Blur Calibration for Depth from Defocus

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Defocus Blur Model

Geometric Model for Point-Spread Functions

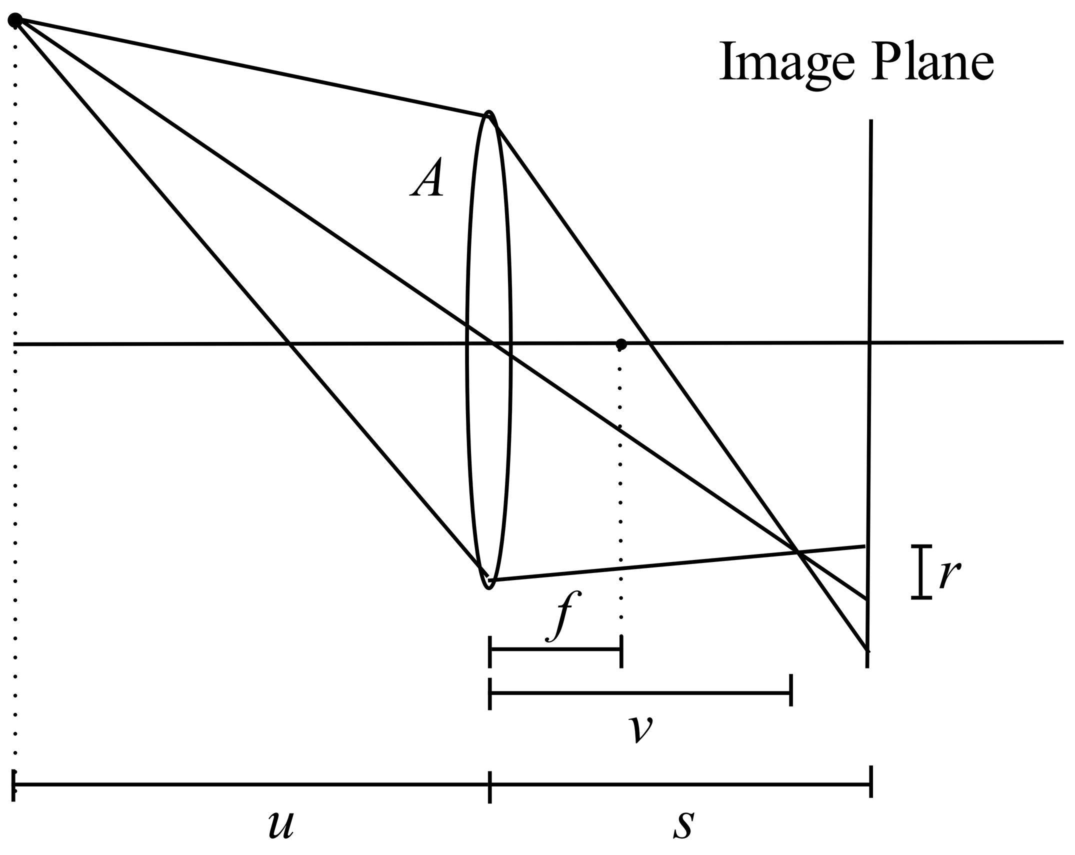


Figure 1: Defocus blur formation.
Blur radius, $r = \frac{As}{2}\left(\frac{1}{f} - \frac{1}{u} - \frac{1}{s}\right)$.

Blurred Image Formation Model

$$i = i_{latent} * h(r) + \mathcal{N}(0, \sigma_n) \quad (1)$$

Relative Blur between Defocus Pair

$$i_{blurrier} = i_{sharper} * h_R + \mathcal{N}(0, \sigma_n) \quad (2)$$

Proposed PSF Estimation Model

$$\underset{h}{\text{argmin}} \sum_{j=1}^{n} \lambda_j \| f_j * (i_S * h - i_B) \|_2^2 + \lambda_{n+1} \|\nabla h\|_2^2 + \lambda_{n+2} \|R \circ h\|^2 \quad (3)$$

subject to $\|h\|_1 = 1\,,\ h \geq 0.$

where f_js are different filters, and R is a spatial prior.

Calibration Pattern We use a grid of disks to avoid point source issues such as: finite size and long exposure time. It also allows estimating blurs for both Eq. 1 and 2.

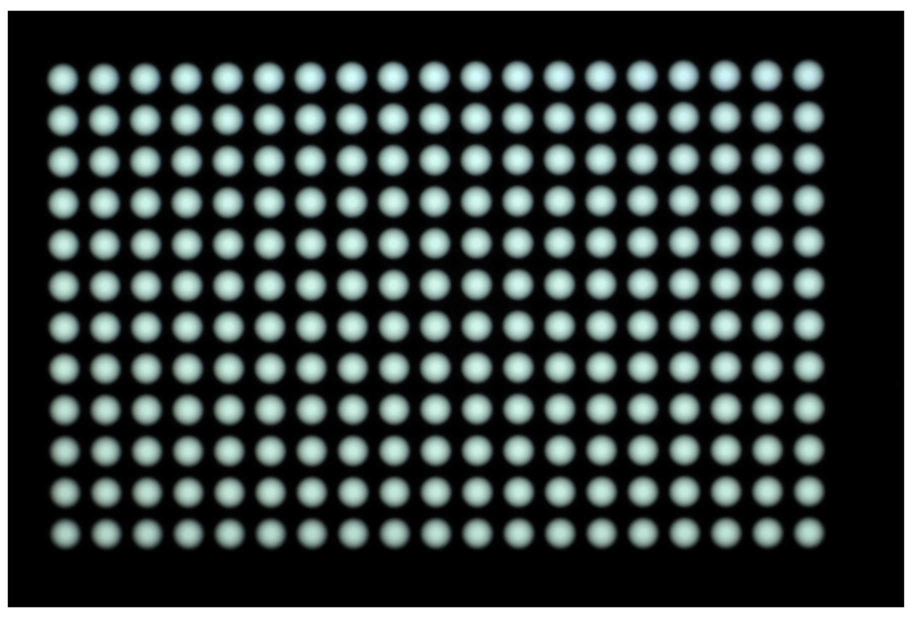
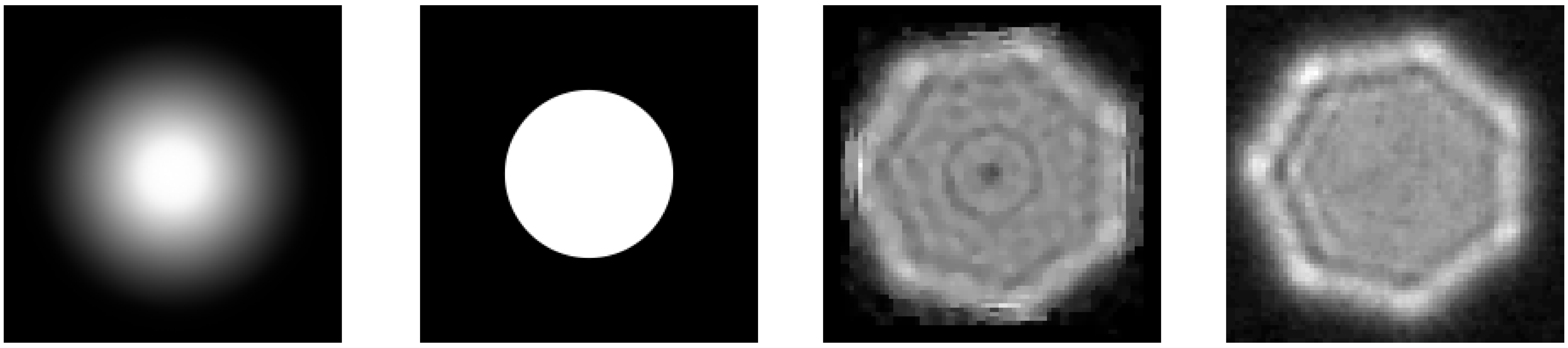


Figure 2: Calibration pattern observed by a defocused camera.

PSF Estimation Overview



a) Observed blurred disk image b) Estimated sharp disk c) Estimated PSF from (a) and (b) d) Observed point source

Figure 3: Steps in PSF estimation involves (a) taking an observed defocused disk image, (b) estimating the latent sharp image, and c) using Eq. 3 to estimate the PSF. (d) Image of corresponding single pixel. Note the reconstructed aperture shape, and diffraction effects in the estimated PSF (c).

PSF Evaluation (for Eq. 1)

Observed image of a single display pixel | Estimated PSF from defocused disk images

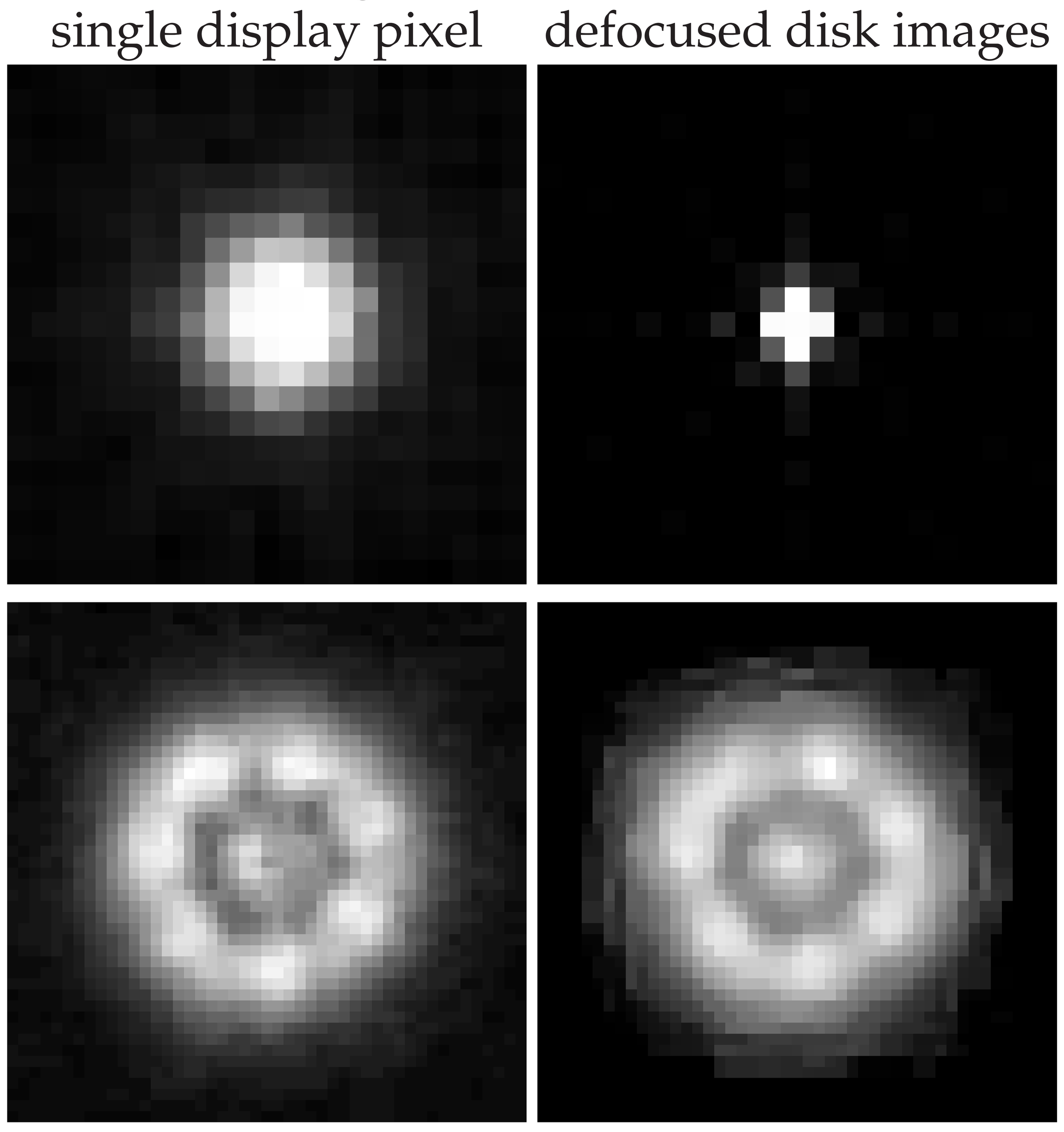


Figure 5: Examples of PSFs when in-focus (top row) and out-of-focus (bottom row). Top row taken with $f/11$ at distance 1.5 m and focused at 1.5 m. Bottom row with $f/22$ at distance 1.5 m and focused at 0.5 m. Focused images of single pixels may not be sharp (top-left) but our approach produces sharper PSFs (top-right). Our approach can also capture various diffraction effects as can be seen in the bottom row.

Relative Blur PSF Evaluation (for Eq. 2)

Sharper PSF | Blurrier PSF | Relative Blur | Reconstruction

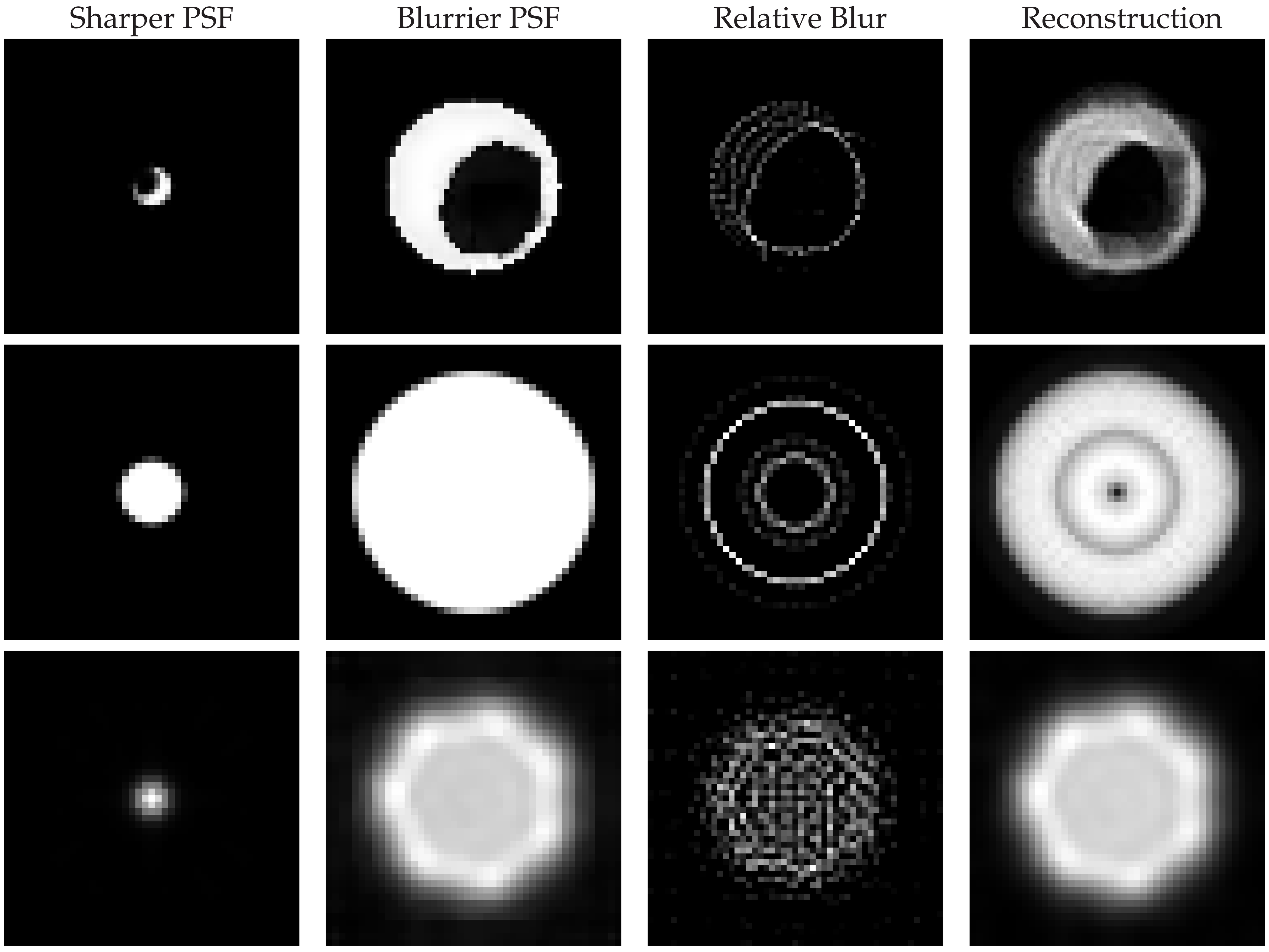


Figure 4: Examples of relative blur estimated from a pair of coded apertures (first row), pillboxes (second row), and real PSFs (last row). We evaluate quality by reconstructing the blurrier PSF from the sharper PSF using the estimated relative blur (fourth column).