Shutter Efficiency and Temporal Sampling

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It is commonly acknowledged that the the instantaneous shutter model used in primitive rendering systems produces images which are unrealistic, and animate poorly. However the introduction of motion blur as implemented in most modern renderers uses a shutter model which is equally implausible. One of the few articles to examine this effect is [Glassner 1999], which considers the behavior of focal plane shutters. While the results obtained from the simulation of focal plane shutters are dramatic, more subtle and useful images can be obtained by considering the case of a leaf shutter, which is embedded within the lens elements.

1 Shutter Efficiency

It is recognized among photographers that a shutter takes a finite time to open, and an similar time to close. While this time may be negligible for small, modern shutters it can have a significant effect on the exposure when larger shutters are used at high speed. Unlike Glassner's focal plane shutters, shutters at the focal point of the lens expose all parts of the negative simultaneously, and equally. However as the shutter is not fully open for the entire exposure, the result is a reduction in light reaching the negative, and this is expressed as a percentage of the exposure that would have been produced by a theoretically perfect shutter.

As the exact behavior of the shutters iris is difficult to model, the aperture as a function of time is typically drawn as a trapezium (figure 1). In the limiting case where the shutter reaches full aperture just before starting to close, the exposure is reduced to 50% of that from a perfect shutter.

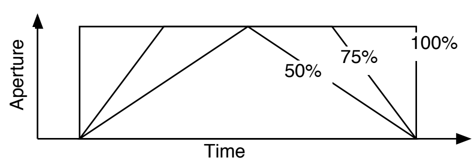

Figure 1: Shutter Efficiency

2 Motion Blur

The concept of shutter efficiency can by applied to synthetic motion blur in rendered images by simply weighting temporal samples towards the center to the shutter time, rather than spreading them equally as is typically done. This can be trivially implemented in both ray-tracing and Reyes style rendering systems without performance cost. A comparison of the two shutter models is shown in figure 2. The image rendered with 50% efficiency is both more clearly defined, and softer. The sudden opening and closing of the shutter in figure 2a introduces artifacts which are removed in figure 2b.

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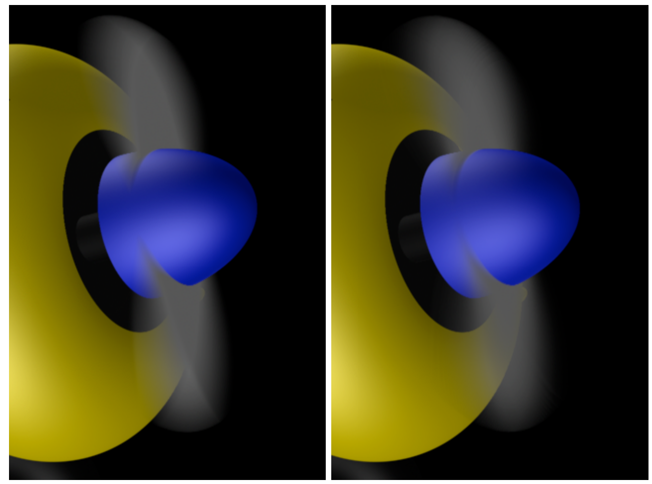

Figure 2: a) 100% Efficiency b) 50% Efficiency

3 Temporal Sampling

The results in figure 2 are simply explained by considering the shutter's aperture/time curve as a sampling kernel. The 100% efficient shutter model in common use is equivalent to a box filter. When used spatially these are recognized as over blurring the image, while at the same time allowing unwanted high frequency artifacts to persist. While still far from ideal, the 50% efficient shutter acts as a tent filter which introduces significantly less blurring, and performs noticeably better at removing high frequency artifacts. The filters behave the same way in the temporal domain as they do in the spacial.

When used correctly for animation, the tent filter requires a larger support than the box filter — that is it requires samples outside of the original shutter time. This can easily be achieved, simply by overlapping the shutter times for consecutive frames. It would in principle be possible to extend the principle of temporal sampling to more complex kernels such as Gaussian or Sinc. However these require infinite (or at least very large) shutter times, and the motion of the subject may not be well defined over large intervals of time.

4 Conclusion

While the concept of shutter efficiency has been discussed previously within the field of computer graphics, it's aesthetic significance has not been recognized. Improving temporal sampling can have a dramatic effect upon the rendered image. Just as spatial filtering is an essential requirement of a high quality rendering system, so temporal sampling must also be considered.

GLASSNER, A. 1999. An open and shut case. *IEEE Computer Graphics & Applications*, 19(3), May 1999.