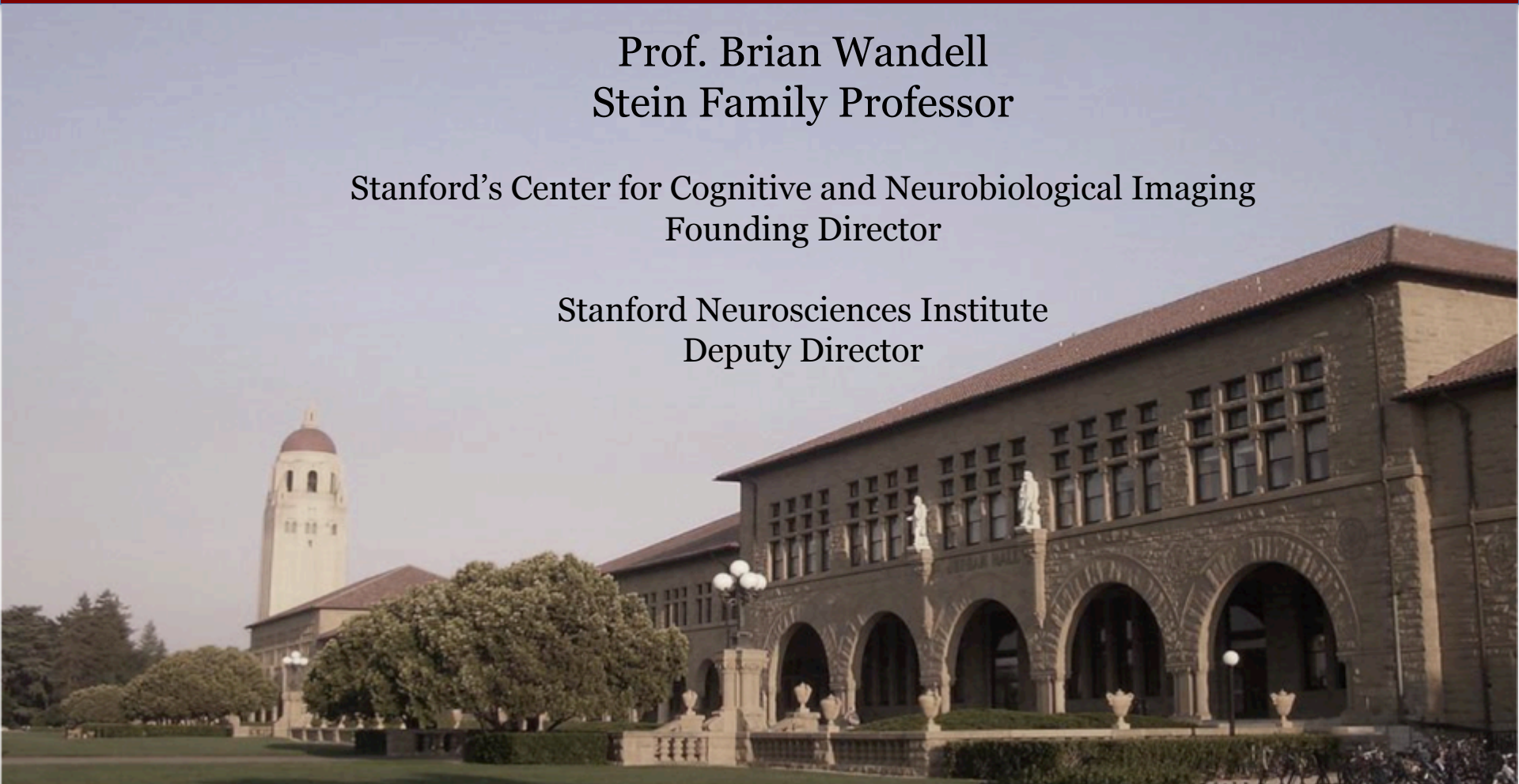
Image systems simulation



Prof. Brian Wandell
Stein Family Professor

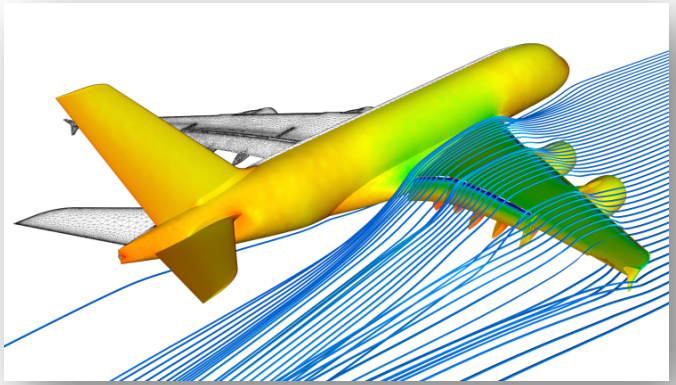
Stanford's Center for Cognitive and Neurobiological Imaging
Founding Director

Stanford Neurosciences Institute
Deputy Director

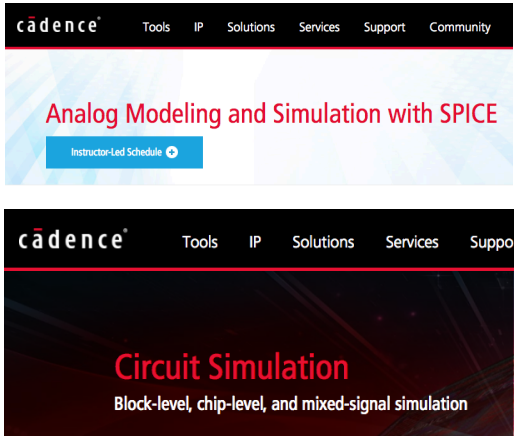
Image systems simulation

System simulation is important in many mature industries

ECU (Electronic Control Unit) Simulation for Automobiles



Numerical flow simulation on an Airbus A380



Integrated circuitry

Imaging industry is large and very innovative, spanning cameras, displays and processing

Multiple lens

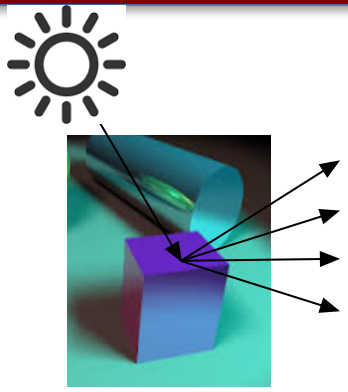
RGB-depth

360 Surround Video

VR, AR and MR HMDs

Light field

Image systems simulation for biology



Scene spectral radiance

Physiological optics

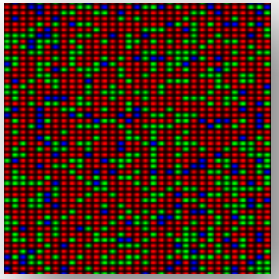
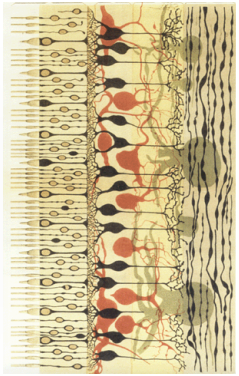
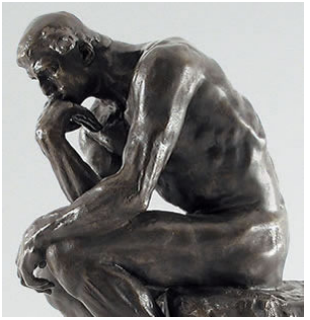


Photo transduction



Retinal processing

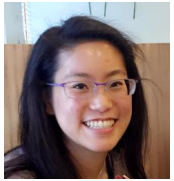


Inference

Brian Wandell

David Brainard

James Golden



Trisha Lian

Nicolas Cottaris

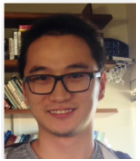
Fred Rieke

E.J. Chichilnisky

Xiaomao Ding

Jon Winawer

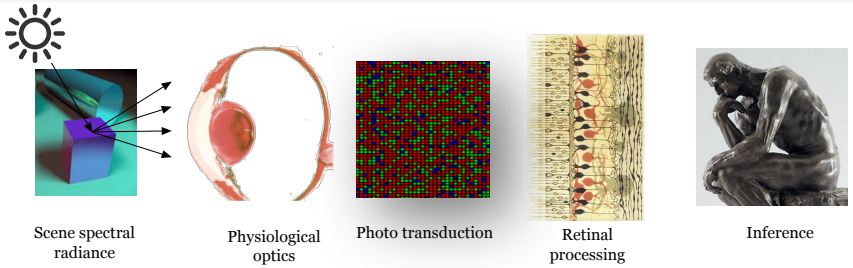
Joyce Farrell



Haomiao Jiang

Image systems simulation for biology

- ISETBIO is a set of computational tools to calculate and model how light from a scene is encoded and processed in the visual circuitry
- The goal is to clarify the impact of the different elements of the eye and neural processing in the retina and brain on visual perception
- The tool is designed to support both basic and applied vision research



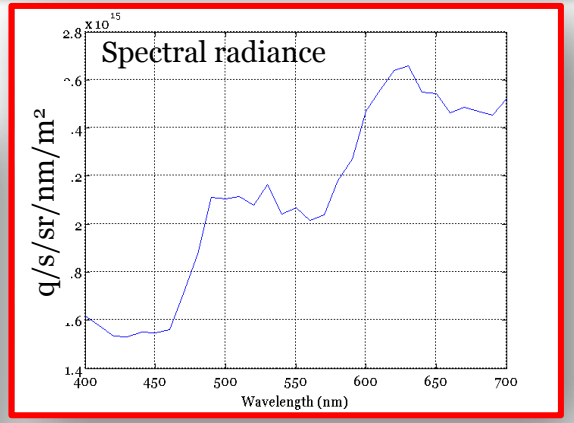
Spectral radiance, refraction, optics, Snell's law, diffraction, Airy disk, photons, energy, Planck's constant, chromatic aberration, retinal irradiance, pupil aperture, eye movements (tremor, drift, saccade), plenoptic function, wavefront aberrations, macular pigment, lens pigment, photopigments, rod and cone absorptions, color-matching functions, transduction, photocurrent, receptive fields, convolution, normalization, linear-nonlinear models, linear classifier theory, ideal observer

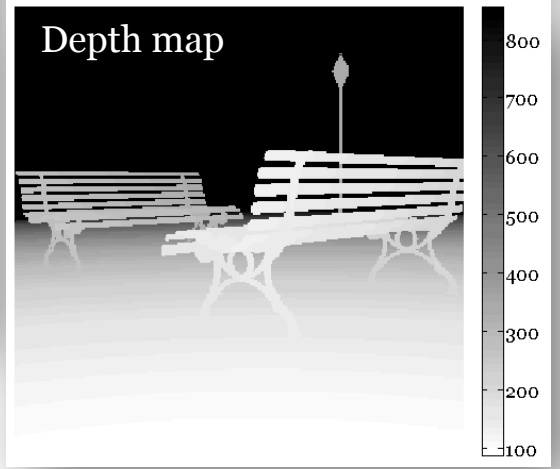
Essential technologies for image systems simulation

- Scene spectral radiance data are critical; depth information is important for many natural images

- Acquiring such data for natural images has been a limitation; some valuable cases are extremely difficult to obtain (e.g. high dynamic range, under water, inside the body, automotive)

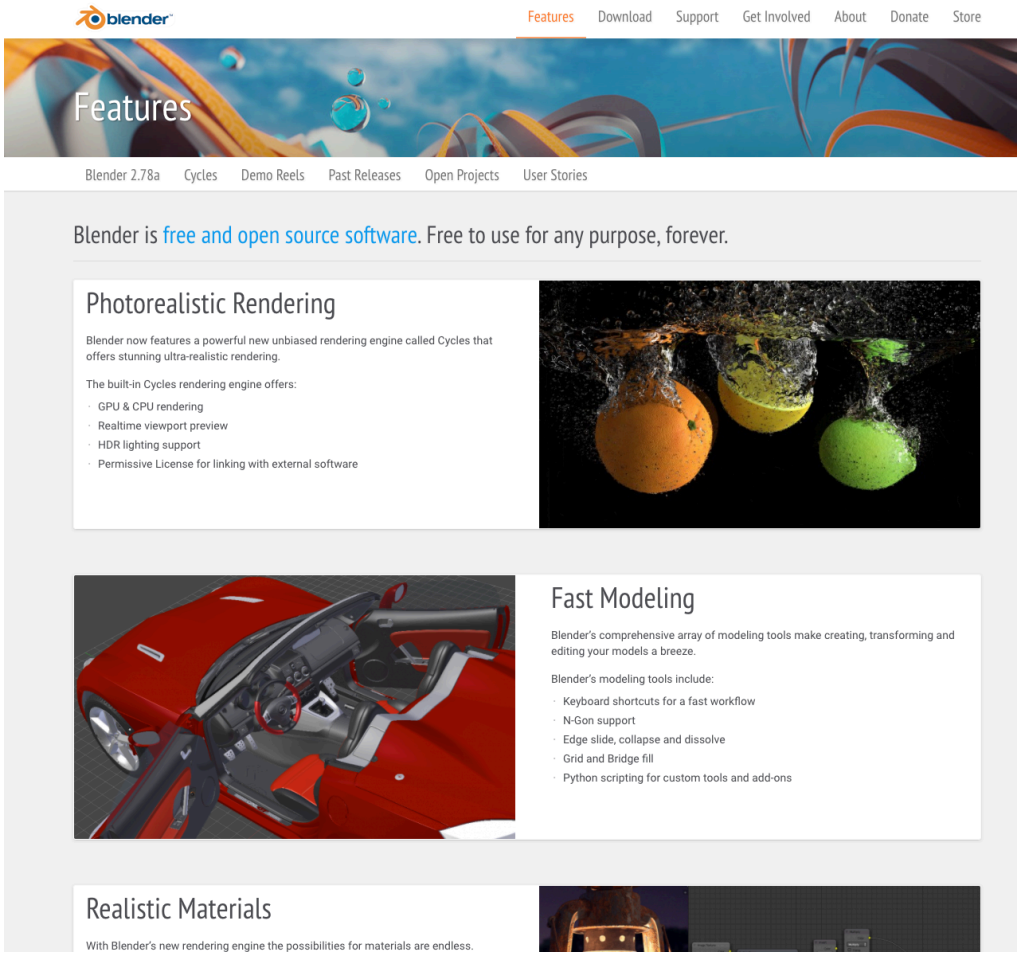
Quantitative computer graphics





Tools for modeling shapes, lights, material geometry

- Progress in computer graphics enables us to create synthetic and yet highly realistic input data.
- We want simulations with meaningful units; quantitative computer graphics
- Challenges remain to complete this work, but there are some encouraging successes

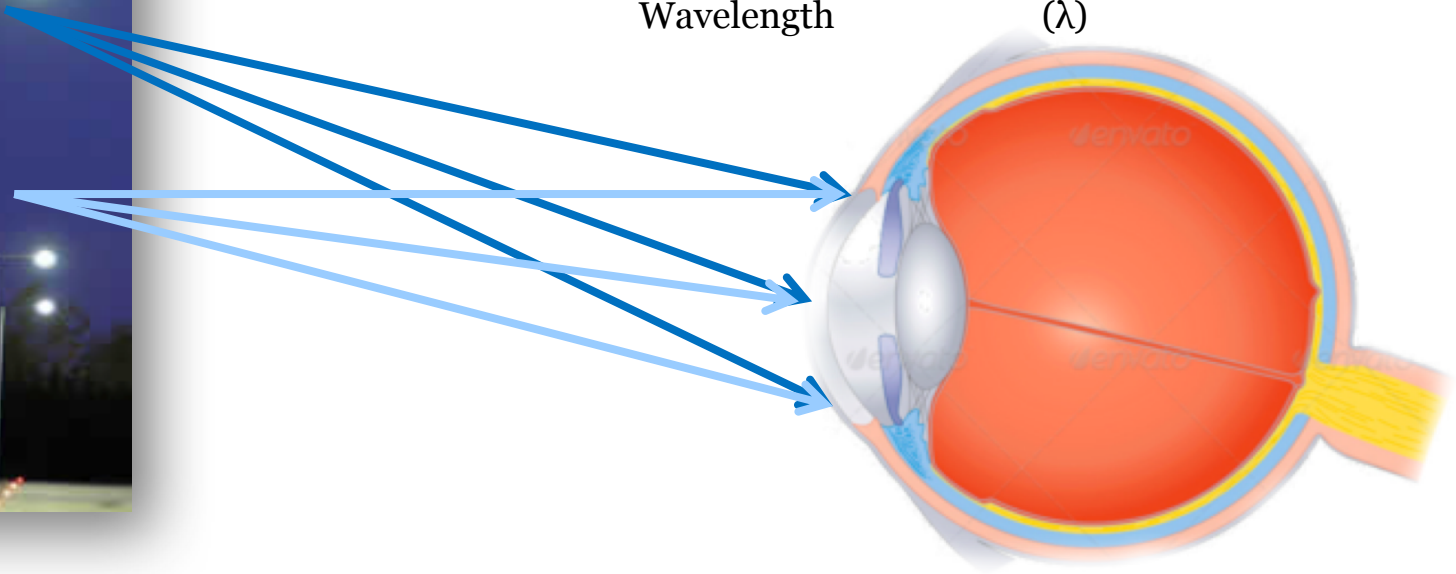


Ray trace methods yield light fields (plenoptic function)

(Adelson and Bergen, 1991; Levoy and Hanrahan, 1996)

$L(u,v,\alpha,\beta,\lambda)$ – light field at the eye

Position	(u,v)
Azimuth and elevation	(α, β)
Wavelength	(λ)



Human encoding overview

Physiological optics

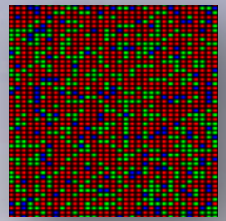
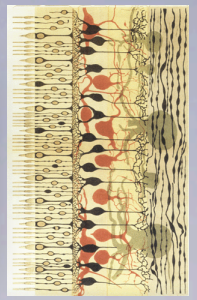
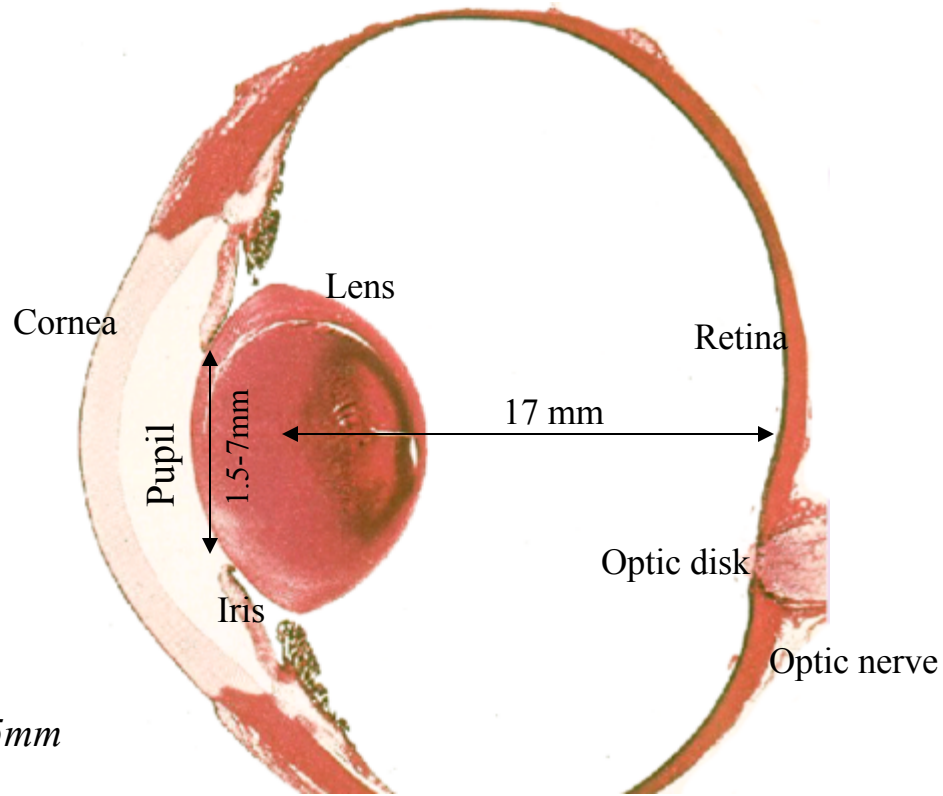


Photo transduction

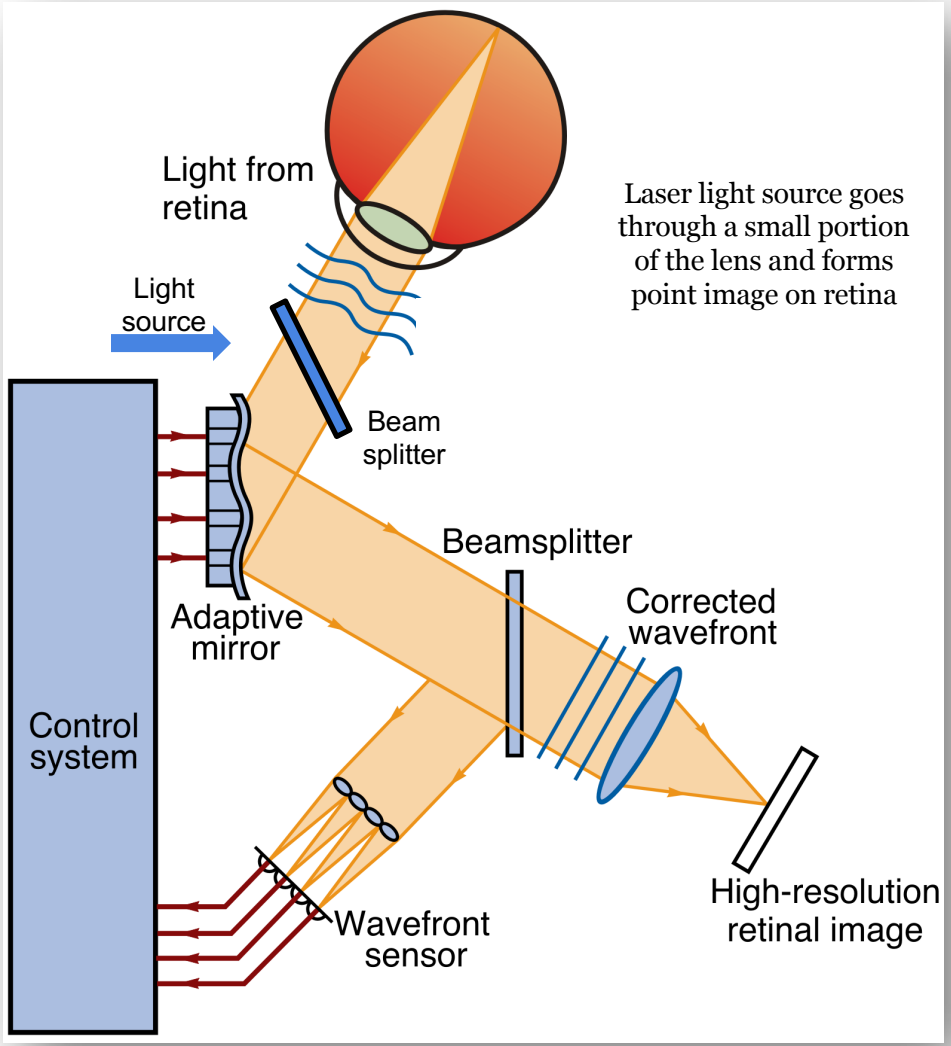


Retinal processing

Human eye in cross-section



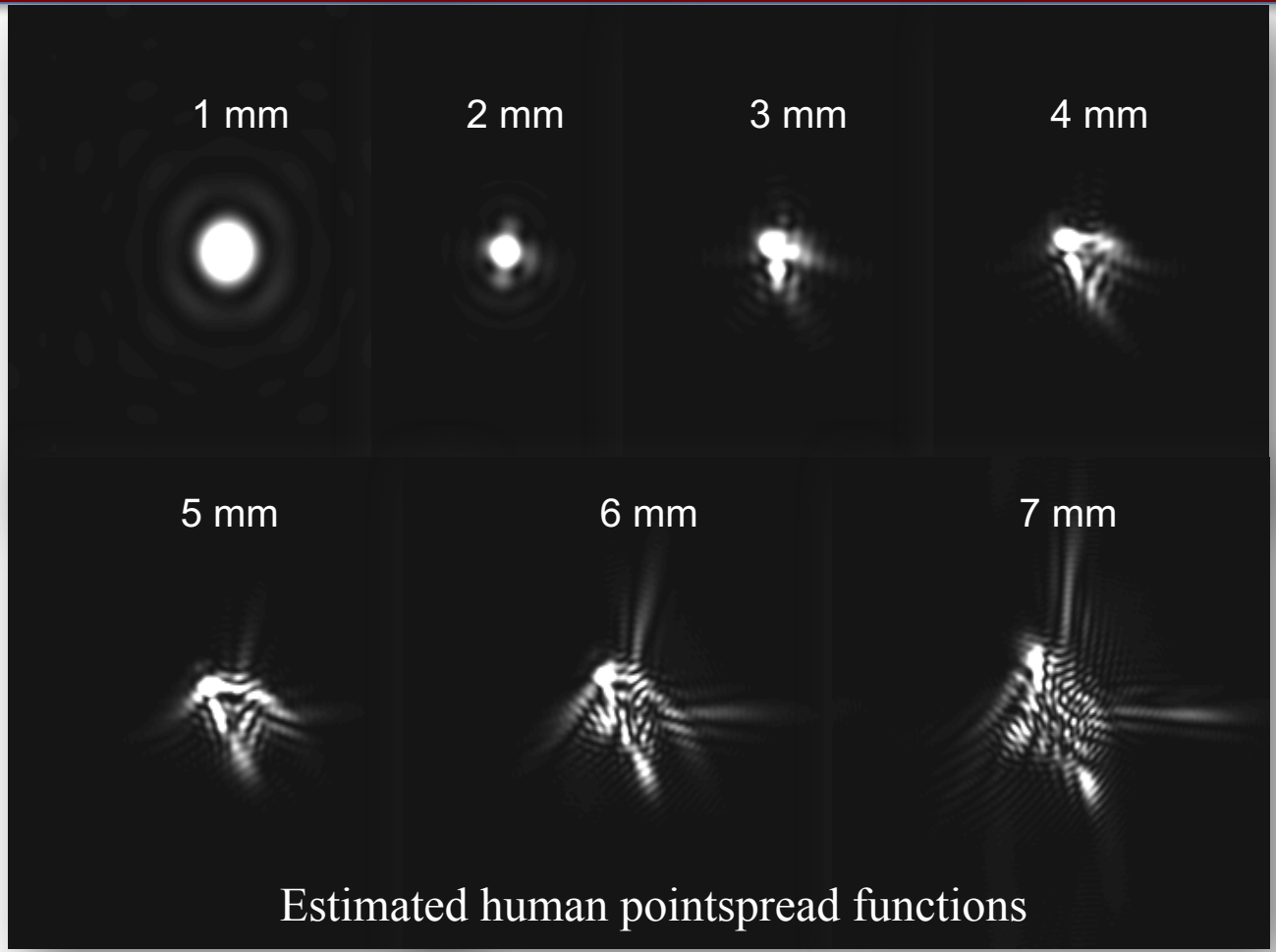
F-number ~ 2.4-11
Retinal thickness ~ 0.5mm



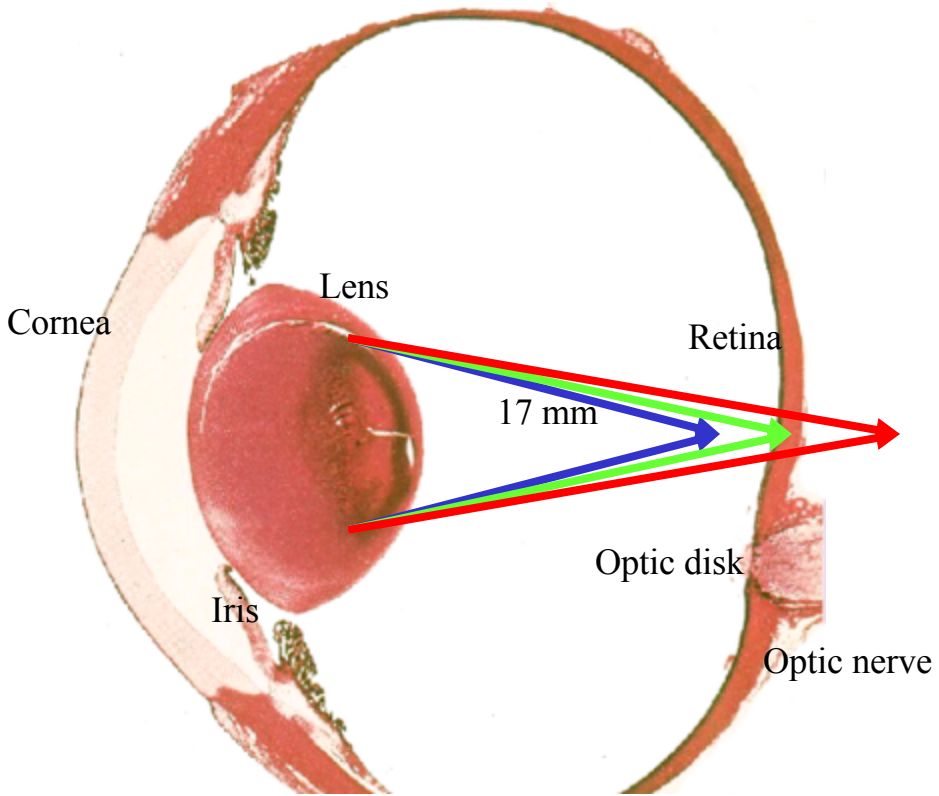
Adaptive optics corrects retinal wavefront aberrations

J. Carroll, D. Gray, A. Roorda, D. R. Williams (2005)

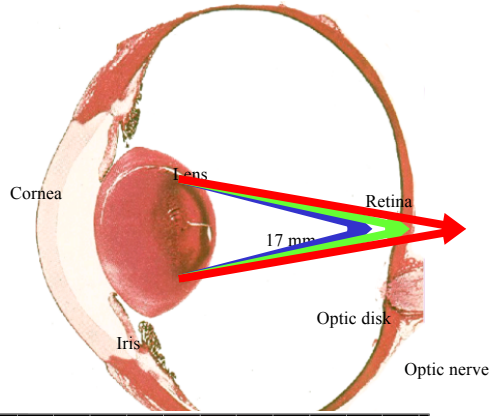
Visual acuity is worse as pupils dilate (Faber, 2001, CFAO)

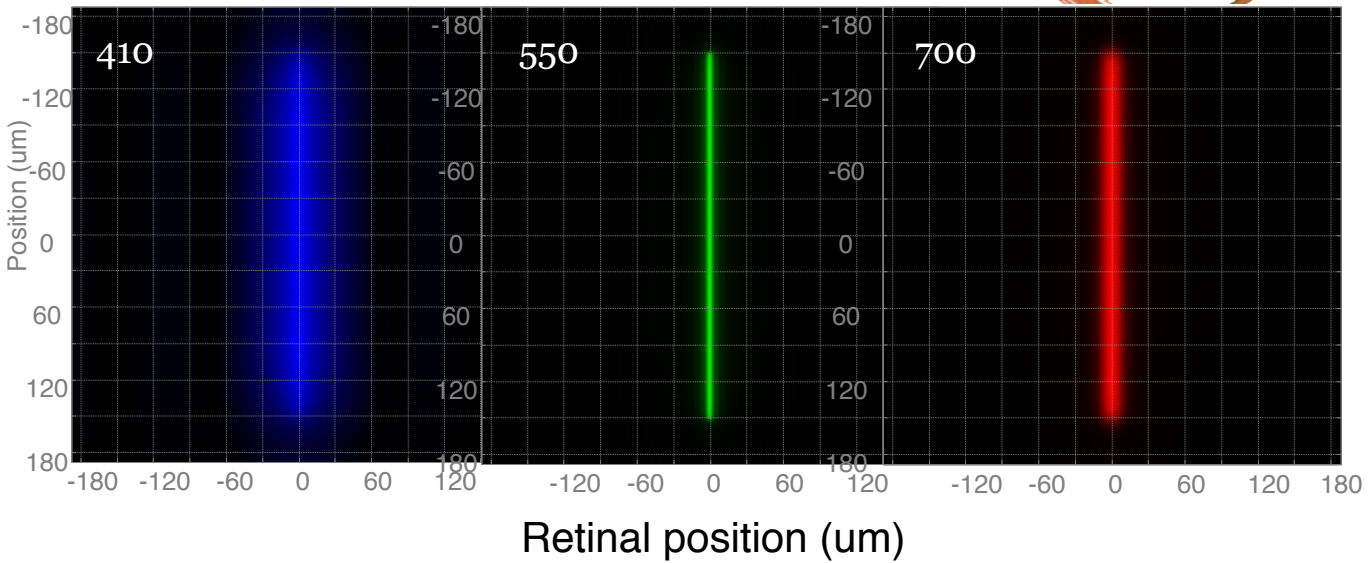


Chromatic aberration is a difference in optical focus across wavelength



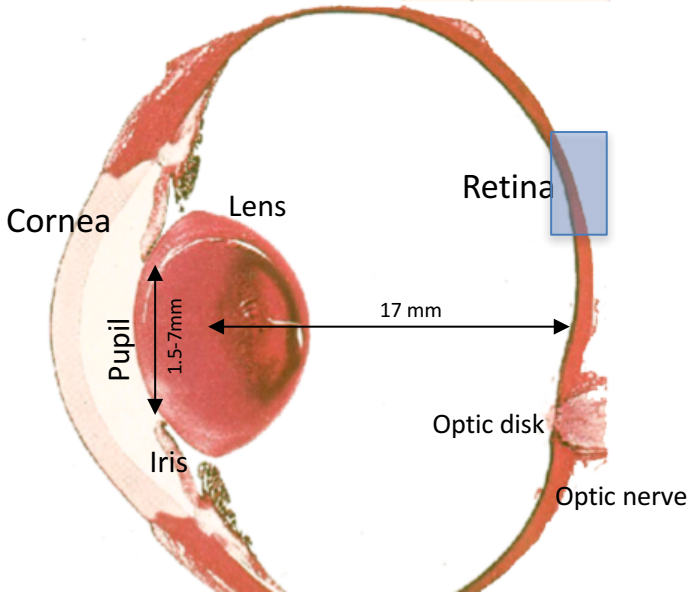
At the retina, the line spread differs by wavelength

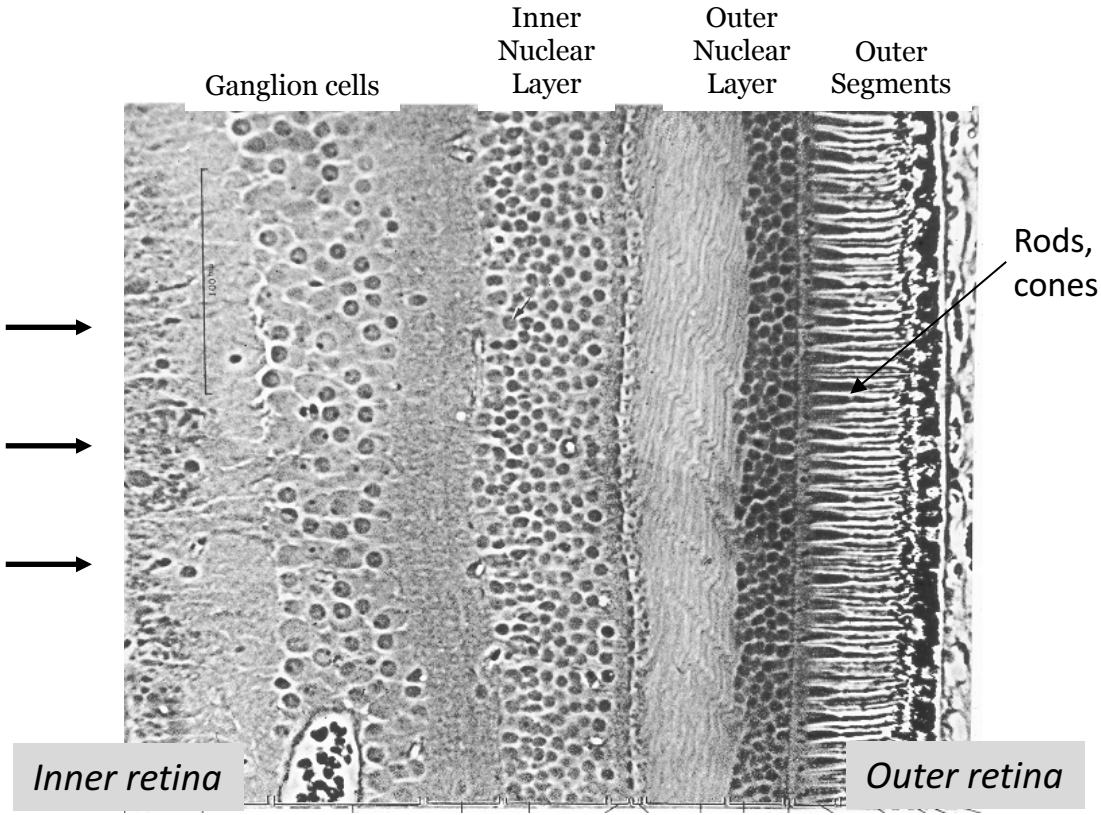




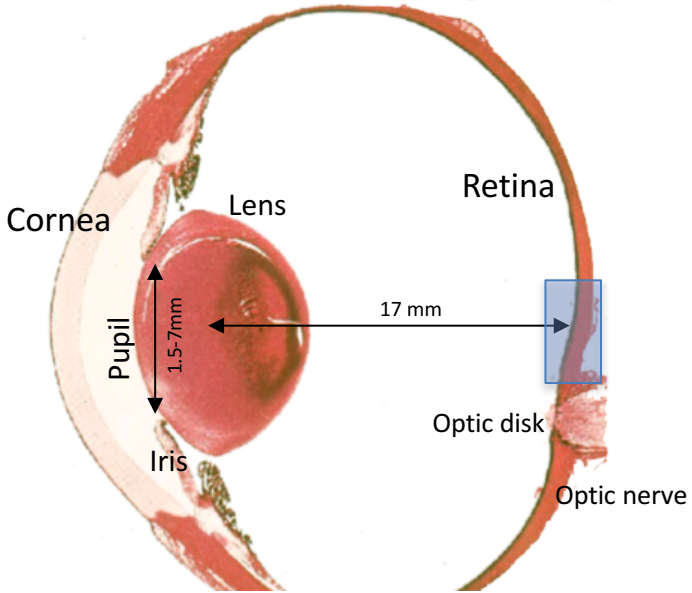
Human eye in cross-section

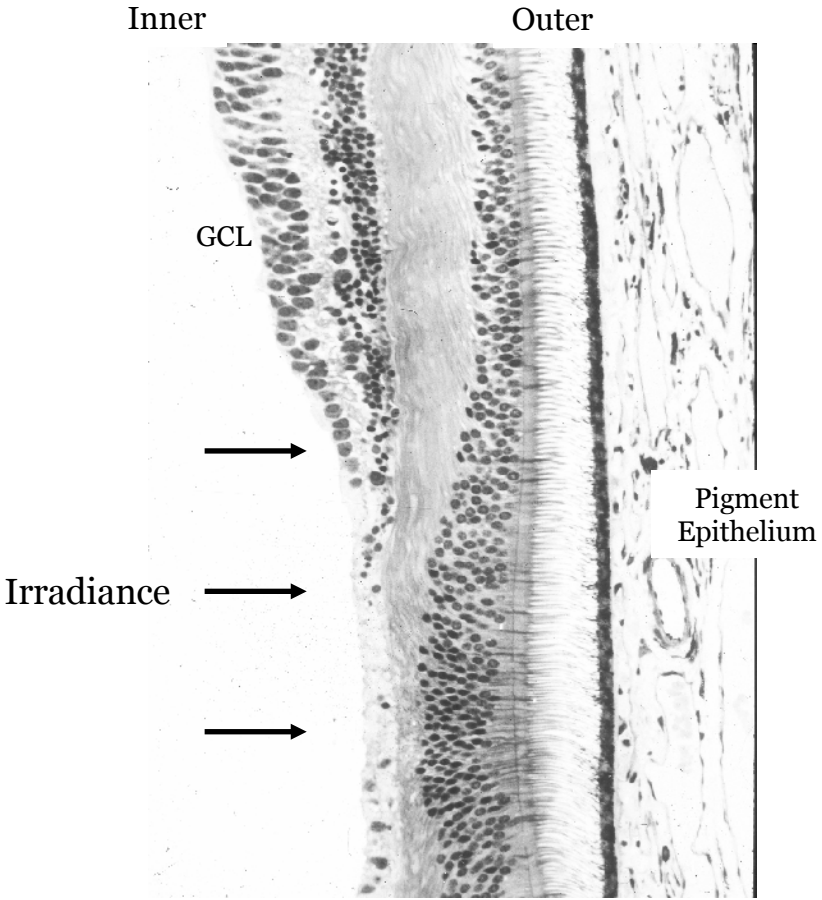
F-number ~ 2.4-11
Retinal thickness ~ 0.4mm





The primate fovea (pit) contains mainly cones and is specialized for high acuity and color





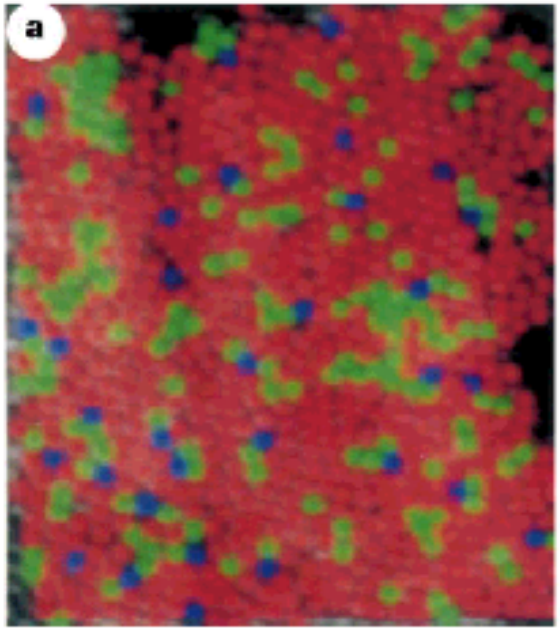
Application: Seeing The Arrangement of Cone Classes in the Human Eye

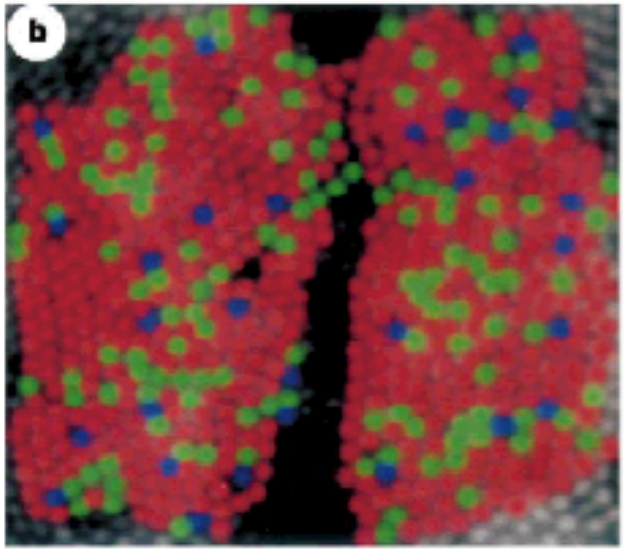
(Roorda and Williams et al., 1999)

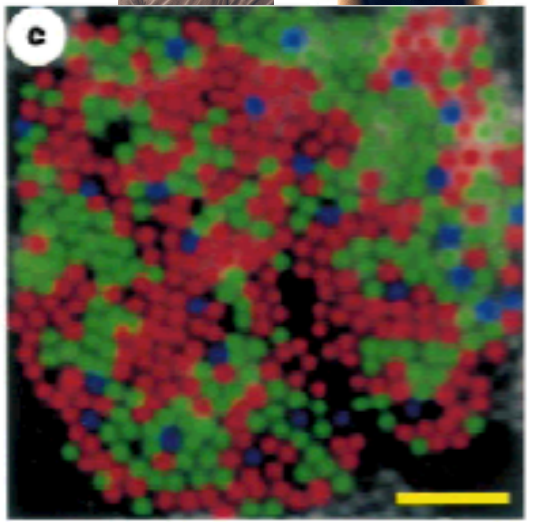
Austin Roorda

Heidi Hofer

letters to nature







Retinal overview

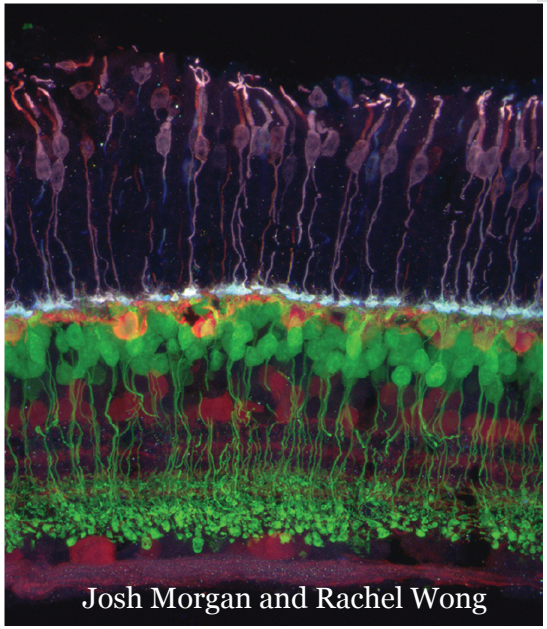
Photoreceptors

Horizontal

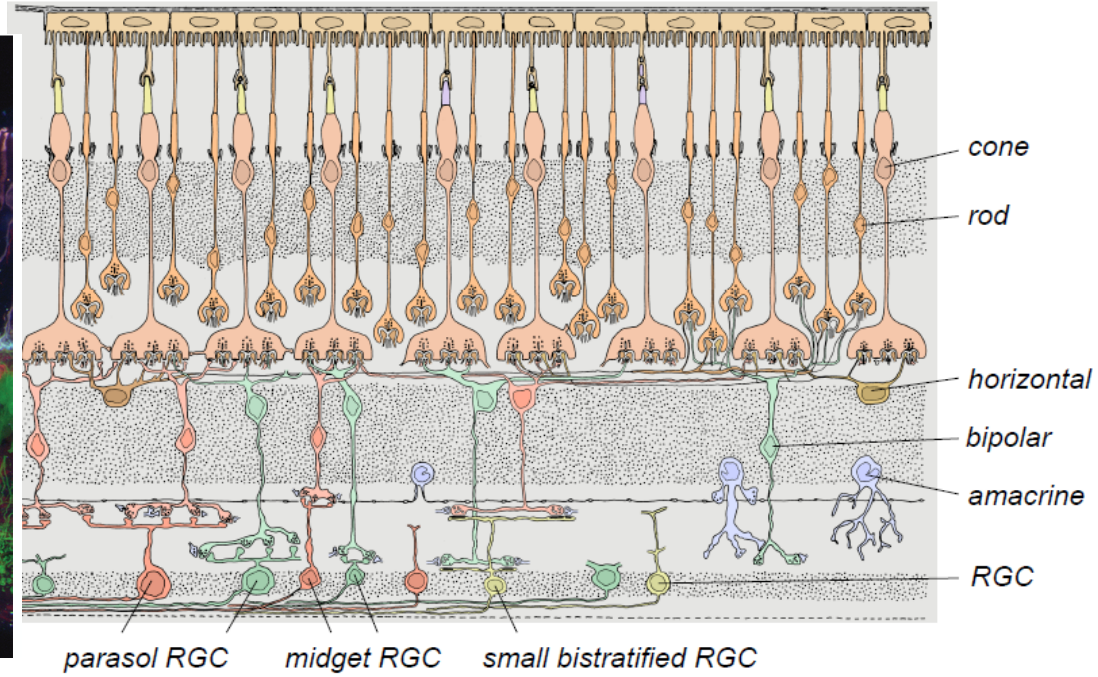
Bipolar

Amacrine

Ganglion

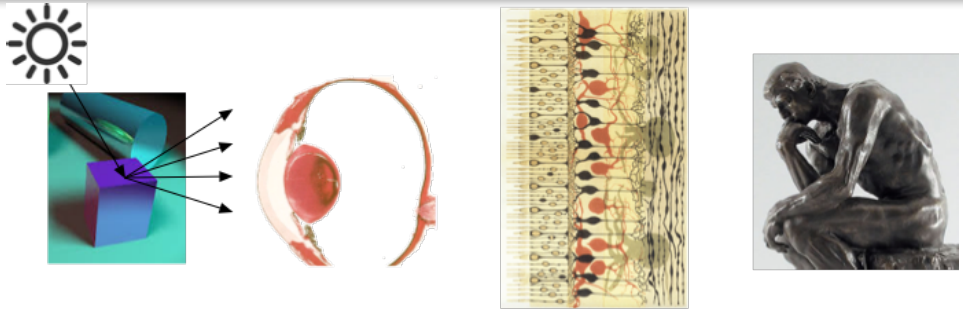


Pigment epithelium



(Chichilnisky and Field, Annual Reviews of Neuroscience)

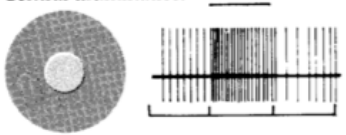
Modeling the Retinal Output



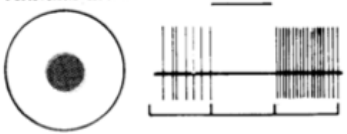
scene representation | physiological optics | photo transduction | retinal processing | inference

classical models

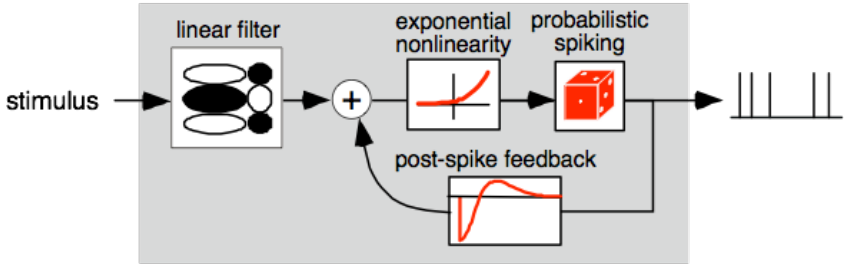
Central illumination



Annular illumination

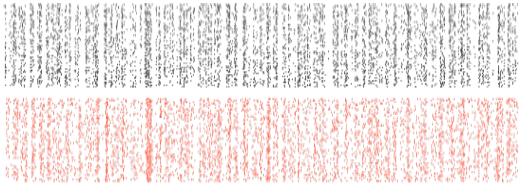


pseudo-linear models

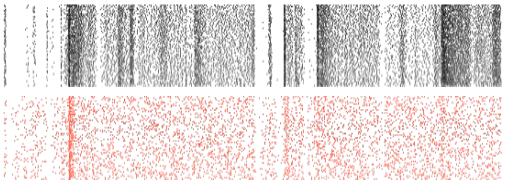


Paninski (2004)
Truccolo et al (2004)

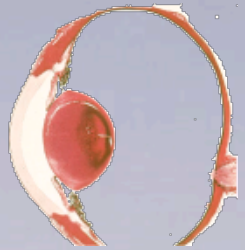
white noise data & model



natural stimuli data & model



Human image formation

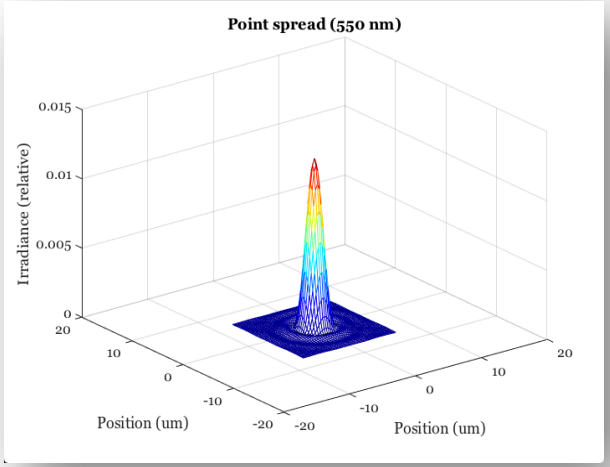


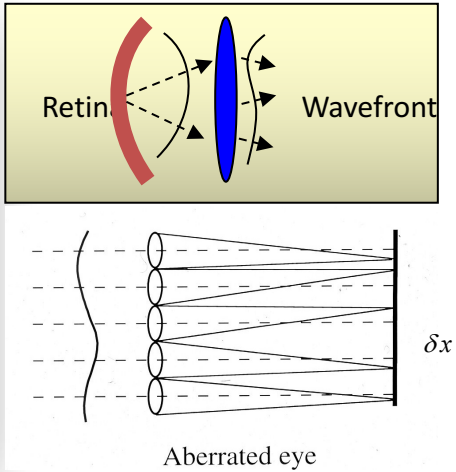
Physiological optics

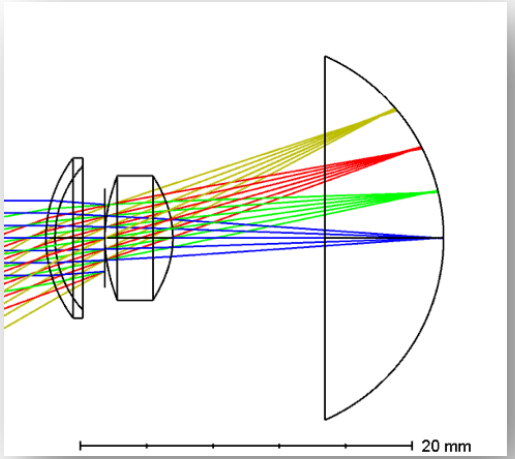
ISETBIO - Ray trace and wavefront optics models

Shift-invariant models from diffraction to AO wavefront measures (Zernike polynomial)

Ray trace with diffraction model (e.g. Navarro eye m model)

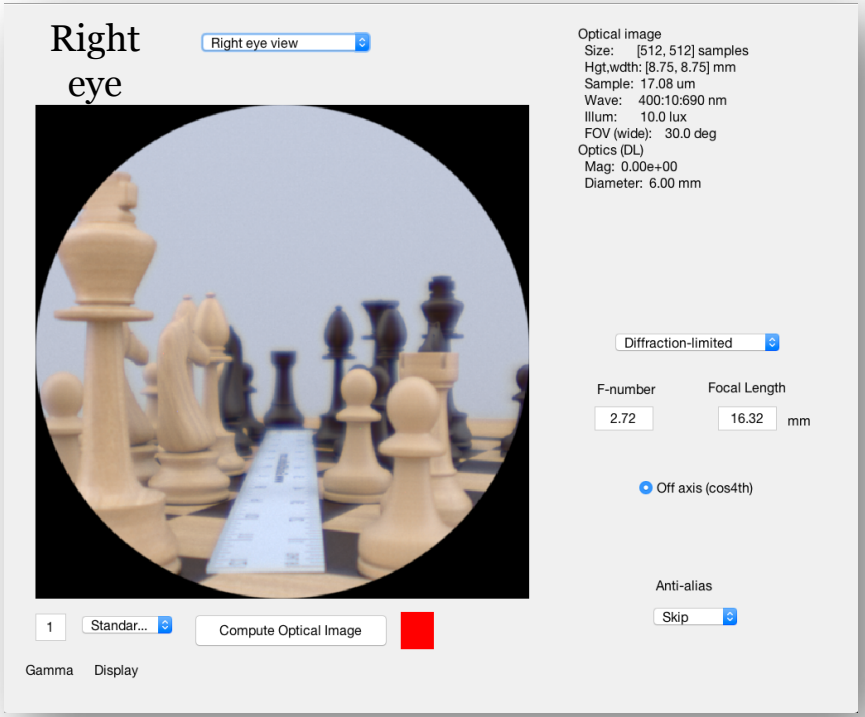






Natural images - Image formation (optics) models and quantitative graphics

Quantitative computer graphics implementation (PBRT) of the Navarro eye model (Trisha Lian)



Depth map (mm)

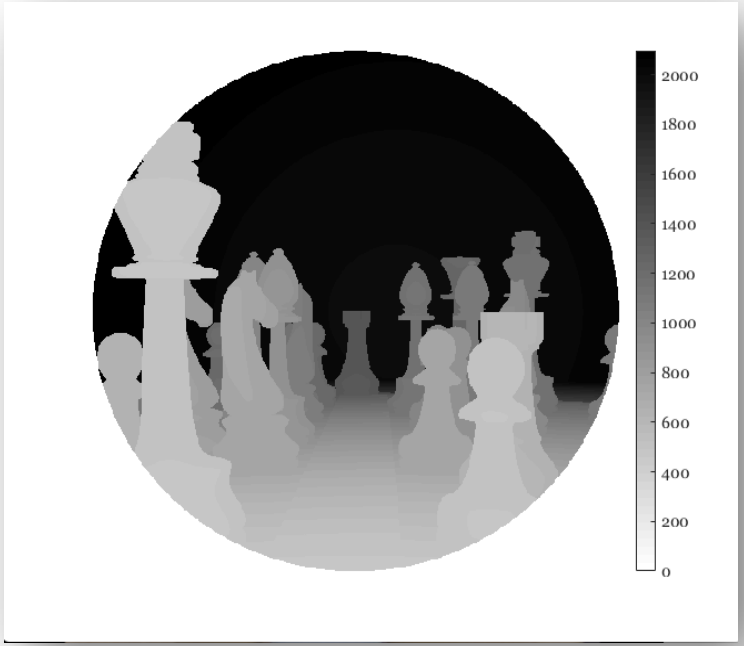
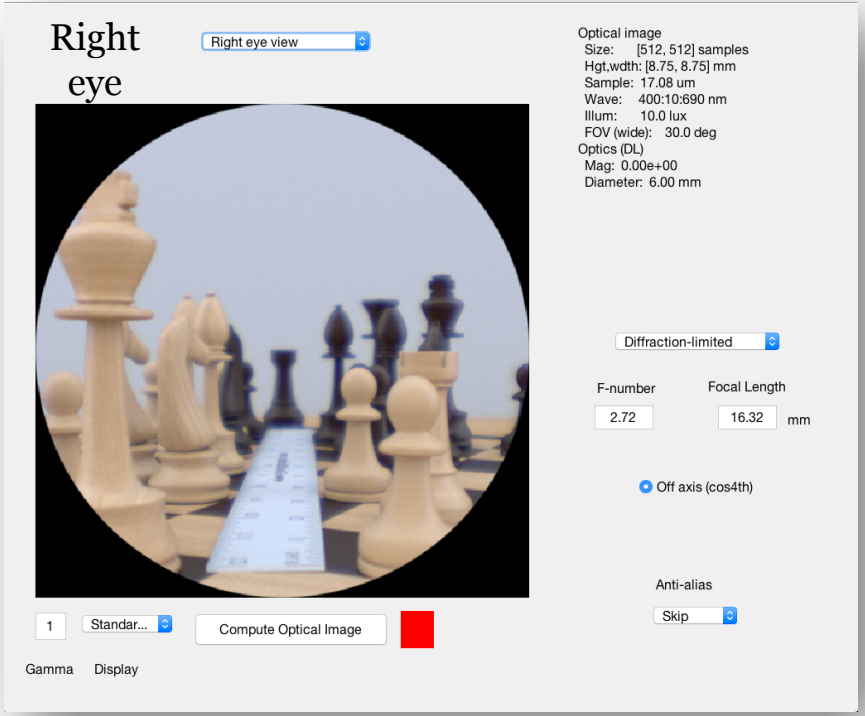
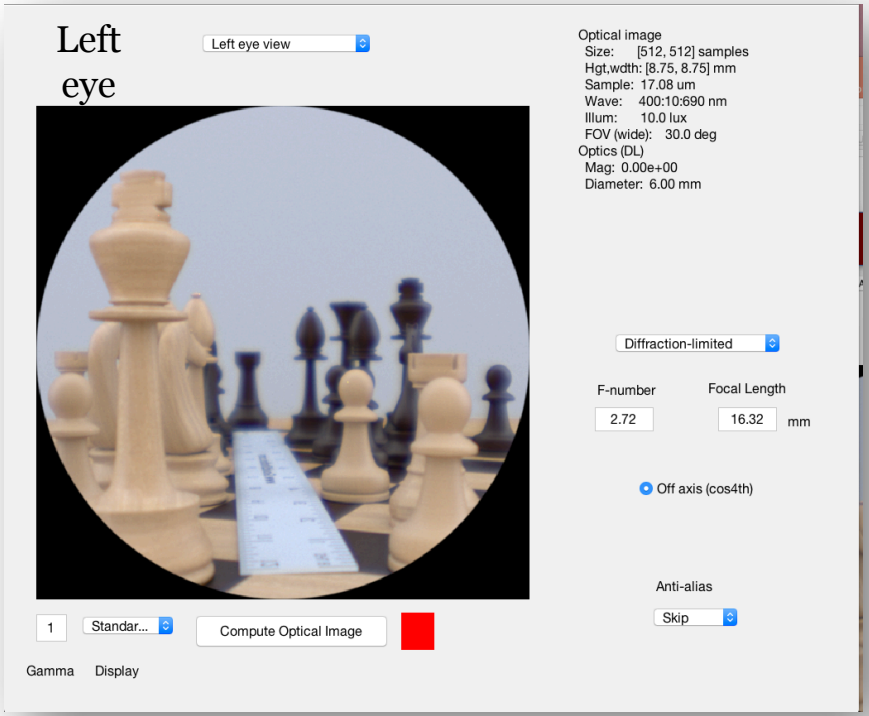


Image formation (optics) models and quantitative graphics

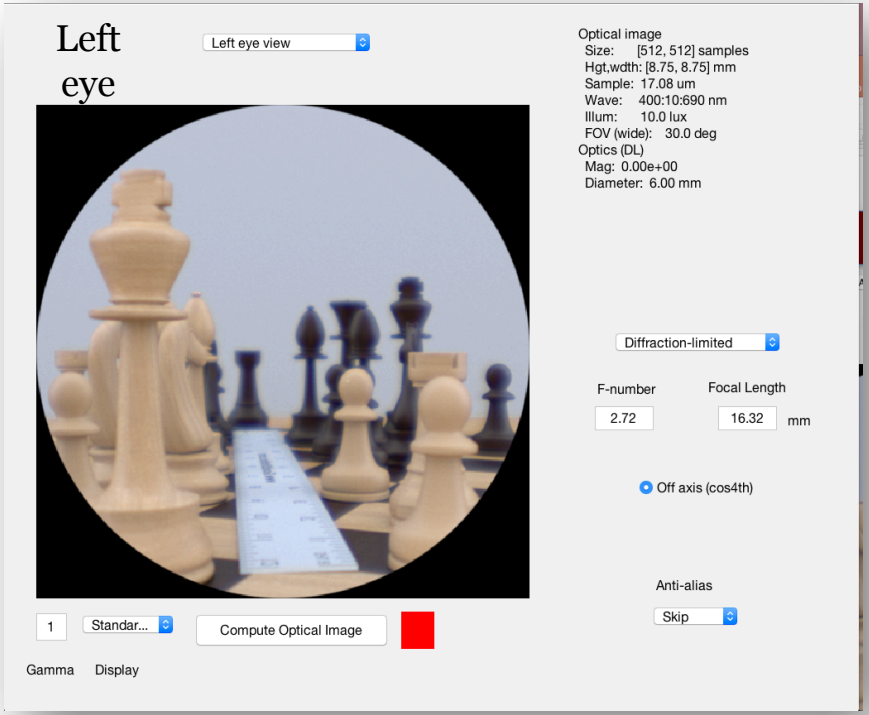
Stereo pairs are straightforward to compute





Natural images - Image formation (optics) models and quantitative graphics

Inert pigments (e.g. lens transmission)



Longitudinal and transverse chromatic aberration

Zoomed view

Notice the spread of the short-wavelength light

Chromatic aberration (and diffraction) are included in both the ray trace calculation and shift-invariant models

Cone absorptions

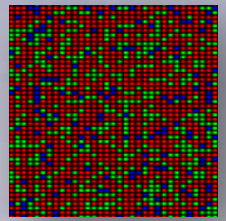
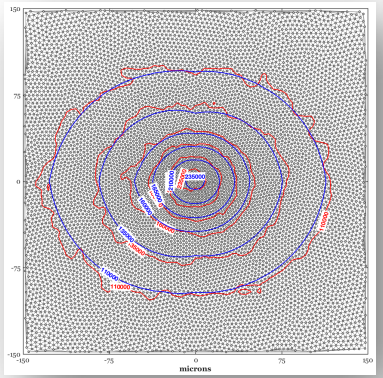


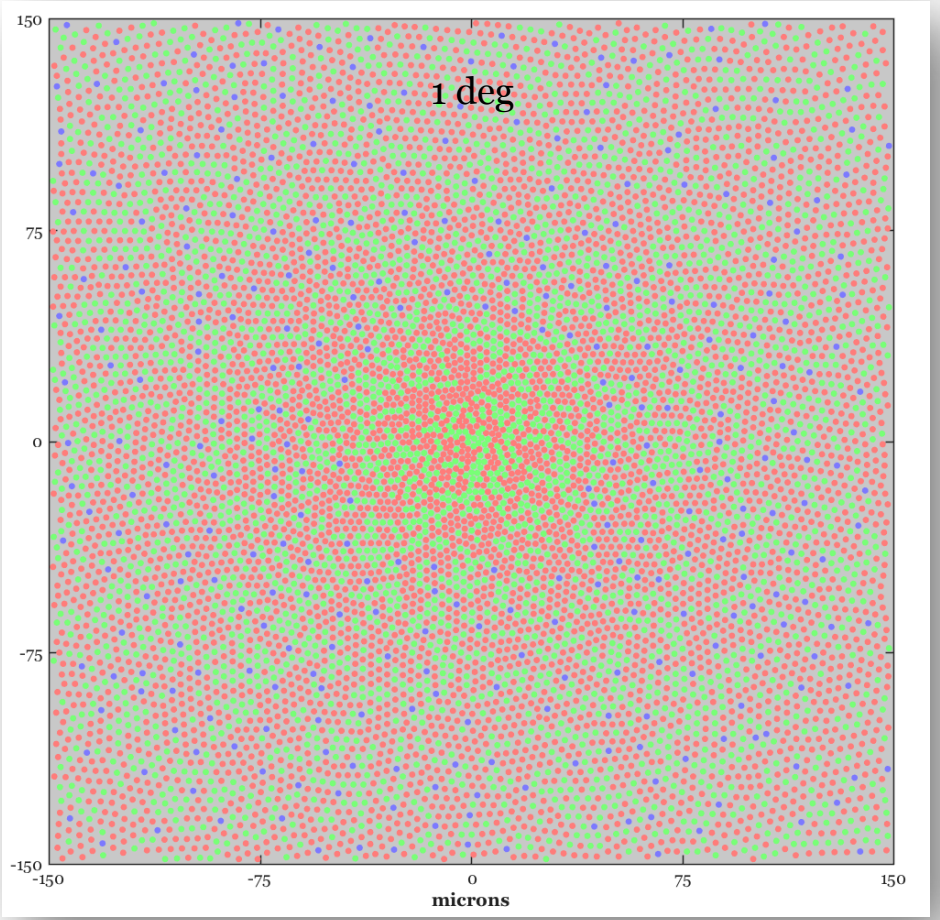
Photo
transduction

Cone absorptions and eye movements

- Uniform and space-varying cone density representations (Nicolas Cottaris)
- Incorporates parameters that specify how cone spacing and cone aperture size vary with distance from the fovea
- Removes S-cones in very central fovea

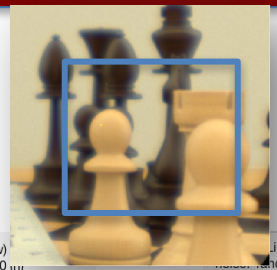
Iso-density lines

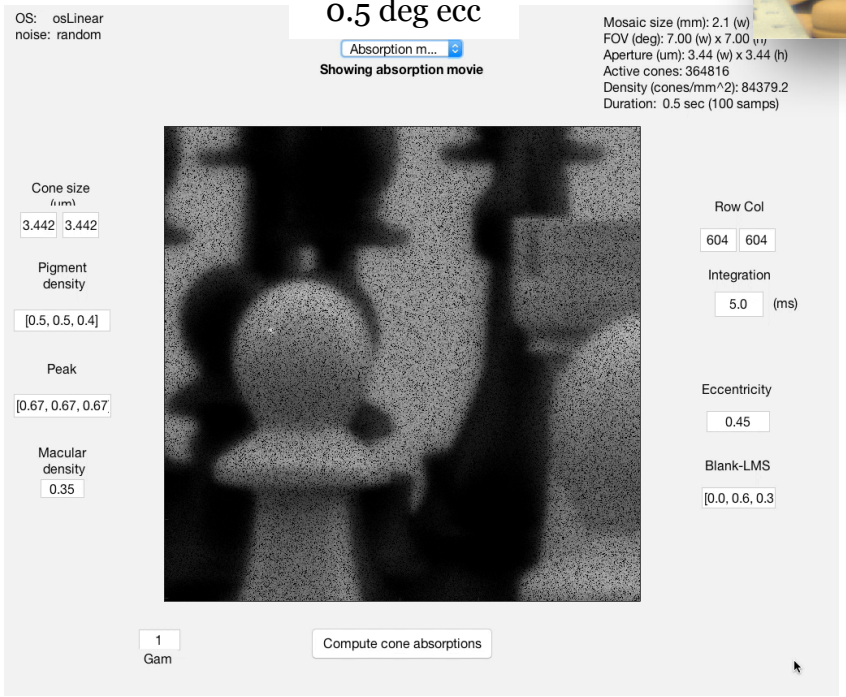


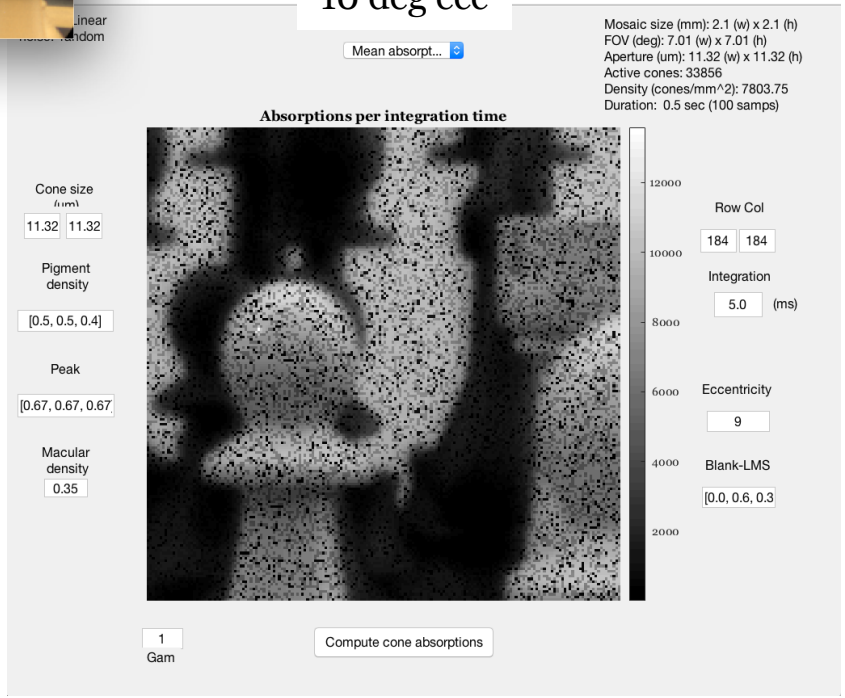


Cone mosaic absorptions and eye movements

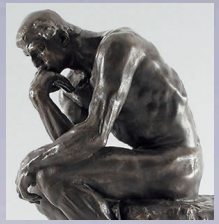
Eye movements (tremor, drift, saccade)
Photo and inert pigment properties (e.g., density)
Cone aperture variations with eccentricity



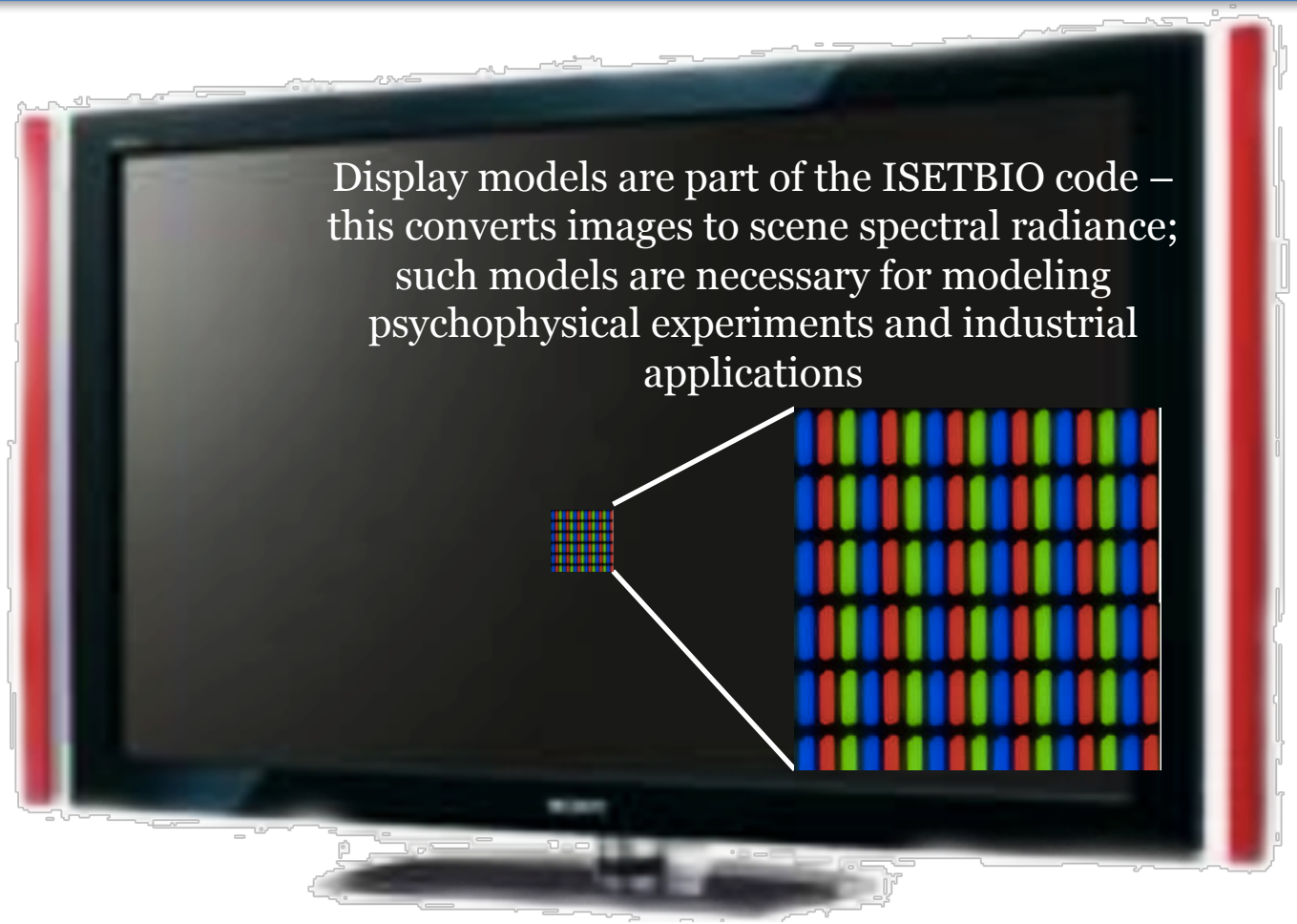




Information analysis



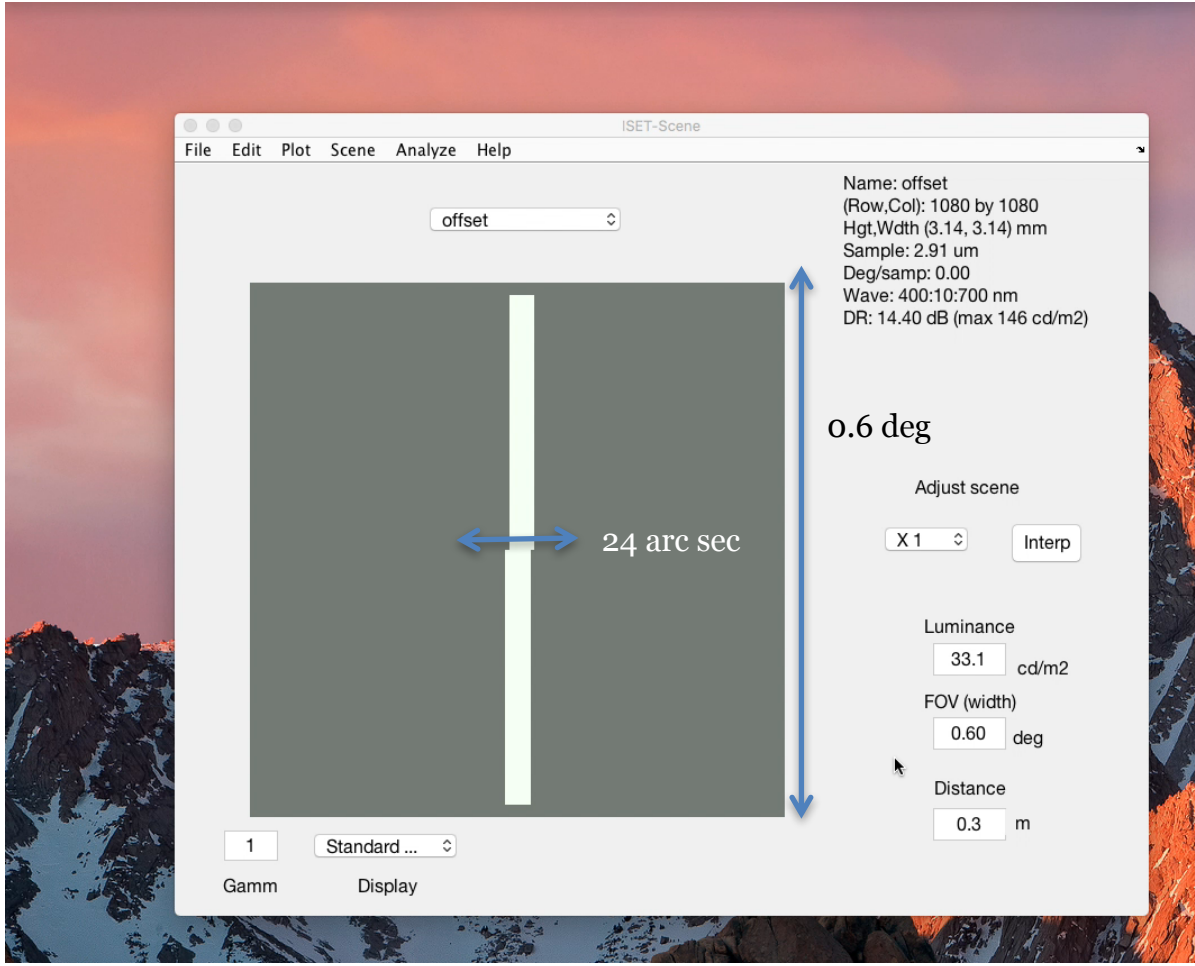
Laboratory experiments display devices



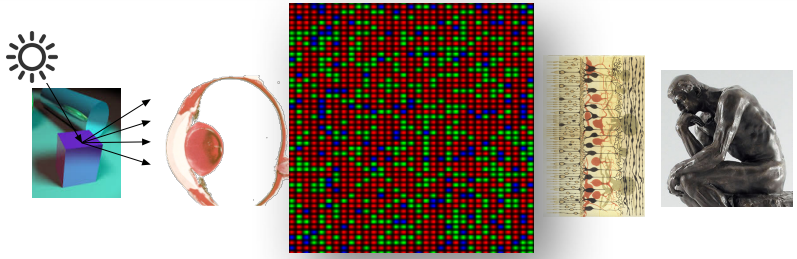
Analyzing psychophysical tasks

Two examples chosen for software validation and applications to industrial issues

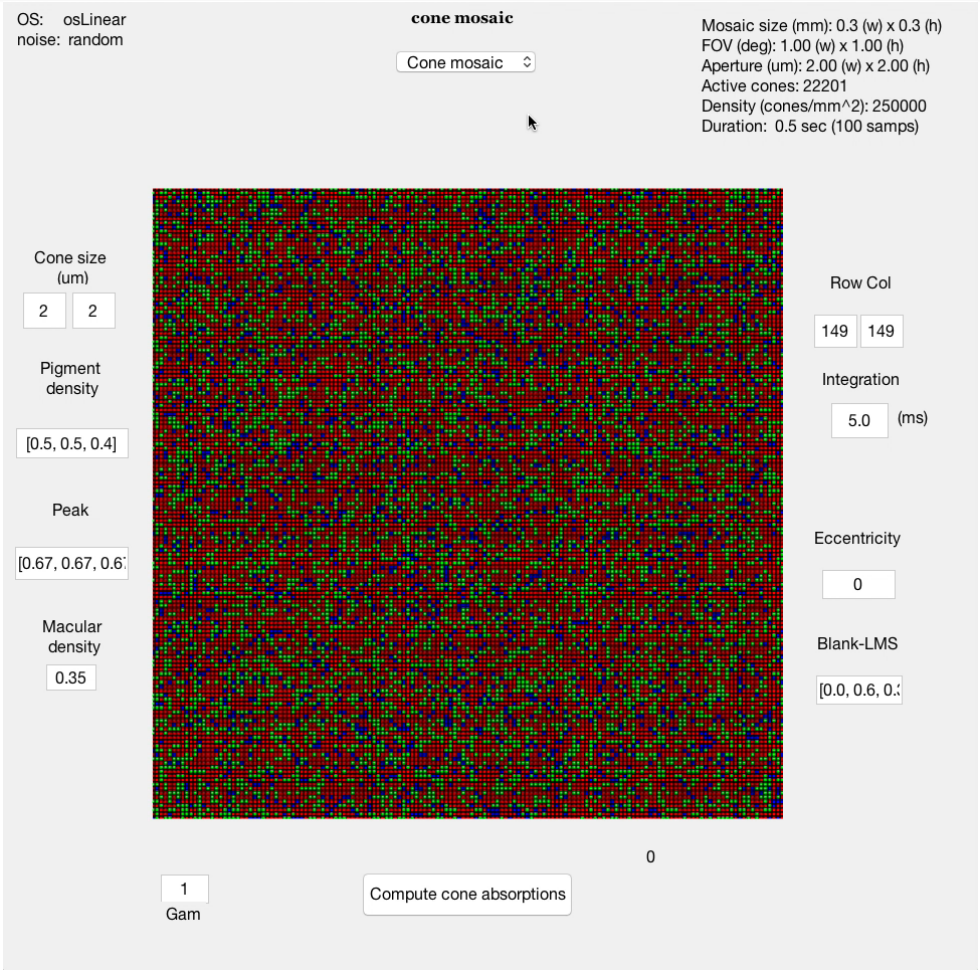
- Vernier acuity (Wandell et al.)
- Contrast sensitivity (Cottaris et al.)



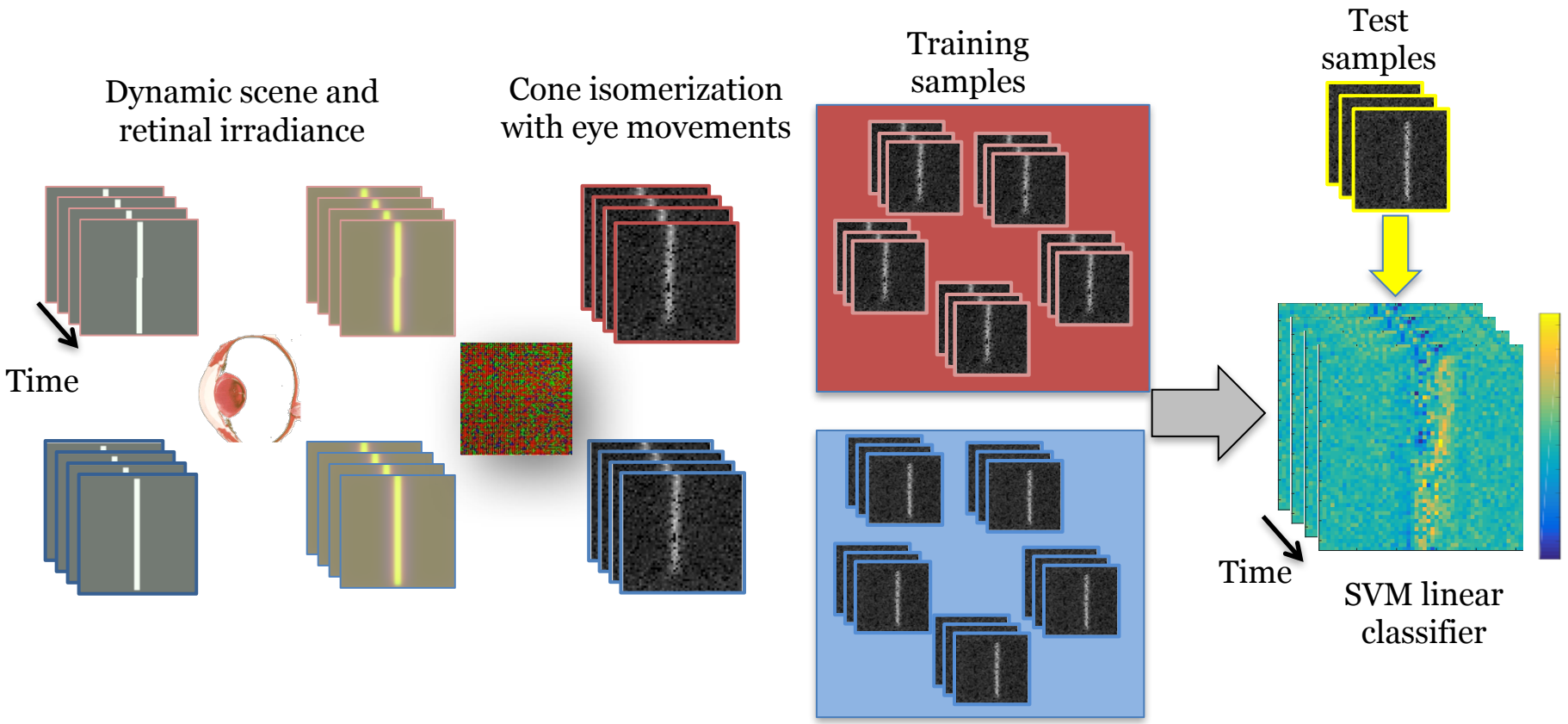
Cone absorptions accounting for eye movements



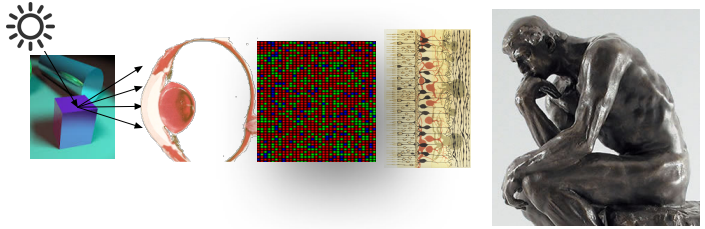
- The calculations here are on a rectangular grid;
- The cone photopigment properties were the standard templates



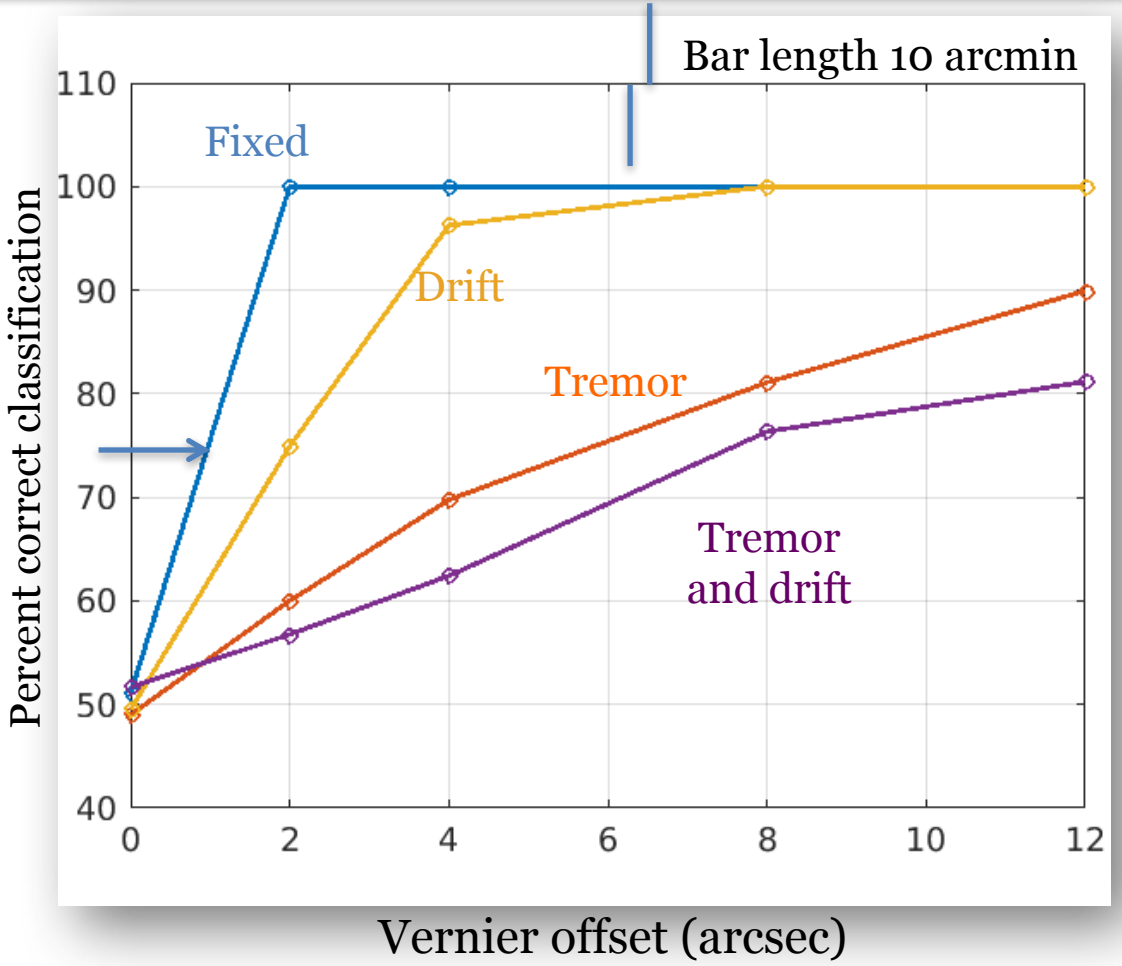
Computational observer pipeline for the Vernier task



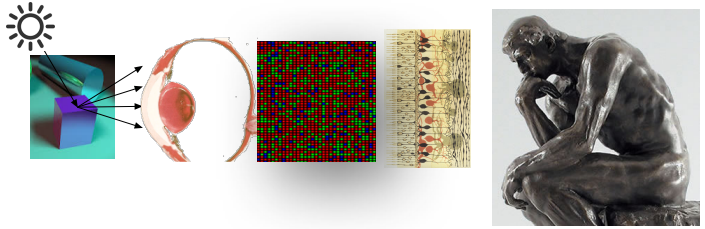
Tremor and drift limit classification accuracy



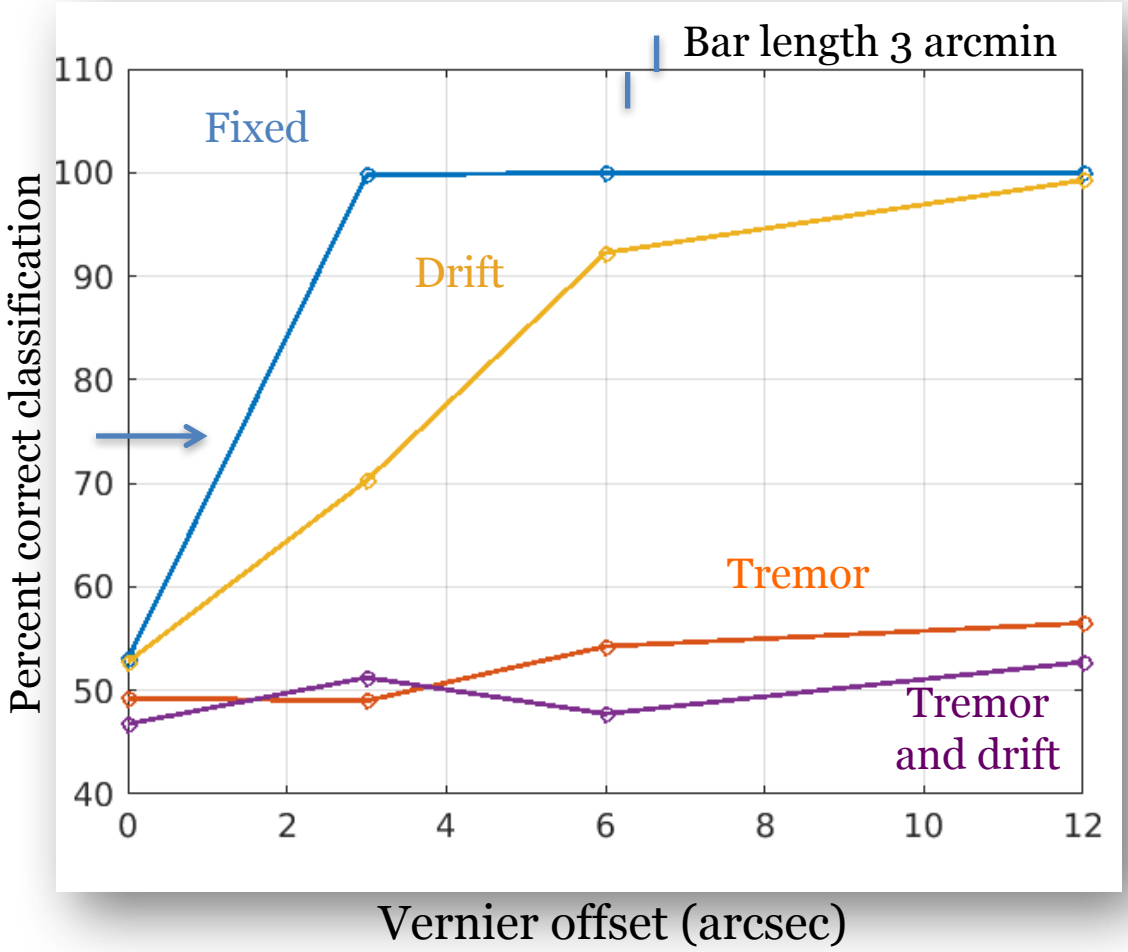
- The SVM linear classifier separates aligned and offset stimuli at very high resolution when we turn off eye movements
- Drift and tremor both degrade performance.



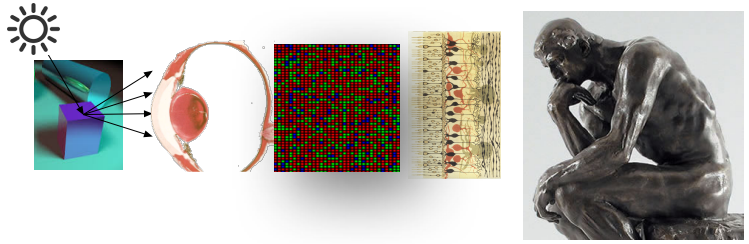
Tremor and drift limit classification accuracy



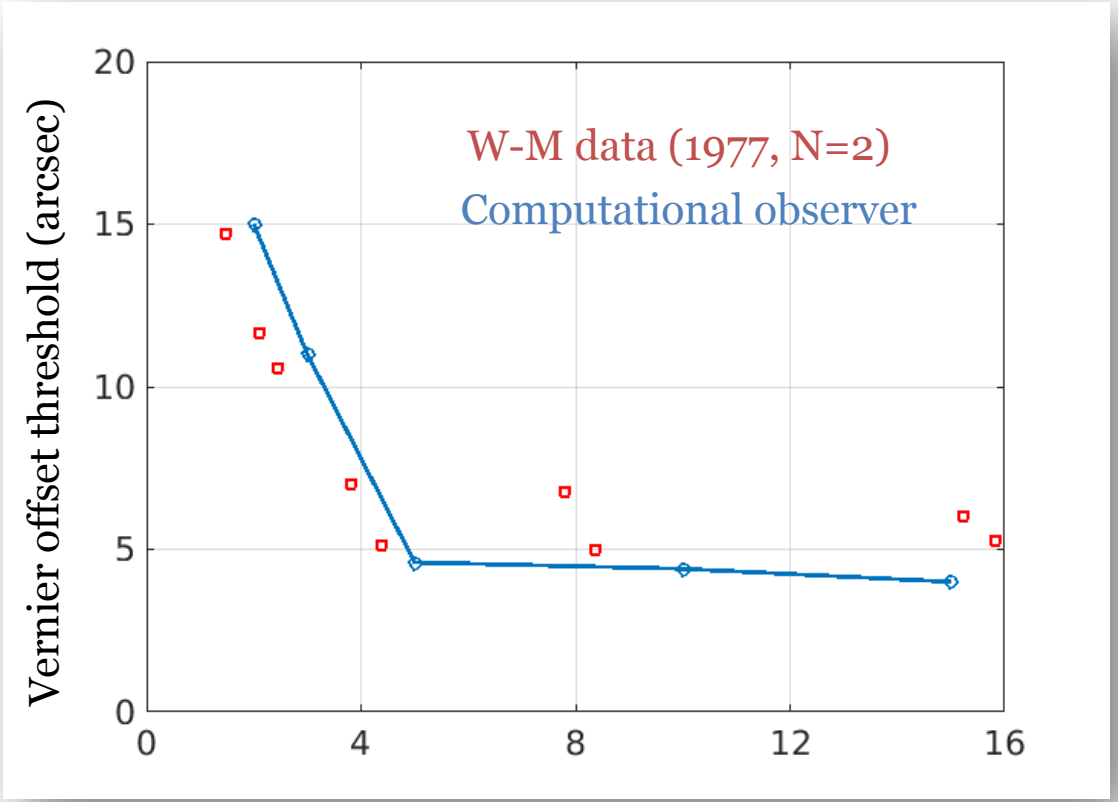
- The SVM linear classifier separates aligned and offset stimuli at very high resolution when we turn off eye movements
- Drift and tremor both degrade performance
- Particularly for small stimuli



A phenomenological description of Westheimer and McKee

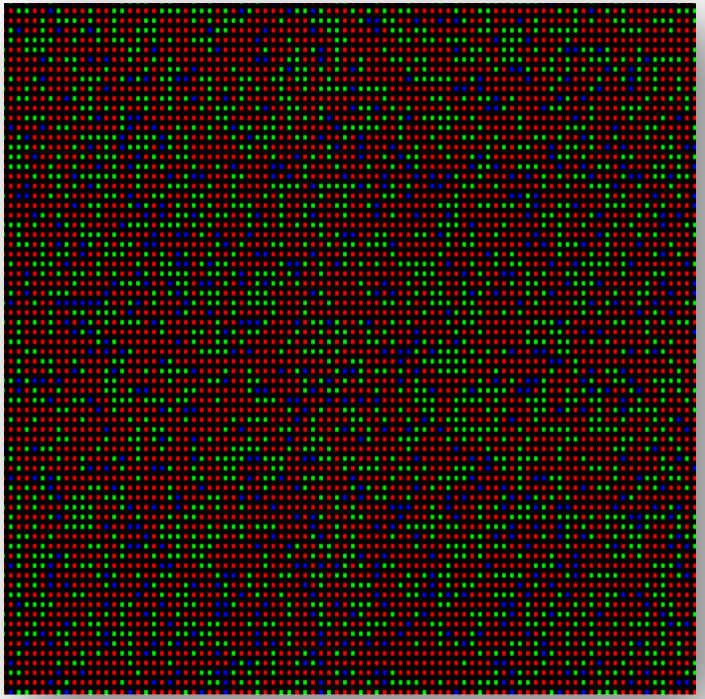


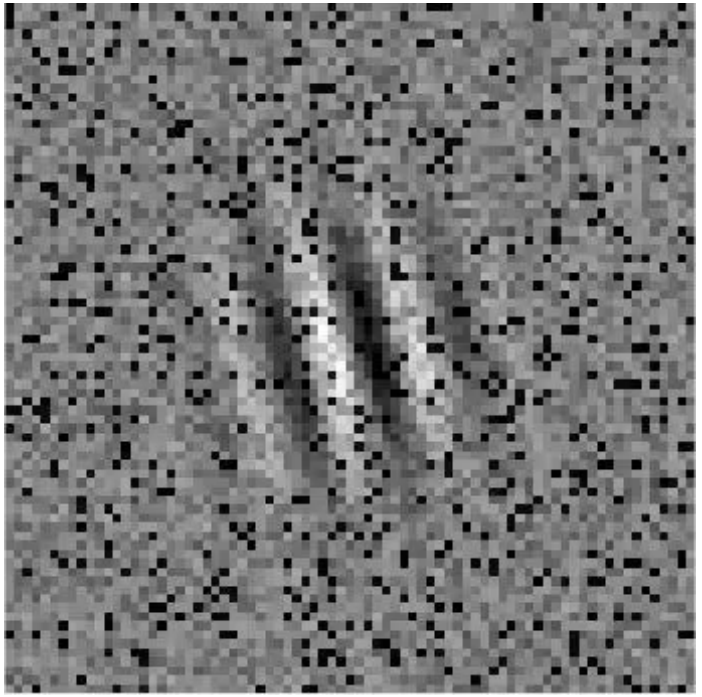
- By choosing to limit the Computational Observer (e.g., size of the cone mosaic), we can make a computational description that matches some properties of the human psychophysics



Contrast sensitivity functions

Limits of contrast sensitivity as a function of spatial frequency

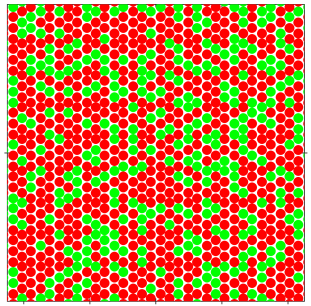




ISETBIO replicates classic measurements in the literature (Cottaris et al., in prep)

Comparison with Banks et al. 1987

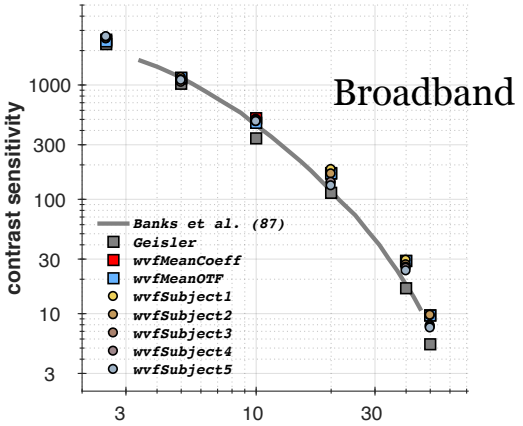
Cone spacing 3.0 um
Cone aperture 3.0 um
Pupil 2 mm
L,M cones
Broadband stimulus

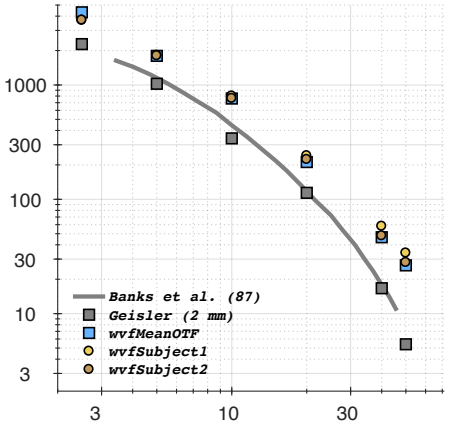


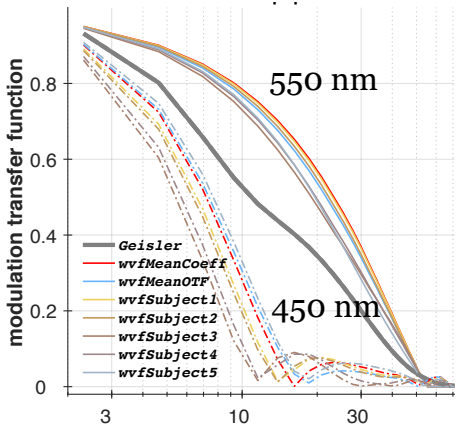
wvfSubjects are samples of wave front measurements

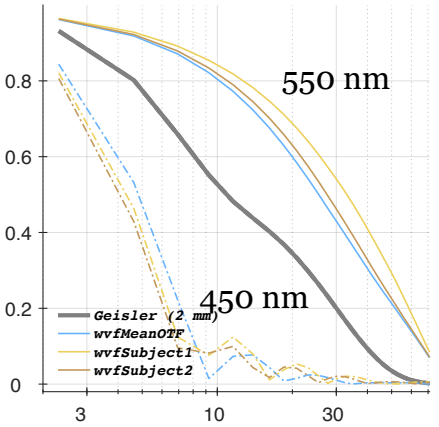
2 mm pupil

3 mm pupil

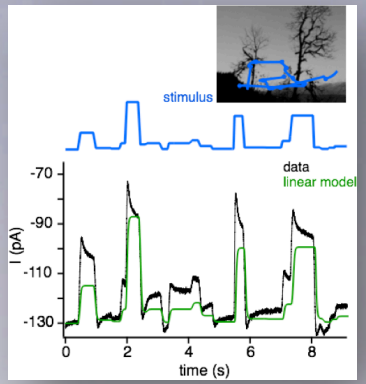




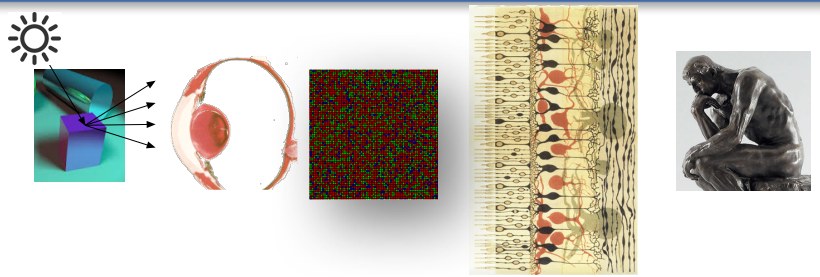




Photocurrent modeling

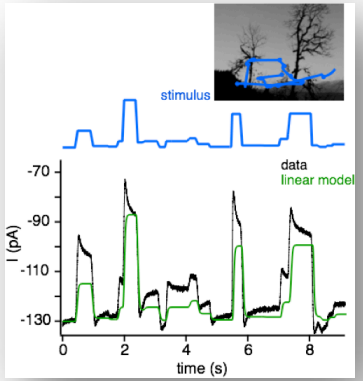


Photocurrent (Rieke model)

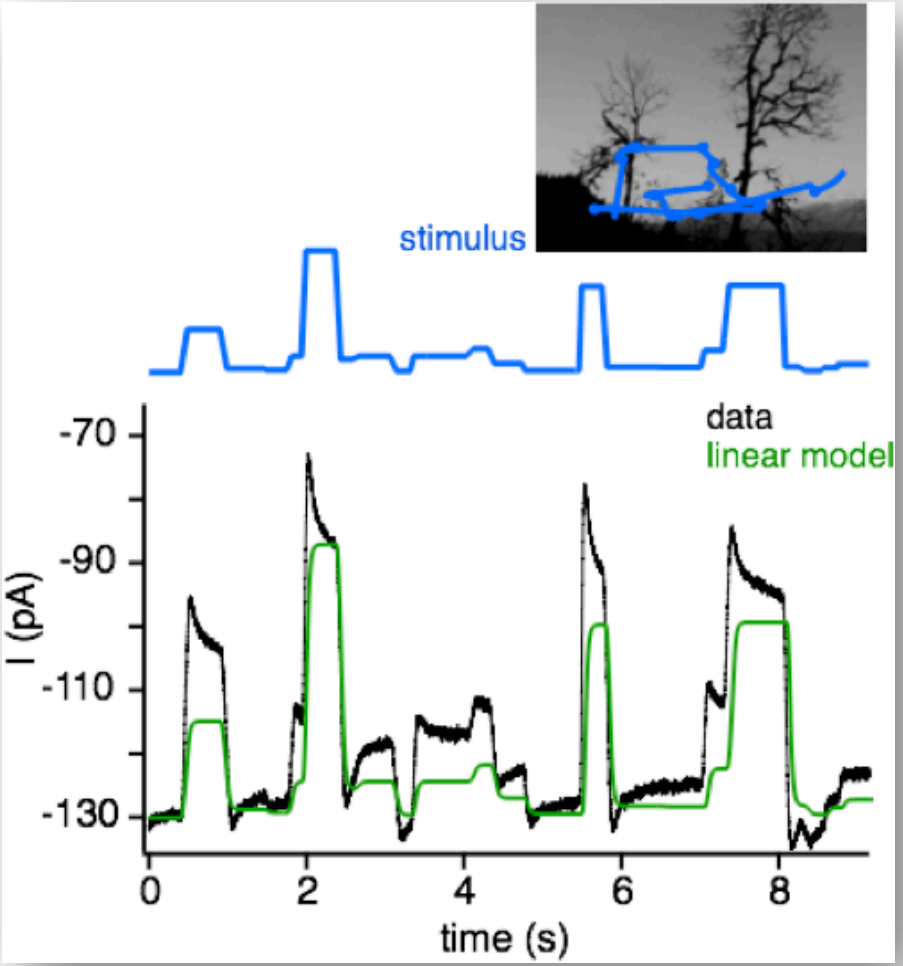


- The photocurrent model derived from electrophysiological measurements
- Comprises a set of differential equations and one nonlinear term
- Nonlinear implemented; linear approximation implemented too

Angueyra and Rieke
(2013, Nature Neuroscience)

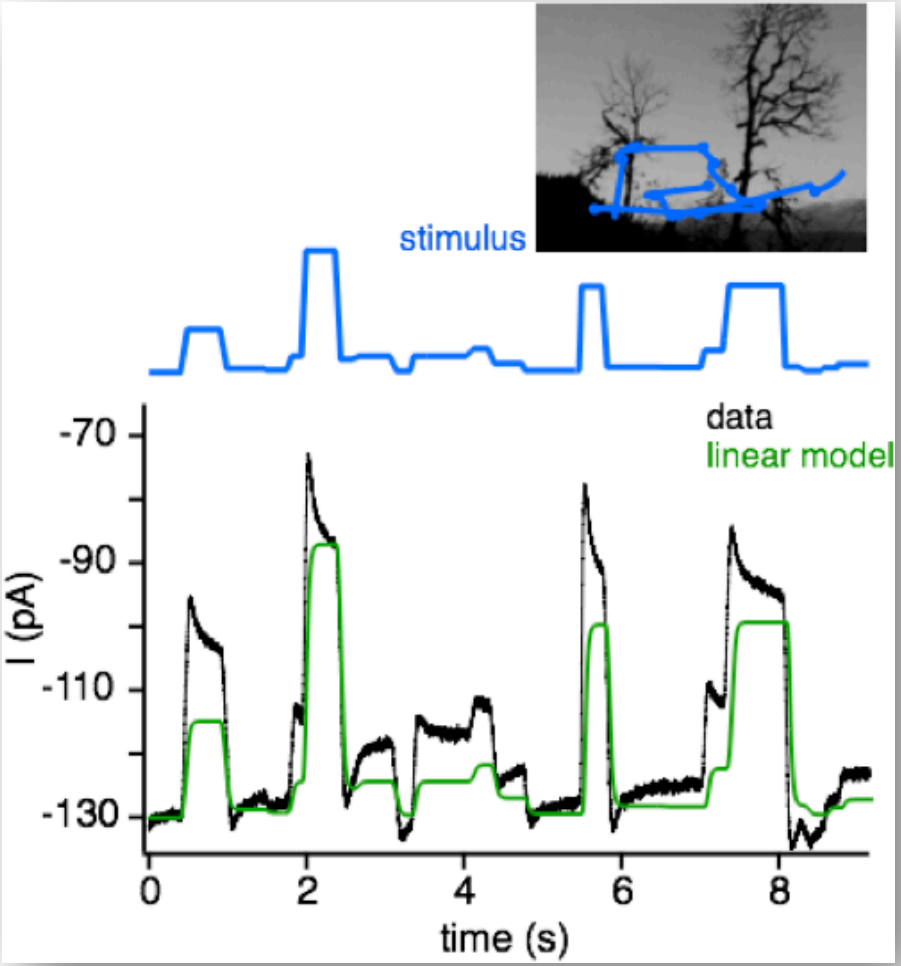


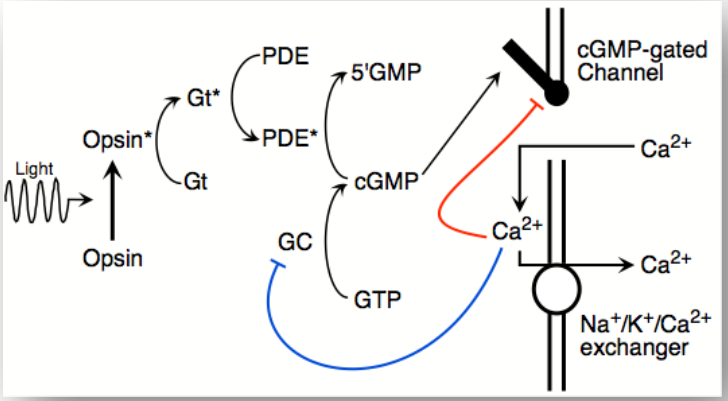
Cone responses exhibit strong time-dependent nonlinearities



- The transients at the transitions are not predicted by linear-nonlinear models
- There is a substantial nonlinear compression

Cone responses exhibit strong time-dependent nonlinearities





$$dR(t)/dt = s(t) - \sigma R(t)$$

$$dP(t) = \gamma R(t) + \eta - \phi P(t)$$

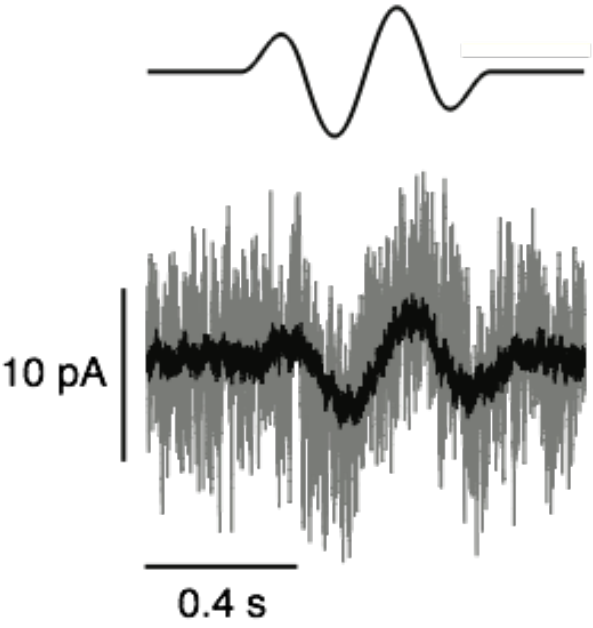
$$dG(t)/dt = s(C) - P(t)G(t)$$

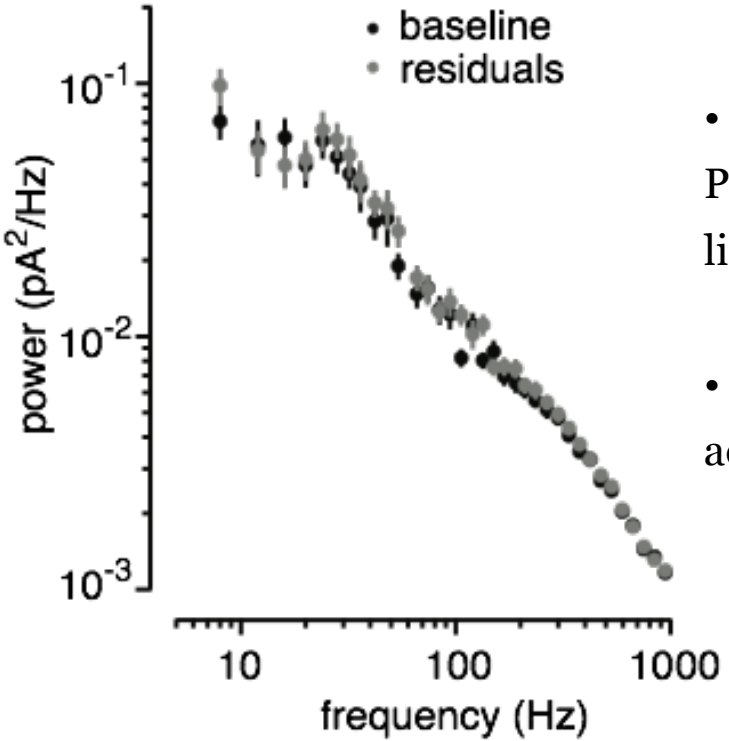
Five more equations and noise

Baylor, Hodgkin and Lamb, 1974
Endeman and Kamermans, 2010

Photocurrent noise

Rieke

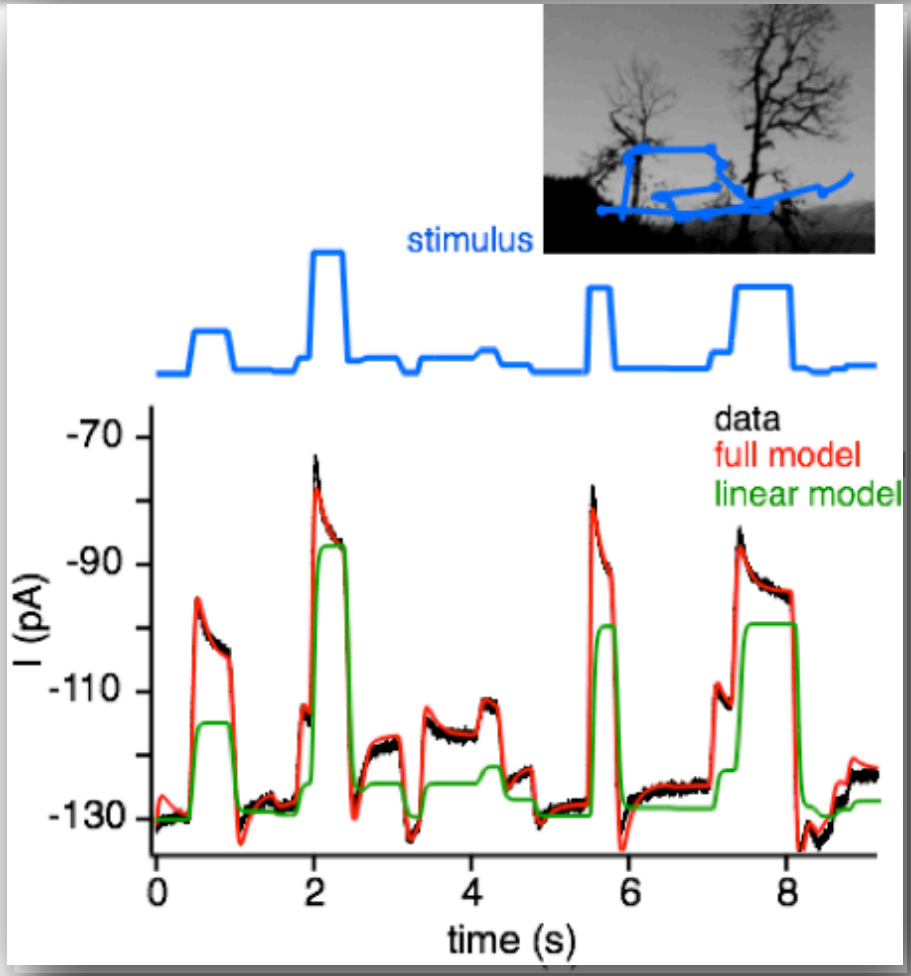




- Cone noise exceeds the Poisson fluctuations at most light levels
- The noise is approximately additive

Charlie Hass
Juan Angueyra
Greg Horwitz

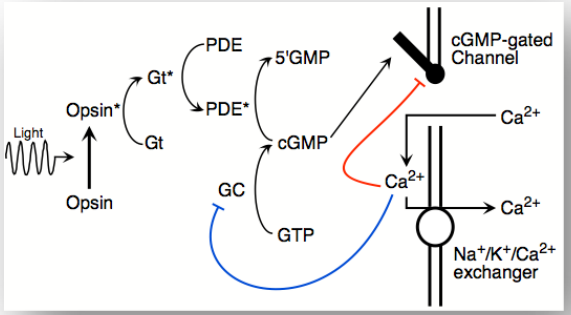
Cone responses exhibit strong time-dependent nonlinearities



- The ISETBIO implementation includes the photocurrent and noise model
- We will visualize the consequences in the next steps

see also Clark at el., 2013

We have an implementation of photocurrent (Rieke Lab)



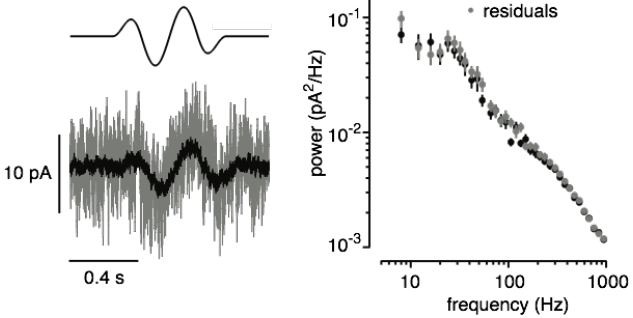
$$dR(t)/dt = s(t) - \sigma R(t)$$

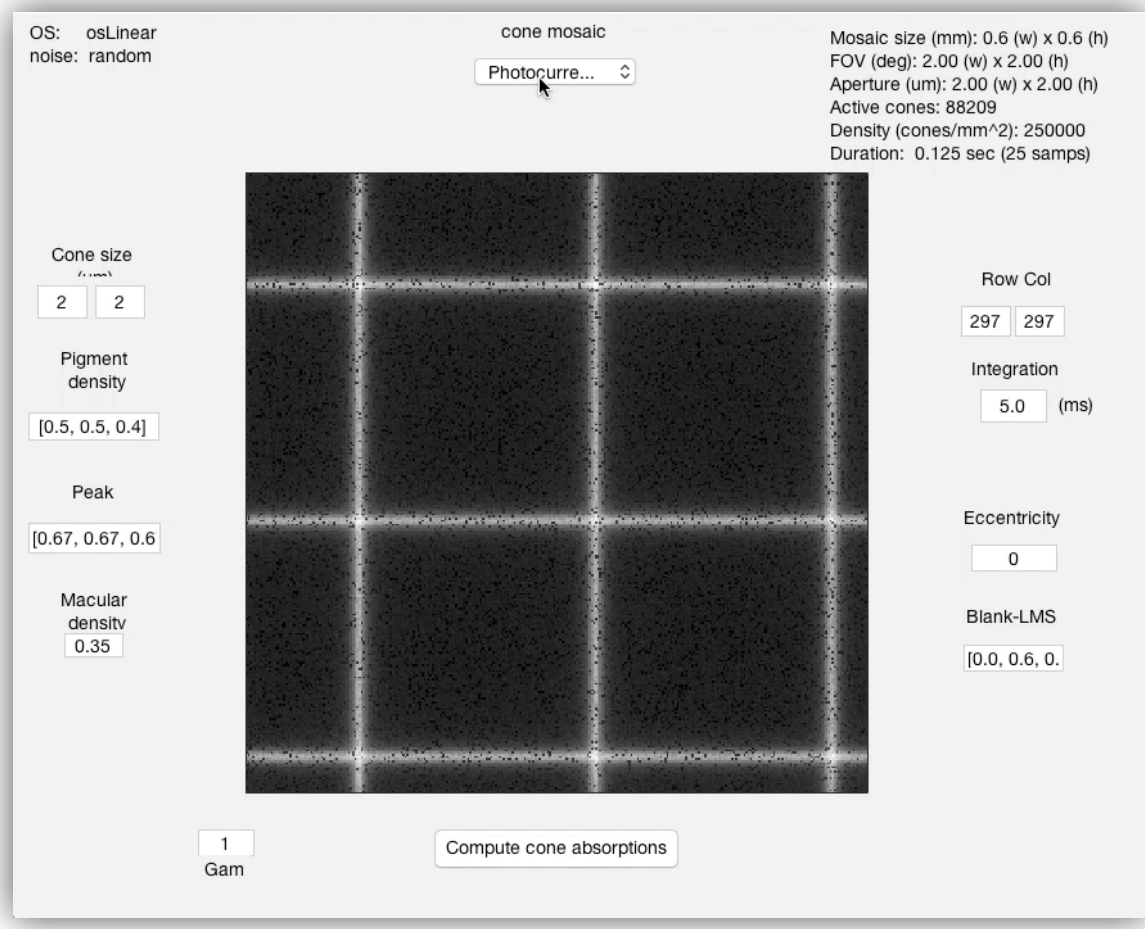
$$dP(t) = \gamma R(t) + \eta - \phi P(t)$$

$$dG(t)/dt = s(C) - P(t)G(t)$$

...

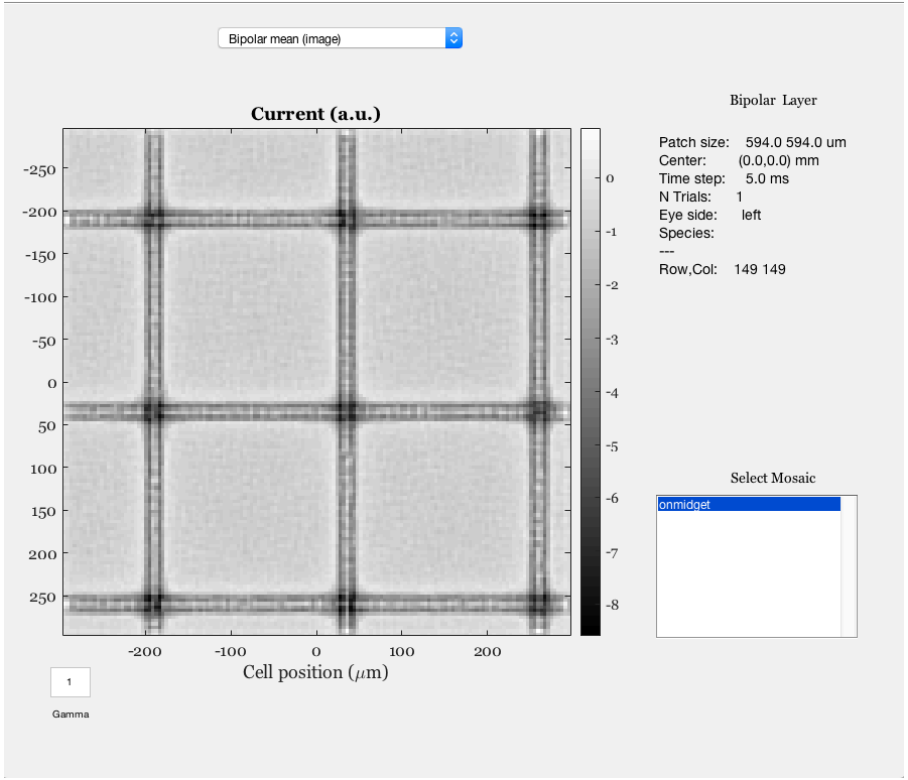
Noise



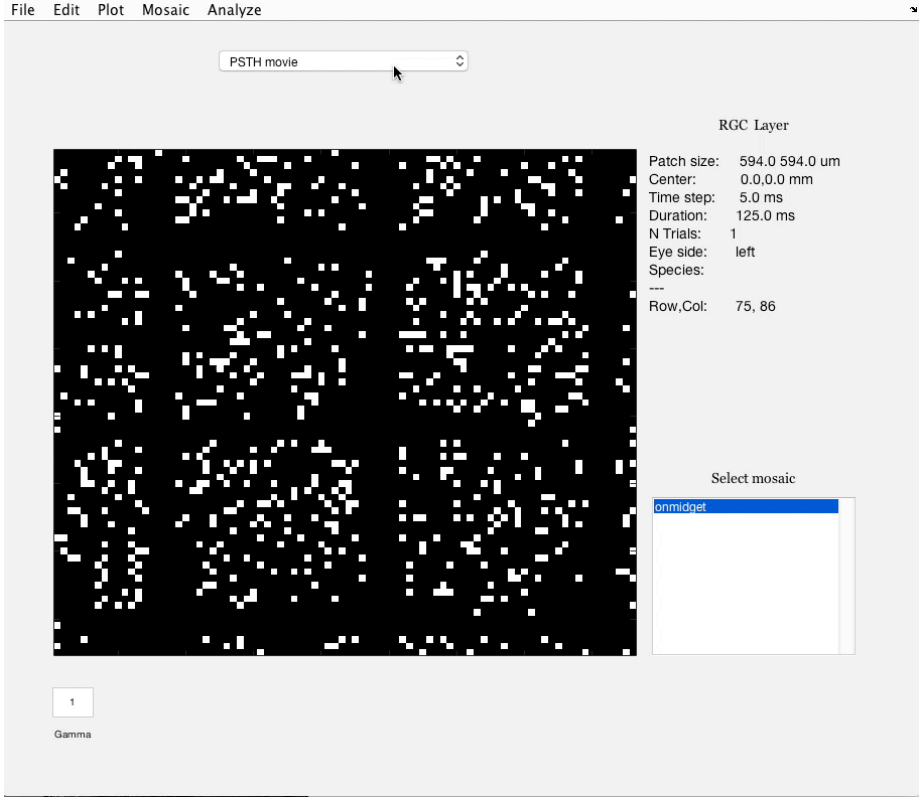


We are working on bipolar and ganglion cell models

Bipolar current



On midget spikes



Github code and wiki – continuous integration

This repository Search Pull requests Issues Gist

isetbio / isetbio

Unwatch 18 Star 12 Fork 10

Code Issues 54 Pull requests 0 Projects 0 Wiki Pulse Graphs Settings

Tools for modeling image systems engineering in the human visual system front end

Edit

New Add topics

1,702 commits 3 branches 2 releases 8 contributors MIT

Branch: master New pull request Create new file Upload files Find file Clone or download

benjamin-heasly ieValidateFullAllAssert -> ieValidateFullAll('asAssertion', true) Latest commit 256fa43 8 hours ago

configuration	Fixed syntax error in isetbioLocalHookTemplate	a month ago
documentation/resources	Initial import of clean version of 0.1 dev branch, now the master bra...	2 years ago
external	Added StructUtils from BrainardLabToolbox	19 days ago
isettools	Took computeDensityMap out of visualizeGrid	a day ago
scripts	Working still on tutorials.	2 months ago
tutorials	Put t_eyeMovement in the right place	3 days ago
utility	Pulled out as much as I could easily find that depends on sensor, pix...	2 months ago
validation	ieValidateFullAllAssert -> ieValidateFullAll('asAssertion', true)	8 hours ago
.gitignore	Updated for DS_STORE and local	2 months ago
LICENSE	Initial import of clean version of 0.1 dev branch, now the master bra...	2 years ago
README.md	Adding build status icon	6 days ago
isetbioRootPath.m	Initial import of clean version of 0.1 dev branch, now the master bra...	2 years ago

build passing

The Image System Engineering Toolbox for Biology ISETBIO is a Matlab toolbox designed for calculating the properties of the front end of the visual system. This includes a description of the scene, the optics and retinal image, the capture of light by the photopigment, the photocurrent responses in the receptors, bipolar responses, and retinal ganglion cell responses.

This repository includes a WIKI that describes the software as well as many examples of how to perform computations to calculate the visual encoding of light in the eye. The WIKI also describes tools to view and and

isetbio / isetbio

Unwatch 18 Star 12 Fork 10

Code Issues 54 Pull requests 0 Projects 0 Wiki Pulse Graphs Settings

Cone mosaic

Edit New Page

Brian Wandell edited this page 26 days ago · 51 revisions

The cone mosaic object converts the optical image irradiance into the cone absorptions and photocurrent. For details, please refer to

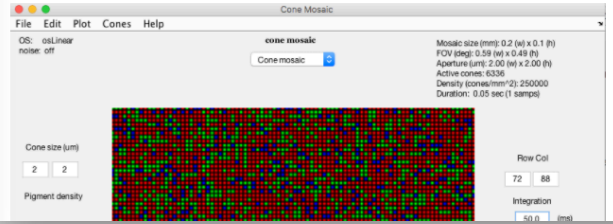
```
doc coneMosaic
```

The main top-level coneMosaic object commands are

```
cmosaic = coneMosaic;    - Create cone mosaic.  Many parameters can be set.
cmosaic.compute(oi);     - Compute the absorptions from the optical image, oi
cmosaic.computeCurrent; - Compute the photocurrent using the attached outerSegment model
```

The coneMosaic class has an interactive window. This window differs from sceneWindow and oiWindow because like all of the newer ISETBIO concepts, the coneMosaic is a class. Also, there is a growing number of plotting methods.

```
cmosaic.window;    - An interactive window to view the mosaic, absorptions and current
cmosaic.plot();    - Plotting methods
```



Pages 47

- Home
- Installation
- Getting Started
- Data types
  - Scenes
  - Retinal image
  - Cone mosaic
  - Bipolar cells
  - Retinal ganglion cells
- Compute overview
  - Retina model comparisons
- Tutorial scripts
- Numerical utility functions
- ISETBIO Data
- ISETBIO Videos
- Validation
- For Developers

Clone this wiki locally

https://github.com/isetbio/

Clone in Desktop

Video tutorials and data resources

STANFORD UNIVERSITY | STANFORD TALKS

TALKS TUTORIALS SERVICES LOGIN SUPPORT ABOUT

Tutorials

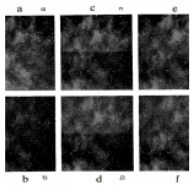
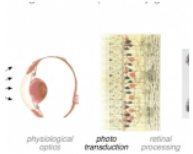


Image Systems

Tutorials in applied vision and image systems. Topics include image formation, optics and other fundamentals of vision science.

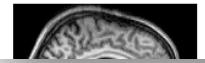
Start watching now!



ISETBIO

Tutorials on the ISETBIO software and its applications in neuroscience.

Start watching now!



Neuroimaging

SEARCH TUTORIALS

September 2015

M	T	W	T	F
	1	2	3	4
7	8	9	10	11
14	15	16	17	18
21	22	23	24	25
28	29	30		

« Aug

SECTIONS

Tutorials

RECENT TUTORIALS

- David Brainard: "ISETBIO: Computa modeling early human vision" (09/09
- Brian Wandell: "Photons and Energy
- Fred Rieke: "Modeling Cone Respor
- PSYCH 204A [Fall 2014]: MRI – Sig
- PSYCH 204A [Fall 2014]: MRI – The

TOPICS

Stanford | VISTA Data Repository

ISETBIO

VALIDATION » SCIEN » ISETBIO

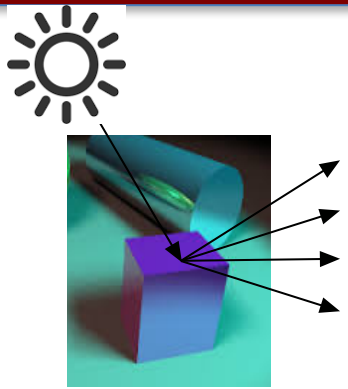
ISETBIO datasets: [6]

- 5BANDPSF
  - *No description.*
  - ReadMe
  - TOC.jsn
- BLIllumDiscrimCache
  - *No description.*
- HDR
  - *No description.*
  - EurasianFemale_Office.mat
  - EurasianFemale_shadow.mat
  - EurasianFemale_window_illuminant.mat
  - EurasianFemaleoffice_illuminant.mat
  - TOC.jsn
- HYPERSPECTRAL

  Hyperspectral scenes collected by JE Farrell using Hyspex and other radiometric devices.
- VESA

  These images were provided by David Hoffman for his VESA analysis. If you are not part of the SCIEN program, please download them from the VESA site which is http:/XXXXXX
- fullvalidation
  - *No description.*

Image systems simulation for biology



Scene spectral radiance

Physiological optics

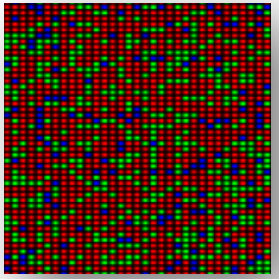
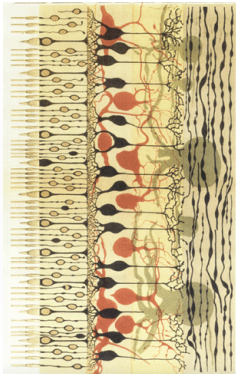
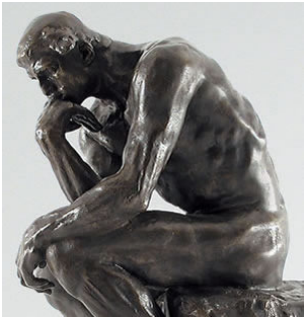


Photo transduction



Retinal processing



Inference

Thanks to Simons Foundation
Oculus Research, Samsung,
Qualcomm