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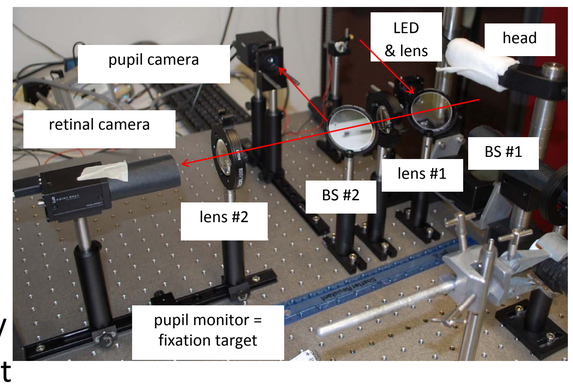
The interaction of light and tissue in the retina

Experiment: try to see cones in normal retina

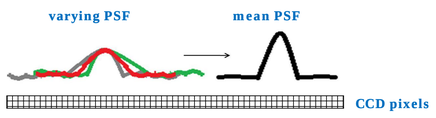
Resolution ~ 5µm, but:
Cone size ~ 2-4µm
Solution: oversample
take multiple frames
use LED, avoid flash
use good eyes



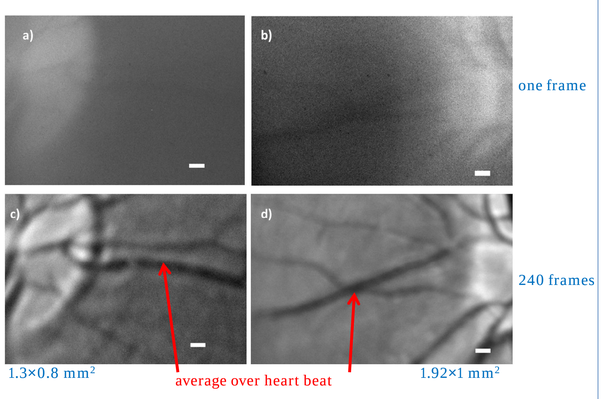
employ *weighted shift-and-add*
borrowed from astronomy

- choose region of interest
- create matched filter
- correlate each image
- calculate weight and shift
- sub-pixel shift to centre, add to previous

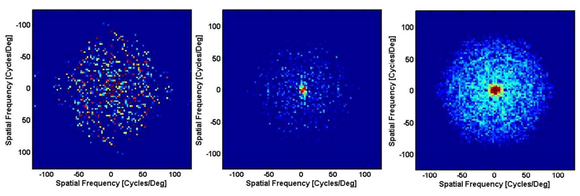
update matched filter, repeat twice
with addition of multiple frames:



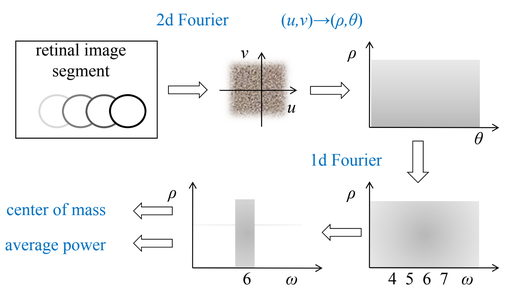
main features add up
side lobes average out
resolution improves:

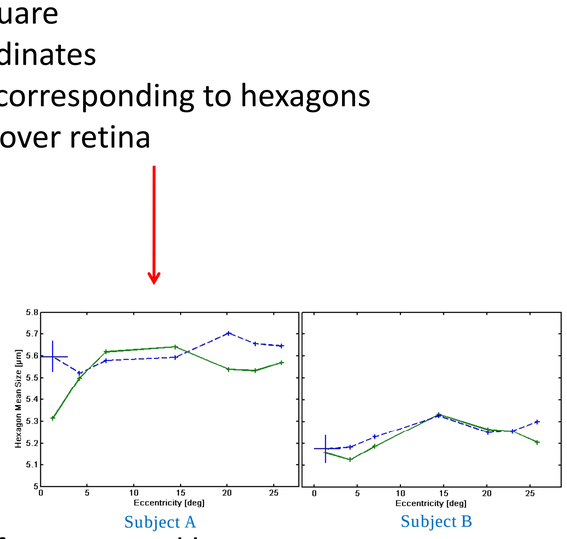


Hexagonal close packing of cones

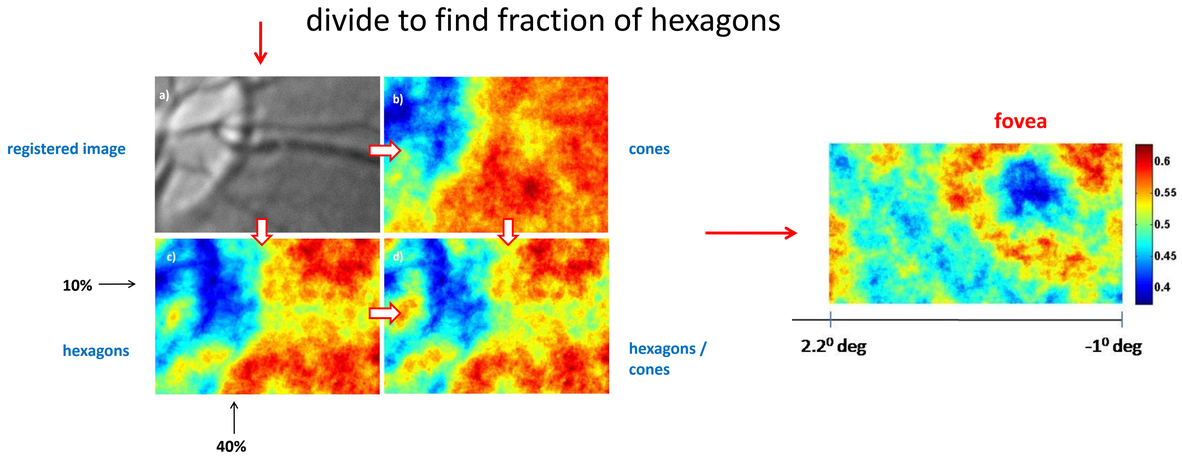


Analytical test: Pick small regions, where cones are ordered
Fourier transform, square
convert to polar coordinates
pick sixth frequency, corresponding to hexagons
find density of cones over retina



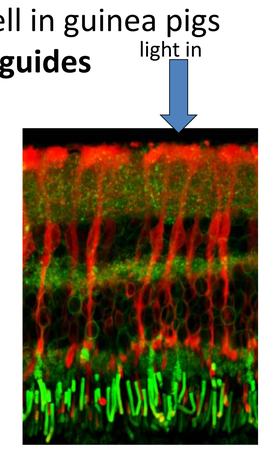


Alternative test: create matched filter for cones and hexagons
apply filters to image
locate all bright signals, for cones or hexagons
divide to find fraction of hexagons

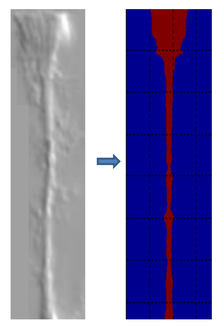


Simulation: try to see light guiding in the retina

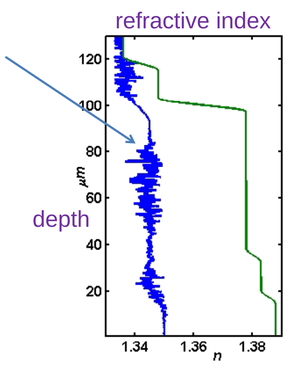
Franze *et al.* (*PNAS* 2007): wave guiding by Mueller (glial) cell in guinea pigs
Test hypothesis that human glial cells are an array of light guides



Shape of glial cells: Chao *et al.*, *J. Neurocyt.* (1997)
Images digitised
Processes (small extensions < λ) ignored
Added random meandering
Neuron and nuclei layers assumed constant across retina



Refractive index for neurons, nuclei by Barrer (*JOSA* 1957)
Recent data for glial cell by Franze *et al.* (*PNAS* 2007)
Random fluctuations added to represent fine neurons

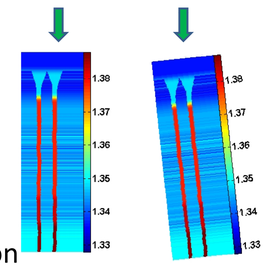


Split-step beam propagation throughout retinal volume

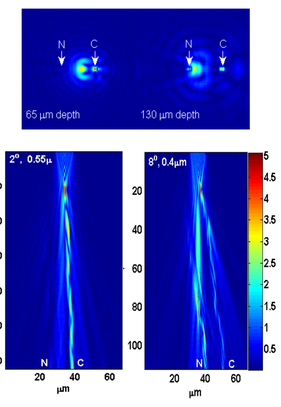
$$\phi(z+h,r) = e^{Ah}e^{Bh}\phi(z,r) = F^{-1}[e^{A_f h}F\{e^{Bh}\phi(z,r)\}]$$

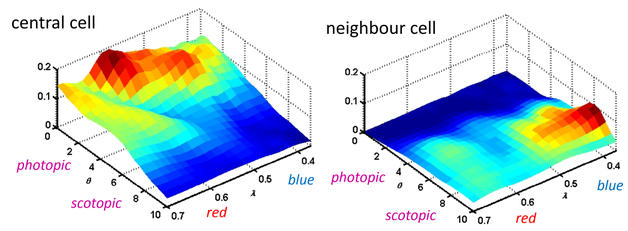
First application

- two nearby cells
- illuminate central cell only
- tilt array, change wave length



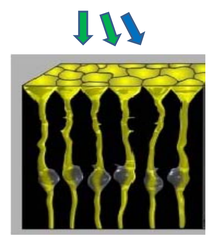
Leakage could decrease image resolution
No leakage at small angles (photopic vision)
Worst leakage is at high angles (scotopic)
Best performance is at green-red
Worst leakage is at blue at high angles



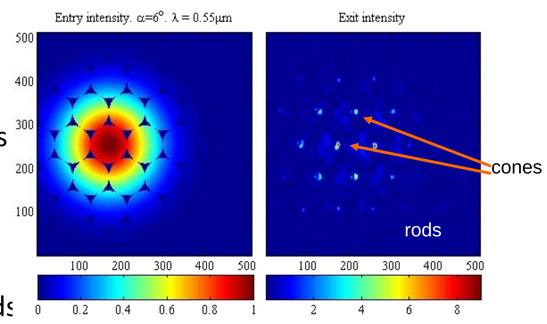


Second application

- an array of cells
- illuminate central cell only, or use a wide gaussian
- tilt light, change wave length
- monitor propagation, bottom distribution



Benefits of inverted retina
Better preservation of photopic images
Reduced sensitivity to longit. chromatic aberrations
Concentrates light by Mueller cells into cones
Reduces loss by blood vessels
Scatters more blue, infrared light out of cones
Improves scotopic vision by scattering light into rods
Results valid for vertebrates, human parafovea



Reference: A M Labin and E N Ribak: "Retinal Glial cells enhance human vision acuity", *Physical Review Letters* **104,** 158102 (2010).