# Image Reconstruction from Cone Excitations using the Implicit Prior in a Denoiser


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1. We developed an algorithm for Bayesian image reconstruction from cone exictations, based on the image prior implicit in a denoising neural network.

2. Our framework allows visualization of information loss due to the initial visual encoding, such as the effect of visual eccentricity and dichromacy.

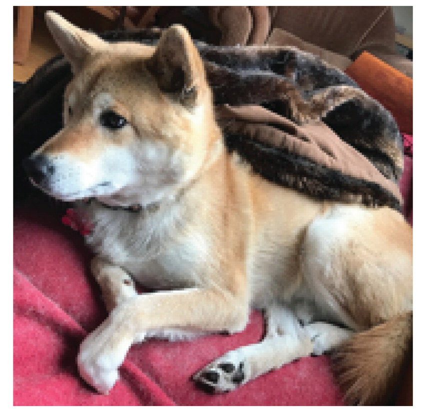
3. We can also analyze the changes in the features of visual encoding as an optimal design problem with regard to the reconstruction performance.

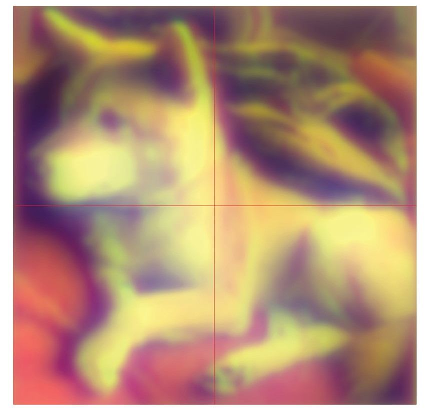
## 1. Methods

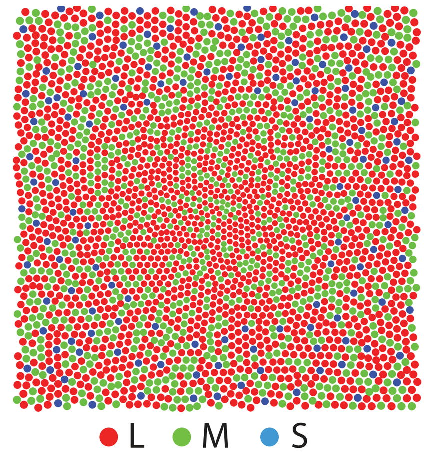
### ISETBio: Forward Model of Cone Excitation

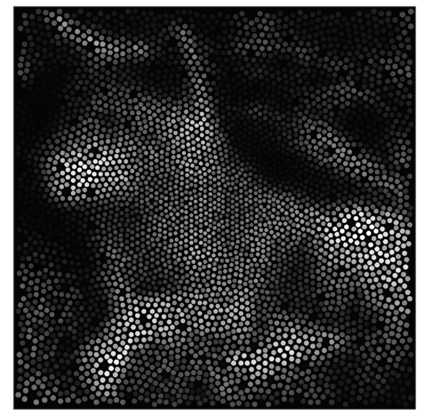
(Cottaris et al., 2019, 2020; Zhang, Cottaris & Brainard, 2022)

RGB Image → Retinal Image → Cone Mosaic → Cone Excitations → (likelihood) Bayesian Reconstruction ← (prior)



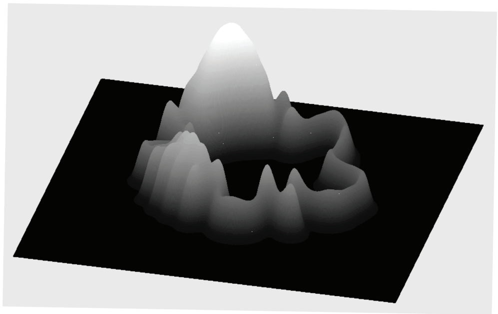




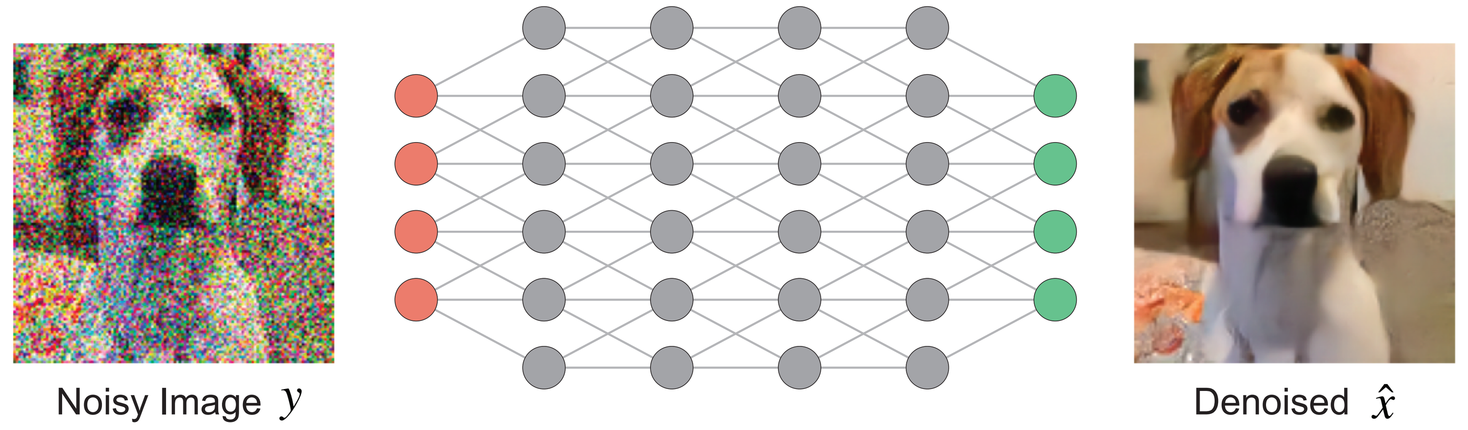



### Implicit Natural Image Prior

(Kadkhodaie & Simoncelli, 2021)



ConvNet Denoiser




- I.I.D Gaussian Noise Removal

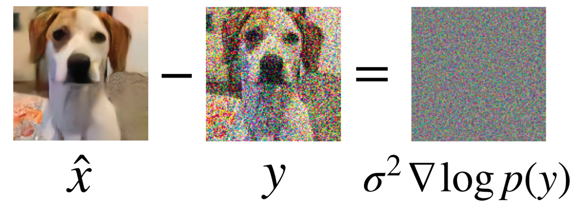
$$y = x + z,\ z \sim \mathcal{N}(0, \sigma^2 I)$$

- Bayesian Least Square Solution

$$\hat{x}(y) = \int x p(x|y) dx$$
$$= \int x \cdot 1/Z \cdot p(y|x) p(x) dx$$
$$= y + \sigma^2 \nabla_y \log p(y)$$

(Miyasawa, 1961)

- Implicit Prior (log prior gradient)




## 2. Visualization

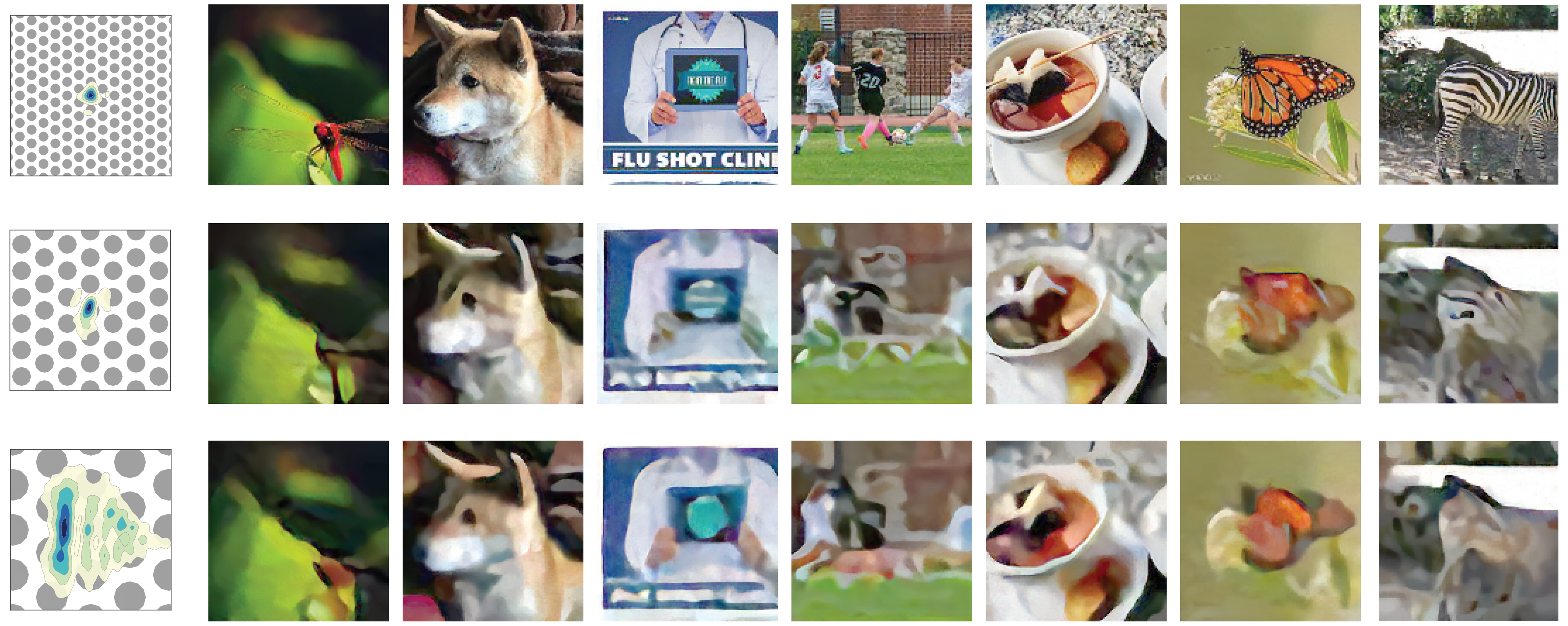
Information loss due to the initial encoding

### Visual Eccentricity

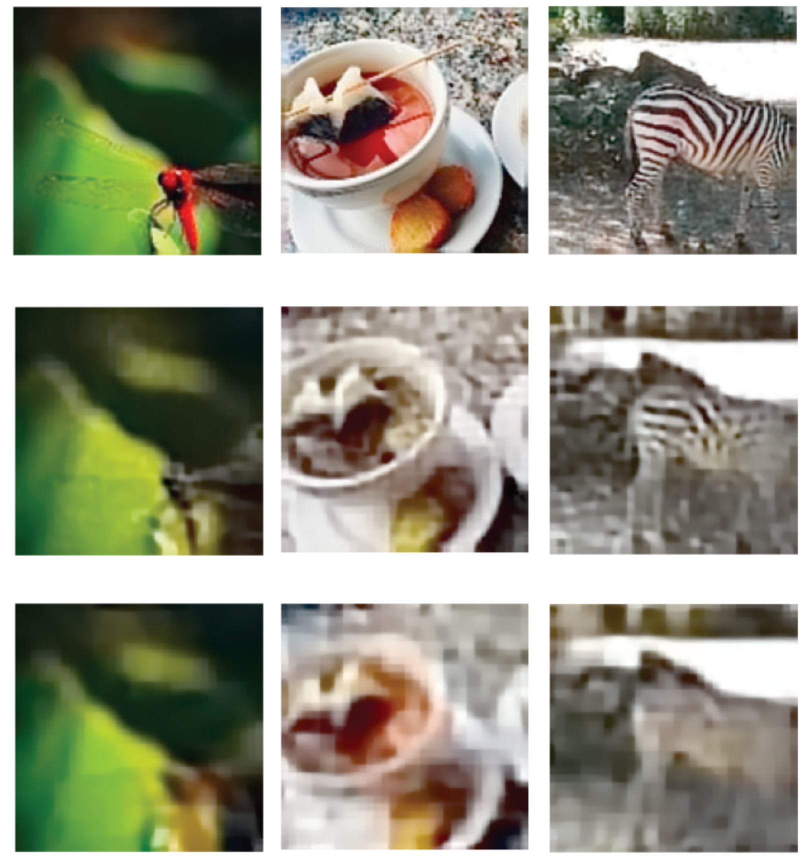
Foveal

5-degree Peripheral

18-degree Peripheral



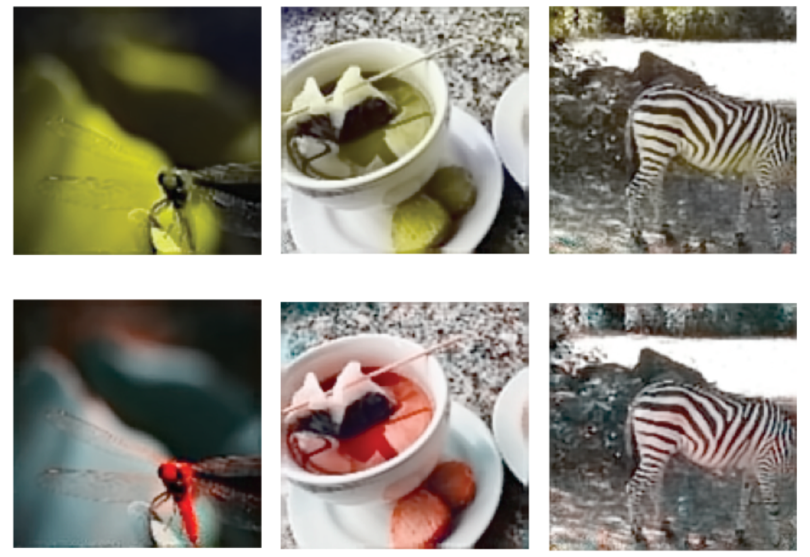

Comparison: Sparse Image Prior



### Dichromacy

Deuteranopia ● L ● S

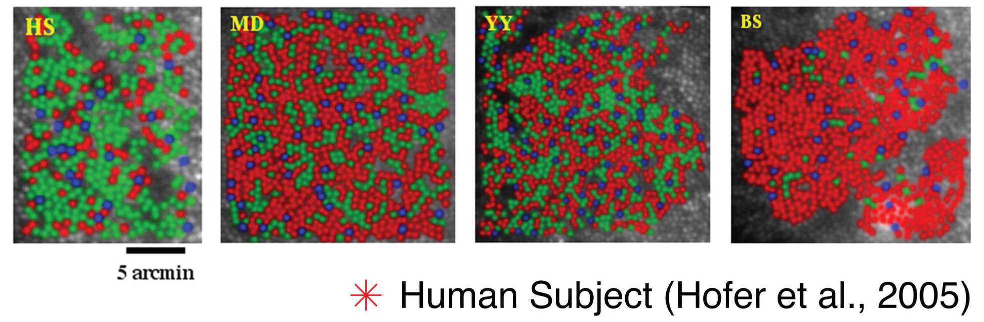
Tritanopia ● L ● M

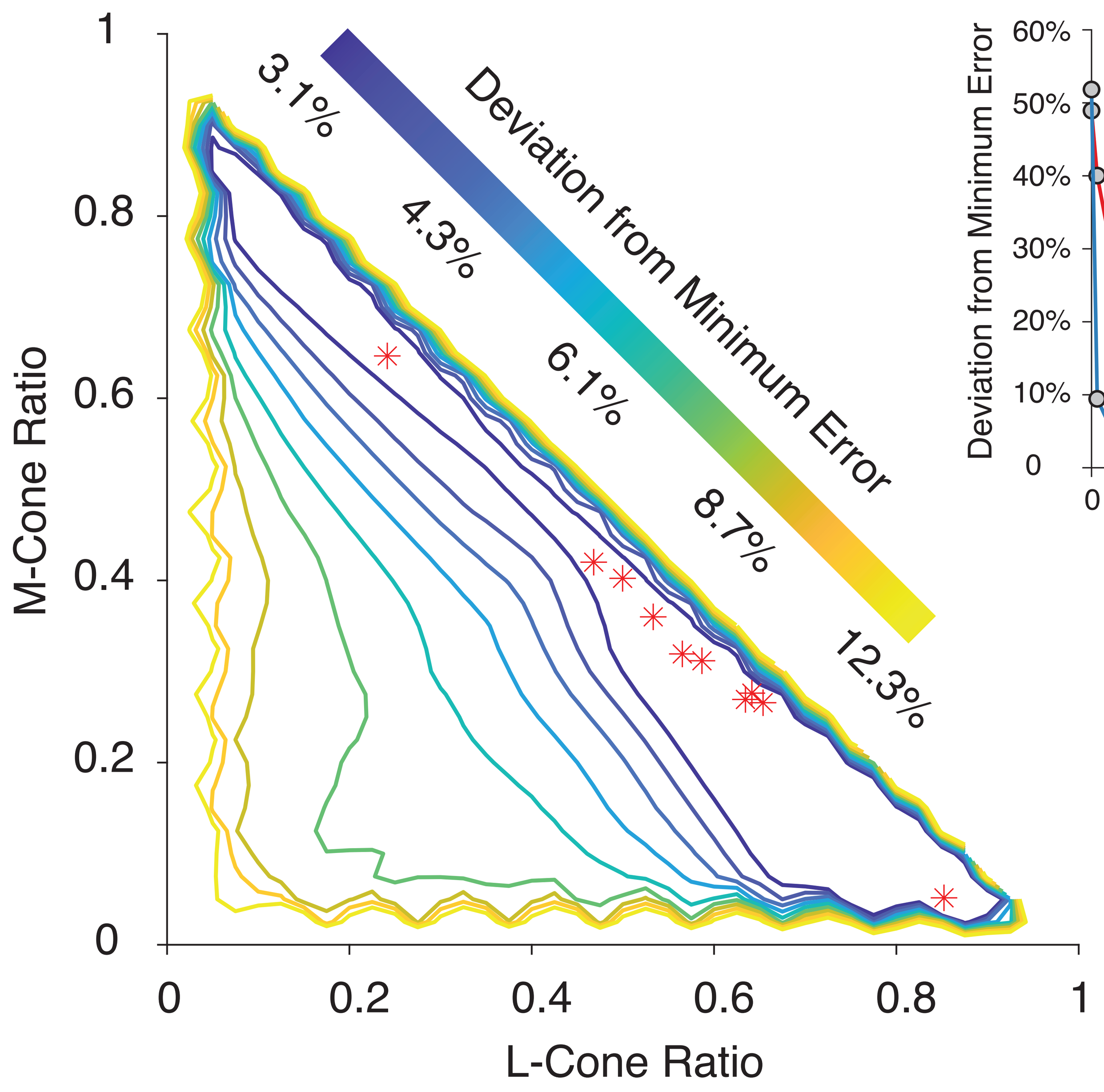
## 3. Optimal Design

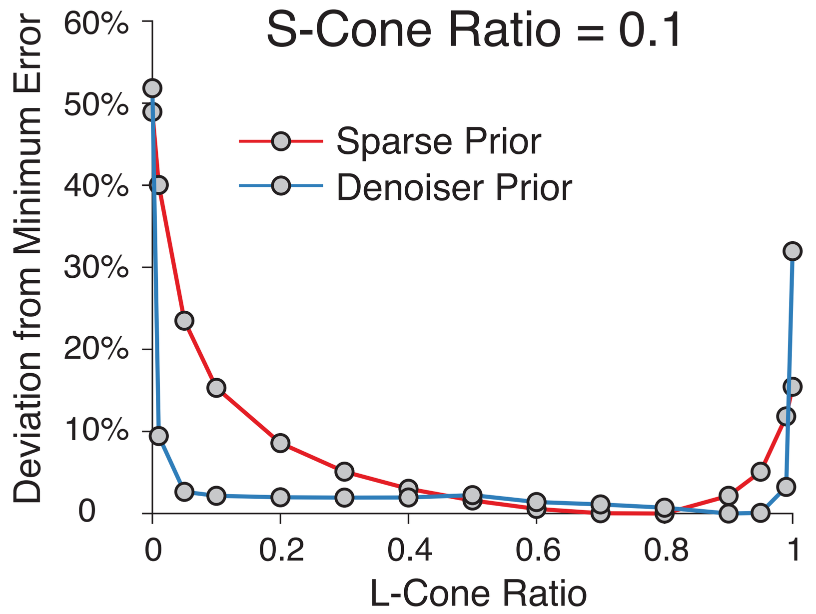
How do the characteristics of different cone mosaics impact reconstruction performance?

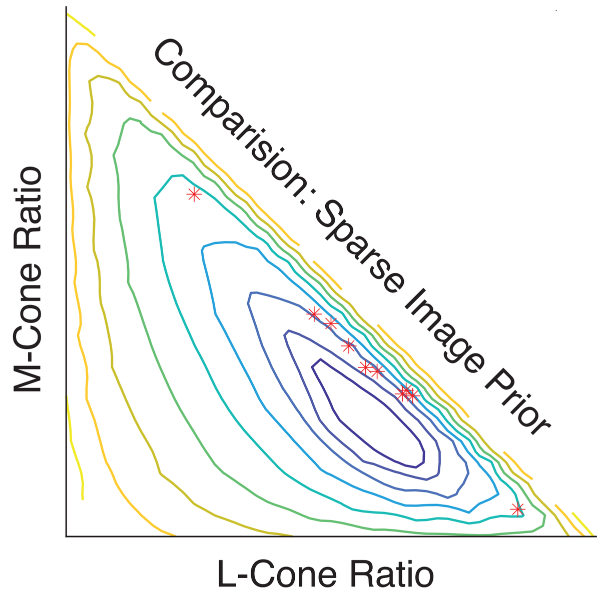
Proportion of L/M/S Cone Type




✳ Human Subject (Hofer et al., 2005)




## Reconstruction Algorithm

Coarse-to-fine stochastic ascent for sampling from the implicit image prior, condition on the cone measurements.

- Linear Measurement Model $m = M^T x$

- Gradient Conditioned on Measurement

$$\sigma^2 \nabla \log p(y|m) =$$
$$\underbrace{(I - MM^T)\sigma^2 \nabla \log p(y)}_{\text{Projection onto Null Space of } M} + \underbrace{M(m - M^T y)}_{\text{Deviation from the Measurement}}$$

- Iterative Sampling Procedure

$$y_{t+1} \leftarrow y_t + \alpha_t \cdot \sigma^2 \nabla \log p(y_t | m)$$

Example Iterations

t = 0 → t ~= 200