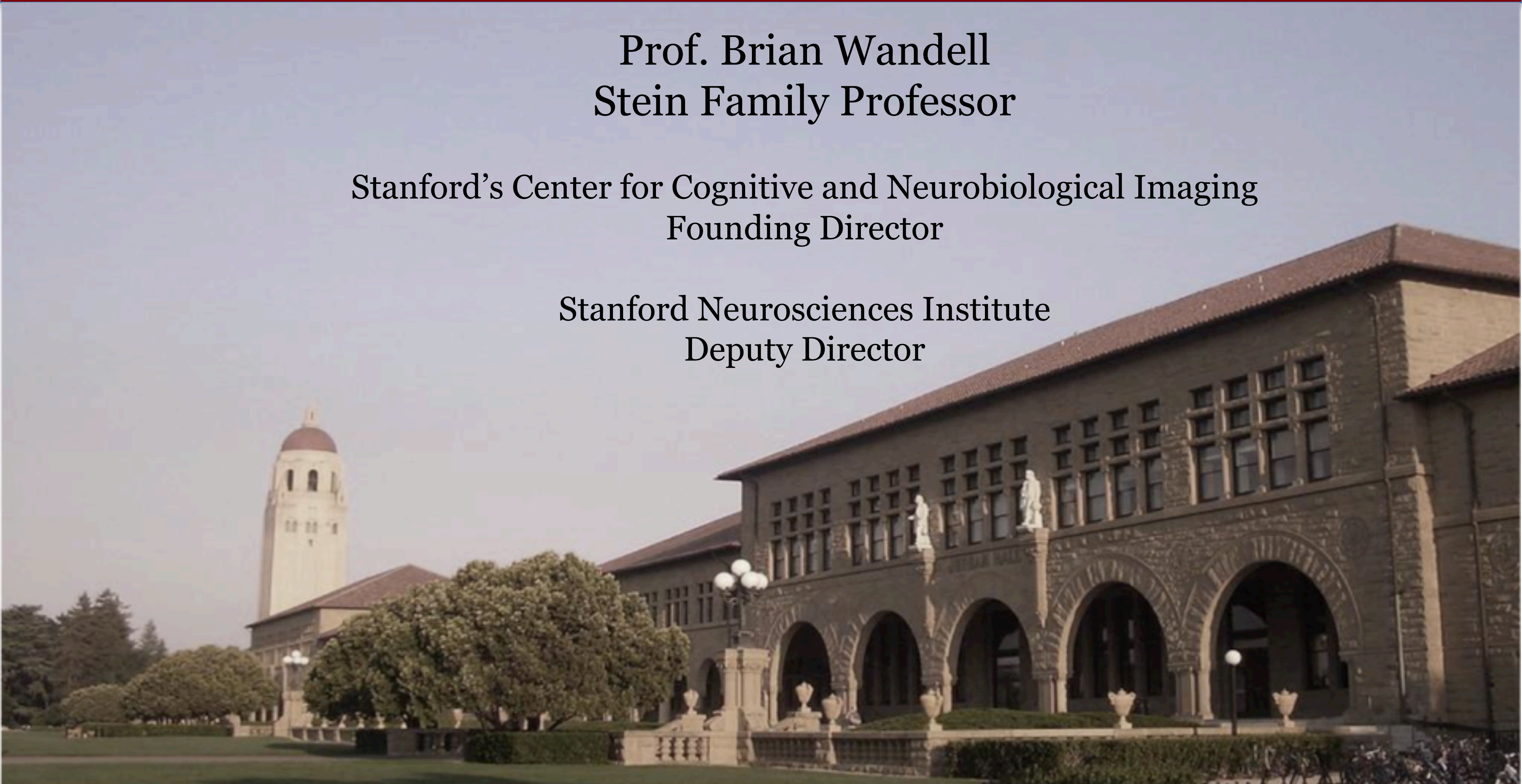
Image systems simulation



Prof. Brian Wandell
Stein Family Professor

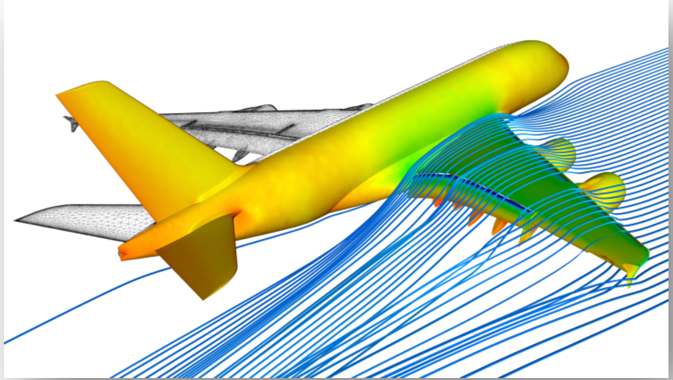
Stanford's Center for Cognitive and Neurobiological Imaging
Founding Director

Stanford Neurosciences Institute
Deputy Director

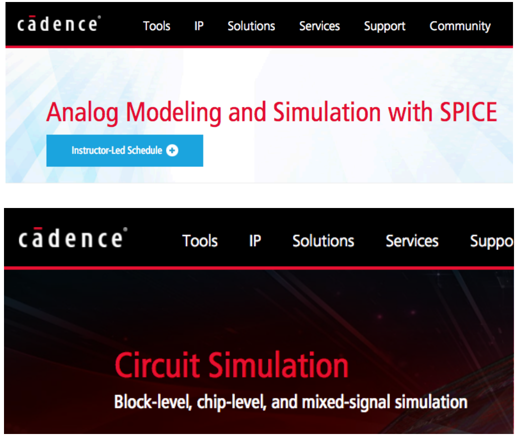
Image systems simulation

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

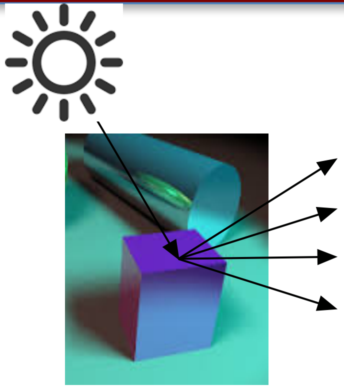
RGB-depth

Light field

360 Surround Video

VR, AR and MR HMDs

Image systems simulation for biology



Scene spectral radiance

Physiological optics

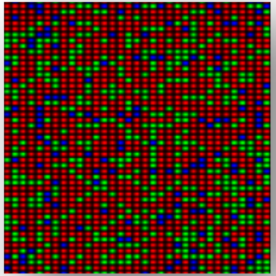
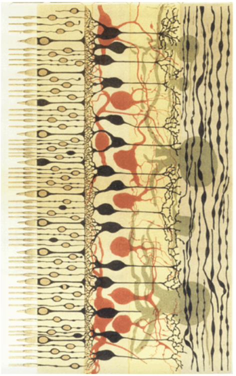


Photo transduction



Retinal processing

Inference

Brian Wandell

David Brainard

James Golden

Trisha Lian

Nicolas Cottaris

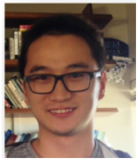
Fred Rieke

E.J. Chichilnisky

Xiaomao Ding

Jon Winawer

Joyce Farrell



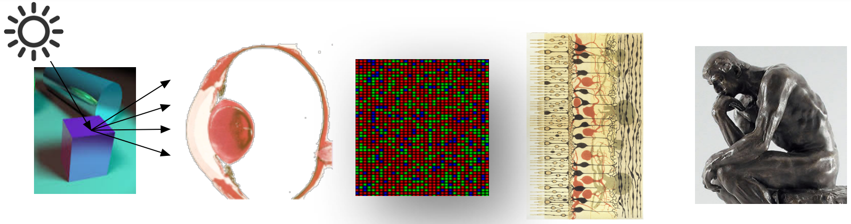
Haomiao Jiang

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



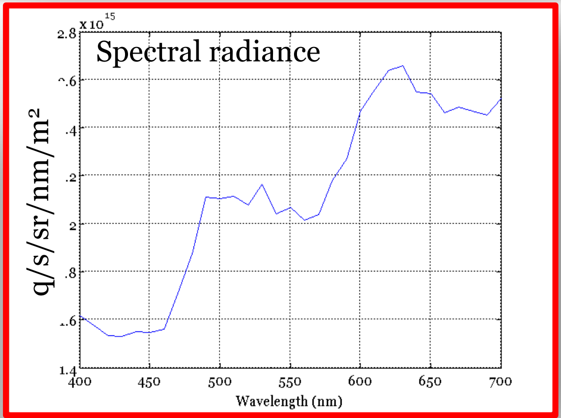
Spectral radiance, refraction, optics, Snell's law, diffraction, Airy disk, photons, energy, Planck's constant, chromatic aberration, retinal irradiance, pupil aperture, eye movements (tremor, drift, saccade), plenoptic function, wavefront aberrations, macular pigment, lens pigment, photopigments, rod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

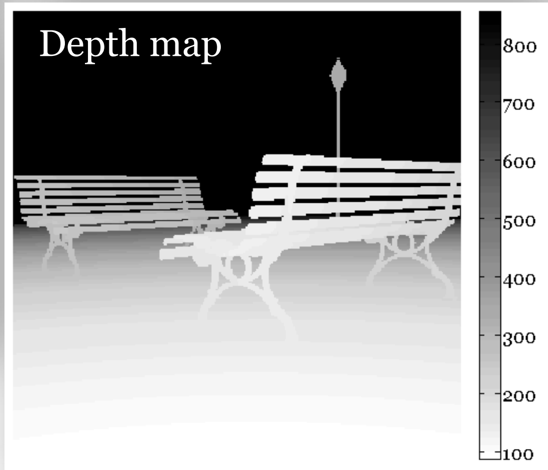
Essential technologies for image systems simulation

- 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)

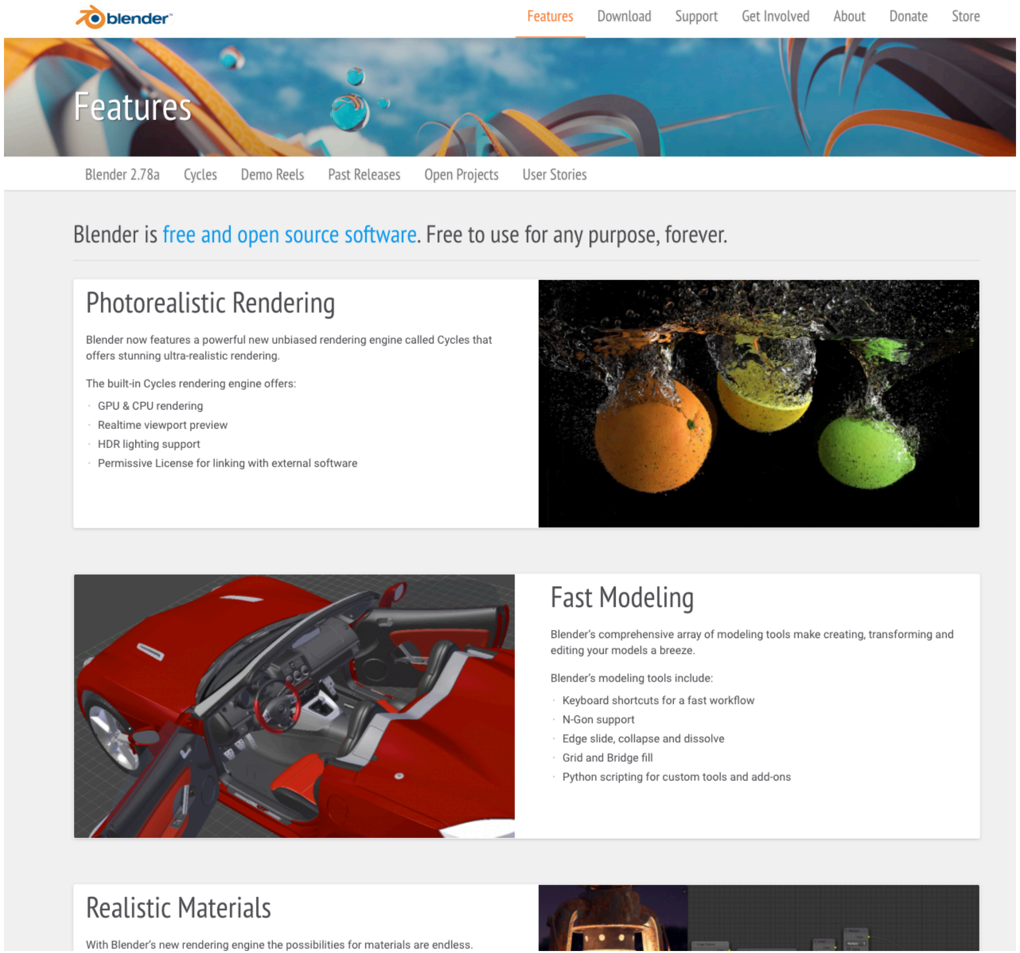
Quantitative computer graphics





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

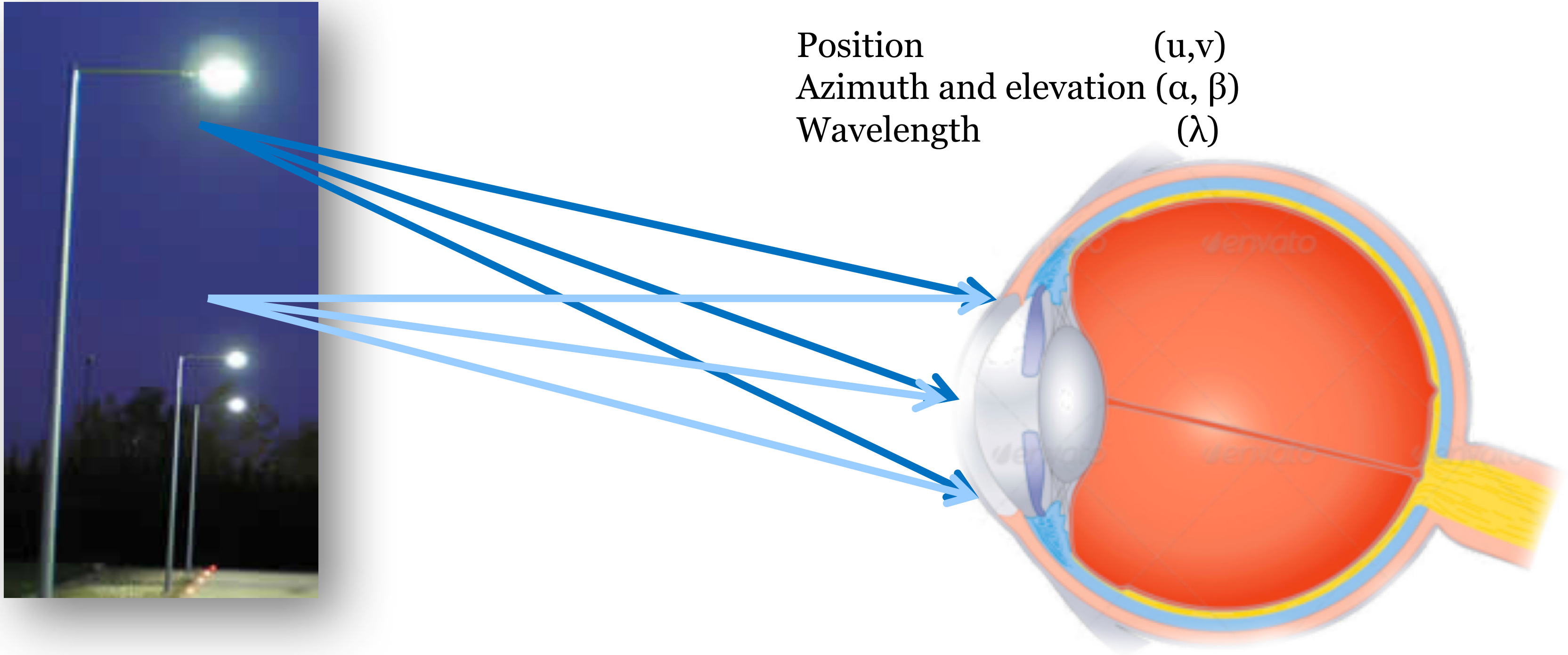


Ray trace methods yield light fields (plenoptic function)

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

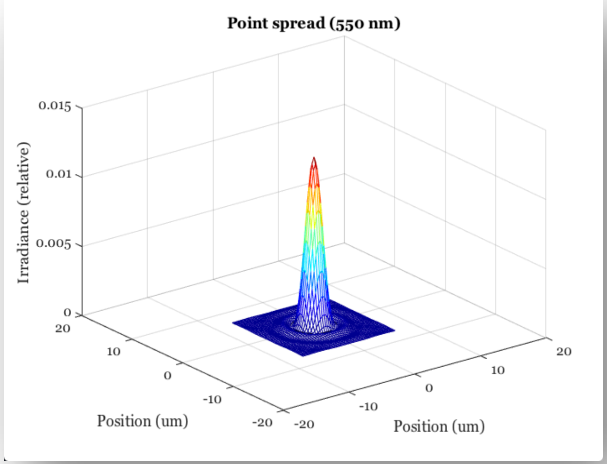
L(u,v,α,β,λ) – light field at the eye

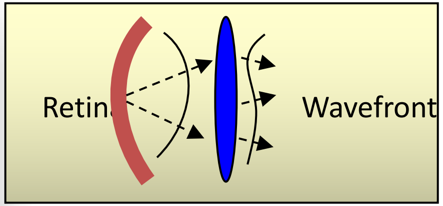
Position	(u,v)
Azimuth and elevation	(α, β)
Wavelength	(λ)

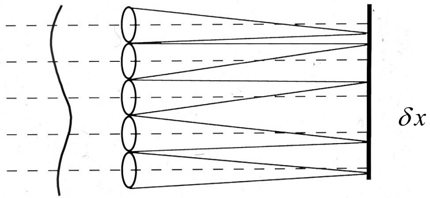


ISETBIO - Ray trace and wavefront optics models

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

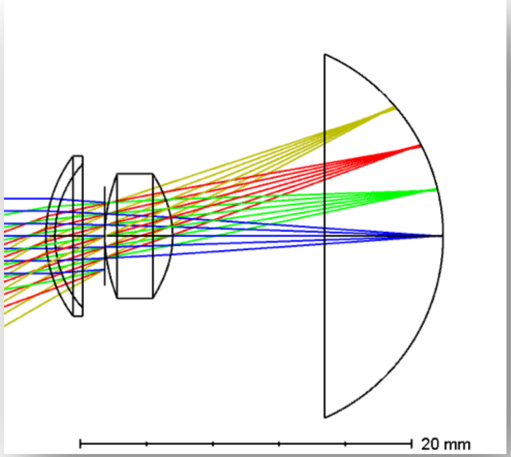






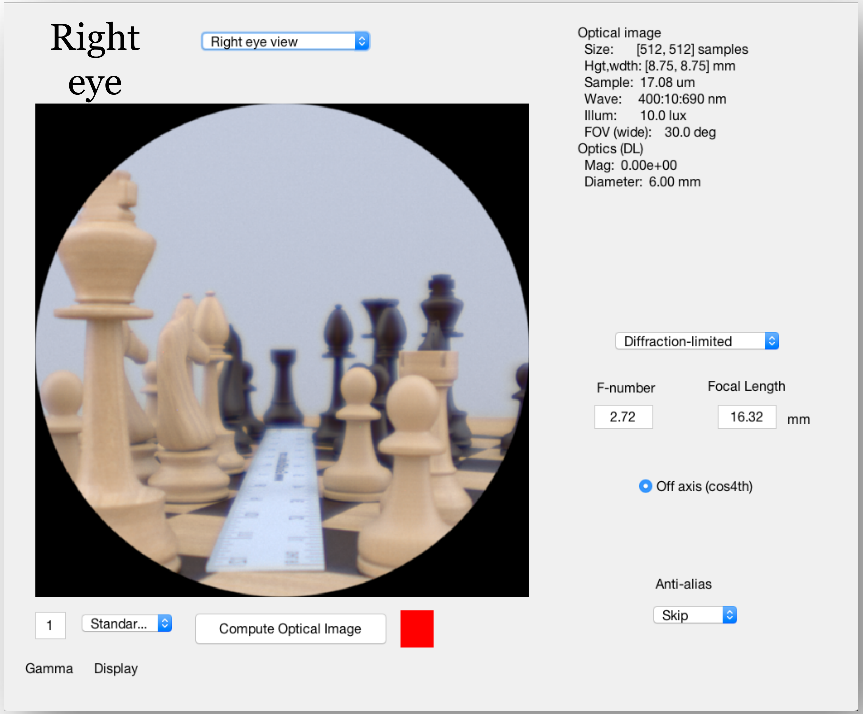
Aberrated eye

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)

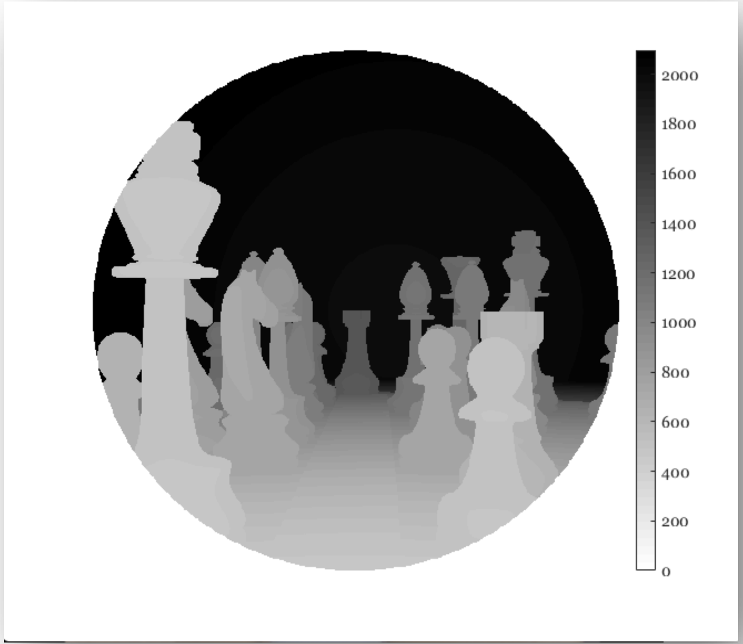
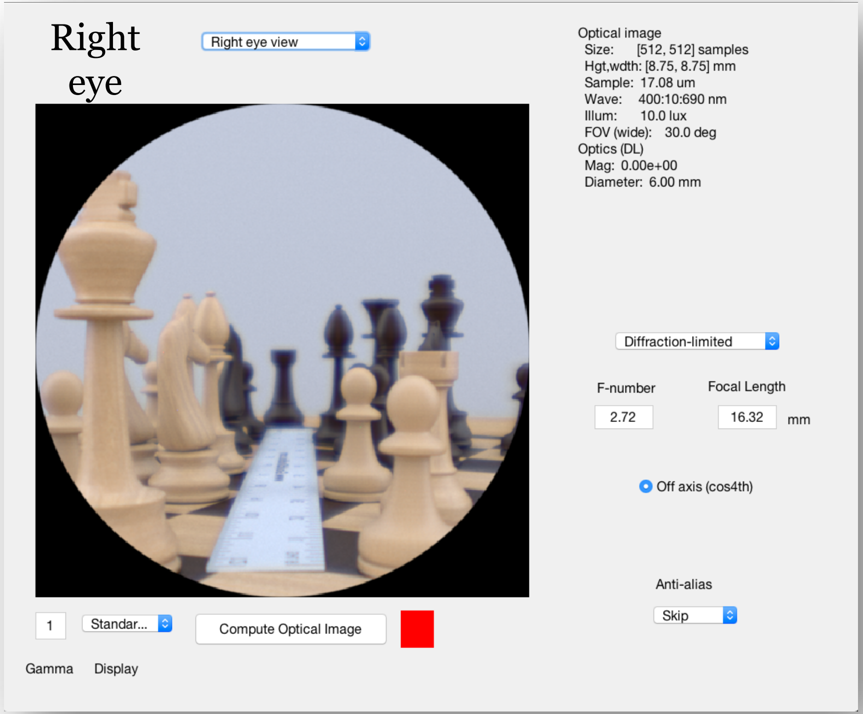
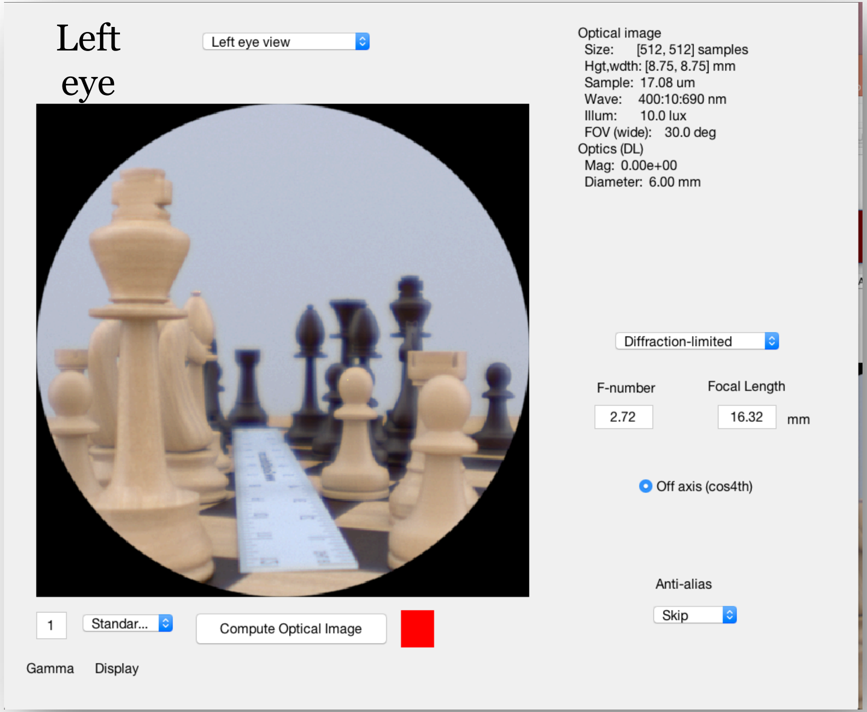


Image formation (optics) models and quantitative graphics

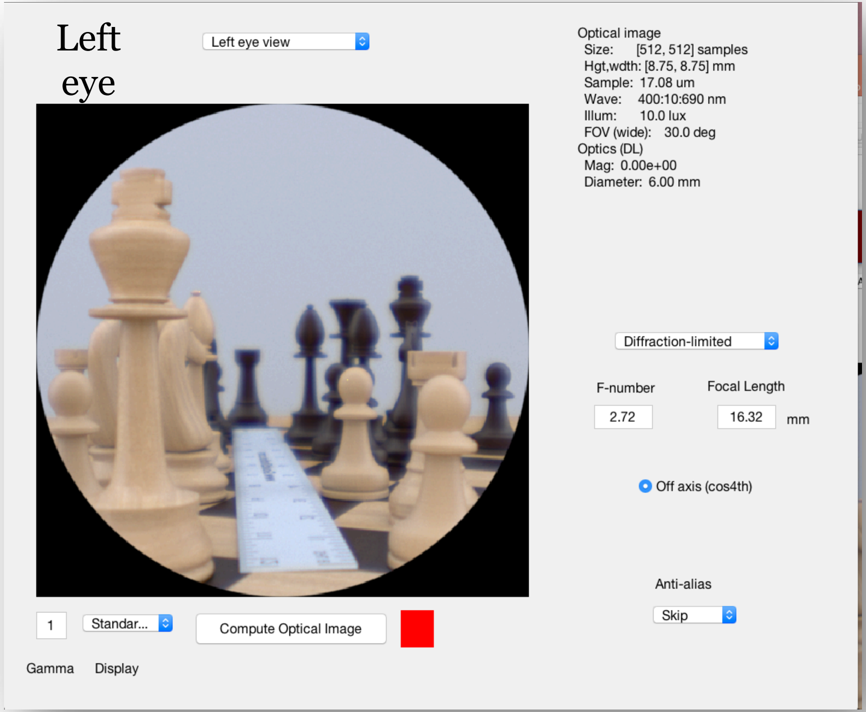
Stereo pairs are straightforward to compute

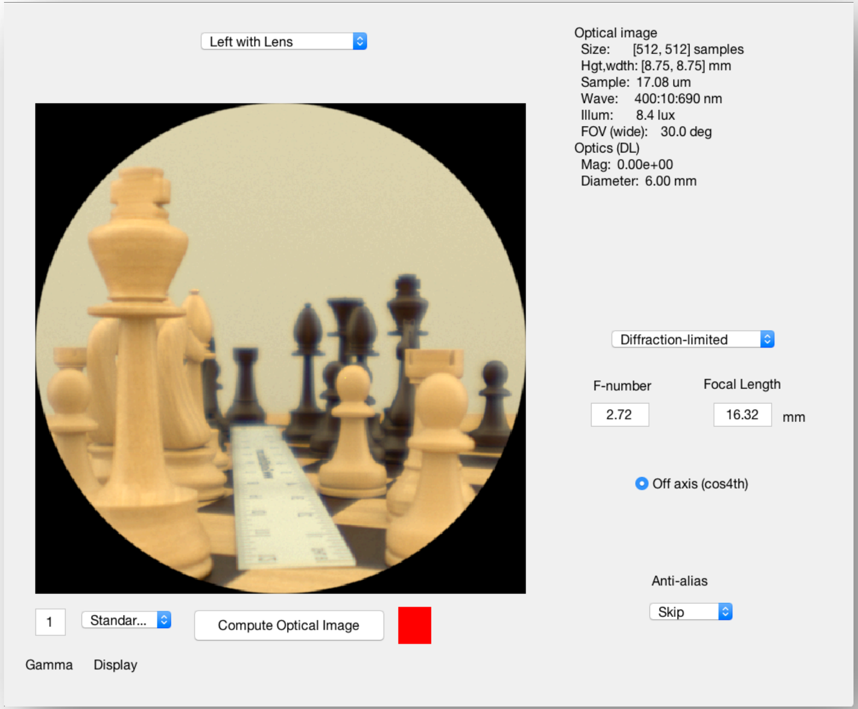




Natural images - Image formation (optics) models and quantitative graphics

Inert pigments (e.g. lens transmission)



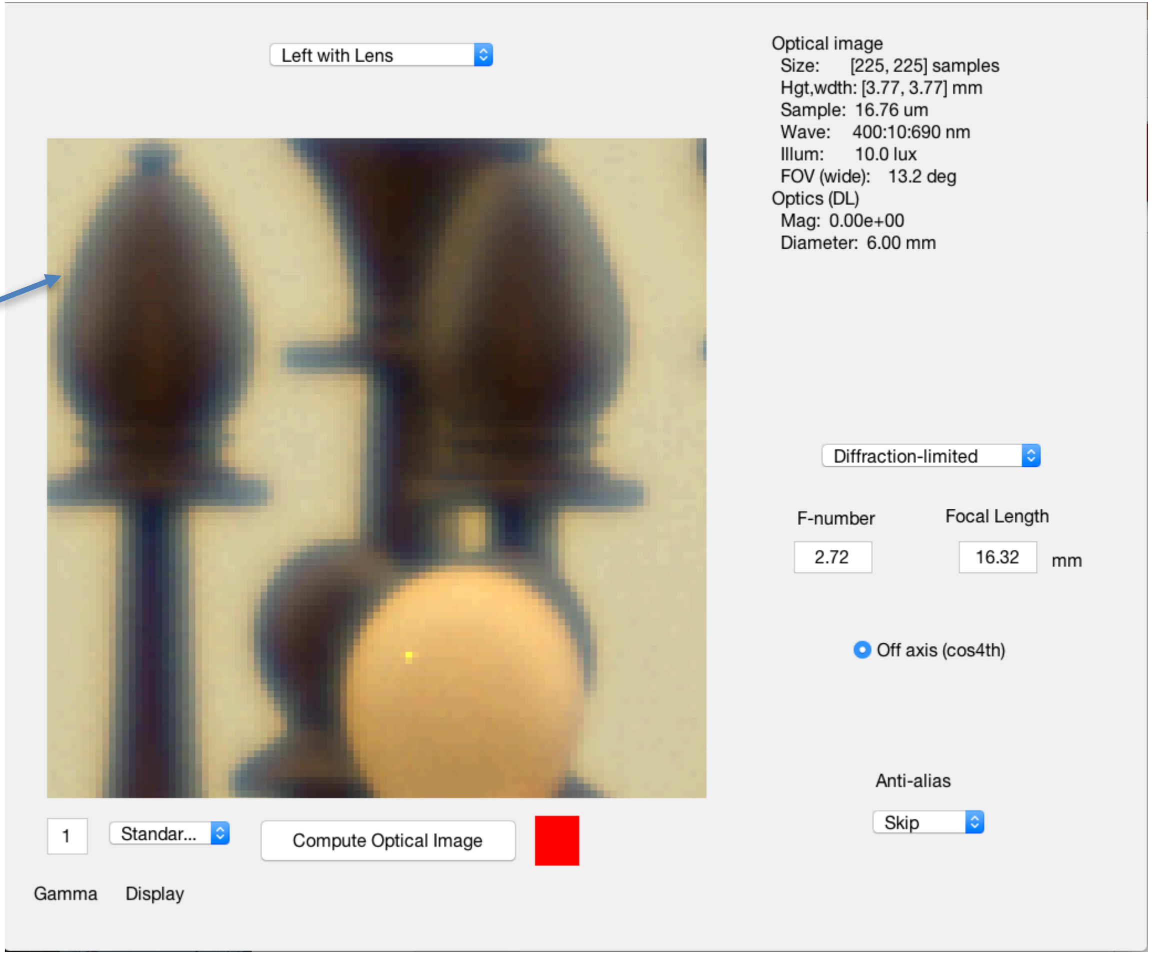


Longitudinal and transverse chromatic aberration

Zoomed view

Notice the spread of the short-wavelength light

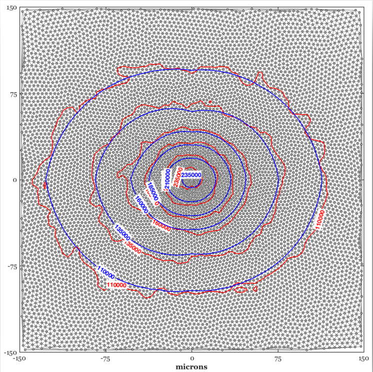
Chromatic aberration (and diffraction) are included in both the ray trace calculation and shift-invariant models

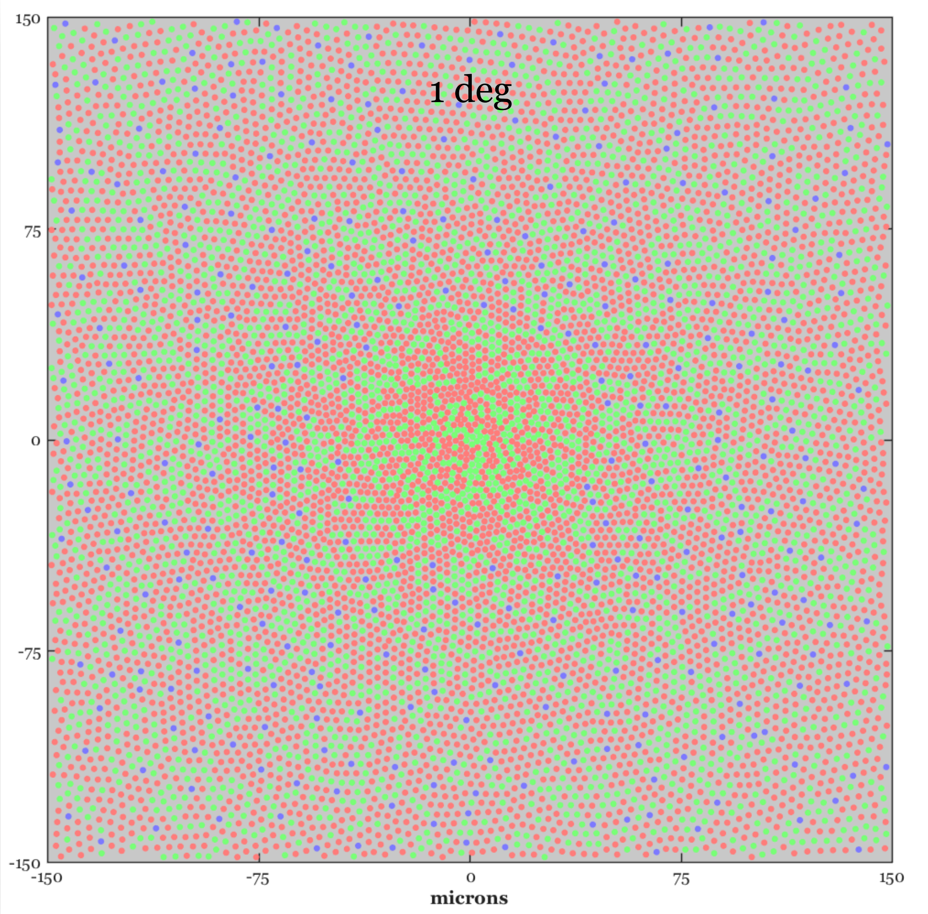


Cone absorptions and eye movements

- 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

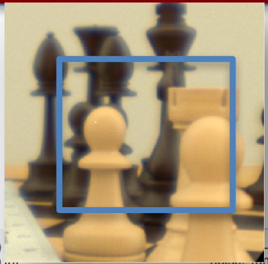
Iso-density lines





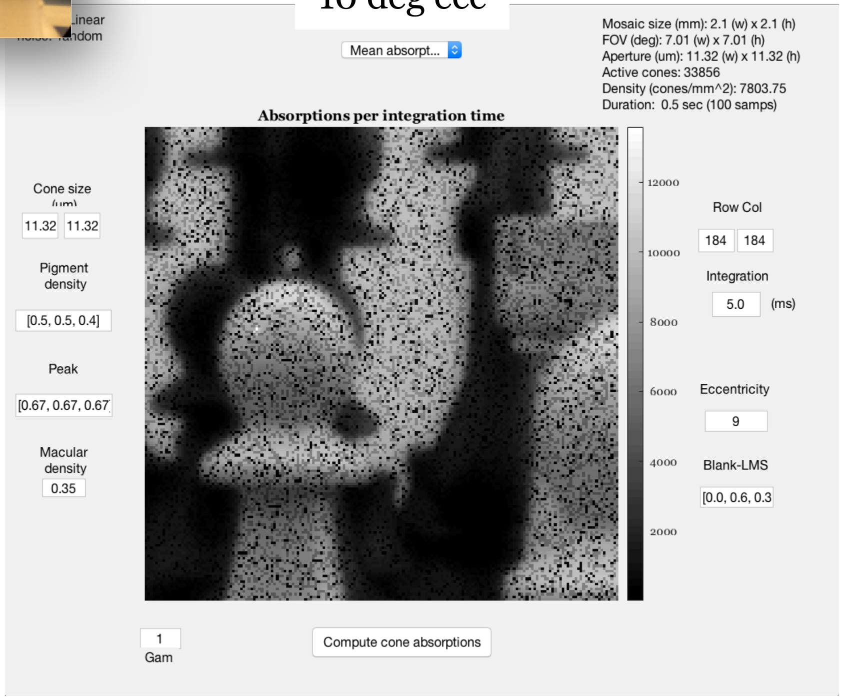
Cone mosaic absorptions and eye movements

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

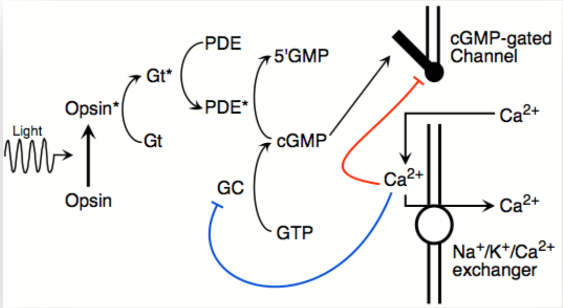


0.5 deg ecc

10 deg ecc



We have an implementation of photocurrent (Rieke Lab)



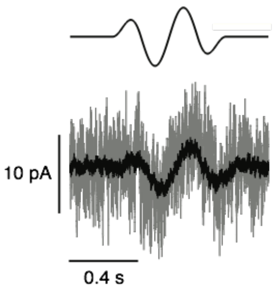
$$dR(t)/dt = s(t) - \sigma R(t)$$

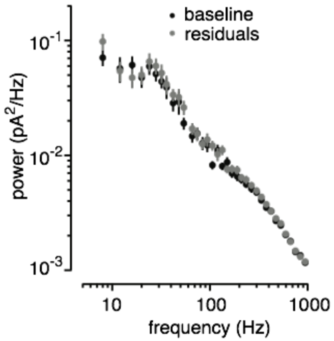
$$dP(t) = \gamma R(t) + \eta - \phi P(t)$$

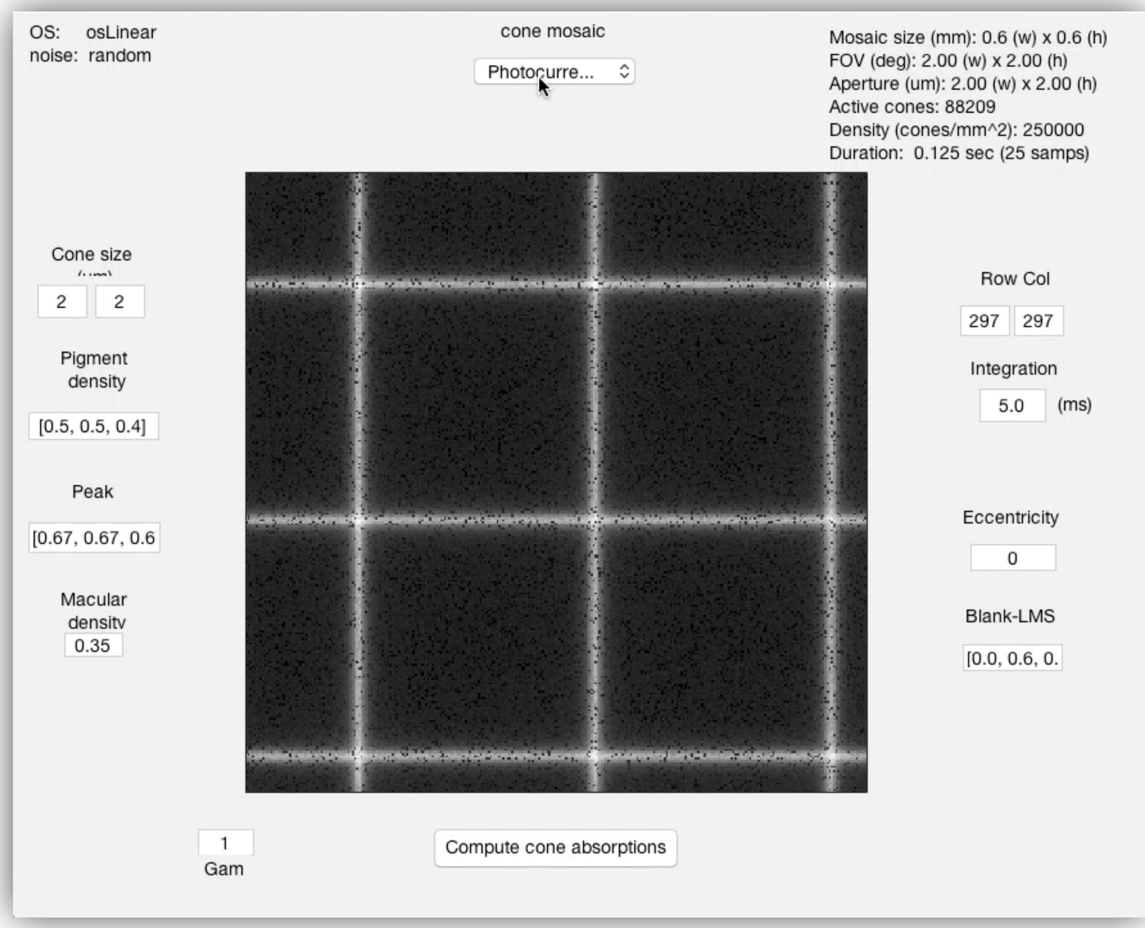
$$dG(t)/dt = s(C) - P(t)G(t)$$

...

Noise

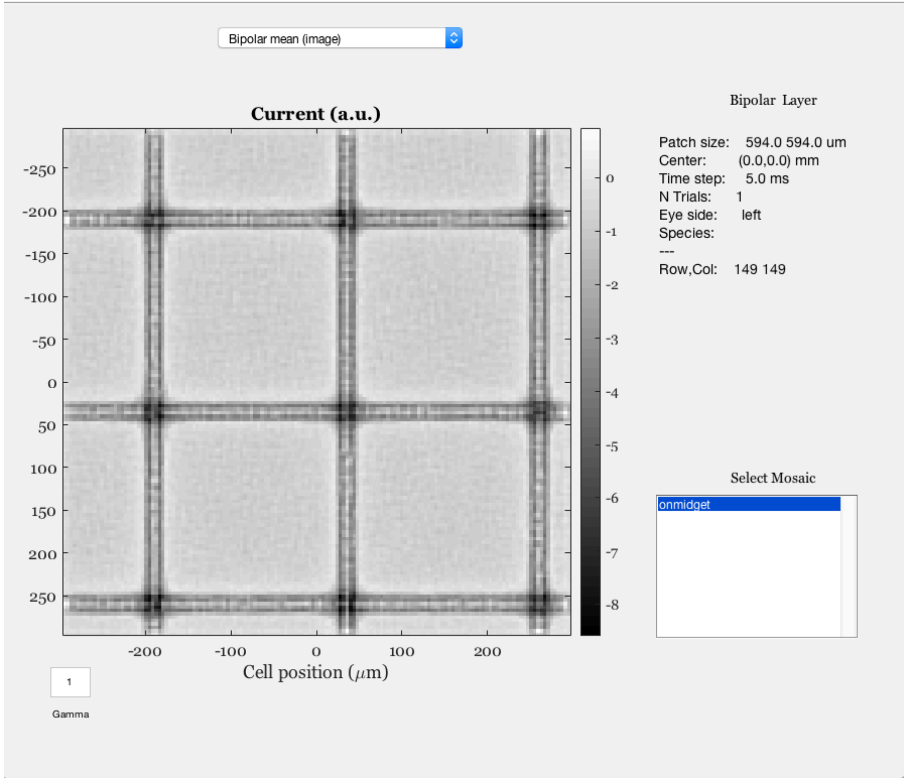




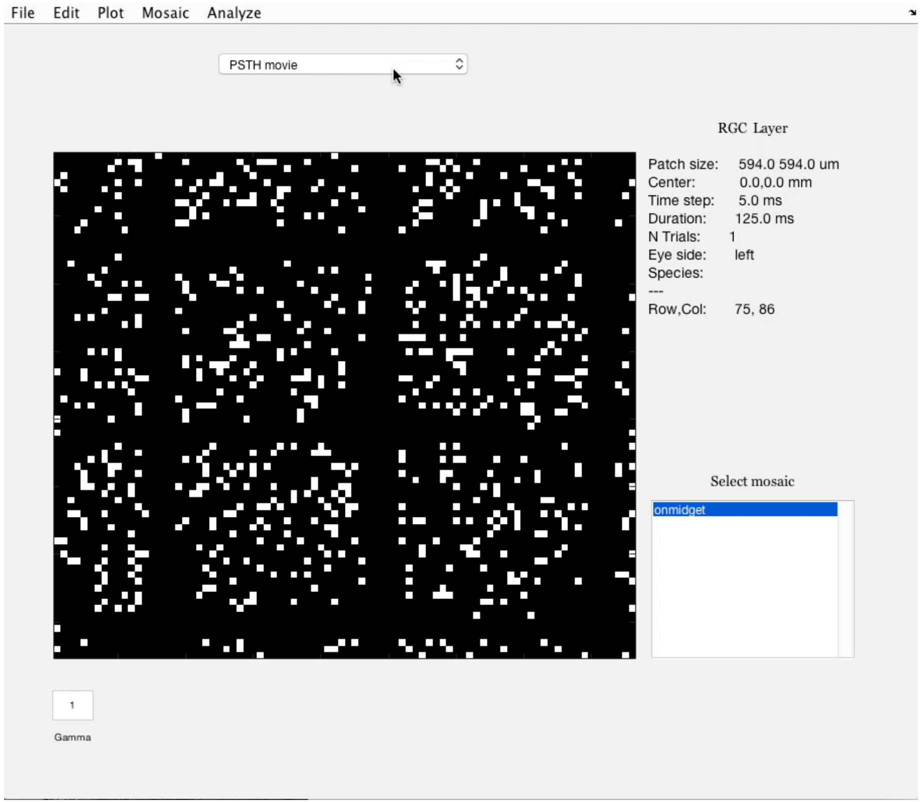


We are working on bipolar and ganglion cell models

Bipolar current

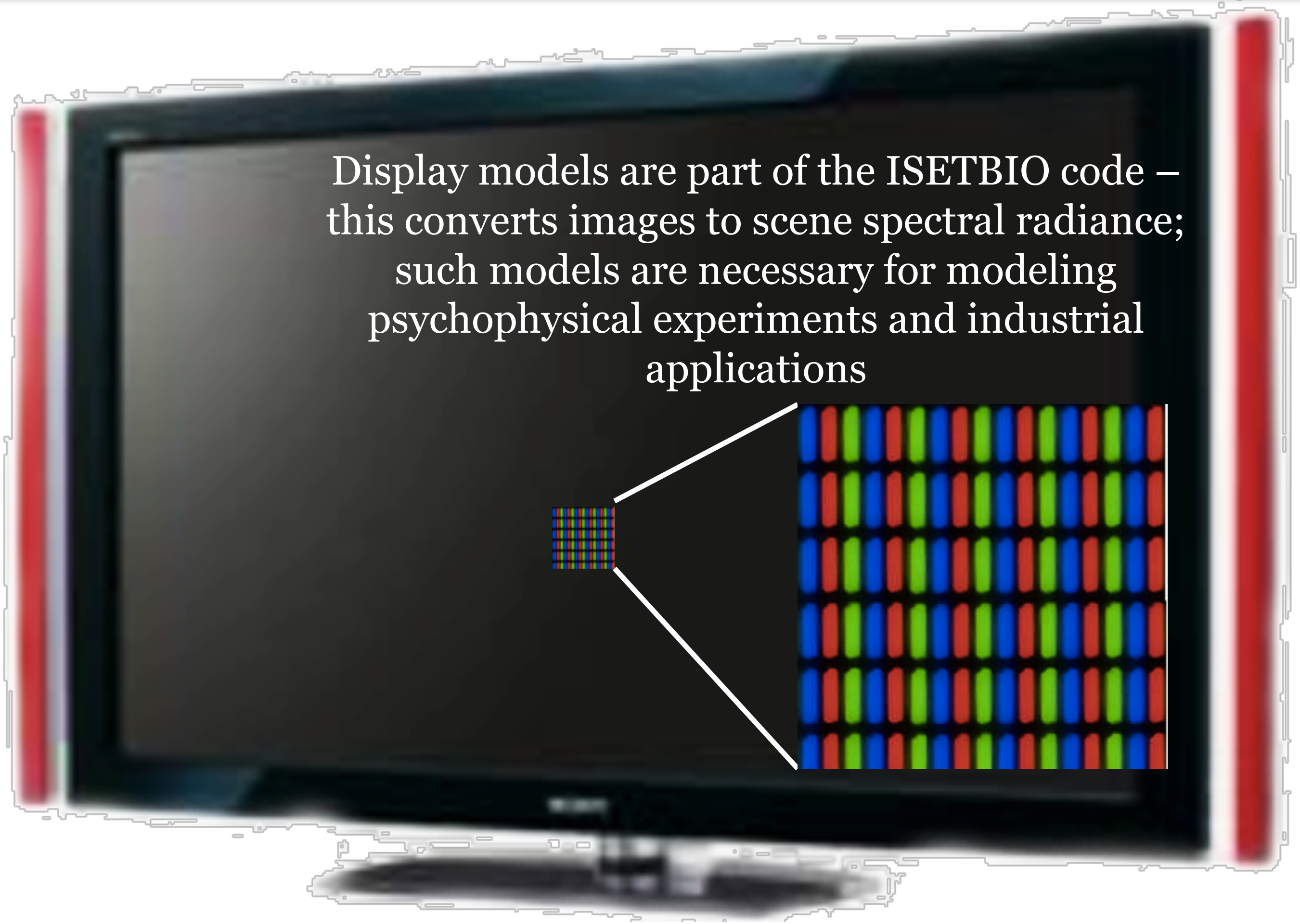


On midget spikes



Laboratory experiments display devices

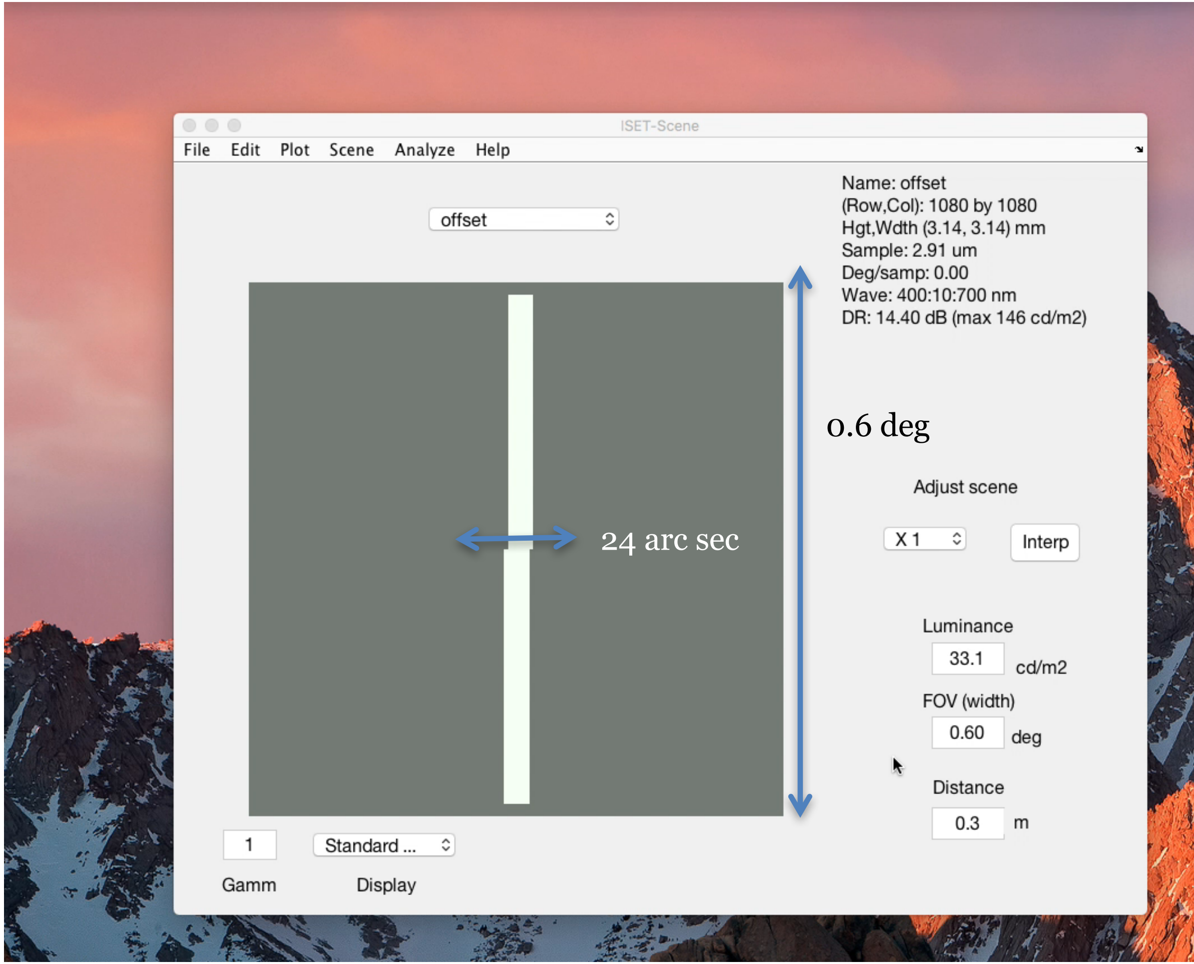
Display models are part of the ISETBIO code – this converts images to scene spectral radiance; such models are necessary for modeling psychophysical experiments and industrial applications



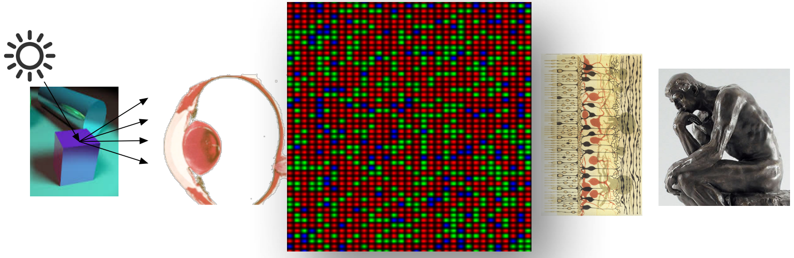
Analyzing psychophysical tasks

Two examples chosen for software validation and applications to industrial issues

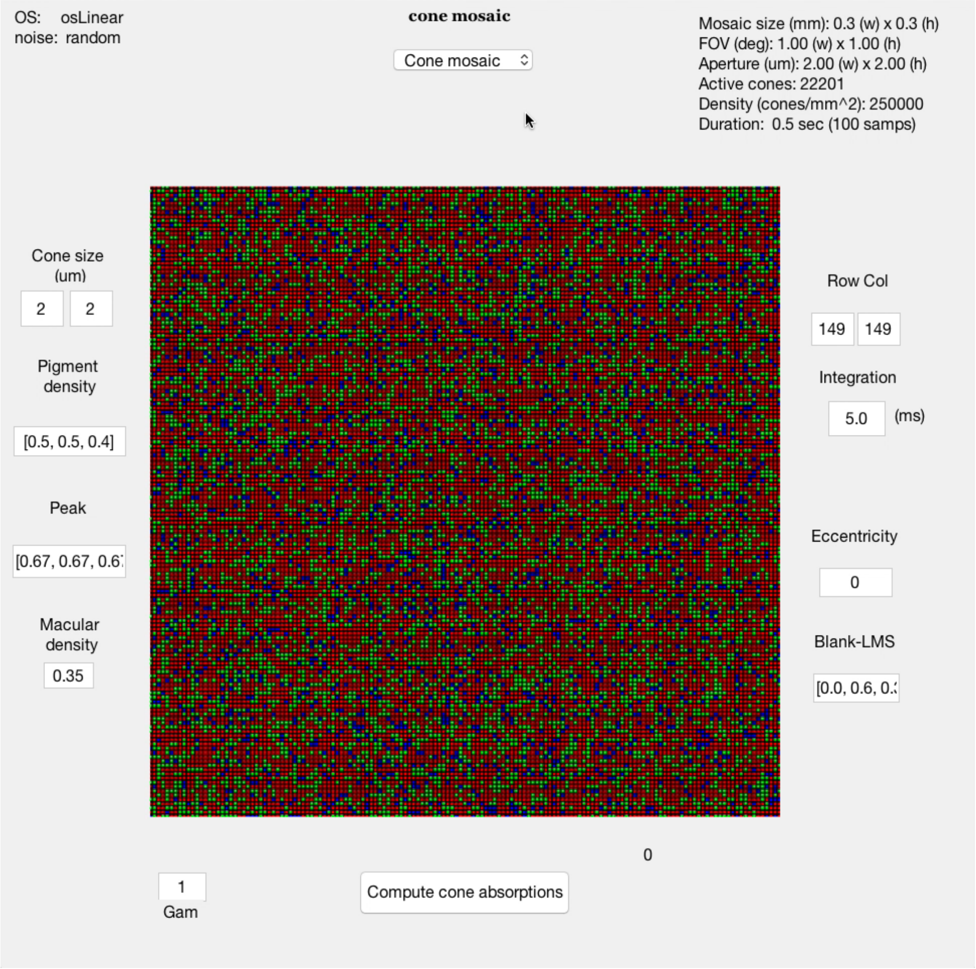
- Vernier acuity (Wandell et al.)
- Contrast sensitivity (Cottaris et al.)



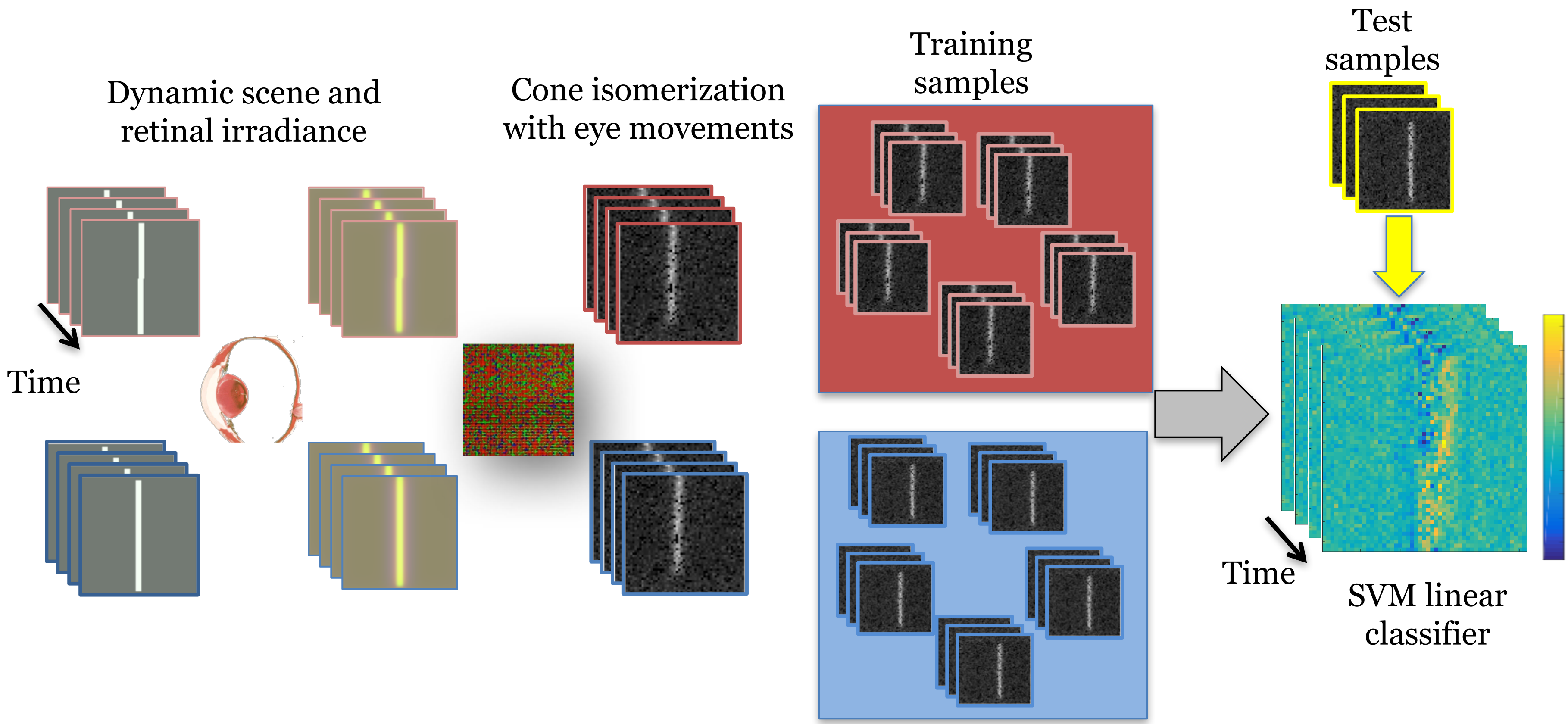
Cone absorptions accounting for eye movements



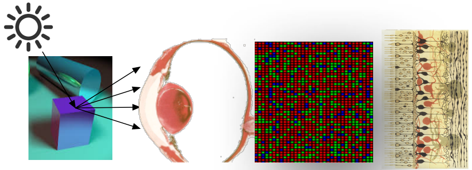
- The calculations here are on a rectangular grid;
- The cone photopigment properties were the standard templates

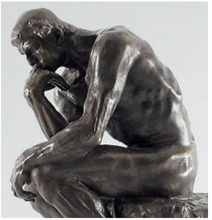


Computational observer pipeline for the Vernier task

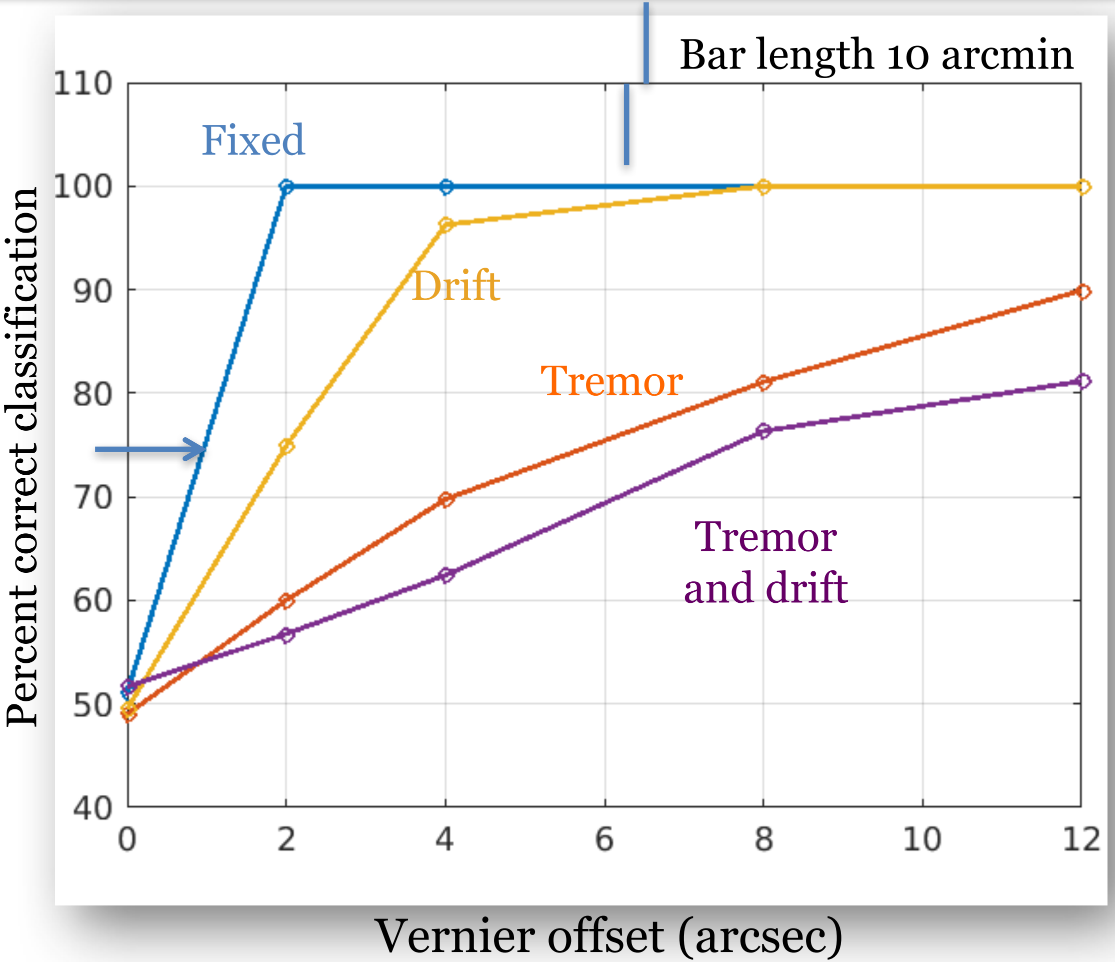


Tremor and drift limit classification accuracy

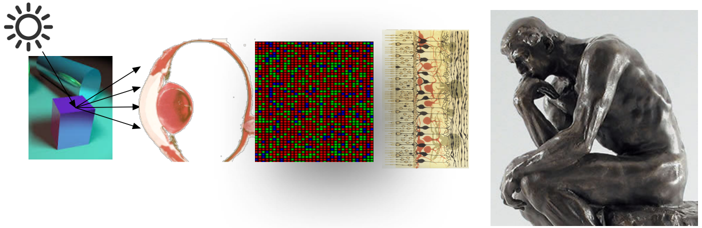




- The SVM linear classifier separates aligned and offset stimuli at very high resolution when we turn off eye movements
- Drift and tremor both degrade performance.



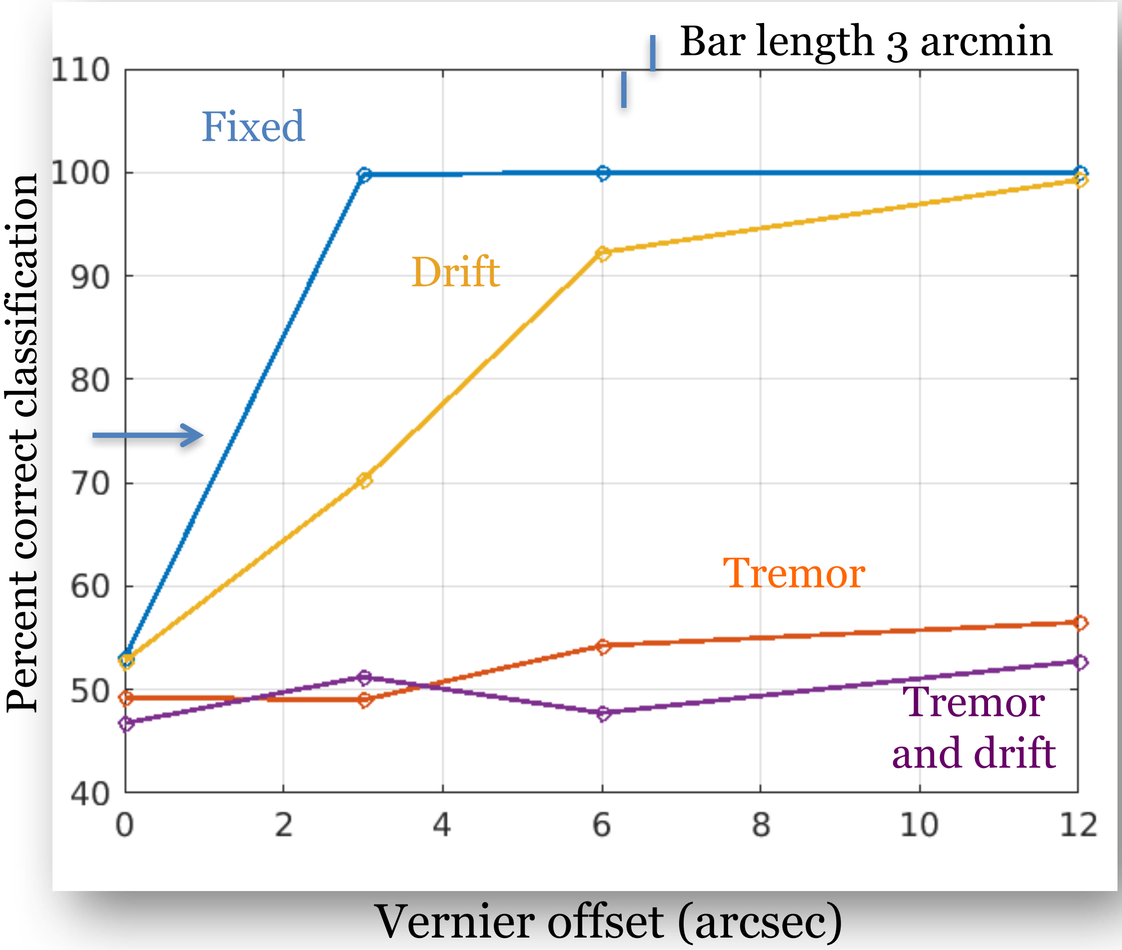
Tremor and drift limit classification accuracy



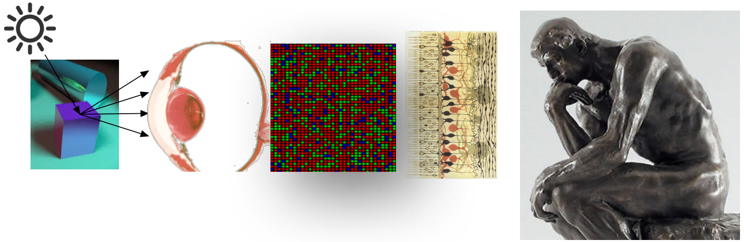
- The SVM linear classifier separates aligned and offset stimuli at very high resolution when we turn off eye movements

- Drift and tremor both degrade performance

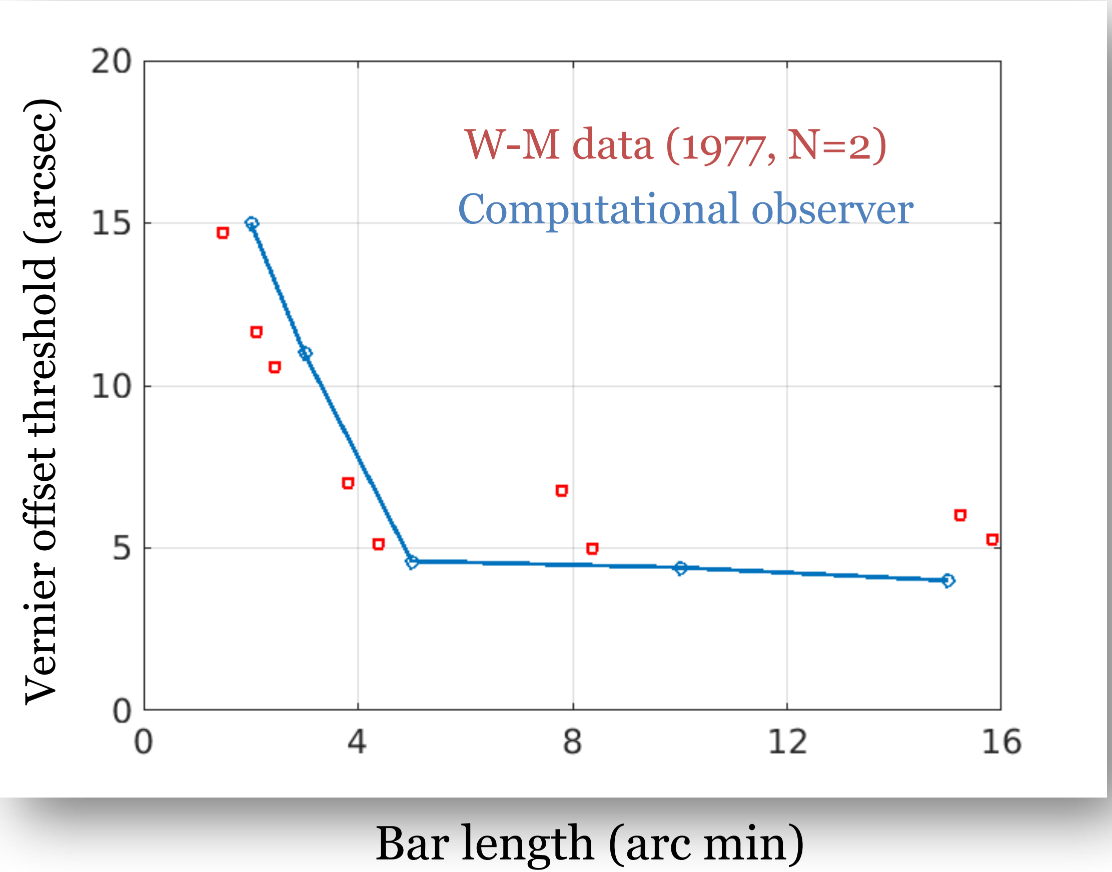
- Particularly for small stimuli



A phenomenological description of Westheimer and McKee



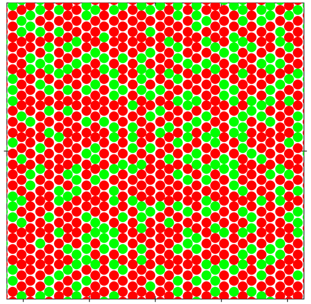
- By choosing to limit the Computational Observer (e.g., size of the cone mosaic), we can make a computational description that matches some properties of the human psychophysics

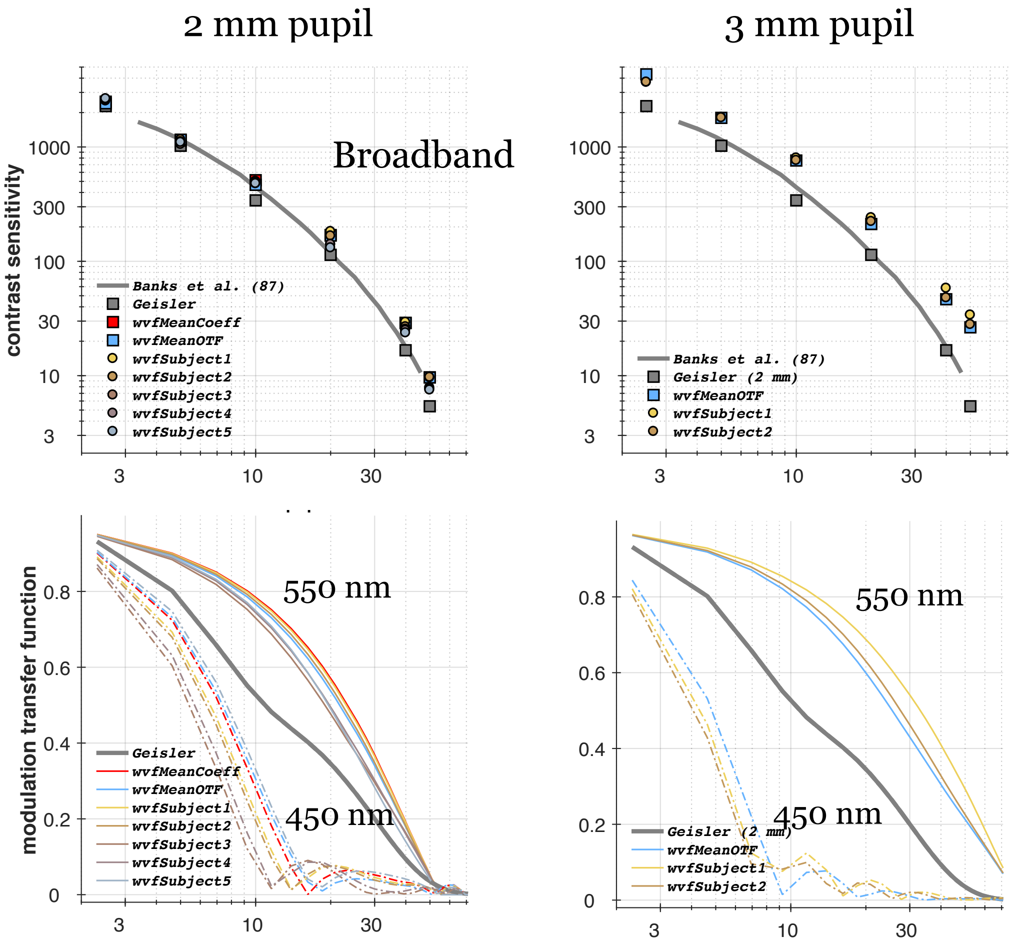


ISETBIO replicates classic measurements in the literature (Cottaris et al., in prep)

Comparison with Banks et al. 1987

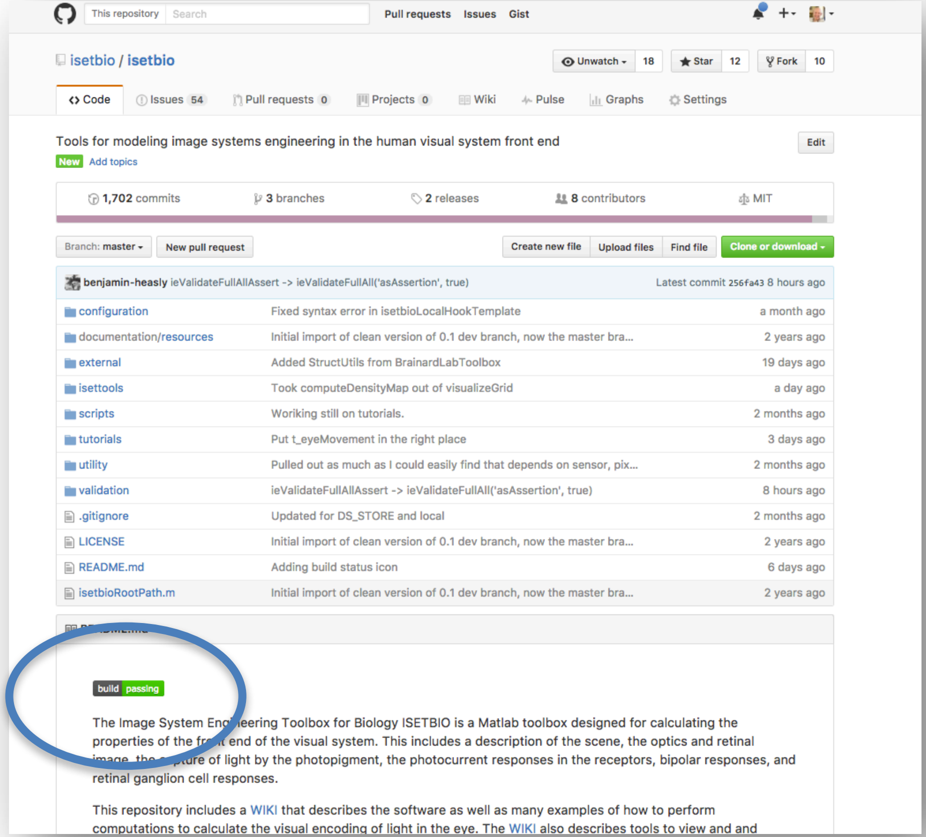
Cone spacing 3.0 um
Cone aperture 3.0 um
Pupil 2 mm
L,M cones
Broadband stimulus

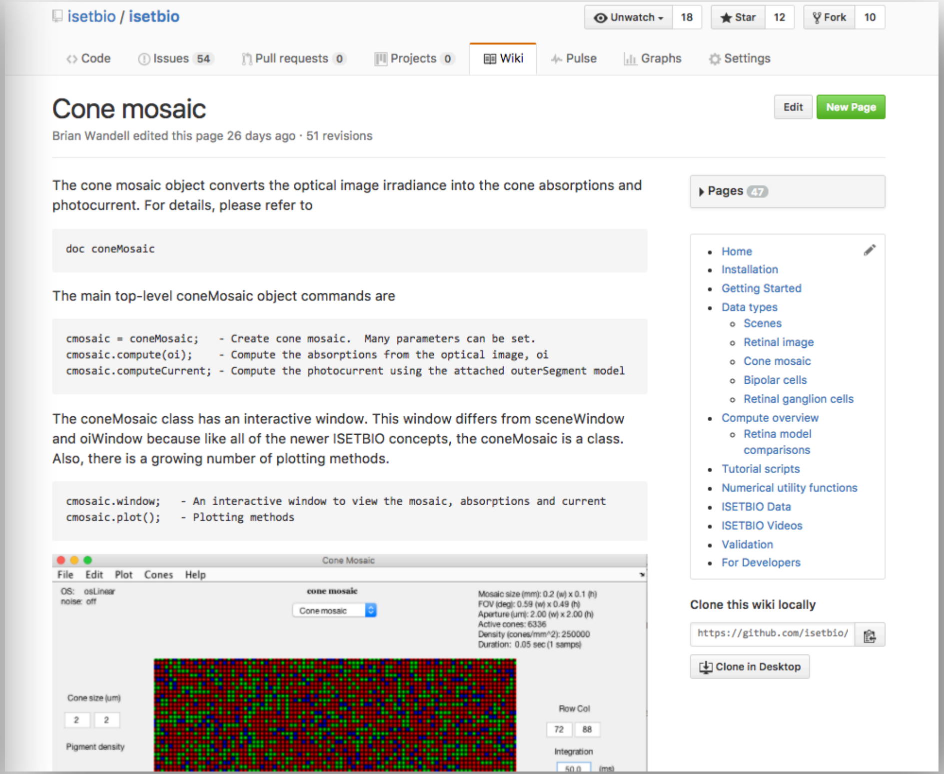




wvfSubjects are samples of wave front measurements

Github code and wiki – continuous integration





Video tutorials and data resources

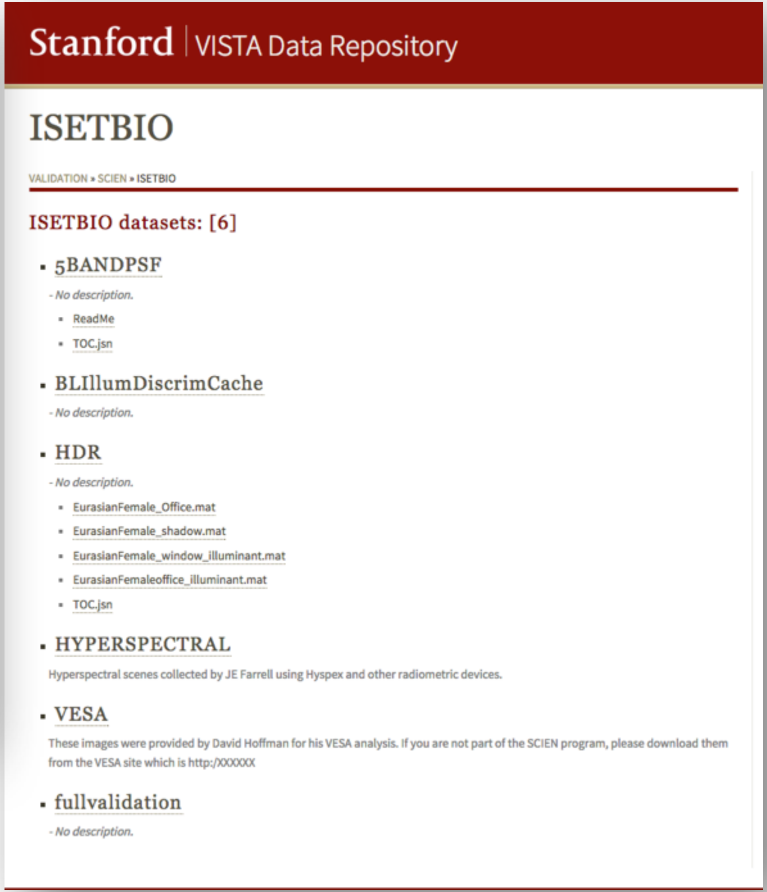
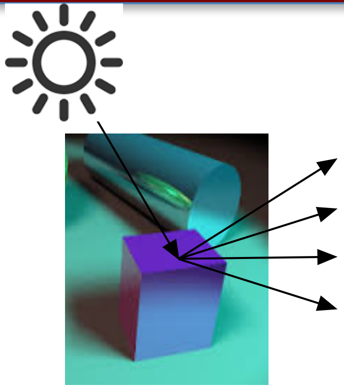


Image systems simulation for biology



Scene spectral radiance

Physiological optics

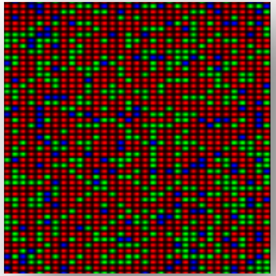
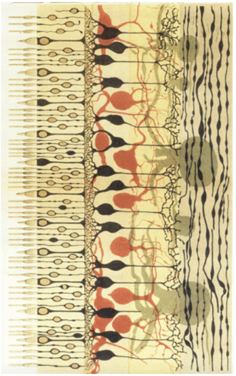


Photo transduction



Retinal processing

Inference

Thanks to Simons Foundation
Oculus Research, Samsung,
Qualcomm

Image systems engineering tools for biology: ISETBIO

20+5 FVM, Washington D.C.

For more than two centuries scientists have developed theories and made measurements that characterize how the visual system converts light into neural signals. This knowledge is contained in a distributed set of textbooks and research papers. We are developing an open-source Matlab toolbox, ISETBIO, that integrates this knowledge into a set of computations that convert 3D scene spectral radiance into retinal irradiance and neural responses. At this time, ISETBIO models the physiological optics, inert ocular pigments, eye movements, photoreceptor sampling and photopigment absorptions, cone photocurrent, bipolar cell responses, and retinal ganglion cell responses. One benefit of the project is that it clarifies which parts of our understanding are secure and which need further definition; a second benefit is that assembling the diverse sources of information into a single integrated package clarifies the contributions from different visual system components. We hope our colleagues will check and extend our work - we are particularly eager to develop models that characterize responses deeper in the nervous system and models that can be applied to animal visual systems. I will explain how the current computations, which characterize the initial stages of visual encoding, can be helpful to research scientists and engineers who aim to understand how information available in the nervous system limits fundamental perceptual judgments, such as Vernier acuity, contrast sensitivity, and color and motion sensitivity.