could you use the motion blur just described to estimate the physical intensity of this light, relative to the other intensities in the scene ?

4. Typical image formats in computer graphics use 8 bits per RGB channel and these represent linear increments in intensities. (Note I am talking abour rendering here, not photography!) This limits the dynamic range. One way to increase the dynamic range when rendering is to use more bits per pixel, say 12 (as in RAW format in photography) or 16.

   Can you think of any other way to represent *rendered* RGB values that would allow you to represent a high dynamic range in an image ?

5. [**ADDED April 26**] In slide 31, I claimed that the dynamic range of an exposure image, $E(x, y) * t$, doesn't depend on the exposure time t. (Note that the quantity $E(x, y)$ refers to the amount of light *arriving* at the sensor per unit time. It doesn't refer to the digital value that are recorded, i.e. it is before the camera response function.)

   Why does that claim hold?

6. [**ADDED April 26**] In the slides 32 and 34 of the lecture, I indicated the dynamic range as an interval on the log exposure axis. (Note: For the blue colored interval, I wrote "scene DR". To be more precise, I should have written "log of scene DR", since the figure uses a log exposure axis.) By drawing and labeling such an interval, I am essentially claiming:

$$\log \frac{max_{xy}(E(x,y)*t)}{min_{xy}(E(x,y)*t)} = max_{xy} \log(E(x,y)*t) - min_{xy} \log(E(x,y)*t)$$

   Why does this claim hold?

Answers

1. If you want to increase the depth of field, then you need to decrease the aperture. But this would reduce the exposure. To keep the exposure constant you could increase the exposure time t (decrease the shutter speed $1/t$). The would make you more susceptile to motion blur, however, either from moving the camera or from objects moving in the scene (leaves blowing in the wind).

   You could also change the focal length. (It turns out, however, that this in itself changes the depth of field. For you to see this, I would need to present more details on how the depth of field varies with camera settings.)

2. The motion began with the white ball at the bottom arriving at the scene. (We can only say this for sure if we know how billards works!) The white ball is not moving in the image, however. This is because it had already stopped by the time the camera shutter opened, because the white ball had hit another ball and transfered its momentum to that other ball. Which ball did the white ball hit? It hit the very motion-blurred ball in the middle. That middle ball is travelling up to the left, after hitting the black ball which headed toward the right. The black ball image hit the maroon (4) ball and put it into motion. All of these motions (except the white ball's) occured while the virtual shutter was open.

   The interesting part of this image is that some of the balls have three components to their image. For example, the black ball has a starting component which is still (and well defined), a brief middle component where the ball moves which gave rise to a motion blur streak, and a final compoent in which the black ball is still again after hitting the 4 ball and transfering its momentum to it.

   The 4 ball also has a strong static component in the image, which is from the time before it was hit by the 8 ball. Fun stuff!

3. Suppose you rotate the camera at a controled rate, and capture a photo during the rotation. The bright object will produce a motion blur in the image, since it will appear at different image positions during the exposure time. By a suitable choise of shutter speed and camera rotation speed, the exposure at each pixel in the motion blur can be reduced enough that the pixel is not saturated. i.e. value much less than 255, but well above 0. Knowing the camera response function and camera rotation velocity and the shutter speed, you could work out how long the source was over each pixel, and from the image intensity within blur streak of the source you could work out the intensity of the source.

4. One possibility is to use a log scale rather than a linear scale.

   Another possiblity, which is more common, is to use a representation akin to floating point. For example, there is a commonly used RGBE format , where RGB have 8 bits each and the E channel holds an 8 bit exponent. If the RGB values are interpreted as number between 0 and 1 (or 0 and 255), the exponent allows us to multiple the values by a power of 2. The same power is used for each of the RGB.

   Notice that this scheme takes a bit more space than RGB along, but not as much as if we went to just 12 bits per RGB channel. And the RGBE scheme gives much more dynamic range.

5. The question is asking, why is the ratio $\frac{max_{x,y} E(x,y)*t}{min_{x,y} E(x,y)*t}$ independent of t? The answer is that since the max and min operations are over (x, y) and $E(x, y)$ is independent of t, the t's factor out and cancel.

6. Since *log* is a strictly increasing function, the log of the max (or min) of a set of values is equal to the max (or min) of the log of the values. Thus,

$$\begin{aligned} & \log \frac{max_{xy}(E(x,y) * t)}{min_{xy}(E(x,y) * t)} \\ = \; & \log(max_{xy}(E(x,y) * t)) - \log(min_{xy}(E(x,y) * t)) \\ = \; & max_{xy}(\log E(x,y) * t) - min_{xy}(\log E(x,y) * t) \end{aligned}$$

   Note that the size of the blue interval in slide 34 doesn't depend on t since

$$\begin{aligned} & max_{xy}(\log E(x,y) * t) - min_{xy}(\log E(x,y) * t) \\ = \; & max_{xy}(\log E(x,y) + \log t) - min_{xy}(\log E(x,y) + \log t) \\ = \; & max_{xy} \log E(x,y) - min_{xy} \log E(x,y) \end{aligned}$$

   which is independent of t.