High Dynamic Range Simulation of Multifocal Lenses

Jim Schwiegerling
College of Optical Sciences
University of Arizona
Tucson, Arizona, USA
Motivation

- Multifocal and Extended Depth of Field lenses create design dependent visual artifacts.
- Understanding the root cause of these artifacts is beneficial for
  - Patient education
  - Design optimization
  - Objective comparisons between existing designs
- The visual artifacts are most obvious under conditions with an bright source against a dark background
- Simulating these high contrast scenes is challenging because
  - Common image formats are typically limited to 256 luminance levels.
  - Standard displays are typically limited to 256 luminance levels.
  - Non-linearities in the response of the retina.
  - Localization of retinal response.
BMP and JPEG are typically used to represent 24-bit (8-bit per color channel) images. This represents at best 2.4 orders of difference between the darkest and lightest portions of the image.

There is typically 6 or more orders of luminance in this class of image.

There is also a non-linear compression of the luminance in these images that tend to clip the bright and dark regions to keep the mid-tones roughly linear.
Most DSLRs also enable images to be saved as RAW files. These are typically 10-bit (3 orders) or 12-bit (3.6 orders) linear images that can represent a higher dynamic range, but still tend to saturate for typical light sources.
In HDR imaging, multiple exposures are typically taken of a static scene. Based on the exposure time, pieces of the scene that are properly exposed can be picked out and placed in a composite image.
Images are stored as RGB values plus a common exponent that scales these values to different orders of magnitude.

Radiance HDR files are fairly common these days for HDR Images.

One new issue is that many of them are in 360° spherical panoramas.

This image has luminance values ranging from $10^{-4}$ to $10^4$. 

https://www.hdri-hub.com/free-hdr-city-night-lights
Unwrapping Spherical Panoramas

The spherical panorama maps the surface of a sphere to a 2D image. To remove distortion in a conventional flat image, we need to take a plane tangent to the sphere and find the correspondence between pixels on the plane and pixels on the sphere.
For the PSF, we often know the lens design, so the PSF can be calculated mathematically and is automatically high dynamic range.

If PSF is measured directly, the high bit depth camera is needed.
Tone mapping is a non-linear process of compressing the HDR image back down to 8-bits per color channel.

Global tone mappers are applied to the entire image and necessarily clip the bright and dark portions of the image.

Local tone mappers adapt to the local luminance levels and operate much more like the retina.
Summary

- Most standard images like bmp and jpg and even RAW images are not suitable to simulating scenes with high dynamic range content.
- HDR images preserve the full range of luminance levels, but are limited to static scenes.
- Lens design must be known or high bit depth camera are needed to accurately measure the PSF of multifocal lenses.
- Tone mapping should use local operators to mimic retinal processes.
- Validation techniques are needed.