Laser Beam Shaping with Membrane Deformable Mirrors

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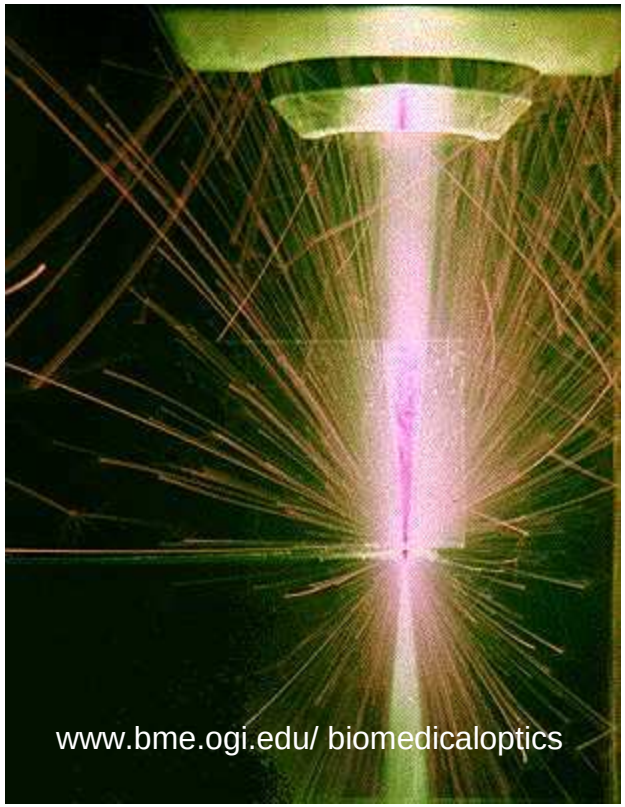
Outline

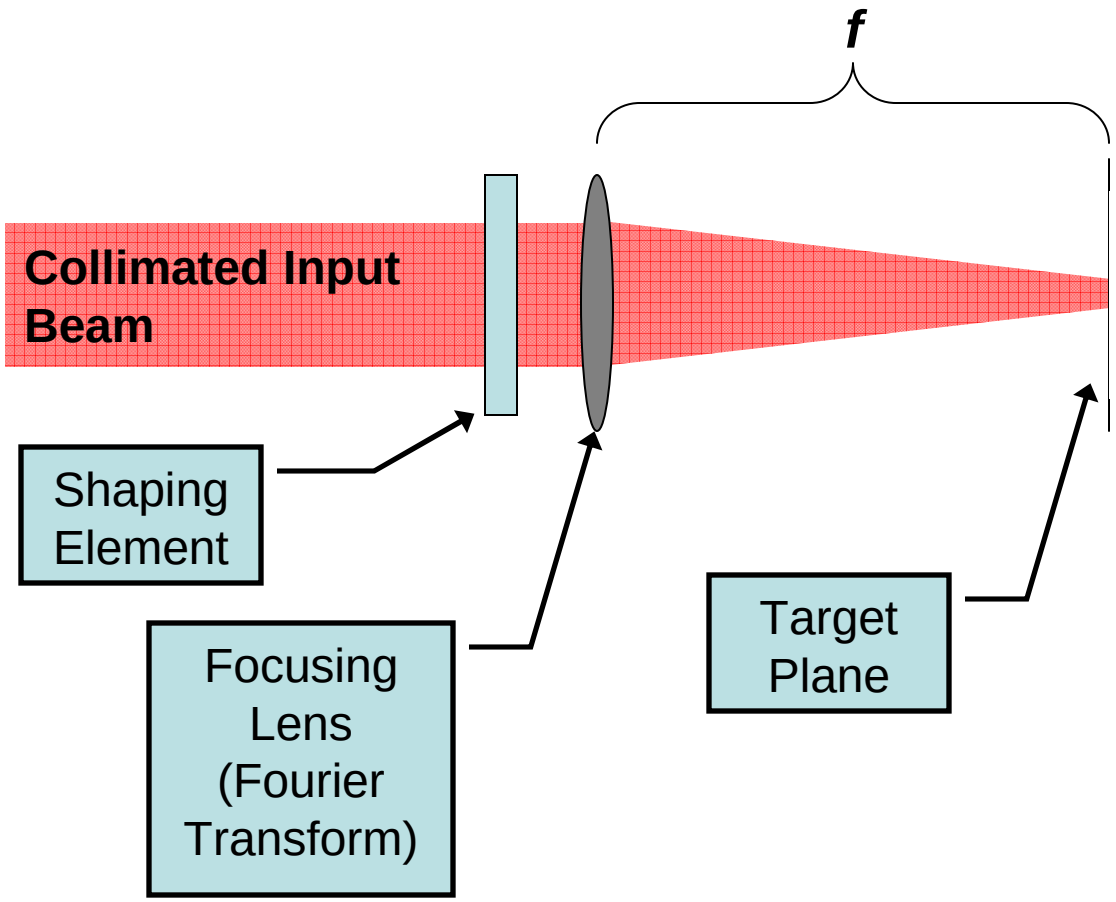
- Introduction and Motivation
- Approach
- Beam Shaping Demonstration
- Conclusions and Future Work

Laser Beam Shaping

- The process of remapping the intensity profile of a laser beam
- Beam shaping tasks are common in many industrial applications
  - Laser Machining
  - Photolithography
  - Medical Applications

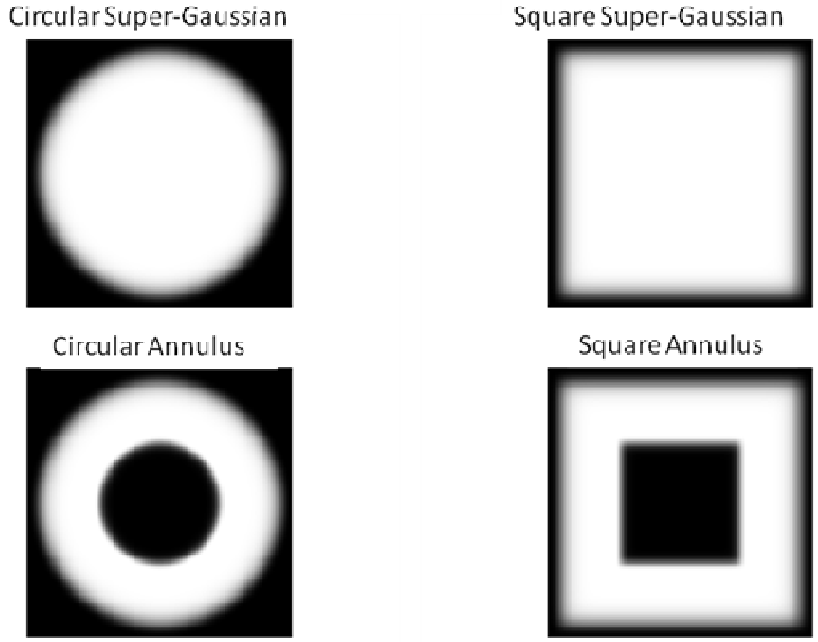


Simple Beam Shaping System



Goal

- Attempt to shape beam into four shapes commonly used for industrial applications using a low cost polymer membrane deformable mirror

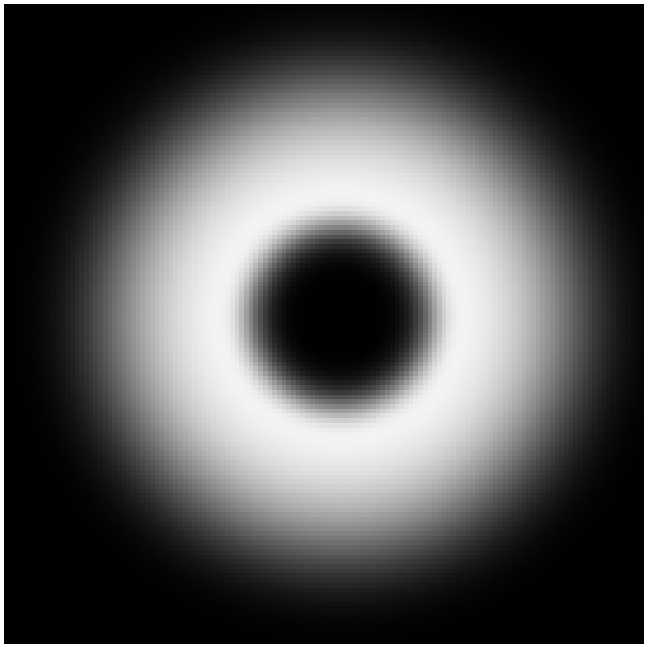


Approach

Metric AO Beam Shaping

Metric AO

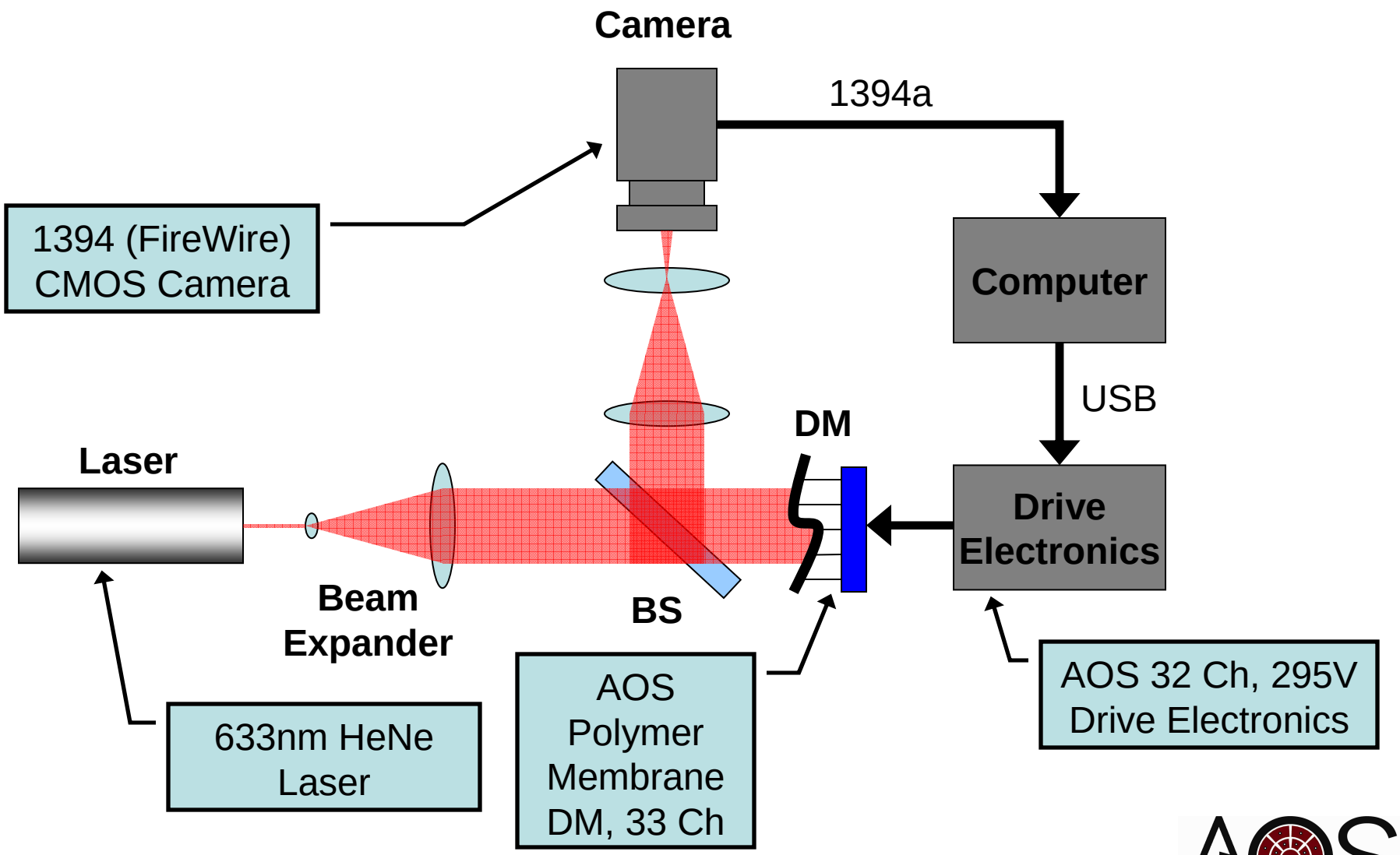
- Sometimes called Target-in-the-Loop AO or stochastic AO
- Adjust DM actuator commands to optimize some metric
  - Spot Size
  - Intensity
  - Sharpness
  - **Shape**



Adaptive Optics

- Using an adaptive optics system to shape a beam has several advantages:
  - Desired shape can be easily changed
  - Static aberrations in the system can be corrected while shaping the beam
  - Beam shaping can be accomplished with non-ideal (non-Gaussian) input beams.
  - Rejection of some non-common path (non-sensed) aberrations

Experimental Setup



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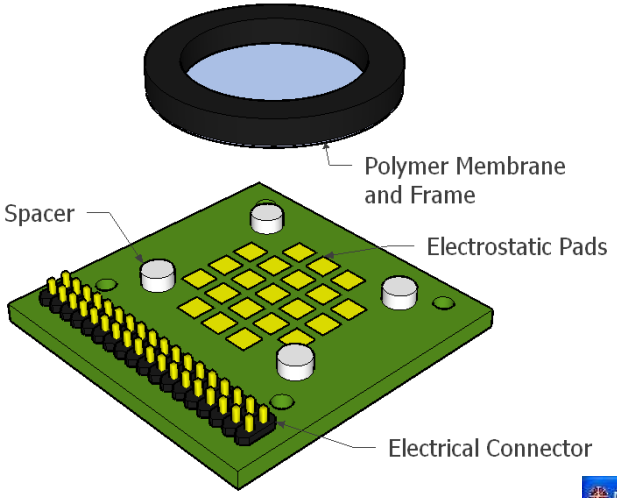
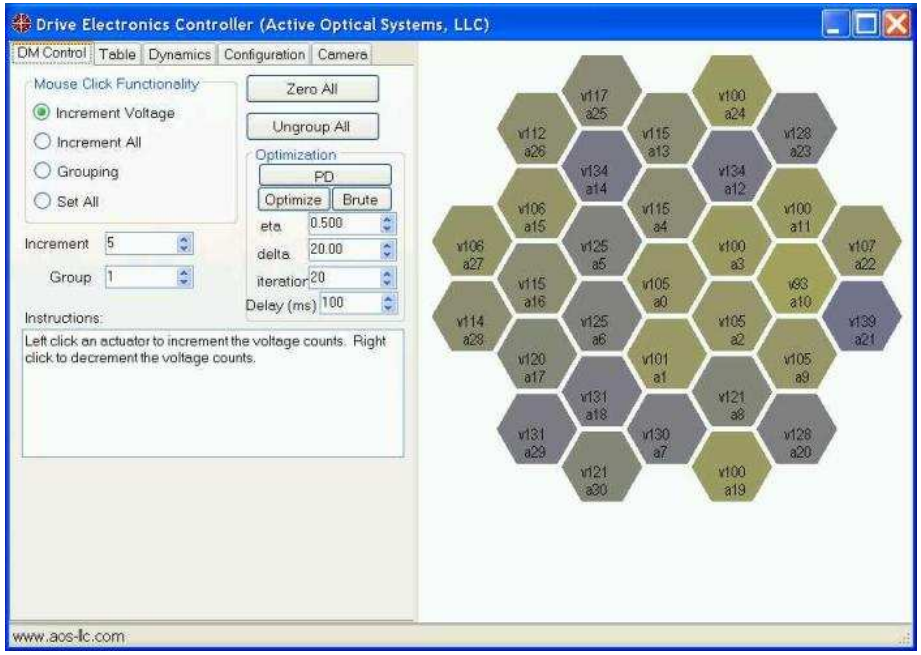
AOS Metric AO System

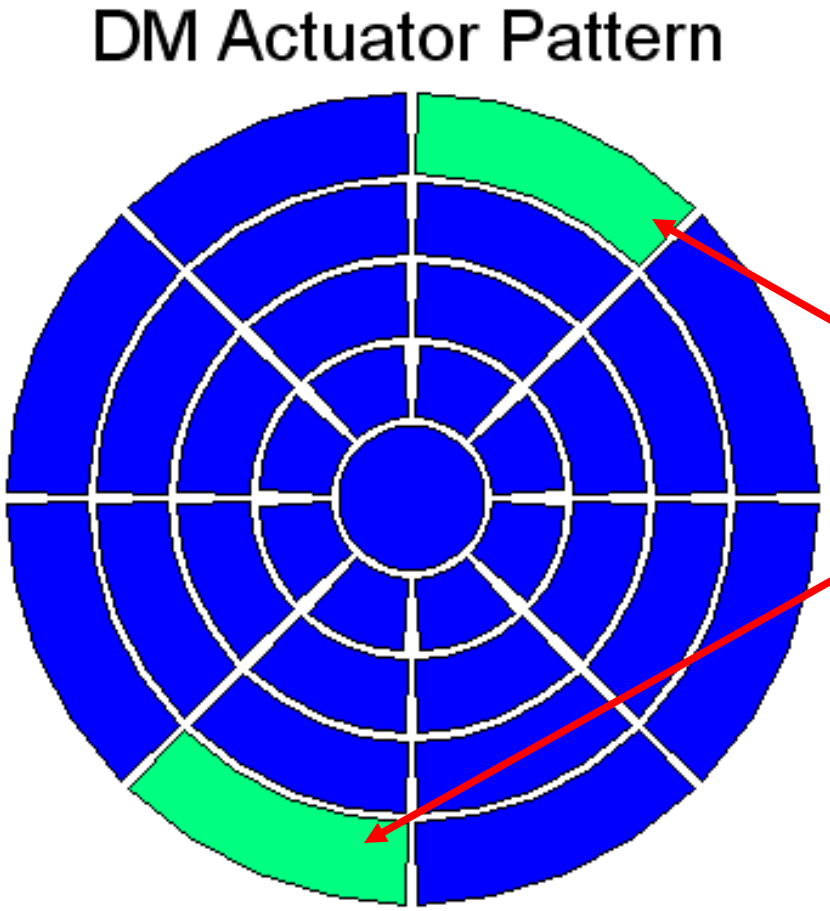


1” DM Characteristics

- ~500 Hz first mechanical resonance
- Continuous surface capable of HR coating
- 10µm of throw at 300V



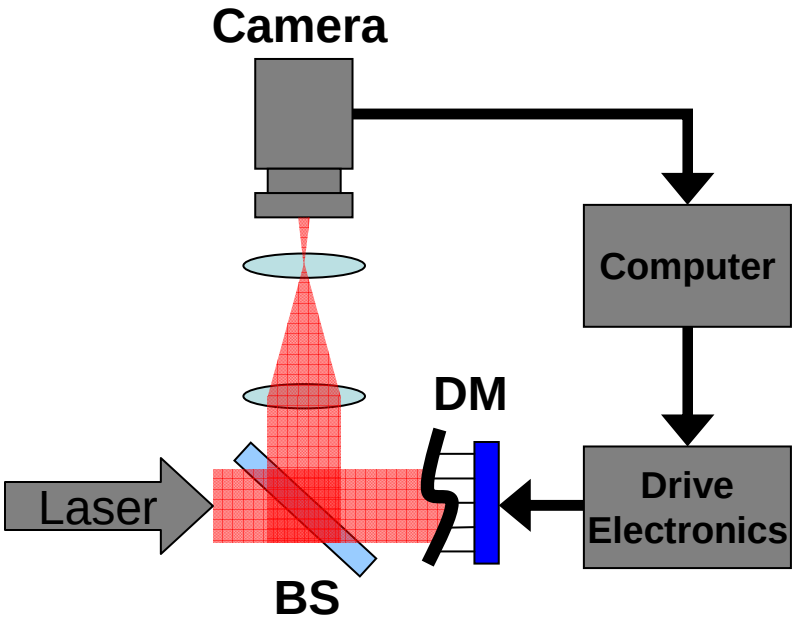
33 Actuator DM



These two actuators are tied together to reduce channel count to 32

Shape Metric AO

1. Measure far field shape *M*
2. Compute far field shape centroid *C*
3. Center desired shape *D* on computed centroid *C*
4. Compute merit function *F(c)*
5. Update DM commands according to GESA



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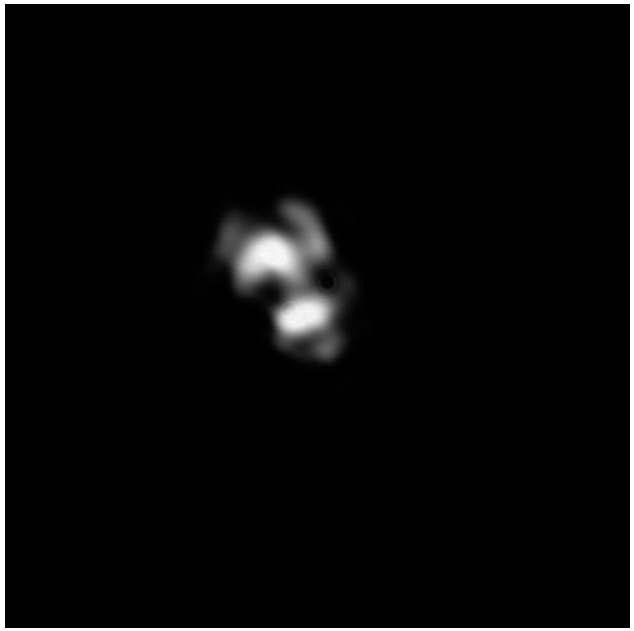
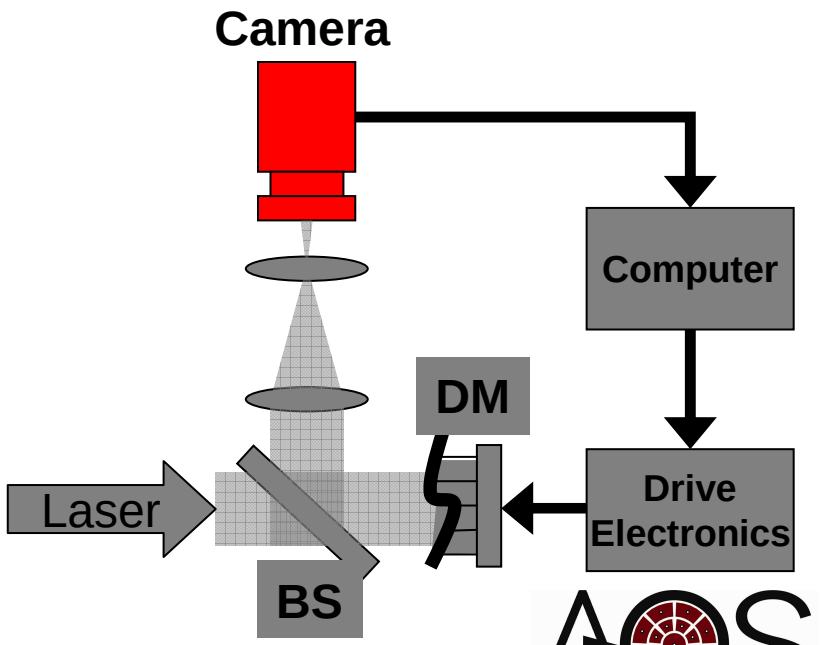
1. Measure Far Field Shape





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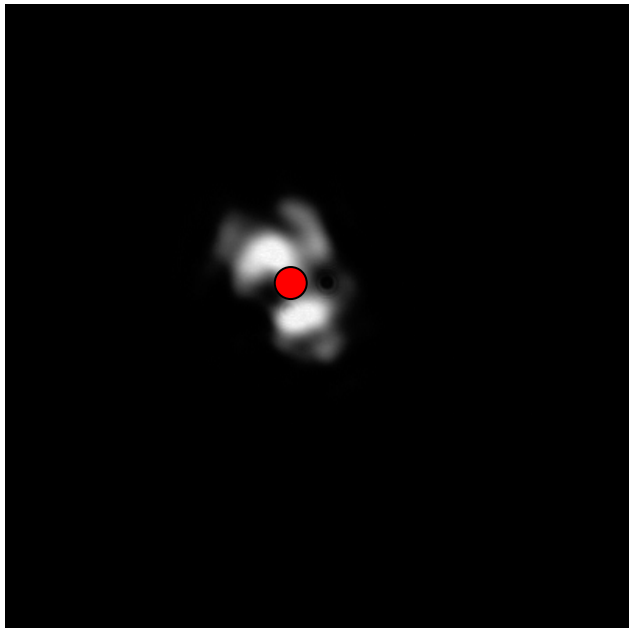
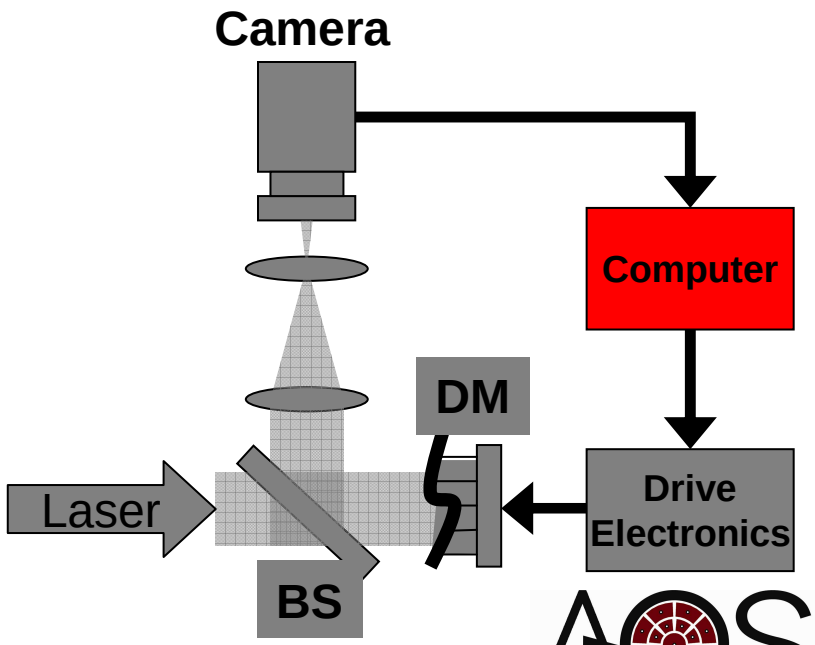
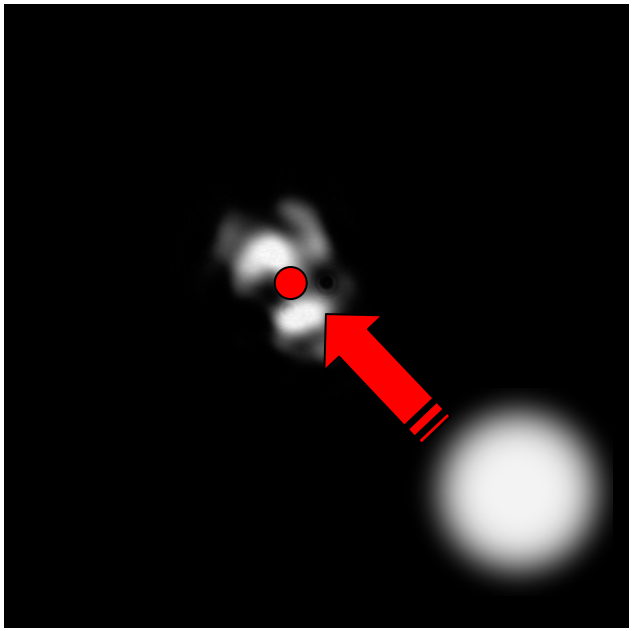
2. Compute Centroid

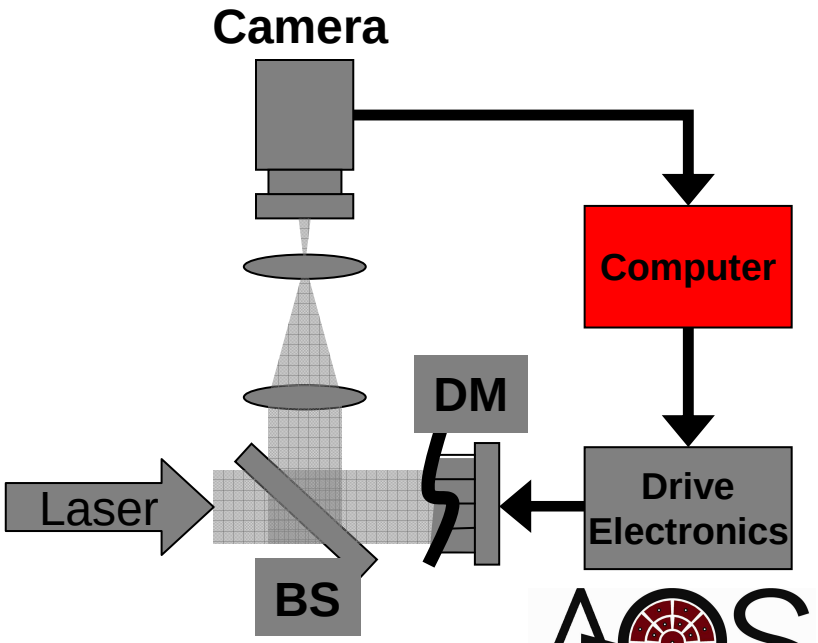




3. Re-Center Desired Shape on Centroid



Re-Centering the desired shape over measured shape removes the effect of global tilt from the optimization



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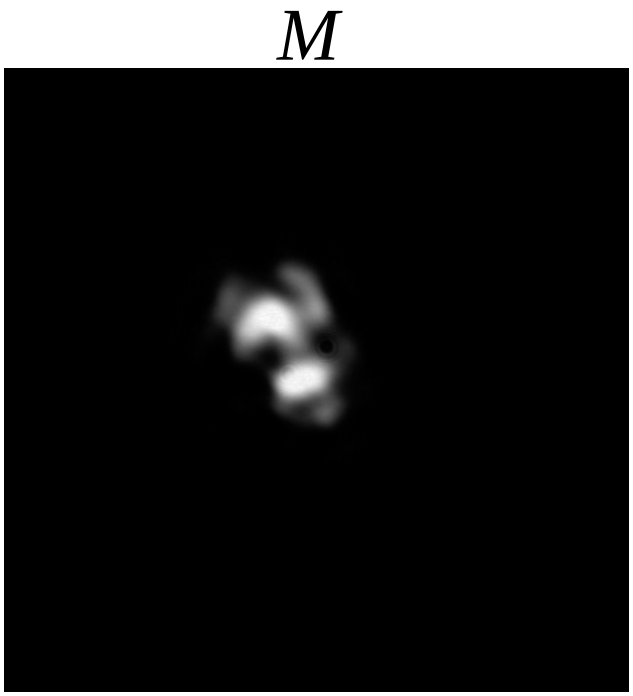
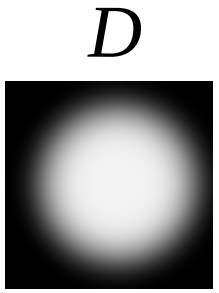
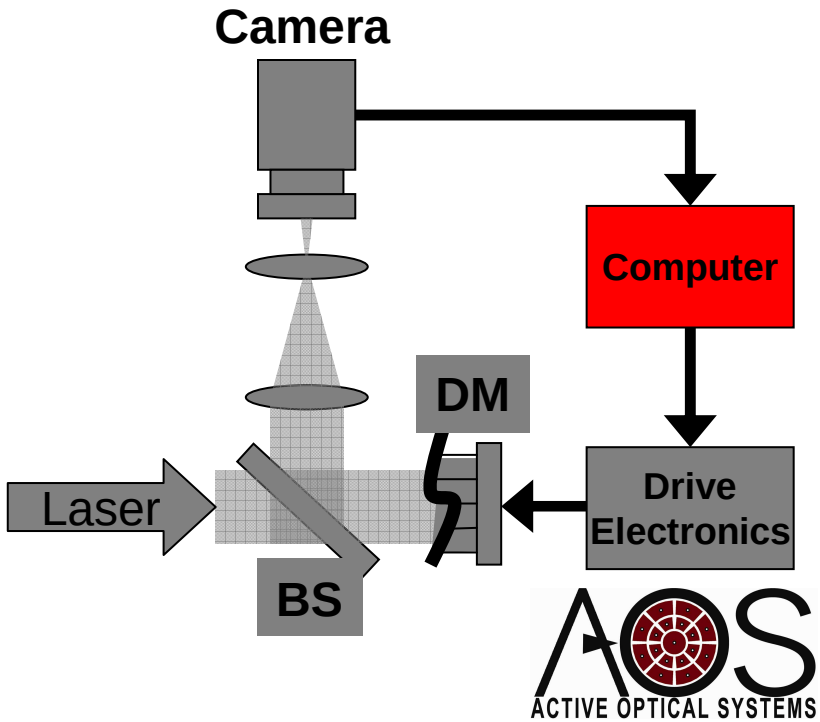
4. Compute Merit Function





$$F(\vec{c}) = \sum_x \sum_y \left| M(\vec{c}, x, y) - D(x, y) \right|$$

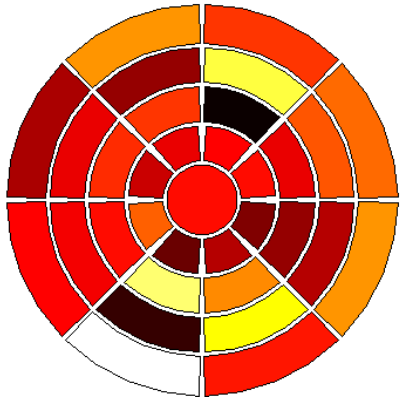


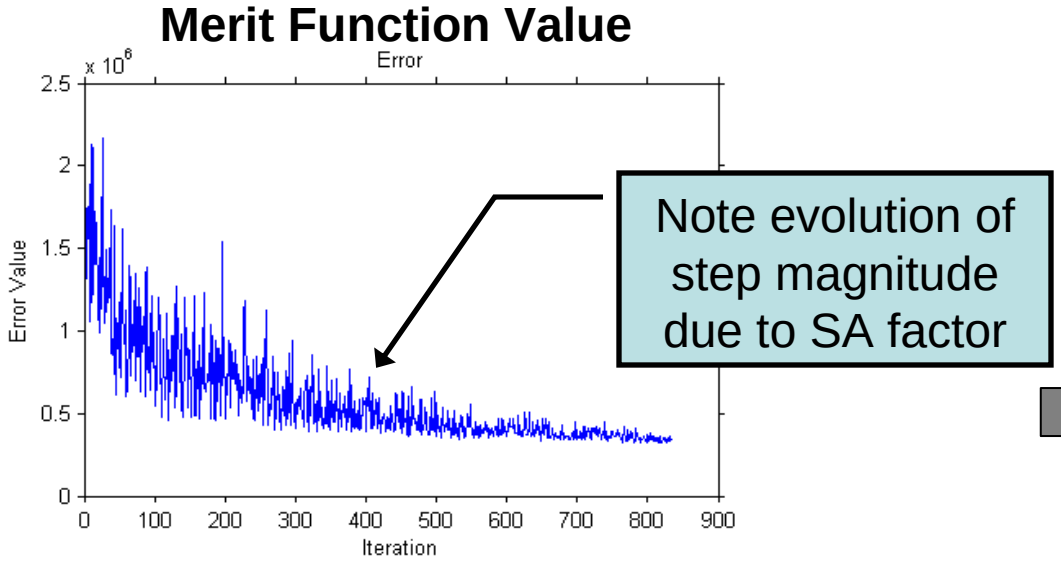
5. Update DM Commands According to GESA

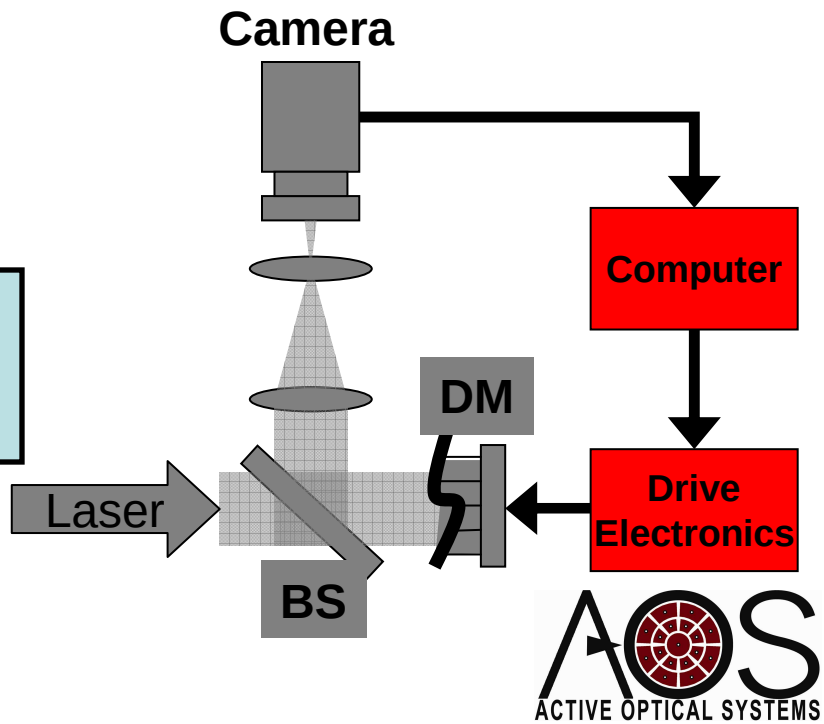
Guided Evolutionary Simulated Annealing

GESA is very robust to errors in the experiment such as frame delay and finite response time of the mirror

We have also coded SPGD, SAS, and Axial Searching algorithms in our metric AO software







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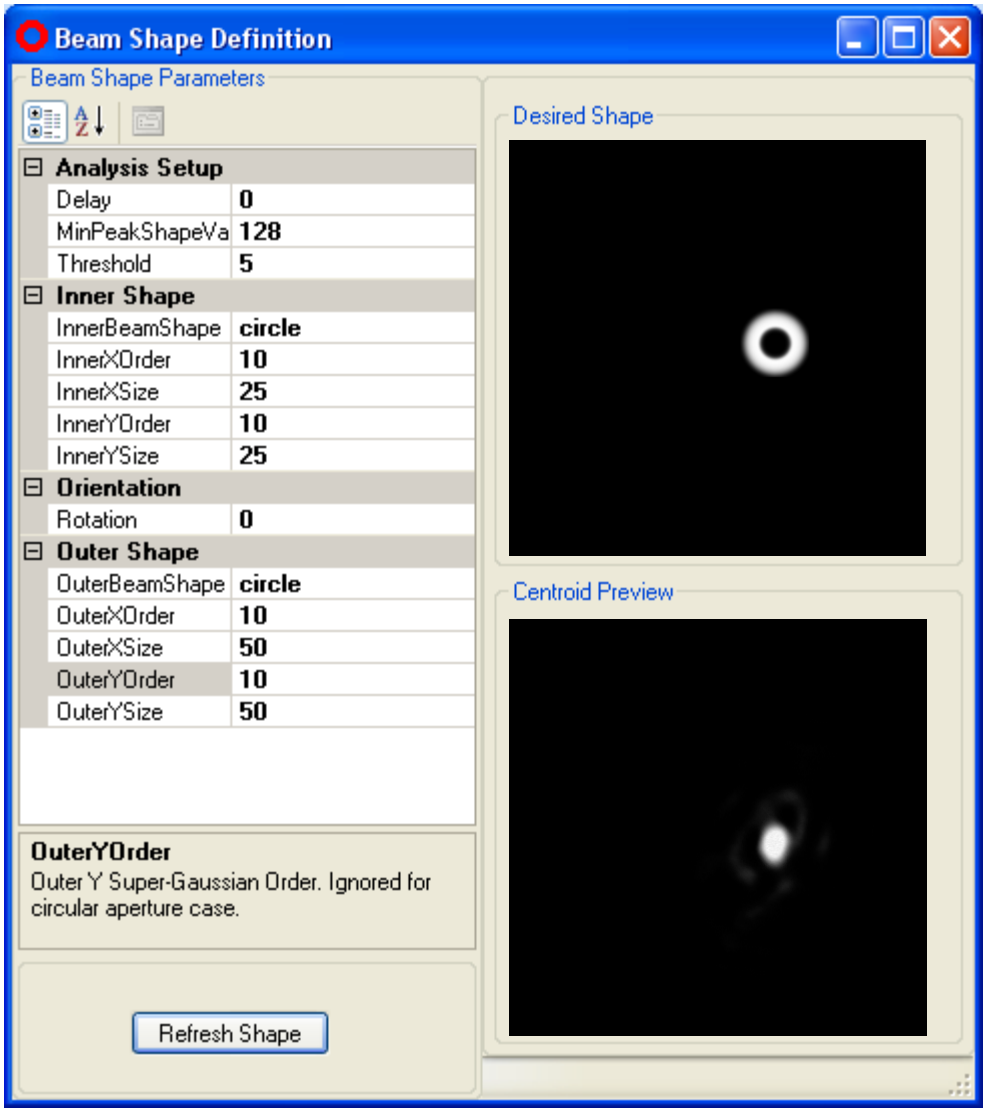
Shape Definition GUI



$$S_{elliptical}(x,y) = Ae^{-\left[\left(\frac{x}{x_s}\right)^2+\left(\frac{y}{y_s}\right)^2\right]^{\frac{n}{2}}}$$

$$S_{rect}(x,y) = Ae^{-\left[\left(\frac{x}{x_s}\right)^{n_x}+\left(\frac{y}{y_s}\right)^{n_y}\right]}$$

$$D(x,y) = S_O(x,y) - S_I(x,y)$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

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Experiment Initialization

- We found it useful to initialize each experiment by running the Metric AO system to obtain the smallest focused spot on the camera

$$F(\vec{c}) = \frac{\sigma_x + \sigma_y}{2}$$

Second Central Moment

$$\sigma_x^2 = \frac{\iint (x - x_0)^2 I(x,y)\,dx\,dy}{\iint I(x,y)\,dx\,dy}$$

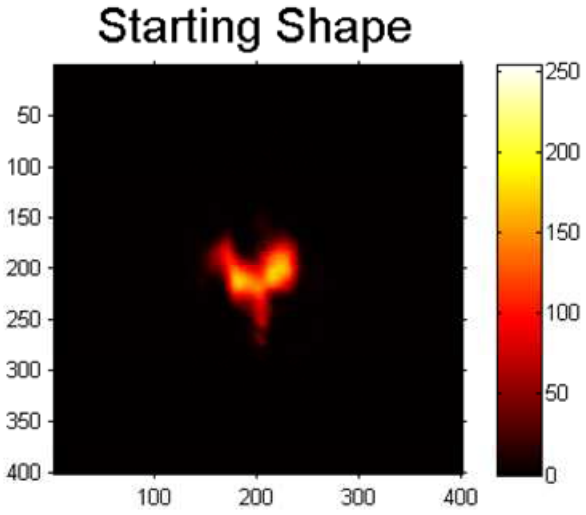
$$\sigma_y^2 = \frac{\iint (y - y_0)^2 I(x,y)\,dx\,dy}{\iint I(x,y)\,dx\,dy}$$

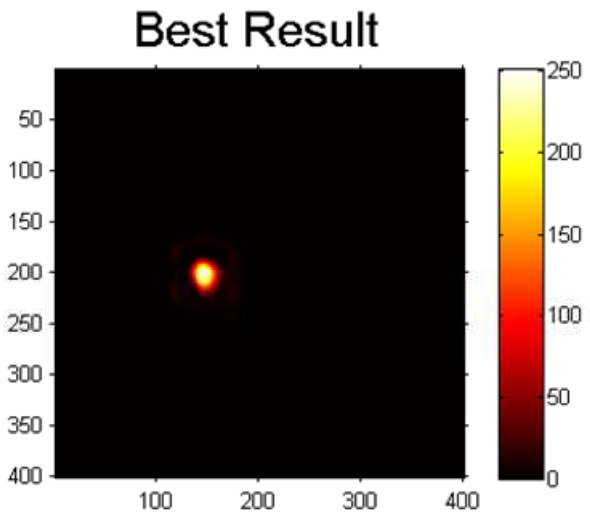
where

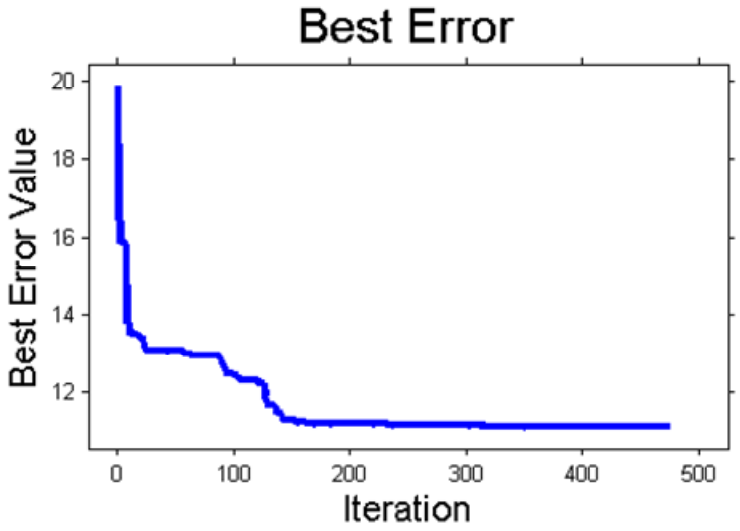
(x_0, y_0) = Beam Center

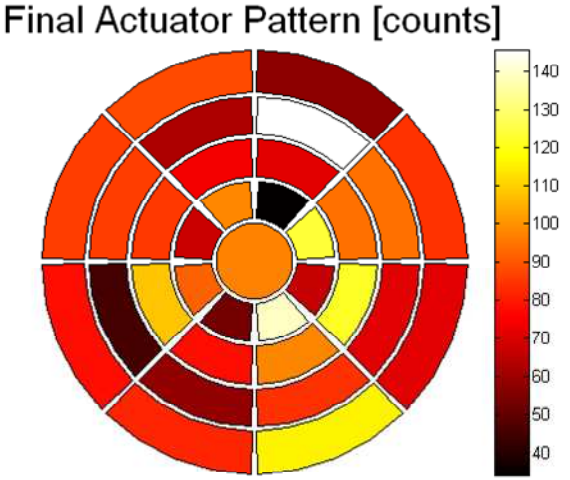
$I(x,y)$ = Irradiance Profile

Experiment Initialization









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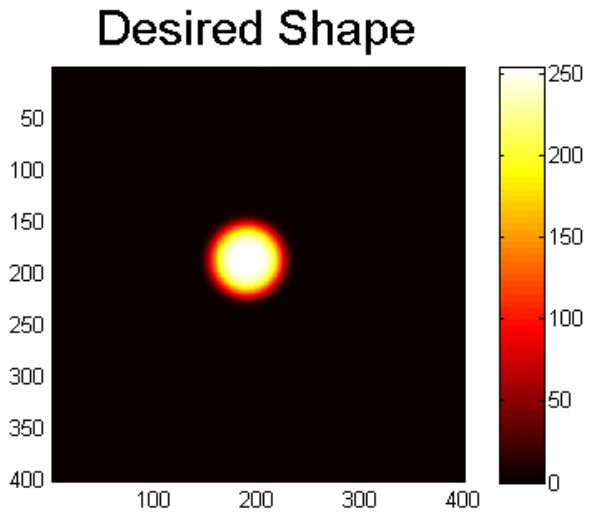
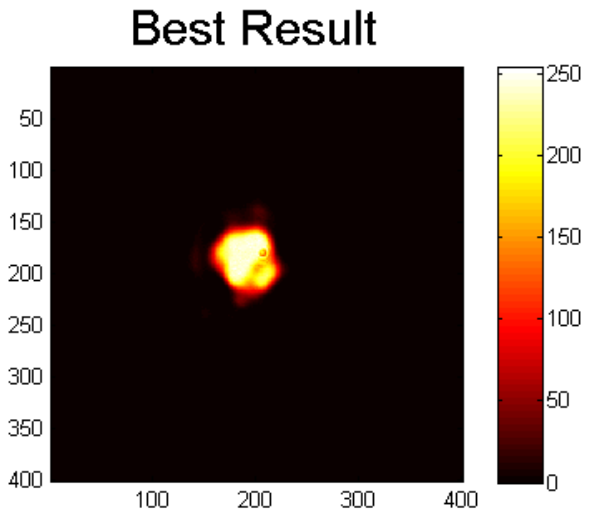
Results

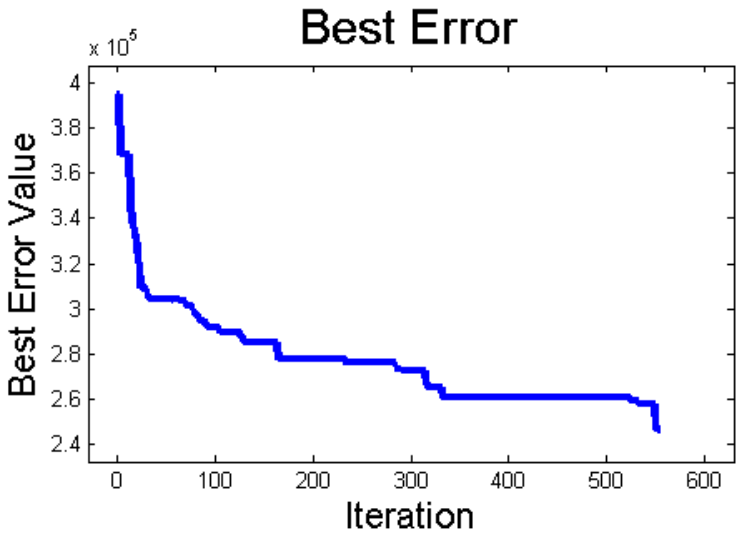
Experiment Specifics

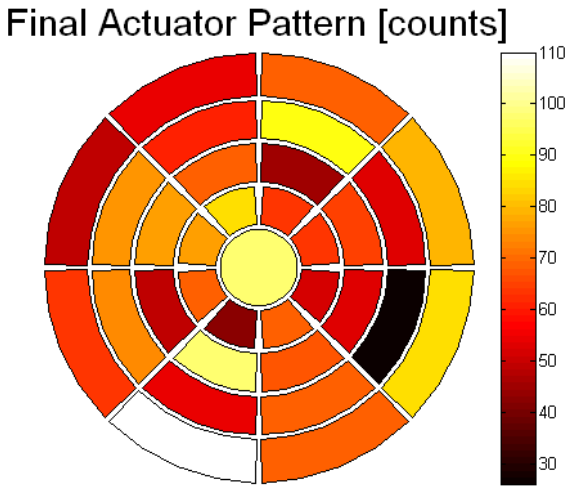
- Feedback image size: 400X400 pixels
- Frame-rate (with processing): ~10Hz
  - Recent improvements to software have increased performance for this image size to ~60Hz
- DM Limitations
  - The DM used for these experiments had a manufacturing defect which limited the throw
  - Half of total throw was un-usable due to snap-down

Top Hat









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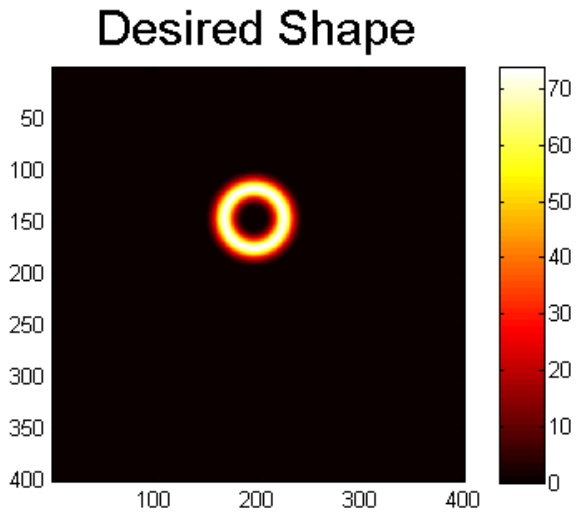
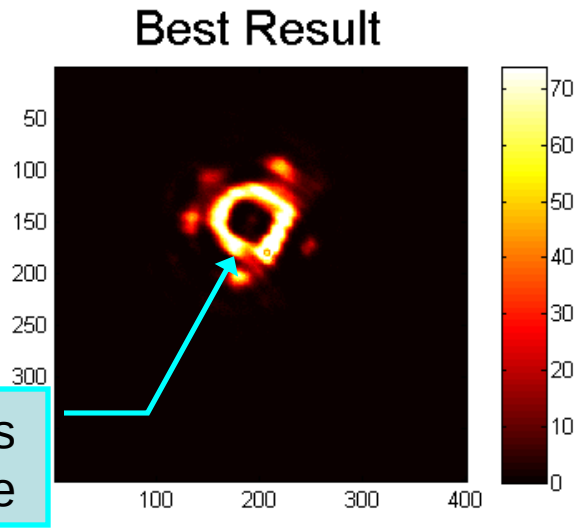
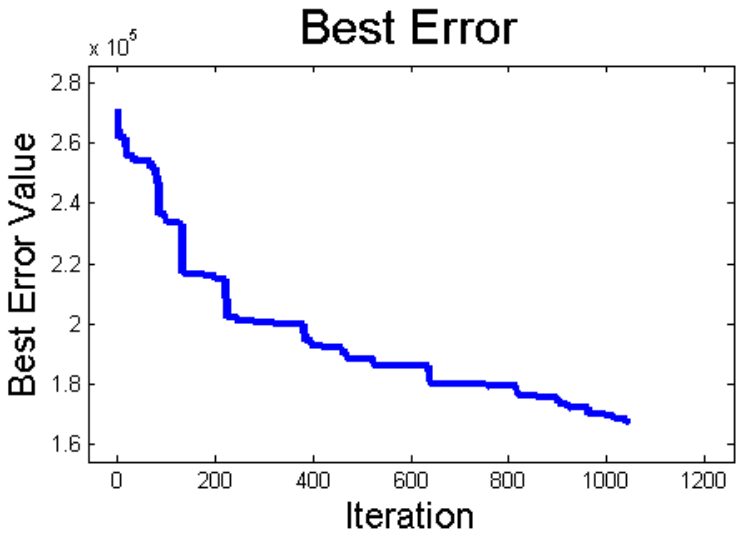
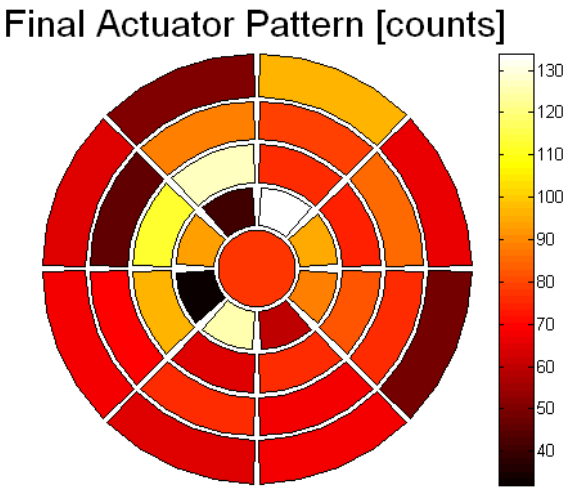
Annular Top Hat





Cover-glass Interference





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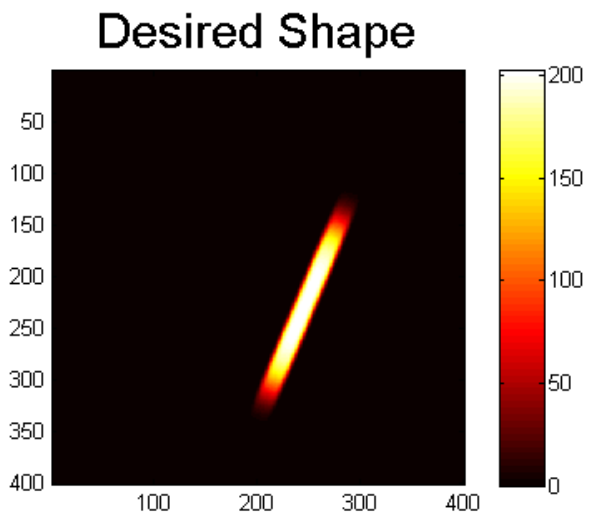
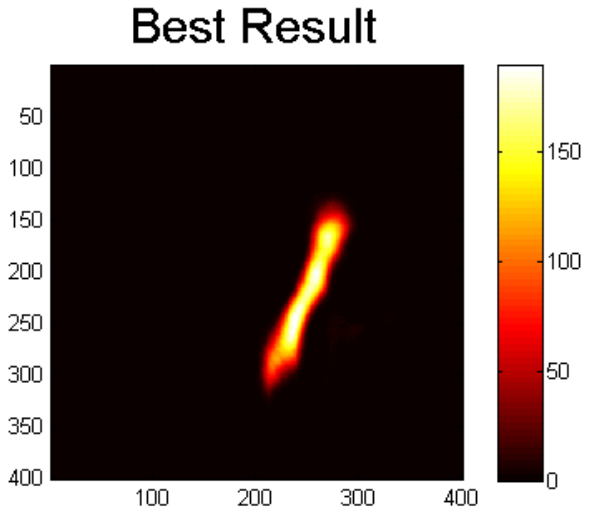
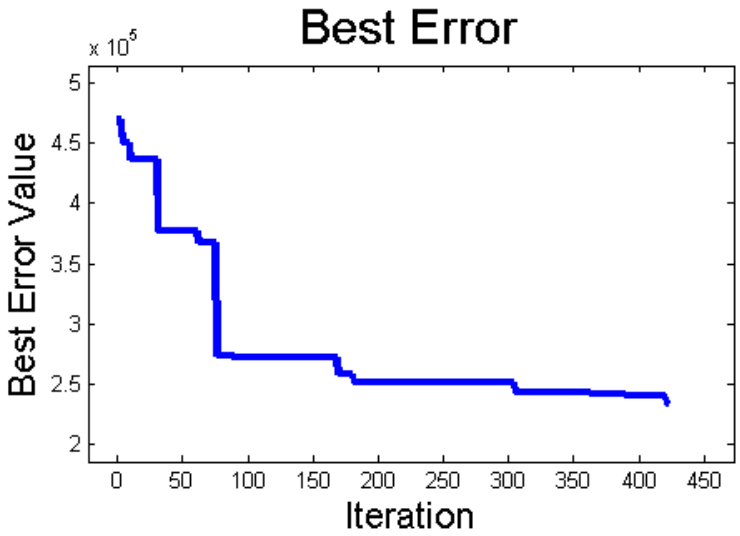
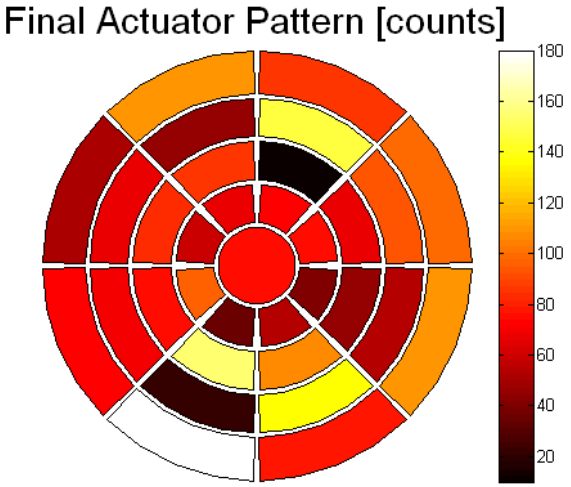
Line Focus









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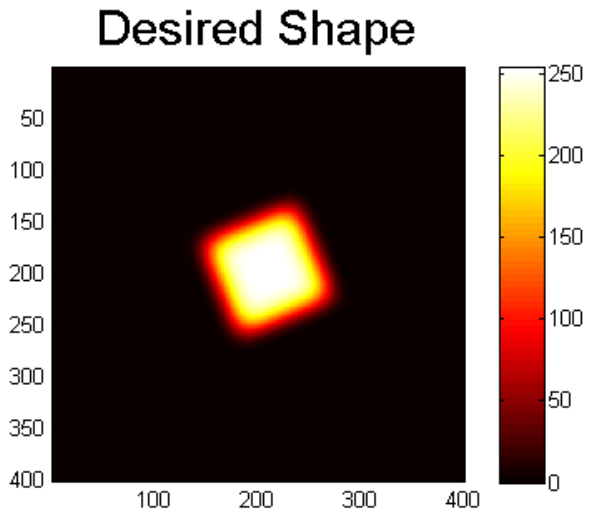
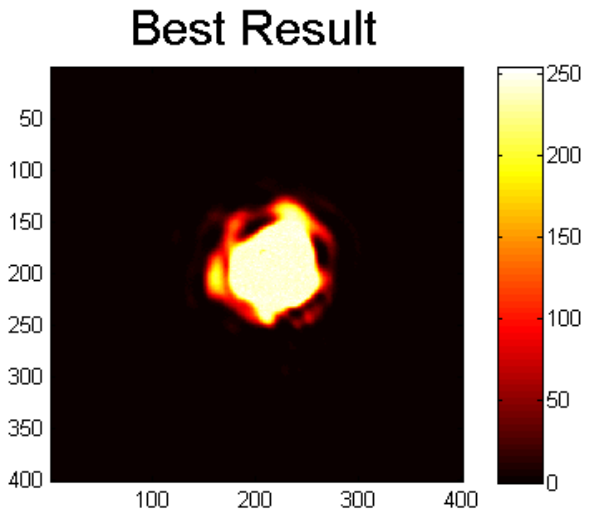
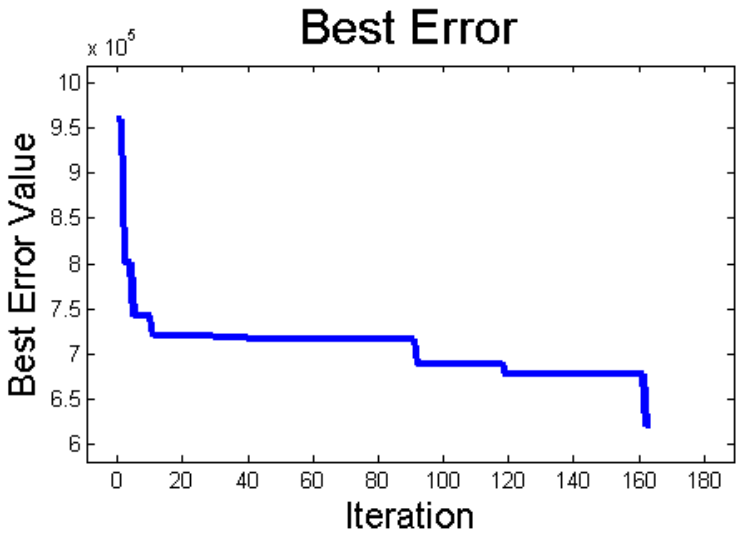
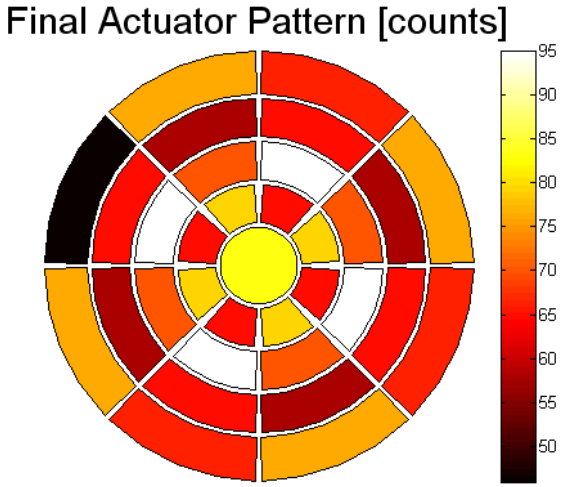
Square Top Hat









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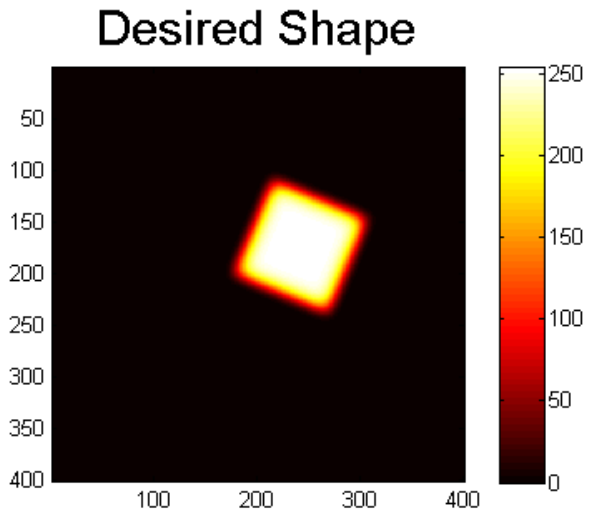
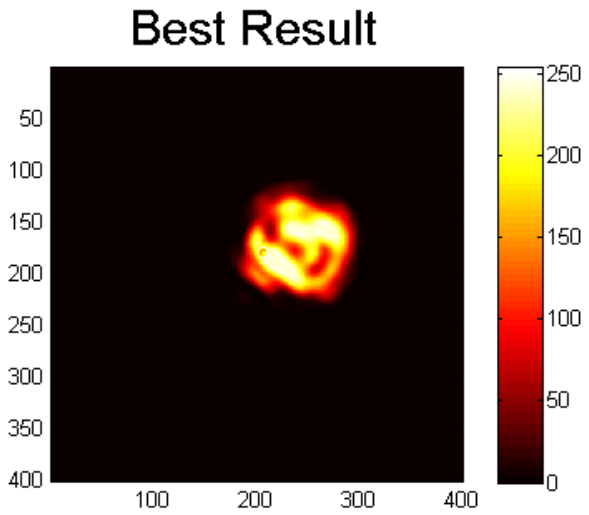
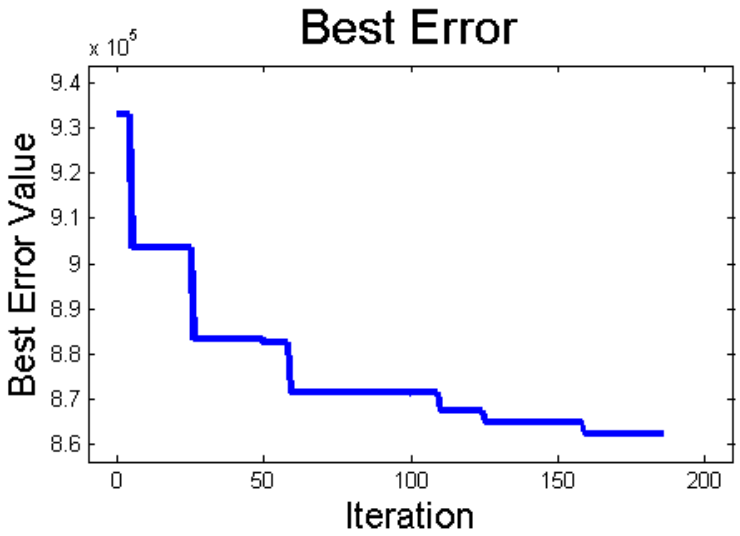
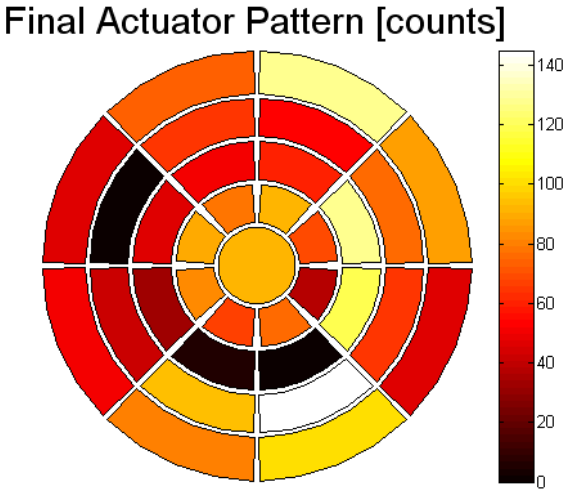
Square Top Hat 2









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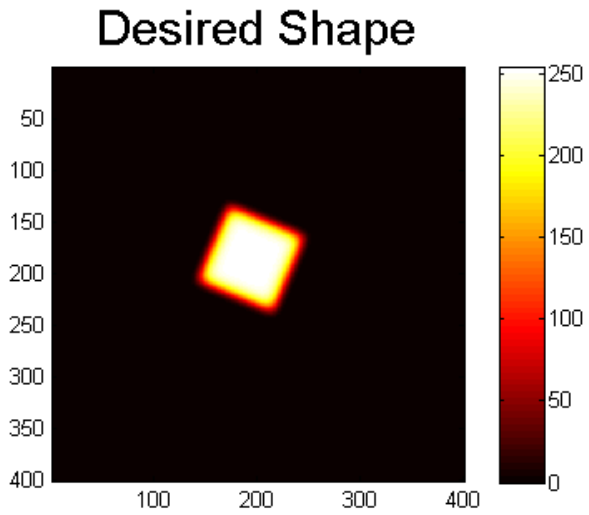
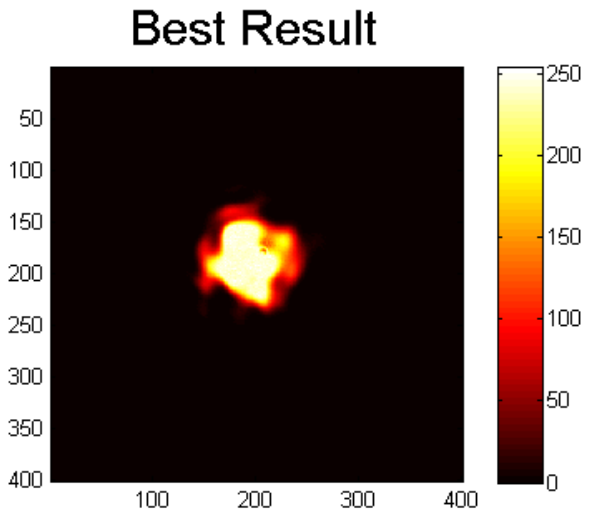
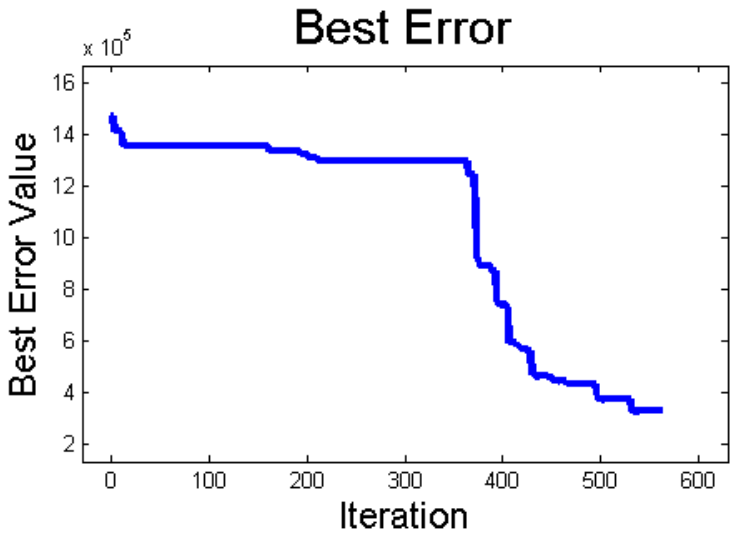
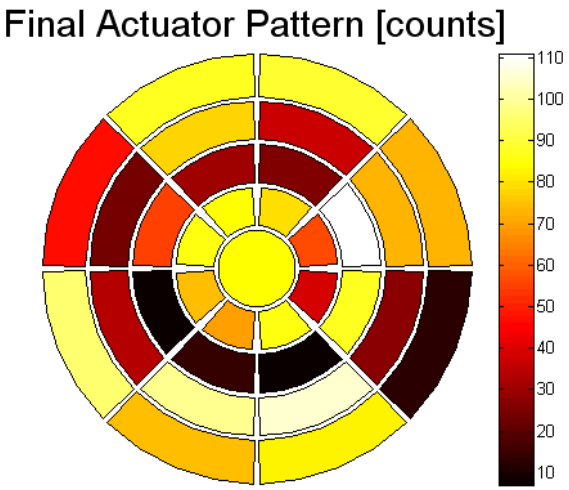
Square Top Hat 3









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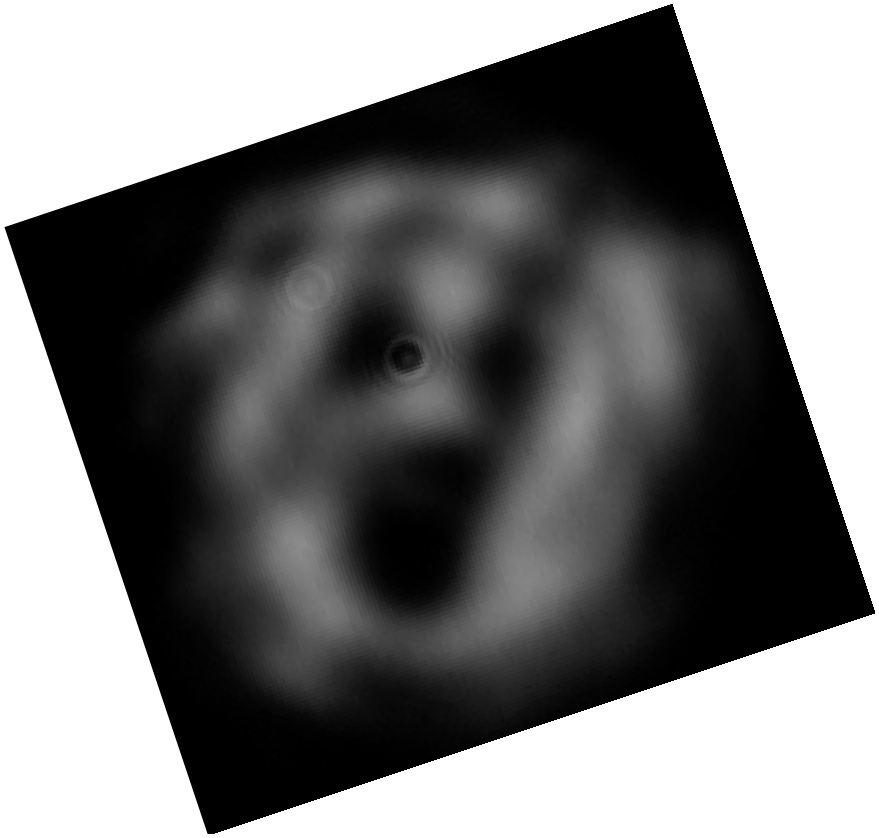
Conclusions

- Low actuator count membrane DMs may be used for creating beam shapes relevant to industrial applications
- We were able to create rectangular shapes, but the results were less than satisfactory
- A better optical setup and improved algorithms should improve our results

Questions?



The Beam
Brian Henderson
Justin Mansell
2008

The Scream
Edvard Munch, 1893

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