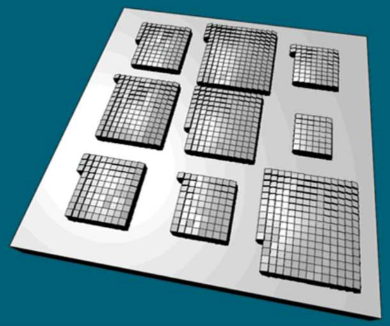
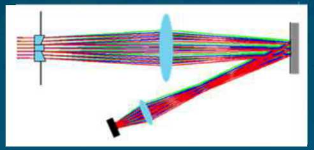
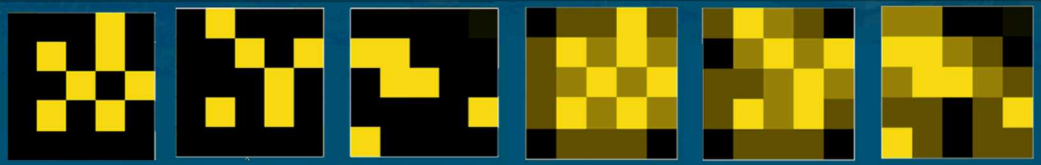
SAND2019-4027C

Design and Evaluation of Task-Specific Compressive Optical System







PRESENTED BY

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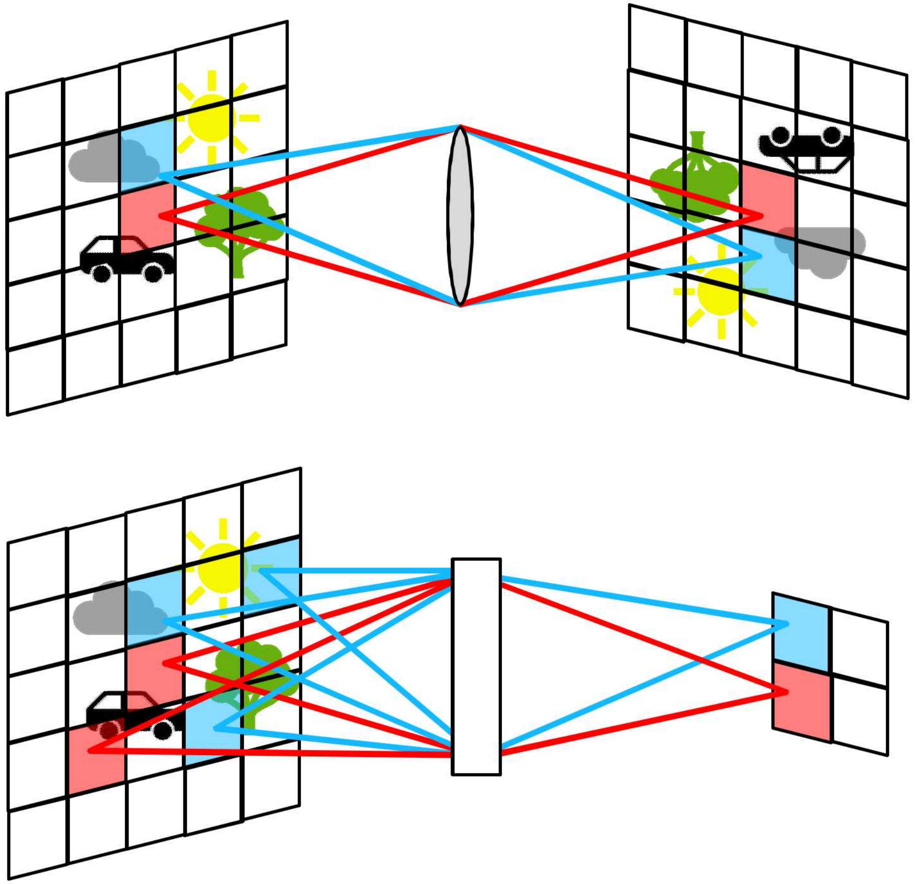
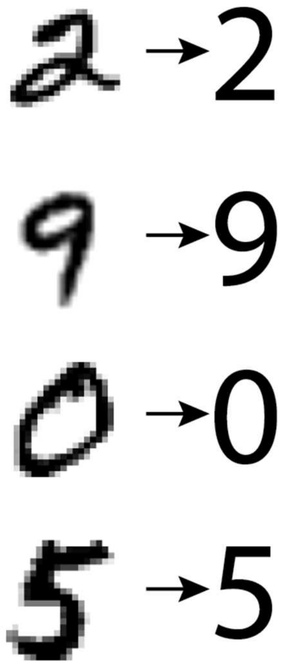
Task-specific compressive sensing

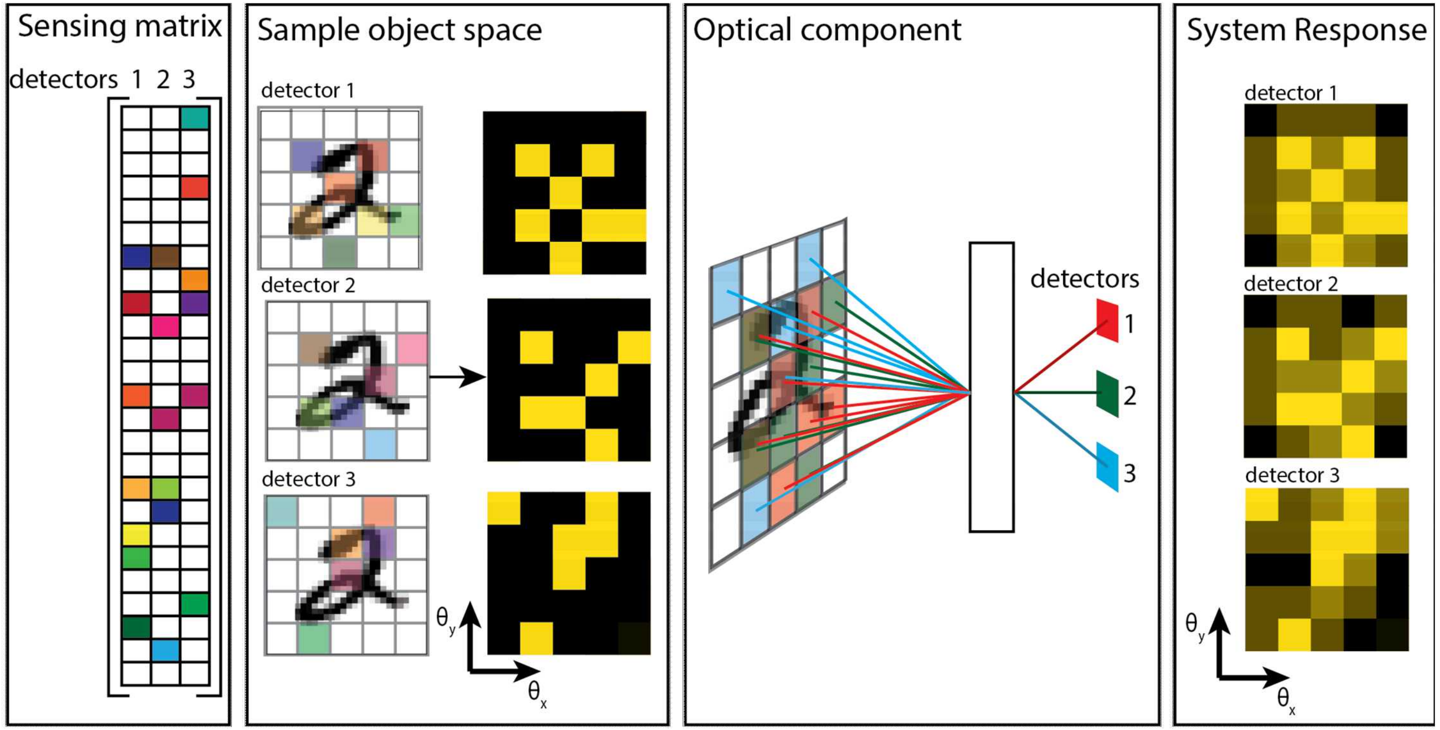
- Traditional Optics
  - 1:1 mapping from scene to detector location
  - Optimized to create image
- Compressive sensing
  - Measures aspects of the scene with high information content
  - Not optimized for human observer
- Classifying MNIST dataset
  - Classifying hand written digits
  - Proof of concept task
- How do we select the to measure data?





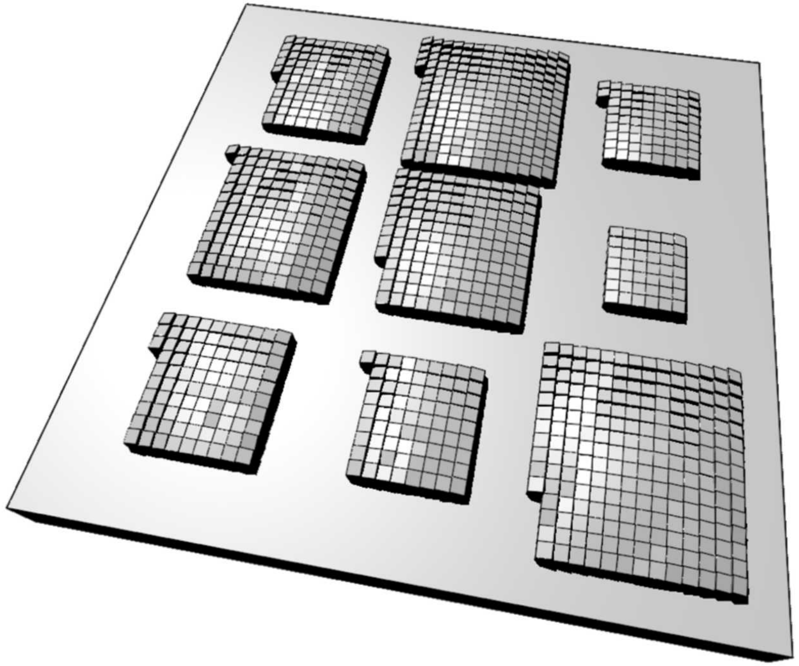
A sensing matrix as hardware

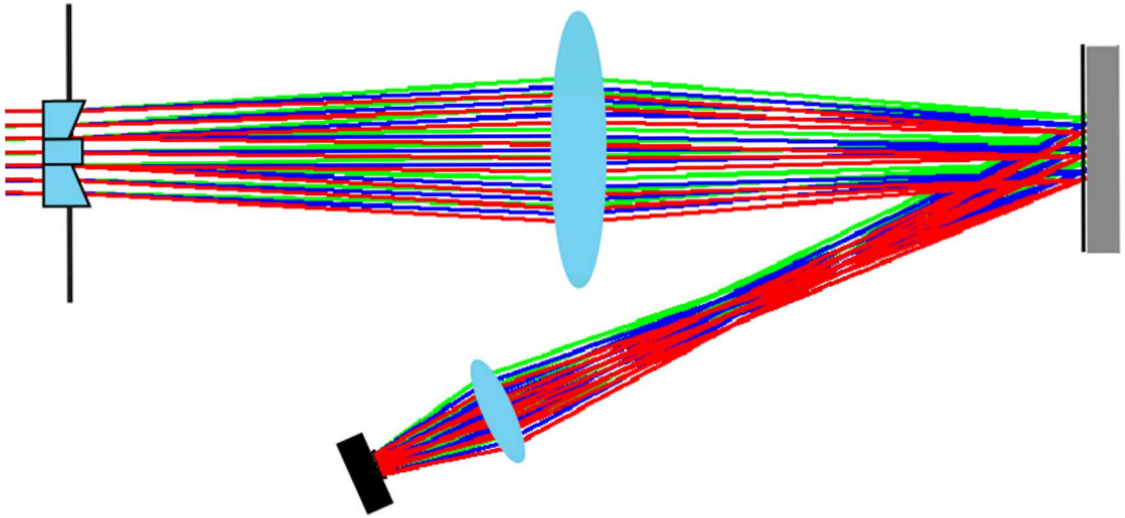
- Mapping object space to measurement
  - Multiple input angle to each measurement
- Distant object
  - input pixel = input angle
  - Multiple input angles to each detector
- Physical optics
  - Constrains sensing matrix
    - Nonnegative
    - Sparse
  - Requires characterization of performance



Optical designs

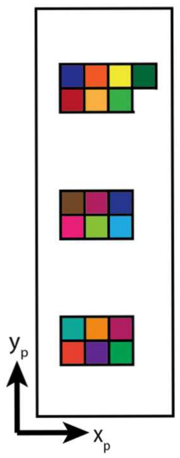
- Multiple architectures possible
  - Direct mapping
    - Prism array
  - Conventional optics
    - DMD architecture

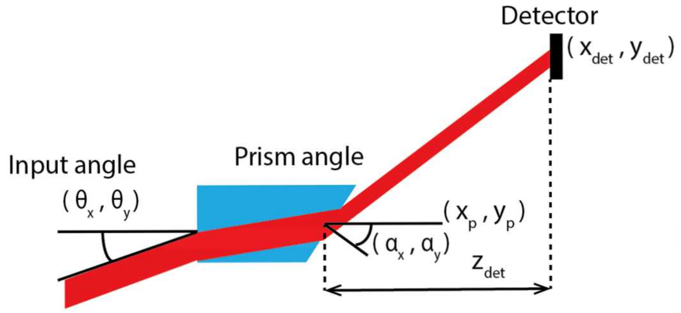


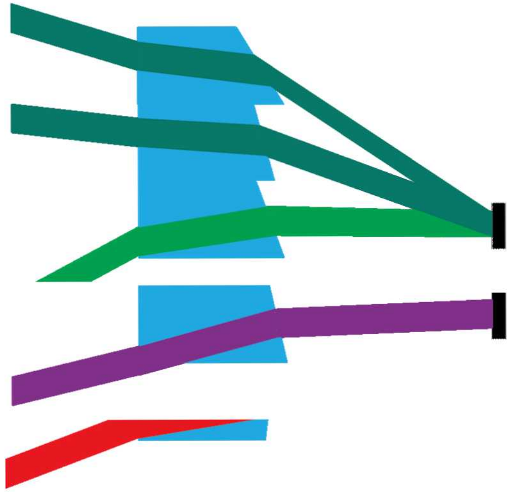


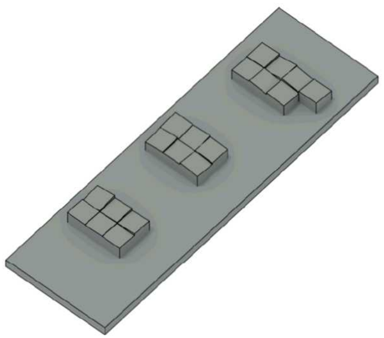
Prism array

- Direct realization of sensing matrix
  - A prism for each nonzero element
  - Maps input angle onto detector
  - Weighted using Absorption
- Parameters
  - Size
    - Overfill detector
  - Position
    - Clusters around each detector
  - Angle
    - Optimized
- Automated generation
  - Inputs
    - basic geometry
    - Sensing matrix
  - Zemax OpticStudio API



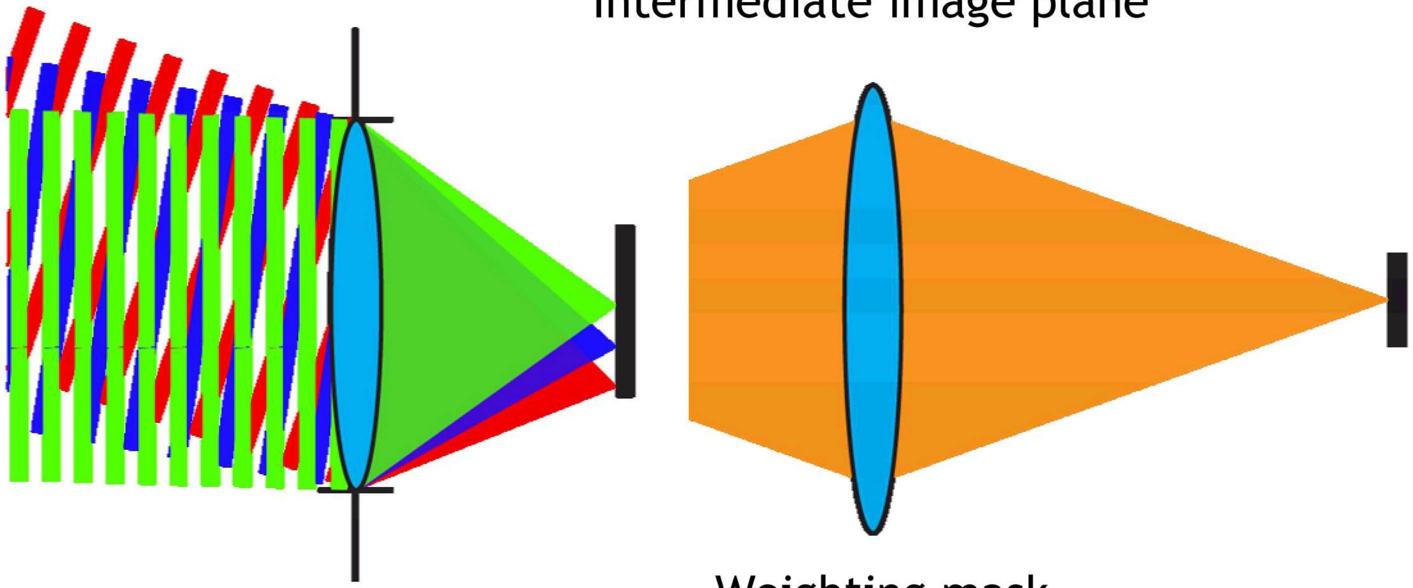






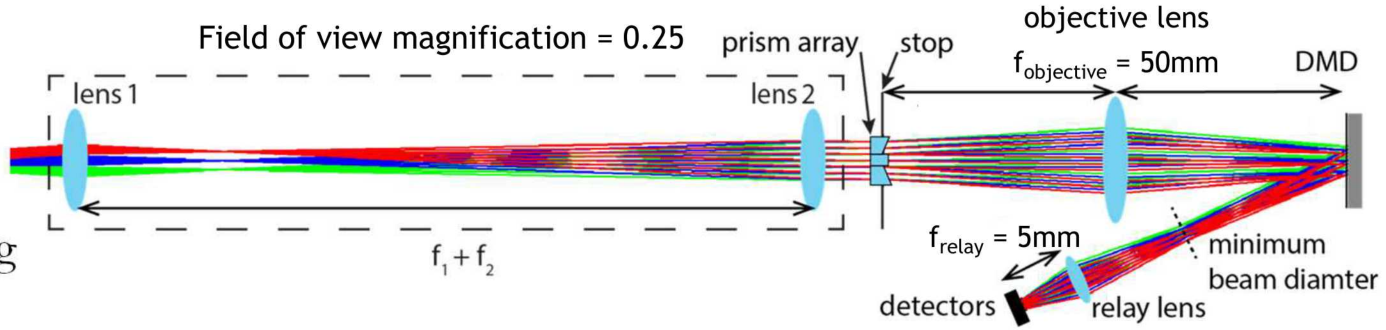
Parallel measurements conventional optics

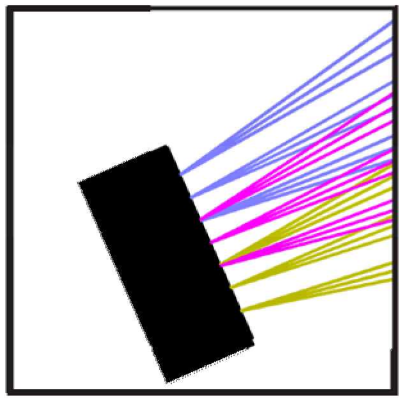
- Direct imaging
  - 1:1 mapping
- Image stop
  - Uniform irradiance at detector
- Telecentric
  - Intermediate image plane
  - Magnification independent of lens separation
- Division of aperture
  - Fields separated at intermediate image plane
  - Parallel measurements

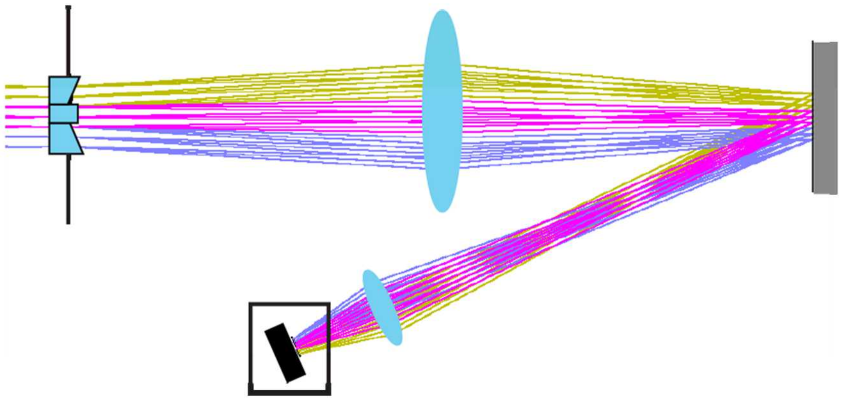


Weighting implemented using a DMD

- Digital micromirror device (DMD)
  - Allows for dynamically setting sensing matrix without changing hardware
  - At image plane
- Separating information
  - DMD - channels separated, fields separated
  - Detectors - channels separated, fields overlapping
- Optimizing throughput
  - Maximize magnification of detector
  - Maximize field of view
  - Constrained by DMD size
  - Constrained by realistic lenses

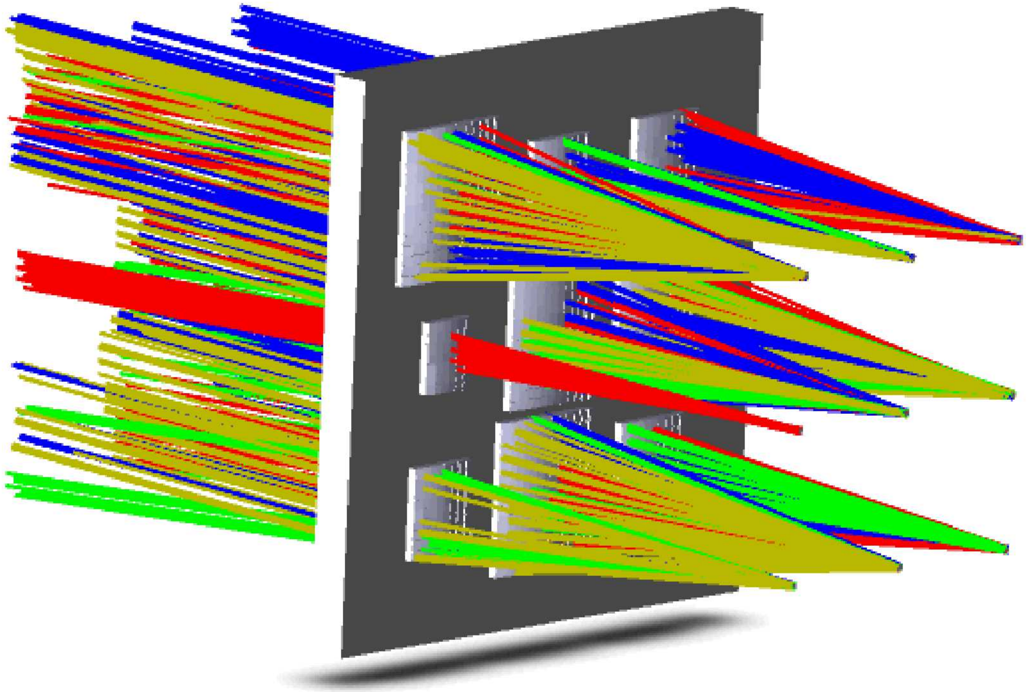






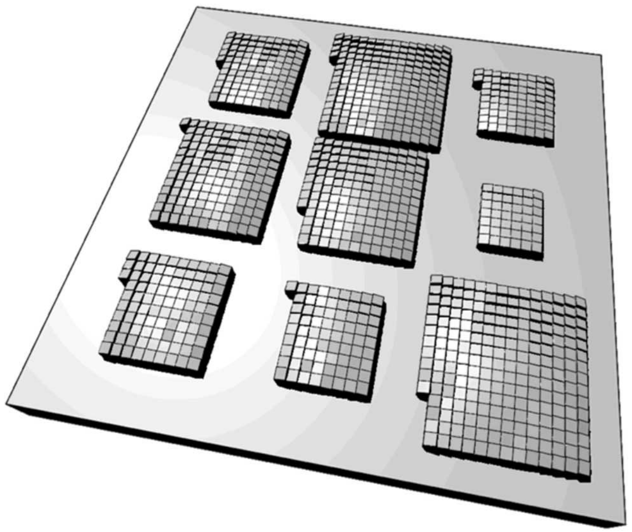
Simulating system performance

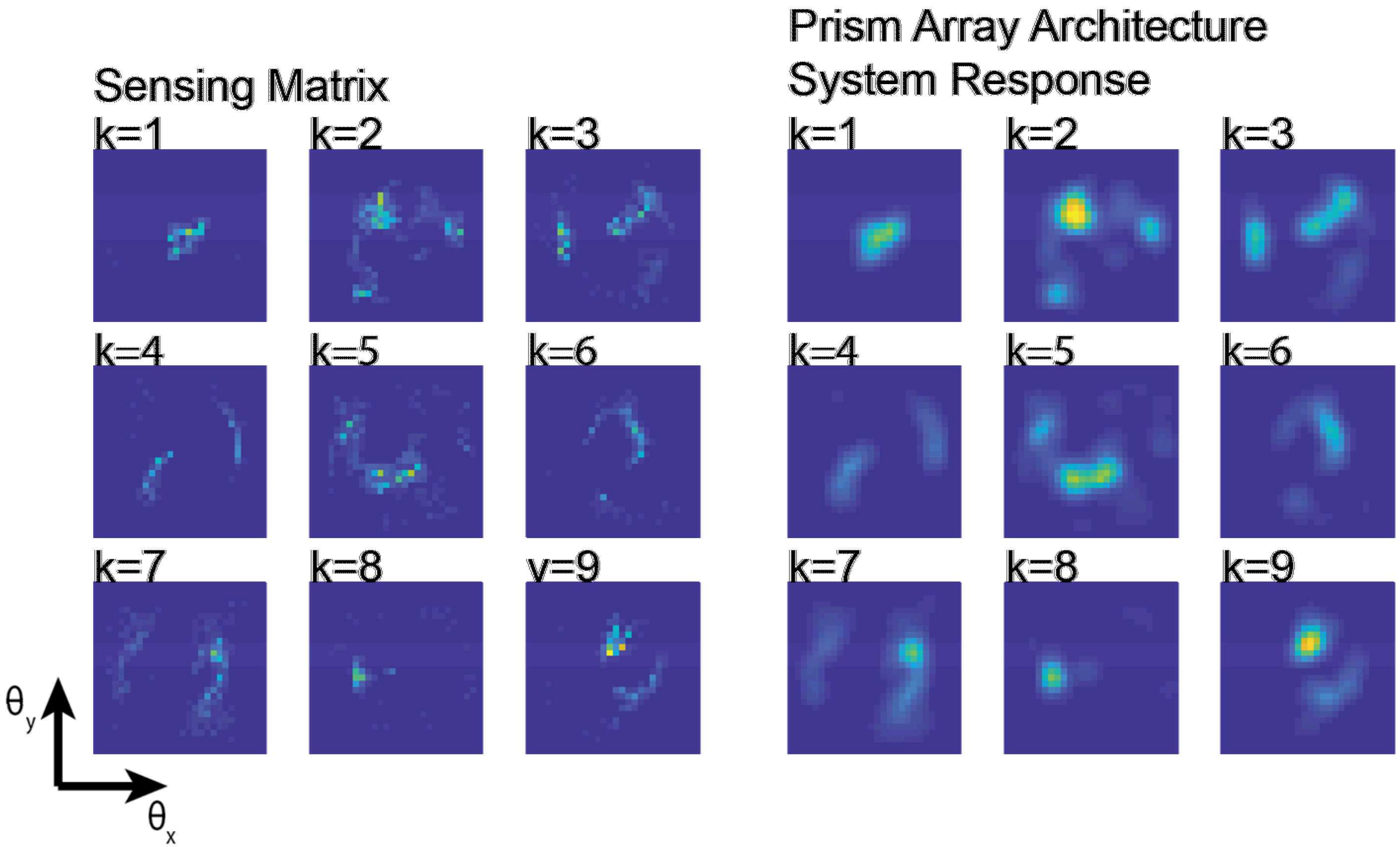
- System response
  - Detector sensitivity to each input angle
- Non-sequential raytrace
  - Scan over 28 by 28 input angles
  - Zemax OpticStudio API



Prism array blurs sensing matrix

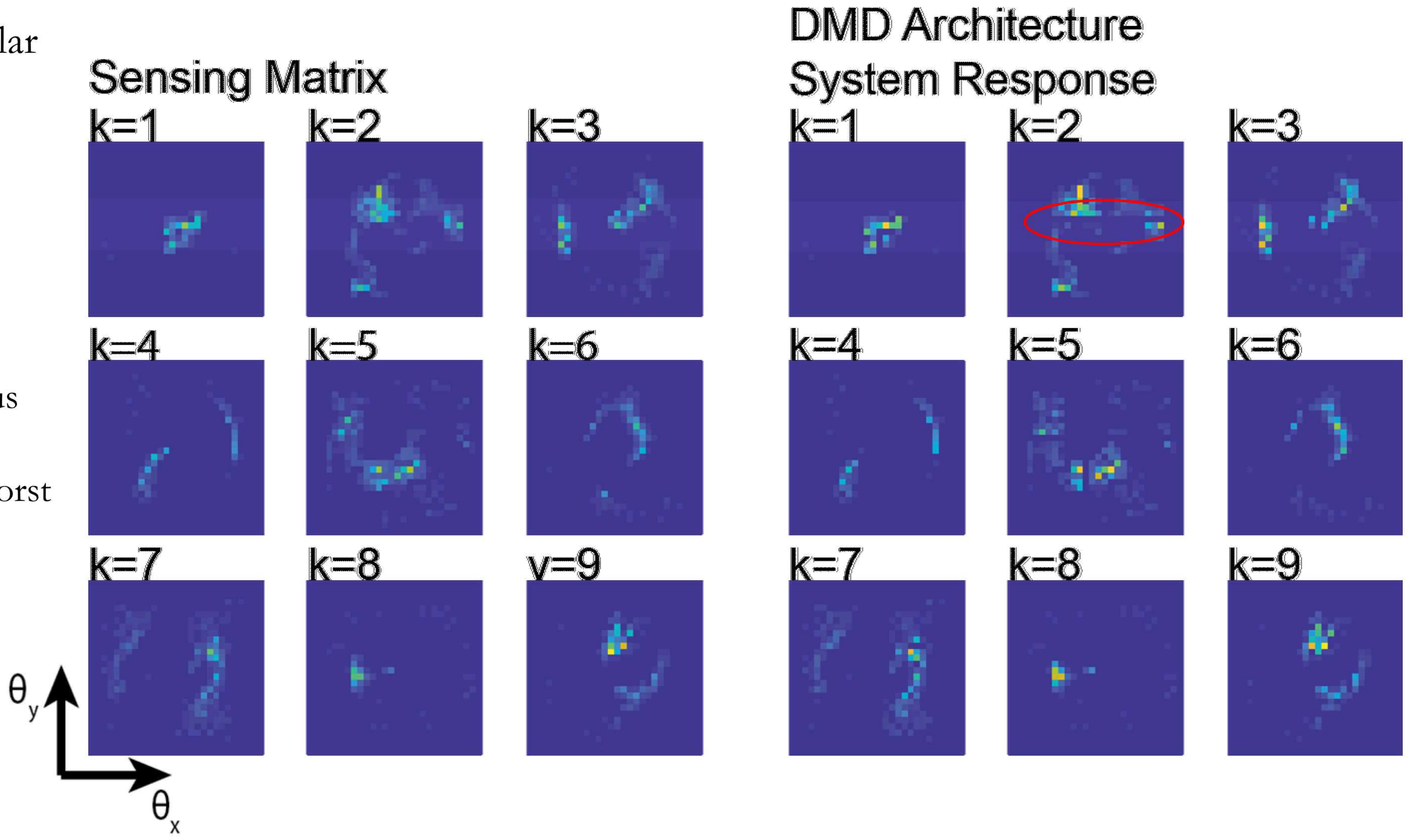
- Example case
  - 9 detectors





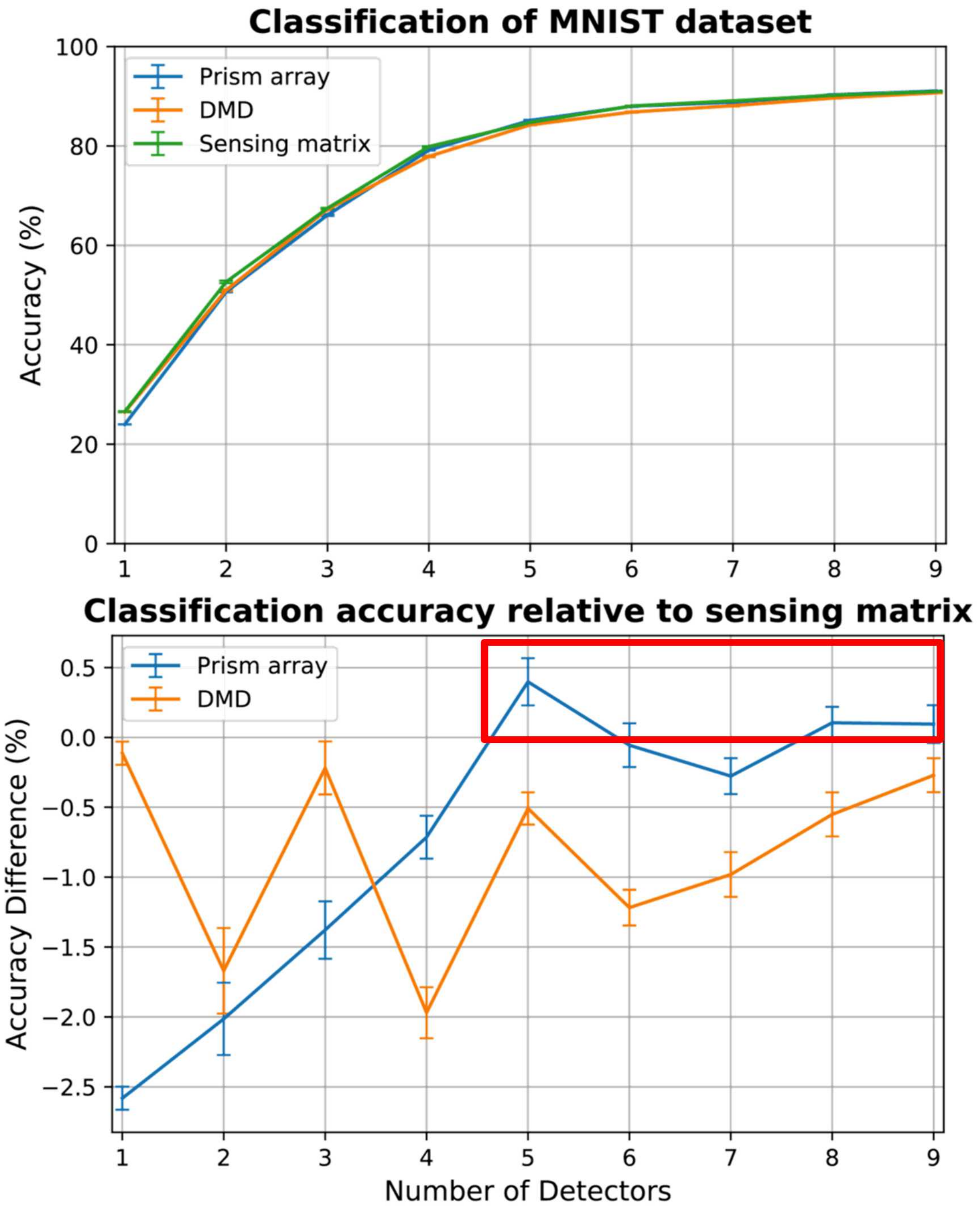
DMD design faithfully reproduces sensing matrix

- System response very similar to sensing matrix
  - Minimal blurring
- Lost values
  - Ray trace hits edge of micromirror
  - Expected to be removed with nonzero instantaneous field of view.
  - Collimated source gives worst case



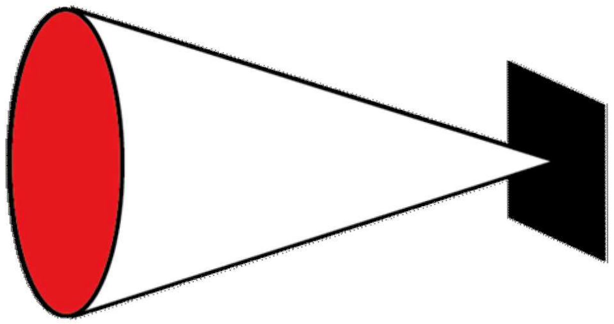
Good reproduction of sensing matrix

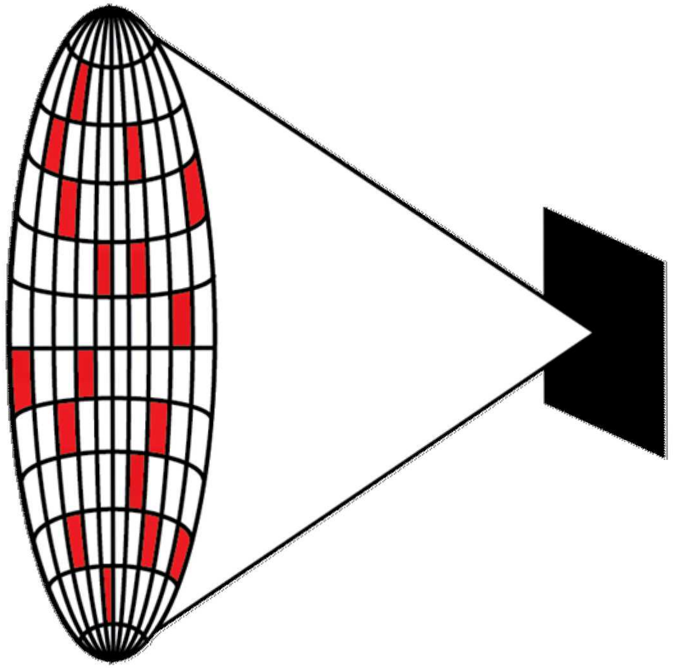
- Classifier trained on compressed data
  - Random forest
  - 60,000 training points, 10,000 test points
  - 10 random training/test data sets
- Both architectures have similar performance to sensing matrix
  - Within 3% over the range of 1 to 9 detectors
- Blurring improves performance
  - Decreases sparsity without increasing elements



Similar throughput to imaging optics

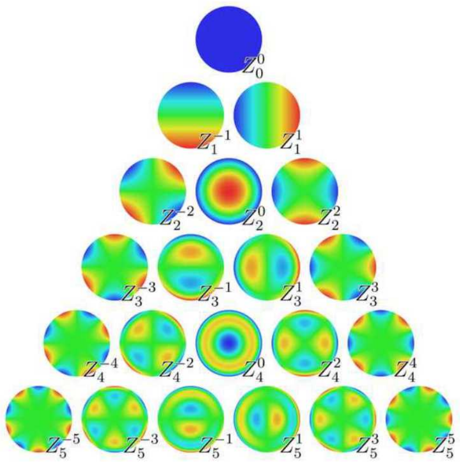
- Imaging optics throughput
  - Instantaneous field of view
  - Area of aperture
- Compressive sensing throughput
  - Instantaneous field of view
    - Large field of view
    - Weighted by sensing matrix
  - Effective area
    - Prism array – area of detector
    - DMD design – effective area at prism plane
- Comparison
  - F/4 lens with 5μm pixel –
  - 9 detectors prism array –
  - 9 detector DMD design –

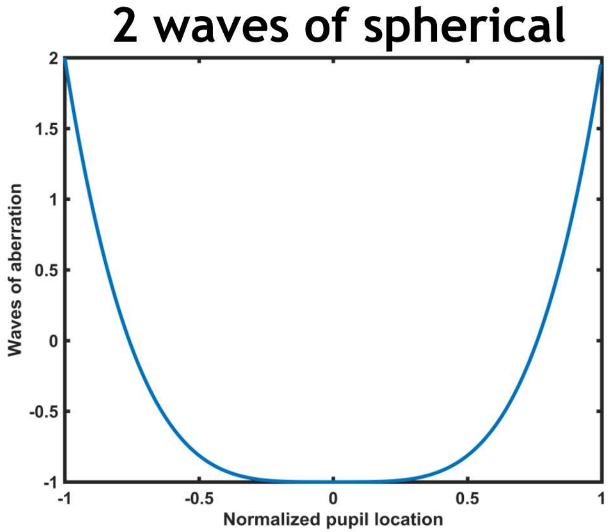


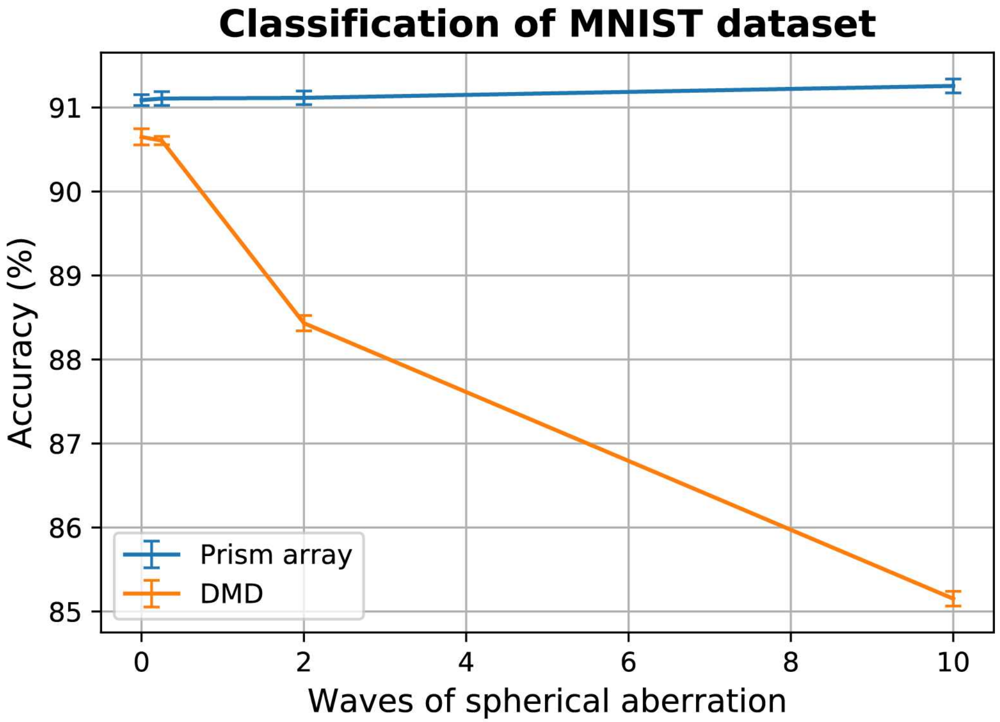


How do the systems perform under non-ideal inputs

- Added aberration to the system
  - 9 detector case
  - Spherical aberration at the aperture plane
- Zernike surface
  - Converted to waves of Seidel aberrations
- Architectures respond very different to aberration
  - DMD architecture
    - Performance decreases with increasing aberration
  - Prism architecture
    - Performance slightly increases with increasing aberration
    - Similar to improved performance due to blurring







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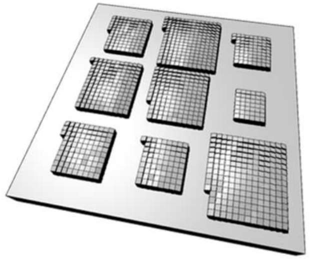
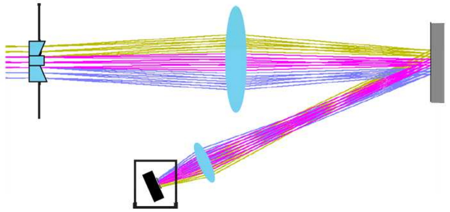
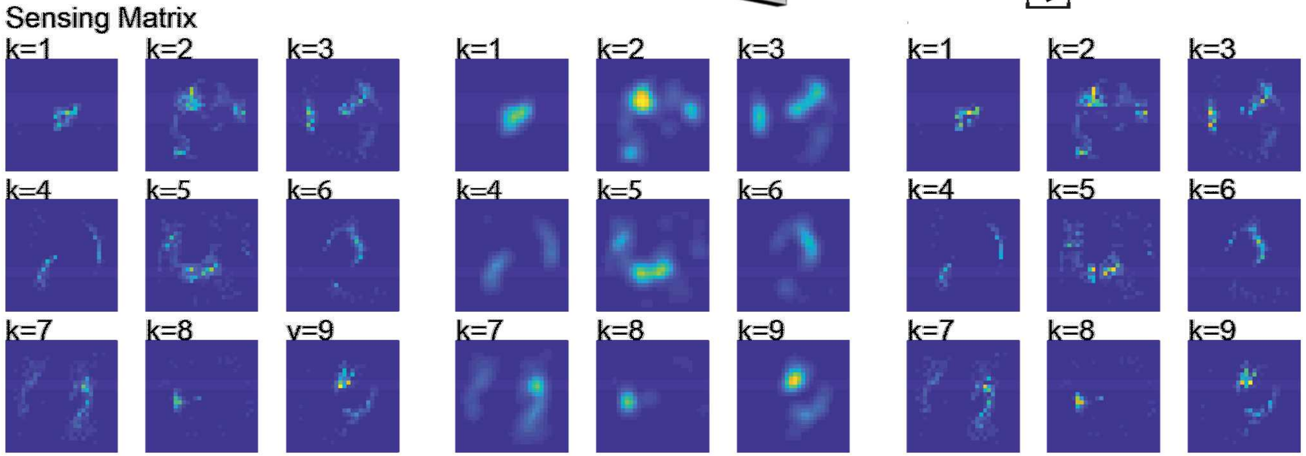
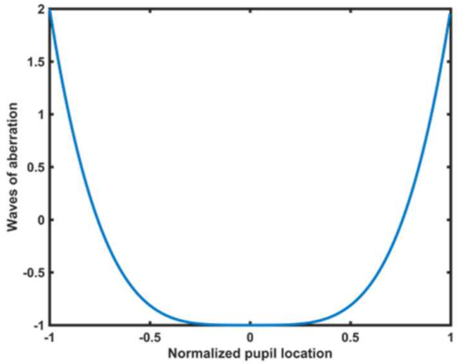
Questions?

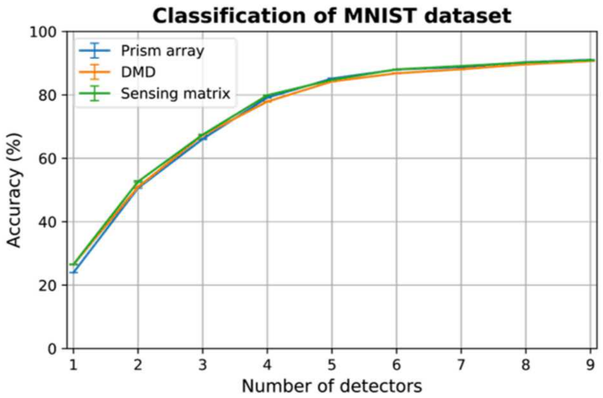


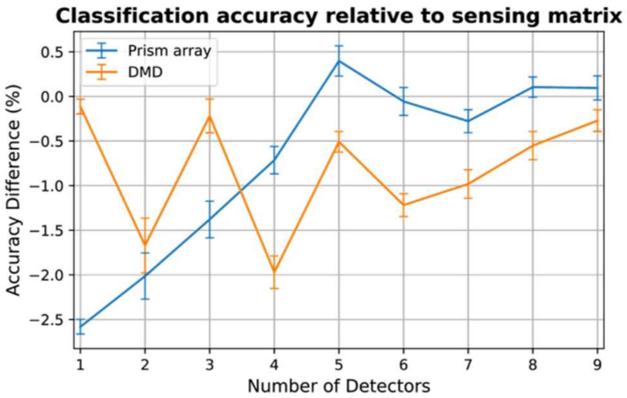


- Radiometric
  - Similar to F/4 lens with 5μm pixels
- Raytracing
  - System response matrices
- Classification accuracy
  - Similar to sensing matrix
  - Blurring improves performance
- Aberration
  - Performance change highly dependent on architecture









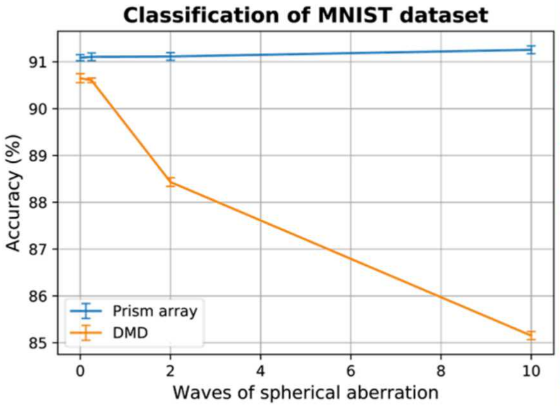


Image References

- https://commons.wikimedia.org/wiki/File:Zernike_polynomials2.png