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PSFs and Bokeh

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Computational Photography, Sept. 28, 2011

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Computational Photography

- About using cameras to capture data for computational processing, rather than making a pretty image on the sensor...
  - Multispectral image processing
  - New camera/sensor models
  - Intelligent computer control of capture
  - Detection/manipulation of image properties

Spring 2009, EE499

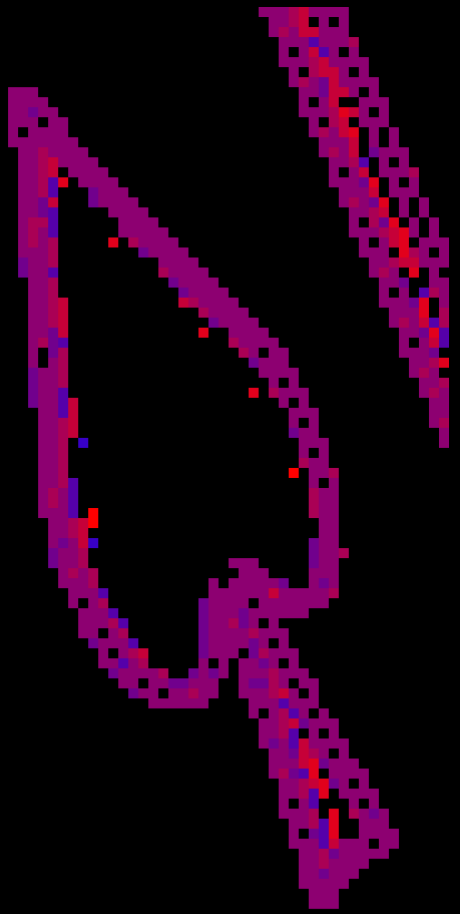
- Jennifer Danhauer, Joe Lanford, Ross Levine
- Project to capture a depthmap inside a Canon PowerShot using depth-from-focus
- CHDK scripting used so single press captures a sequence with different focus distances
- CHDK processing modified with custom C code to measure blur & combine images
- Blur measurement was fairly state-of-the-art

Measuring Focus Blur

- This is how contrast-detect autofocus works
- Various algorithms in the literature for determining local contrast between pixels... Sobel worked best
- Actually done on raw sensor data using just the green pixel values (they have less noise)
- Limited memory in camera... some cleverness to avoid keeping N images in memory

How Good Is The Depthmap?

- Accurate depths at edges
- No depth in featureless fields
- Wrong depths near edges!
  - Wrong by a lot
  - Wrong both directions
  - Seems to “echo” edges



What Went Wrong?

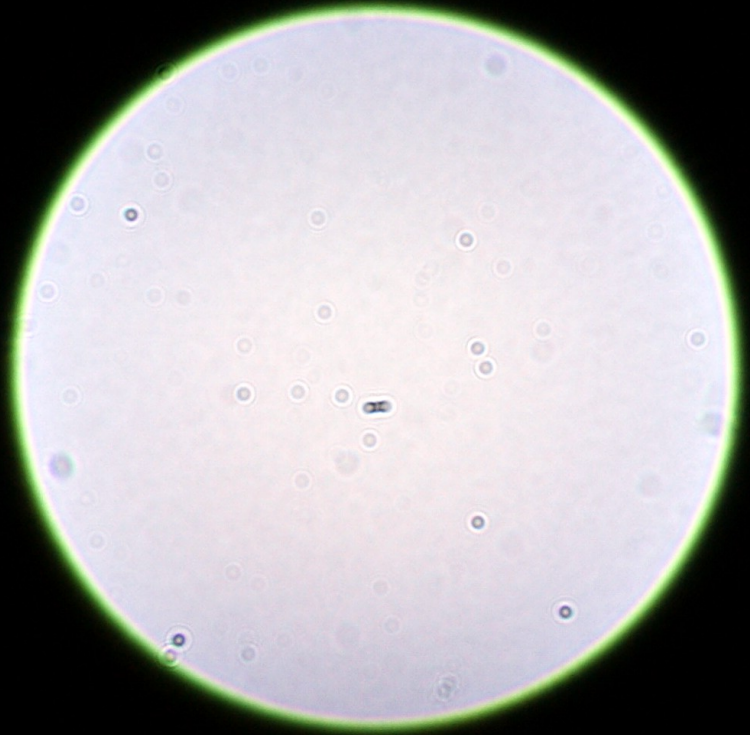
- What does an out-of-focus (OOF) point light source - point spread function (PSF) – look like?

What Went Wrong?

- Most image processing algorithms treat OOF point light sources as Gaussian blur:

They Look Like This

- Note the sharp edge!

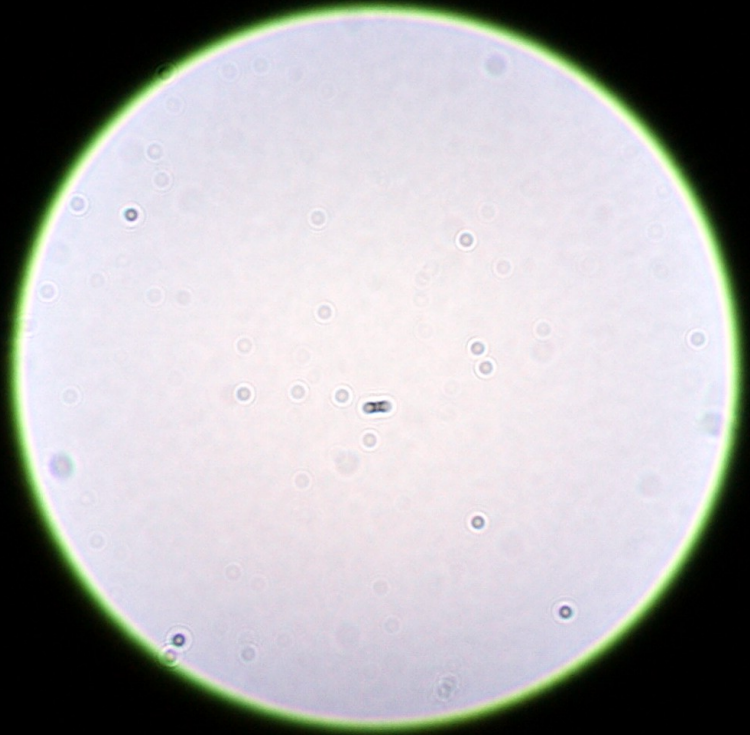


Point Spread Function (PSF)

- Describes the response of an **imaging system** to a point source (impulse response)
- The spatial domain representation of the Modulation Transfer Function (MTF)
- An image is essentially the sum of the PSFs of all points of light in the scene
- PSF size grows in proportion to how OOF

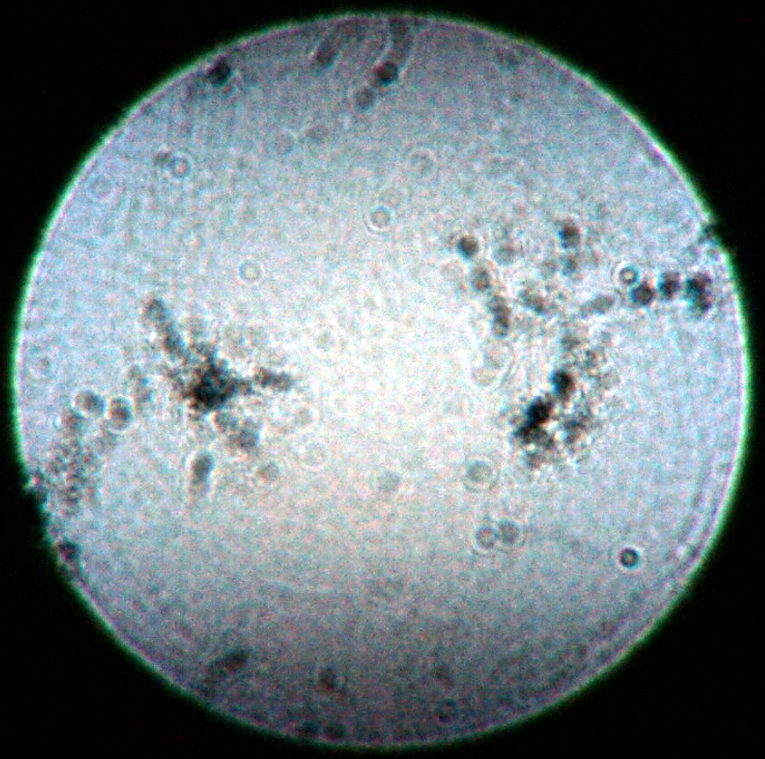
The Wrong PSF Model!

- But an OOF point light source imaged by a real lens (Takumar 135mm f/2.5) looks like:



Each Lens PSF Is Unique

- For a Minolta 50mm f/1.7 with barely visible fungus it looks like this:

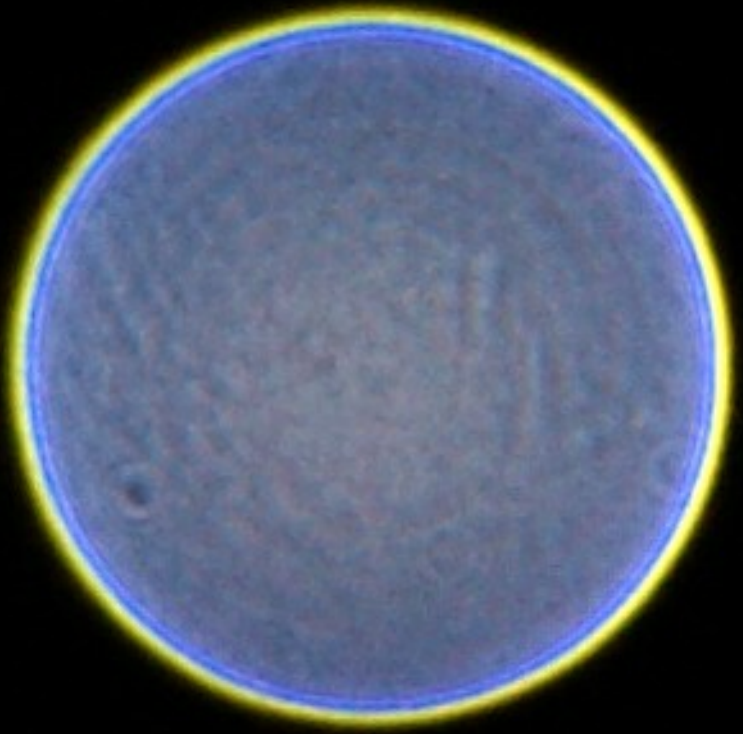


Optical Formula Affects PSF

- For my Sony 18-70mm zoom at 18mm f/3.5 the PSF looks like this:

A Simple Retrofocus Lens PSF

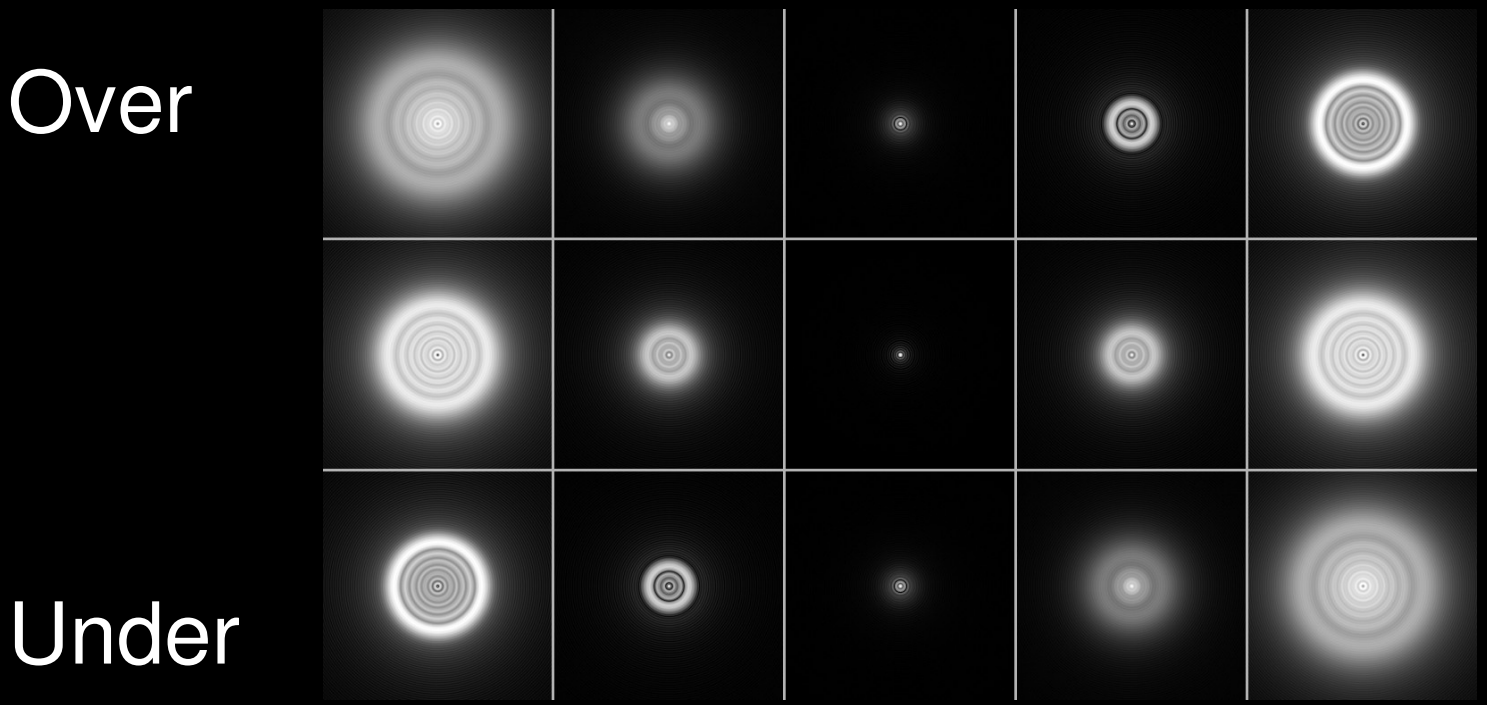
- For my Vivitar 28mm f/2.5 it looks like this:



A Classic Mirror Lens PSF

- For my Bower 500mm f/6.3 mirror lens the PSF looks like this:

PSF with Spherical Aberration



Axial Chromatic Aberrations

Cat's Eye / Swirl Vignetting

Symmetric Near & Far

- Before and after focus are inverses
  (no, they are not ambiguous!)
- Funny things happen around focus
  - Different colors in focus at different depths
  - Partial “inversion” of pattern

Computational Photography Using PSF Structures

- After characterizing 100+ real lenses...

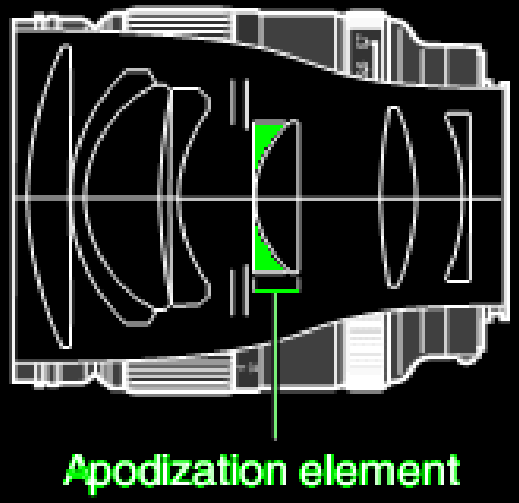
- Depth-from-focus/defocus, refocus/all-in-focus
- Diagnose lens defects like contamination and fabrication flaws (e.g., decentering)
- Forensically identify the type of lens
- Forensically identify the specific lens
- PSF substitution
- Structured apertures & apodization

Bokeh

- Japanese-derived word for the general properties of OOF regions
- Good bokeh come from Gaussian blur PSFs
- Nisen bokeh – double line artifacts

Minolta's STF (Smooth Trans Focus)

- The Sony/Minolta 135mm f/2.8 t/4.5 STF incorporates an apodizing element



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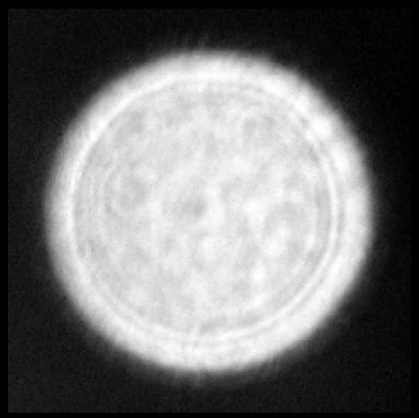
Minolta's Maxixum 7 STF Mode

- Fakes apodization using multiple exposures!
- Here's my version using CHDK:

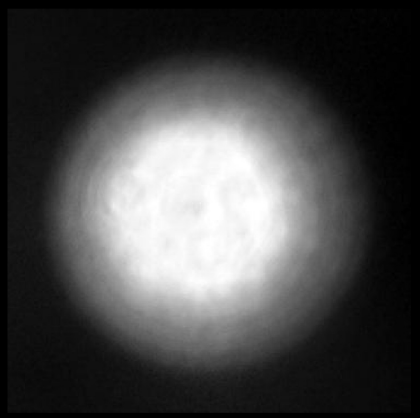
Bokeh Apodization Test, Aug 14, 2009

(bokeh apodization by dynamic variation of aperture)



Native PSF at F4

Gaussian PSF by invention



Manually set PSF by invention

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PSF Substitution

- Commonly attempted for image refocus
- Can improve image Bokeh by replacing native PSF with a Gaussian blur (or other) PSF
- Can directly synthesize “3D” stereo pairs and enhance their apparent depth – more on that next lecture!