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Estimation of the ocular point spread function by retina modeling

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Point spread function

- Motivation: improve retinal imaging by taking advantage of the intrinsic properties of the human eye
- For this, we estimate the point spread function (PSF)
  - Ocular aberrations can be estimated
  - Deconvolution methods that reduce the image blurring can be used by knowing the PSF
  - Blind deconvolution techniques are often biased by the initial guess of the point spread function. PSF estimation gives a better estimate for this initial guess
- Method is independent of the imaging acquisition technique
- Based on identification of retinal cells and modeling them

Theory

- In the case of multi-frame image, made of *m* frames of the same object :

image PSF object noise

$$\sum_{j=1}^{m} i_j(\mathbf{r}) = \sum_{j=1}^{m} p_j(\mathbf{r}) \otimes o(\mathbf{r}) + n_j(\mathbf{r})$$

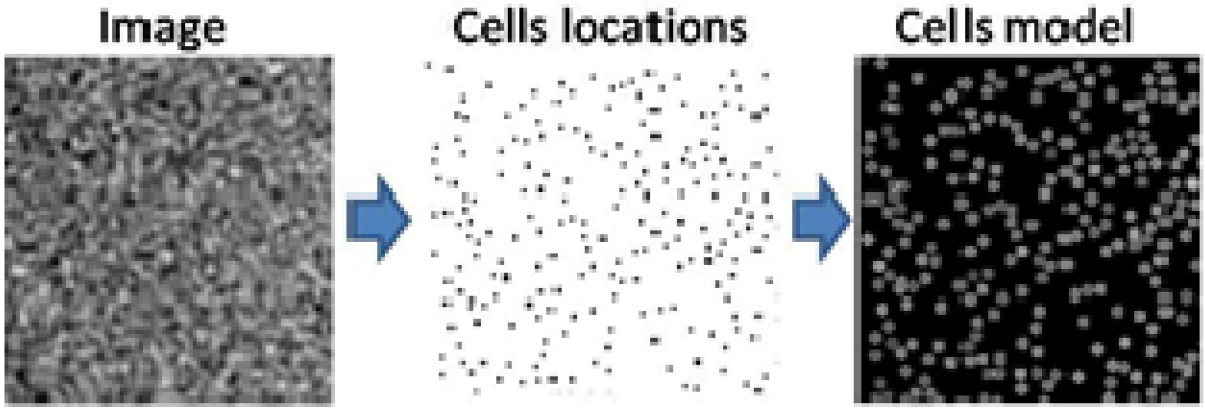
- We wish to replace the object *o(r)* with model *c(r)* of the cells
- To replace the object *o(r)* with *c(r),* we need to introduce a new term, *b(r),* which compensates for all the other features beside cells

$$\sum_{j=1}^{m} i_j(\mathbf{r}) - b_j(\mathbf{r}) = \sum_{j=1}^{m} p_j(\mathbf{r}) \otimes c(\mathbf{r}) + n_j(\mathbf{r})$$

- For a small retinal area, *b(r)* is constant (background)
- In the Fourier domain the PSF is

$$\sum_{j=1}^{m} P_j(\boldsymbol{\omega}) = \frac{\sum_{j=1}^{m} I_j(\boldsymbol{\omega}) - b_j \delta_j(\boldsymbol{\omega}) - N_j(\boldsymbol{\omega})}{C(\boldsymbol{\omega})}$$

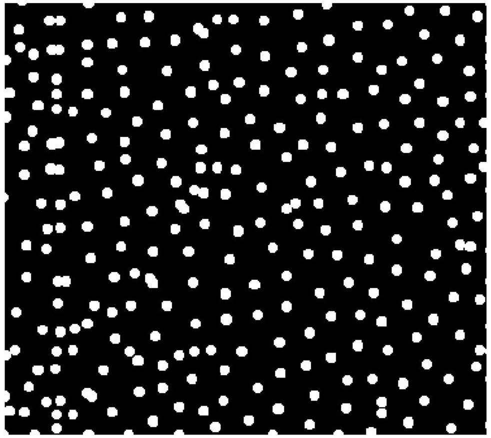
Retinal cells' model - c(r) term



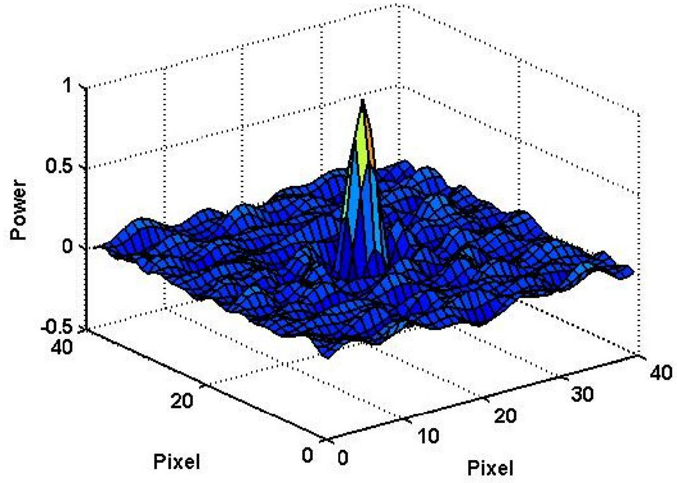
- Finding the cells' positions in the image, using circular matched filter
- We replace each cell location with a fixed size circular disc
  - Discs diameter is determined by the half-height width of their averaged radial intensity profile
- We determine each disc intensity by the average intensity of the cell in the image
- Assumptions:
  - Rods cells are bellow the resolution limit, therefore ignored
  - Cones have approximately the same size in the image

Checking the method – synthetic image

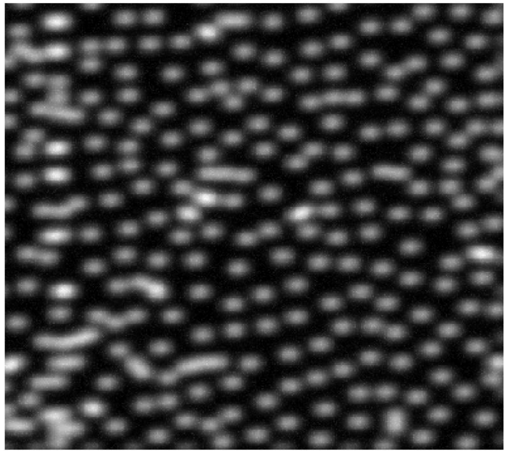
Ideal image



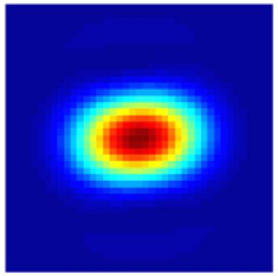
Estimated PSF



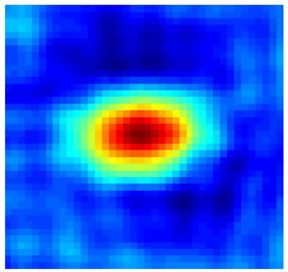
<u>Blurring image using blurring core and noise</u>



Known blurring core



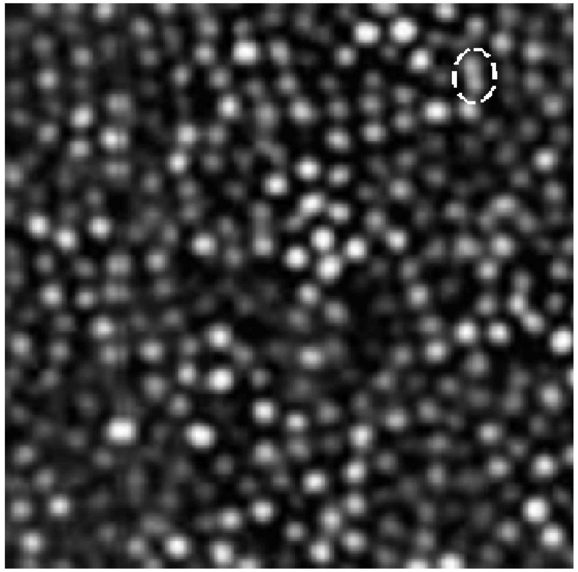
Estimation of PSF

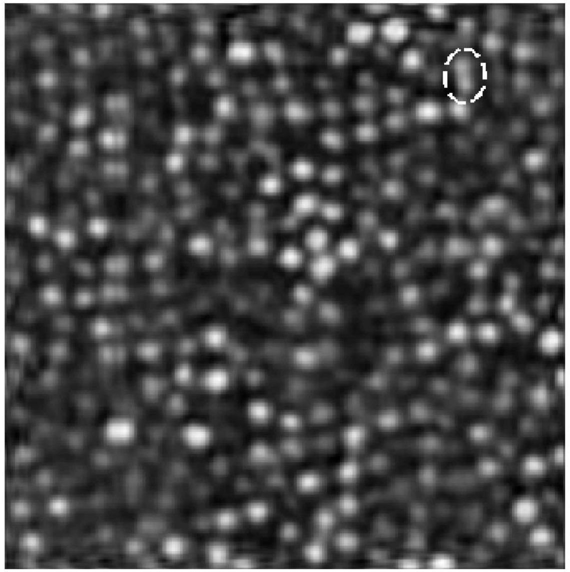


Results – adaptive optics image

- Adaptive optics image, taken by retinal camera (courtesy of Dr. Laurent Vabre, Imagine Eyes).

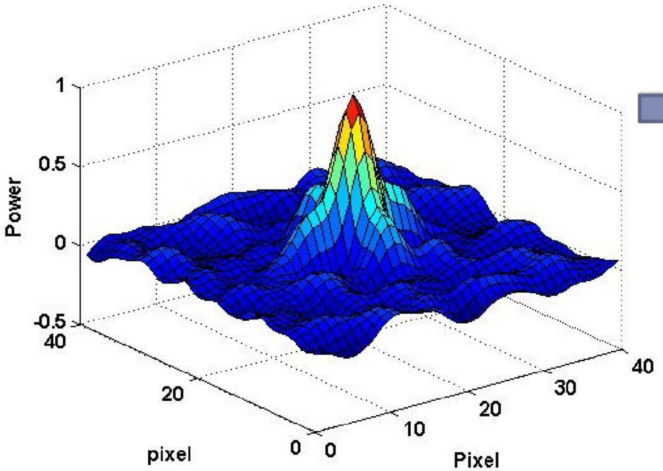
Image





Reconstructed image

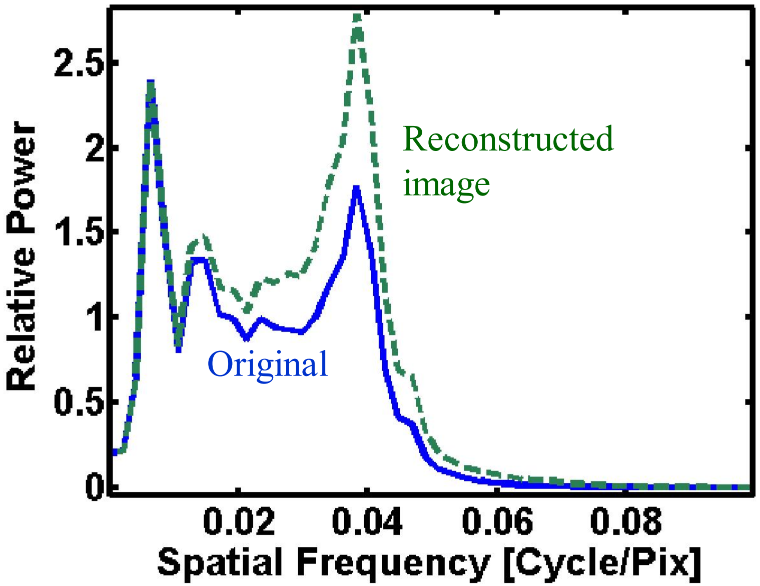
PSF estimation



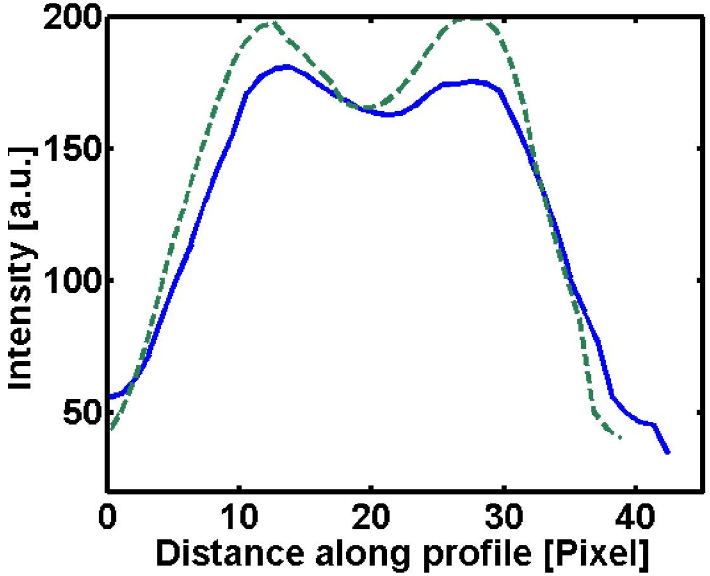
Reconstruction: Wiener filter

Results – adaptive optics image analyze

Power spectrum



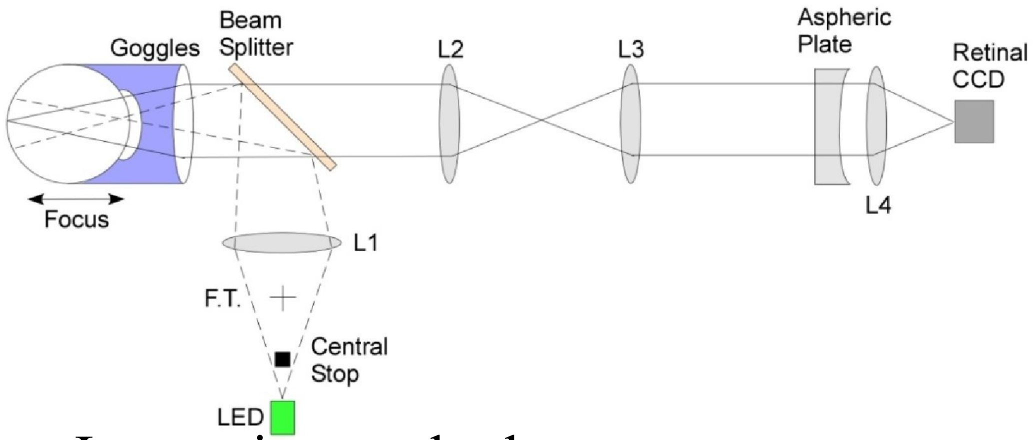
Intensity profile of two adjacent cells



- Biggest improvement in the power spectrum corresponds to the spatial frequency of minimal inter-cell distances
- Intensity profile of two adjacent cells (almost unresolved) shows local improvement in contrast

Other retinal imaging methods

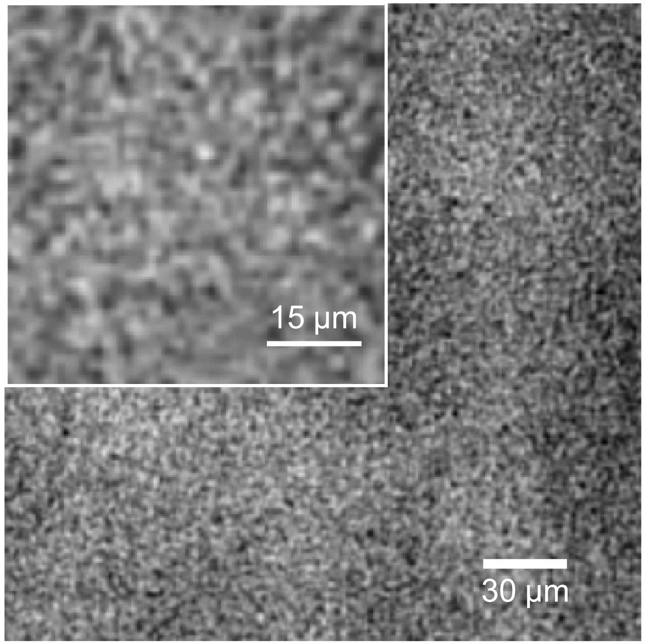
- We implement the PSF estimation method on other imaging methods



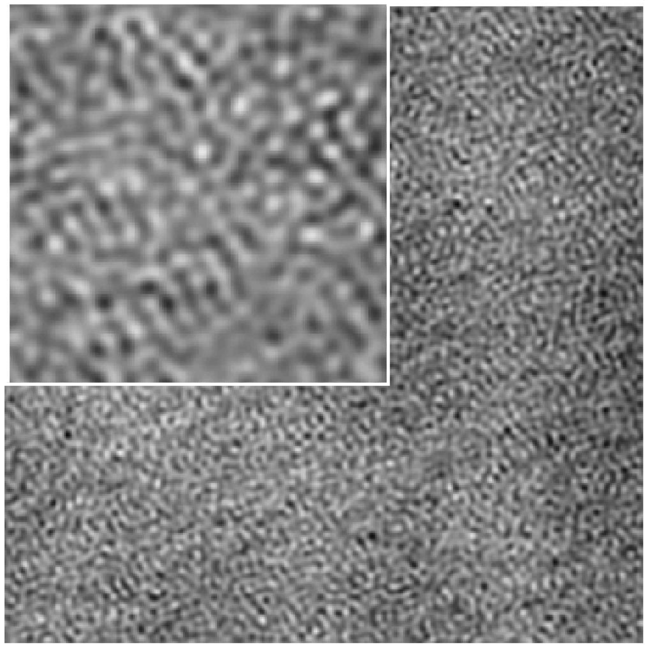
- Immersion method:
  - Corneal immersion by saline solution, to reduce the optical power of the cornea and replacing it by off-the-shelf lens.
  - Reduction of the remaining spherical aberration by aspheric plate
- Direct method:
  - Similar to the immersion method but without immersion goggle and aspheric plate
- We enhance the resolution of both methods by registration of large number of frames.
  - This allows multiple oversampling and dynamic aberrations averaging

Direct imaging results

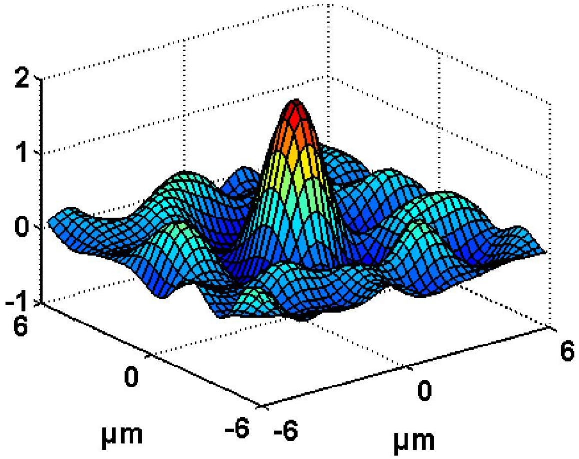
Image



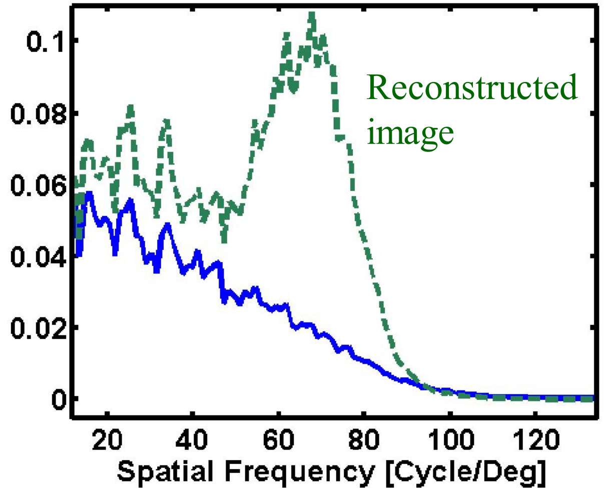
Wiener reconstruction



PSF estimation



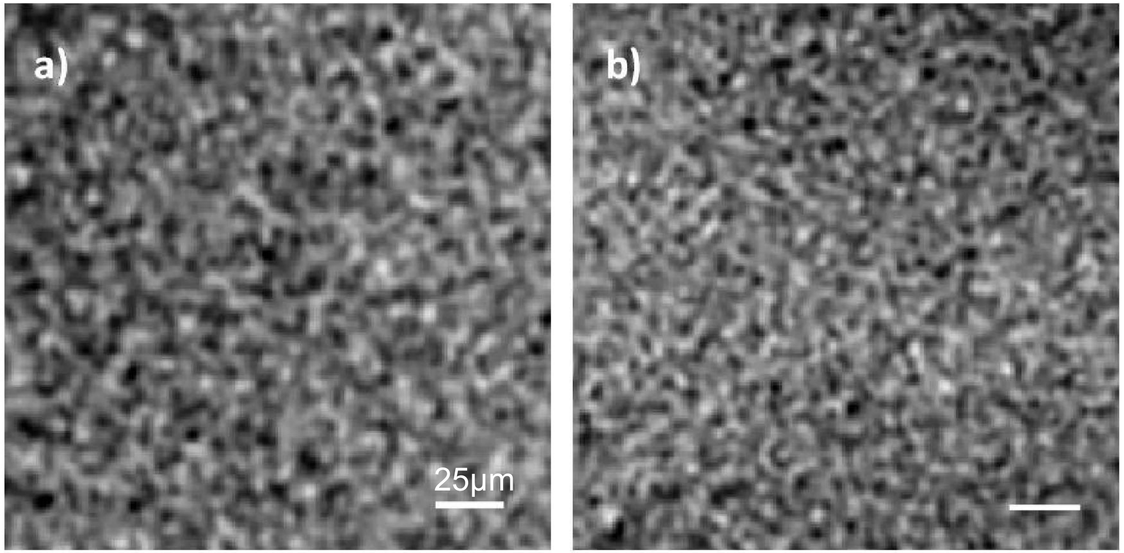
Power spectrum



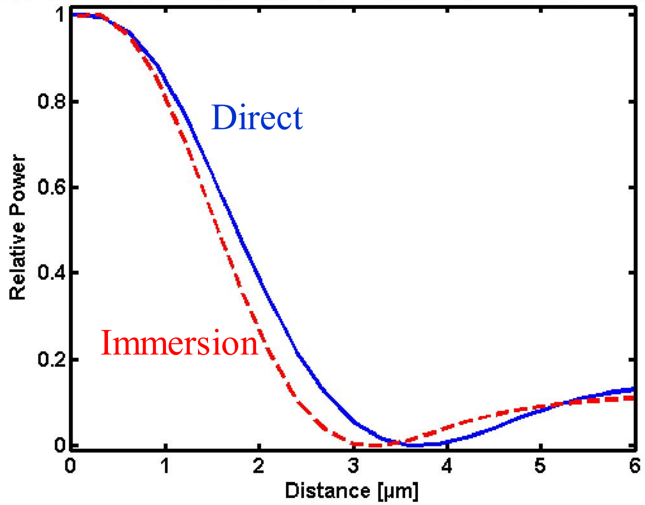
PSF estimation for resolution enhancement analysis

- The PSF profile demonstrates the better resolution of immersion, compared to direct imaging.

Direct image Immersion image



Radial profile of the PSF



Summary

- We present a method to estimate point spread function by taking advantage of the rather simple geometry of retinal cells
- In the absence of measured PSF this method can be used to enhance the visibility of cells by deconvolution methods
- Since the method is based on identification of cells, the estimation is expected to be better when using more resolved images as an input

Reference: N. Meitav and E. N. Ribak, Optics Letters 37, 1466-8 (2012).

Thank you for your attention

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  - Supervisor : Erez N. Ribak
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