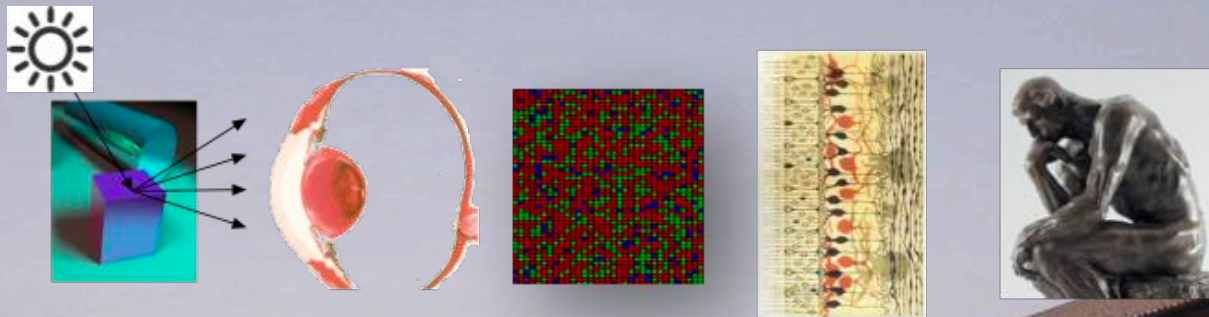


ISETBio and ISET3d: Modeling 3D scenes and human image formation

Brian Wandell and David Brainard



QUANTITATIVE MEASUREMENTS

∞

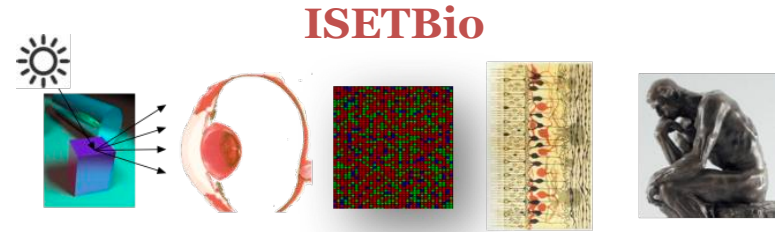
COMPUTATIONAL MODELS

∞

CHECK AND SHARE

What I review and why

- **Background:** ISETBio (Image Systems Engineering Tools for Biology) provides computational tools that implement the ideas developed by vision scientists.



- **What:** ISET3d is are tools that extend ISETBio from planar images into three-dimensional scenes. My goal today is to explain ISET3d.

- **Why:** The extension to 3D may be relevant to scientists and engineers who aim to
 - Model and understand the visual encoding of natural images and stereo vision,
 - Optimize devices, including cameras and displays, for capturing and rendering 3D scenes.

ISET3d



3D scene spectral radiance in the world and at the eye

Gershun (1936)

Ray intensities: $L(x,y,z,\alpha,\beta,\lambda,\theta)$

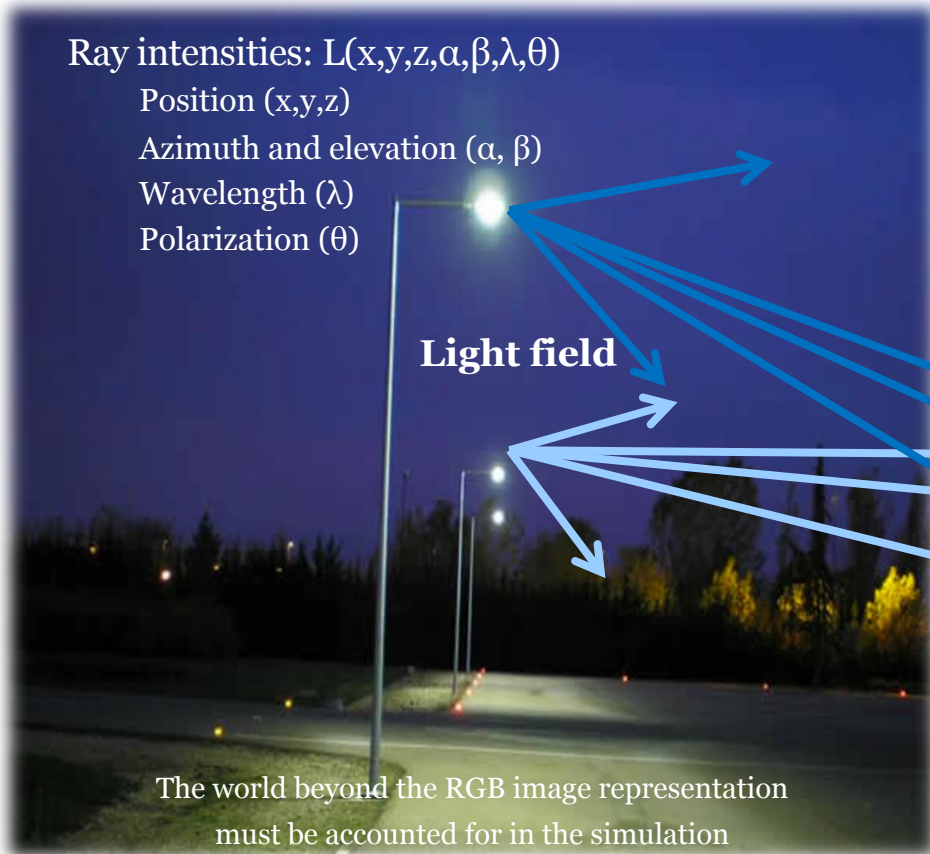
Position (x,y,z)

Azimuth and elevation (α, β)

Wavelength (λ)

Polarization (θ)

Light field



The world beyond the RGB image representation
must be accounted for in the simulation

Adelson and Bergen (1991)

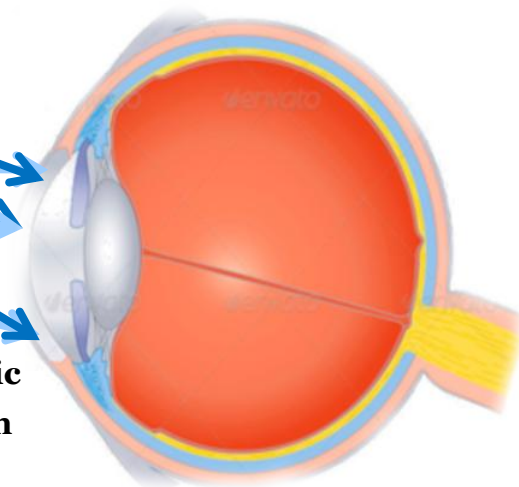
Ray intensities: $L(u,v,\alpha,\beta,\lambda)$

Position (u,v)

Azimuth and elevation (α, β)

Wavelength (λ)

**Plenoptic
function**



Graphics tools: Cinema 4D

- There are many tools for creating realistic 3D scene geometries
- We use Cinema 4D from Maxon because it integrates well with ray tracing methods
- Maxon offers **free** Cinema 4D licenses to students and teachers, and low- or no-cost “lab” licenses for schools.

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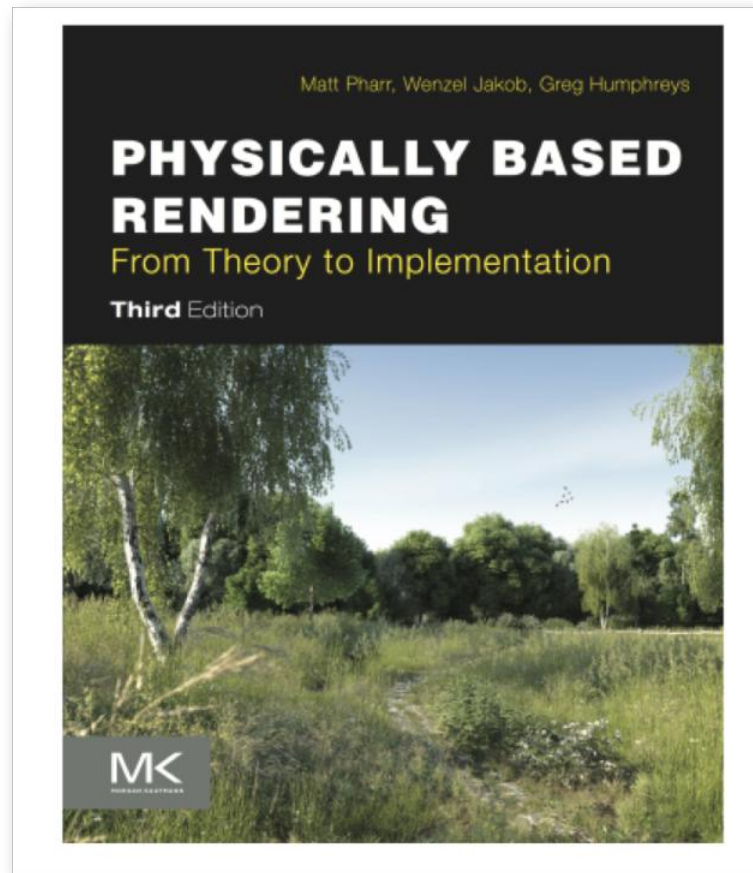
Why Cinema 4D?

Easy to learn and extremely powerful: Cinema 4D is the perfect package for all 3D artists who want to achieve breathtaking results fast and hassle-free. Beginners and seasoned professionals alike can take advantage of Cinema 4D's wide range of tools and features to quickly achieve stunning results. Cinema 4D's legendary reliability also makes it the perfect application for demanding, fast-paced 3D production.

WATCH SHOWREEL

Graphics tools: Quantitative computer graphics is a necessary component

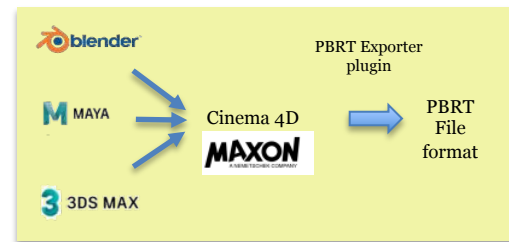
- Progress in computer graphics enables us to create synthetic and yet highly realistic input data.
- We use PBRT because it is open-source, extensible, and taught at Stanford
- The simulations can maintain meaningful units; quantitative computer graphics
- A GPU version is scheduled to be released by Pharr et al. in about 2 months



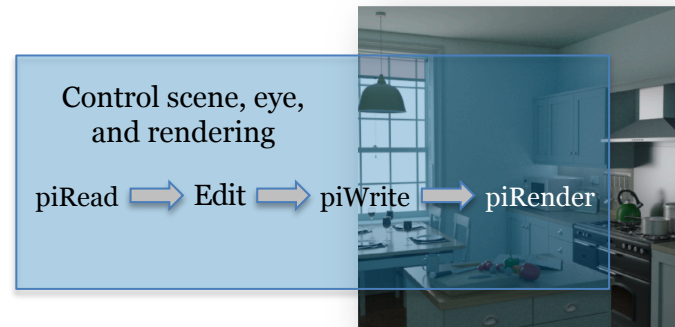
ISET3d: From PBRT to ISETBio (pi)

- In the next 15 minutes I illustrate the ISET3d computational framework
- I will show you
 - The **kinds of stimuli** that we are producing and
 - The programming approach in the specific case of simulating human **physiological optics** (image formation)
- David and I are producing videos of the tools that illustrate many more computations
- We use ISET3d for camera design, autonomous driving, underwater imaging, and medical imaging.

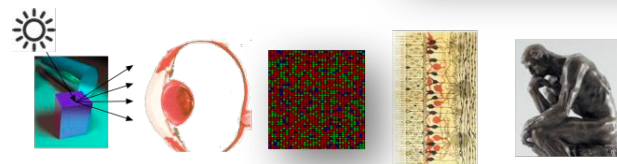
3d models

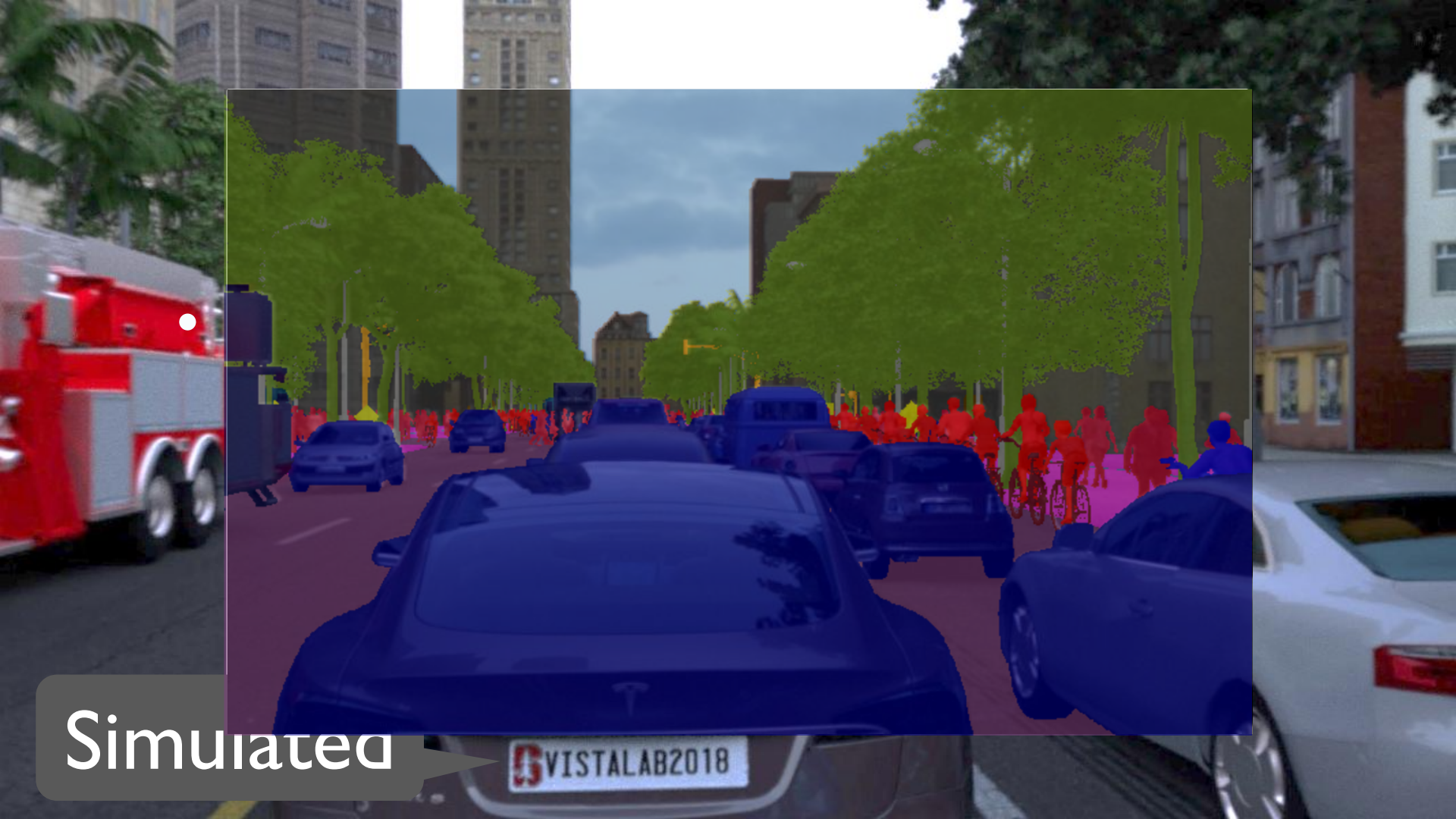


ISET3d



ISETBio





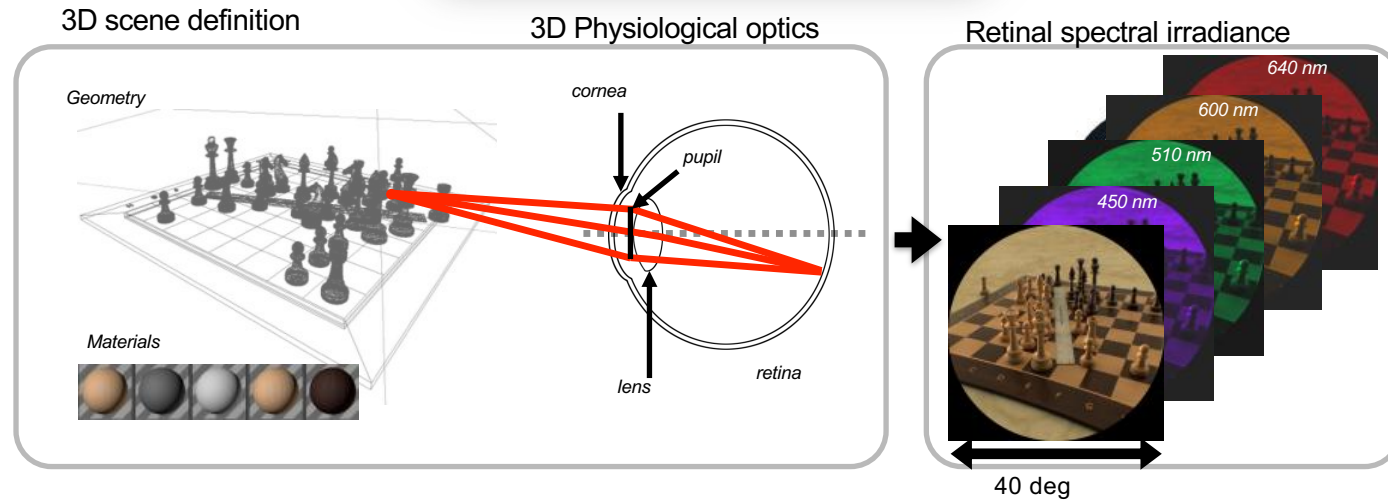
Simulated

VISTALAB2018

IS_{ET}3D extension to incorporate human optics



Gullstrand/LeGrand
Navarro, 1999
Arizona

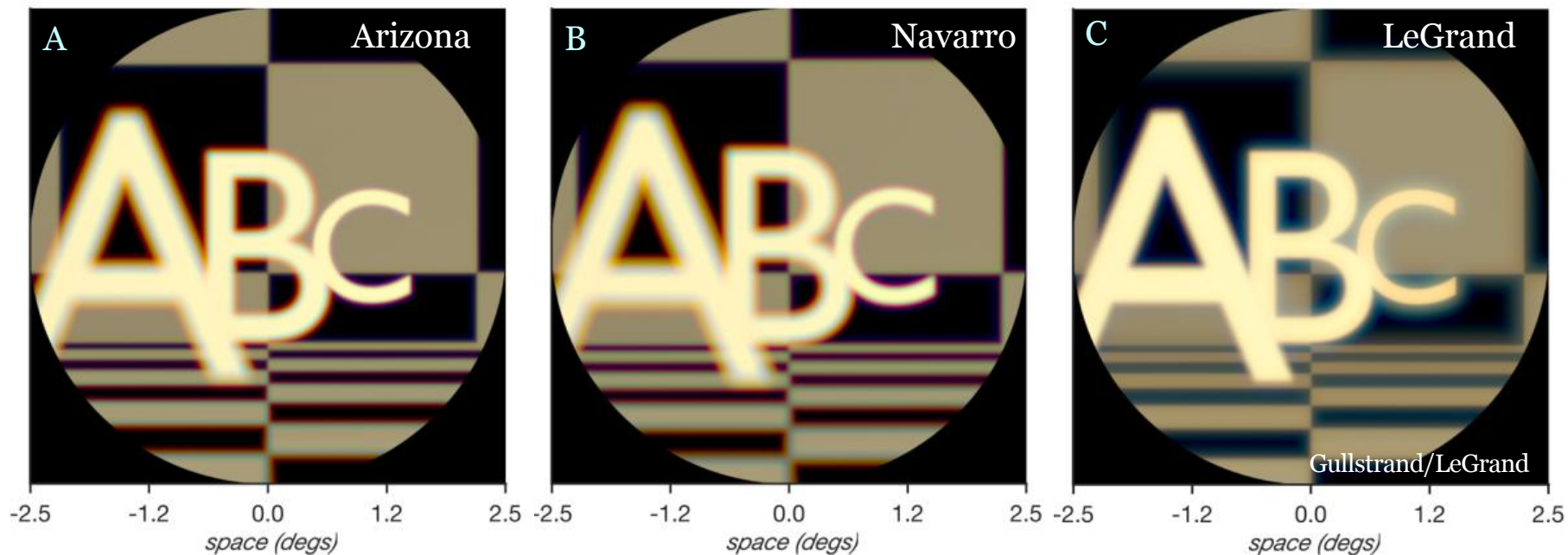


Use computer graphics and ray-tracing to model how spectral, 3D scenes are transformed by human optics to the retinal irradiance.

Comparison of eye models

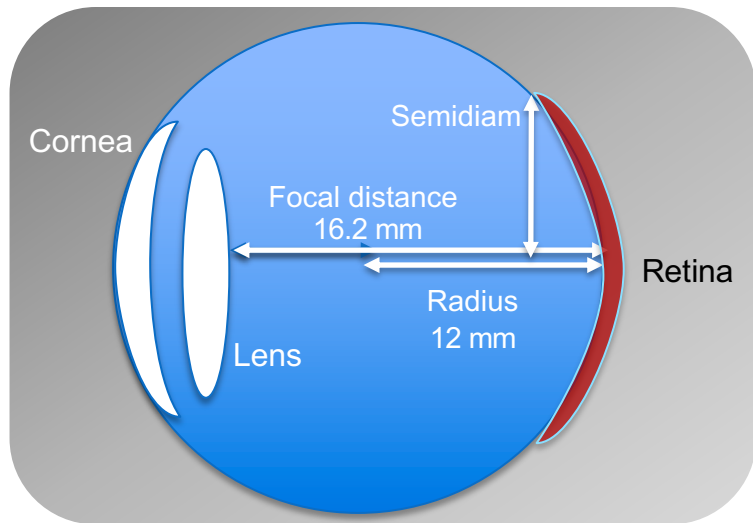
The code flexibility accommodates the major human eye models
(Lian et al. 2019, Journal of Vision).

Remember: these images represent underlying spectral irradiance



Example code: User's perspective

- We aim to make the top-level code easily understood. The computations are embedded in methods, often the set/get methods
- The sceneEye models a spherical eyeball and a curved retina, with inert pigments



The sceneEye class constructor

```
thisSE = sceneEye('letters at depth', 'human eye', 'legrand');
```

PBR files

Human eye model

```
>> thisSE  
  
thisSE =  
  
sceneEye with properties:  
  
    name: 'lettersAtDepth'  
    modelName: 'legrand'  
    usePinhole: 0  
    recipe: [1×1 recipe]  
    lensDensity: 1
```

Example code

- The code doing the computational work in ISET3d is managed within
 - The set/get methods
 - PBRT calculations
- You can ‘set’ many camera, rendering, and scene parameters
- You can ‘get’ many more parameters by calculation
- There are a number of methods ‘render’, ‘summary’ and others

```
% Suppose you are in focus at the proper distance to the edge. And we turn
% on chromatic aberration. That will slow down the calculation, but makes
% it more accurate and interesting. We only use 8 spectral bands for
% speed. You can use up to 31.
nSpectralBands = 8;
thisSE.set('chromatic aberration',nSpectralBands);

% This is the distance we calculate above
thisSE.set('focal distance',1);

% Controls the rendering noise vs. speed by setting the number of rays.
thisSE.set('rays per pixel',128);

% Increase the spatial resolution by adding more spatial samples.
thisSE.set('spatial samples',384);

% This takes longer than the pinhole rendering, so we do not bother with
% the depth.
oi = thisSE.render('render type','radiance');
oiWindow(oi);
```

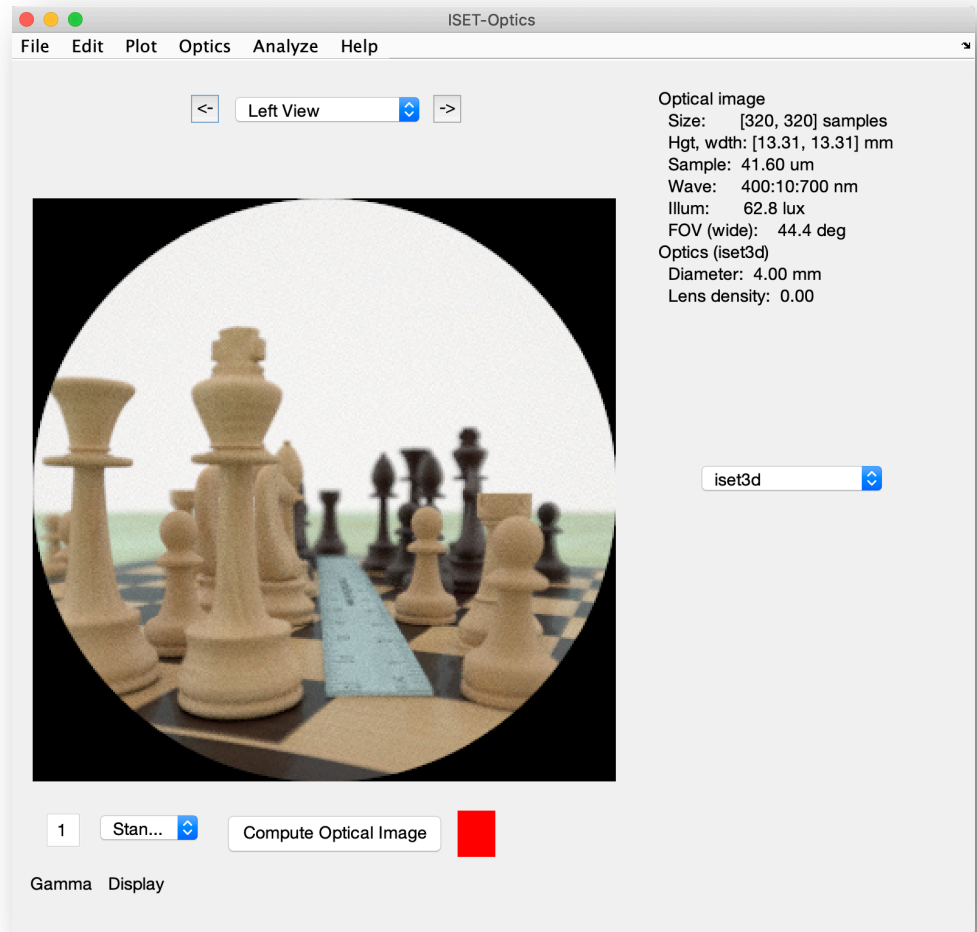
ISET3d: Making a stereo pair

Left eye

This is the position
of the left eye

`from = thisEye.get('from')`

It is the 'from' parameter in
the recipe



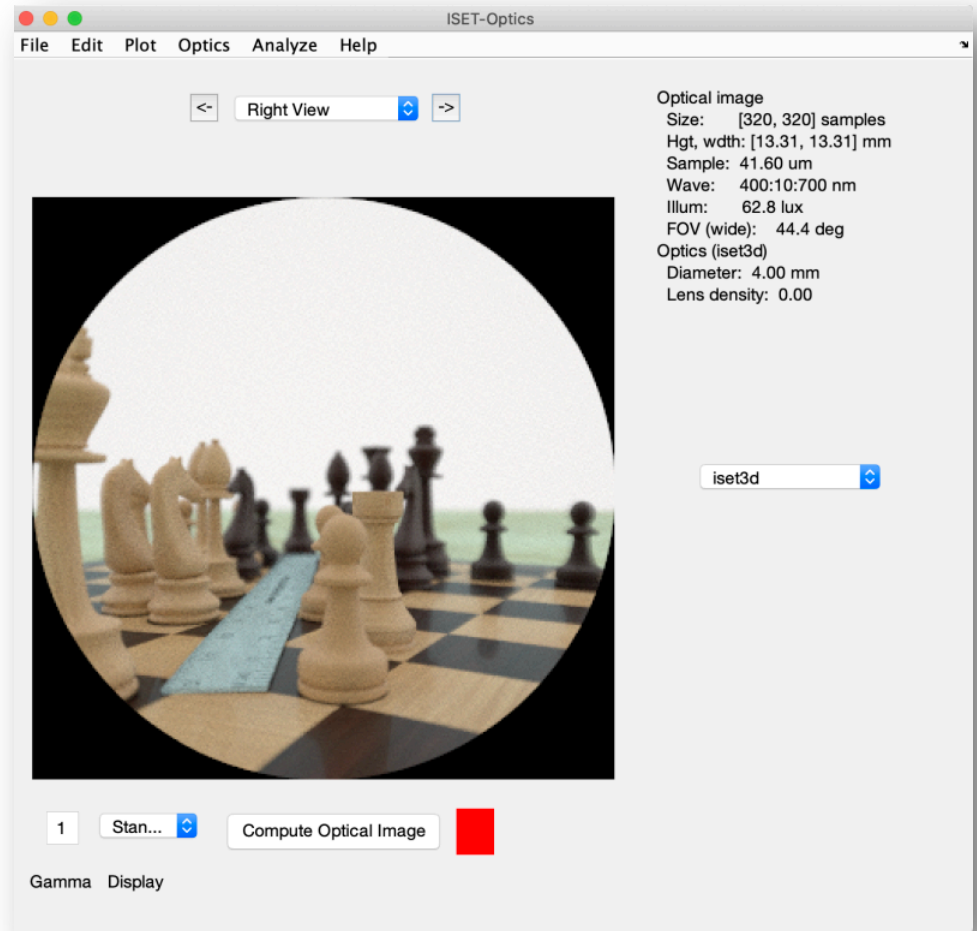
ISSET3d: Making a stereo pair

Right eye

Move the camera position
by 6 cm to the right

```
newFrom = from + (0.060, 0, 0)
```

```
thisEye.set('from', newFrom)  
oiRight = thisEye.render;
```



ISSET3d: Making a stereo pair

- This ISET3d code makes the stereo pair of the Chess retinal irradiance, imaged through the Navarro model eye
- I set the lens density to 0 so the scene would not look very yellow. I will explain this in a moment

```
%% Make an oi of the chess set scene using the LeGrand eye model

thisSE = sceneEye('chess set scaled','human eye','navarro');

thisSE.set('lens density',0); % Just because I can

thisSE.set('rays per pixel',512); % Pretty quick, but not high quality

oiLeft = thisSE.render; % Render radiance and depth, and then show
oiWindow(oiLeft);

%% Shift the eye position

% Change the eye position (from) but stay focused on the same object (to).
% I shifted the eye position by a lot (12 mm) so the image difference is be
% easy to see. The inter-pupil difference is really only 6-8 cm


fromLeft = thisSE.get('from'); % Current camera location
fromRight = fromLeft + [6,0,0]*1e-2; % Shift it 6 cm
thisSE.set('from',fromRight);

oiRight = thisSE.render('render type','radiance');
oiWindow(oiRight);
```

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

Inert pigments (e.g. lens transmission) are included and controlled

Left eye



Optical image
Size: [512, 512] samples
Hgt,wdth: [8.75, 8.75] mm
Sample: 17.08 μ m
Wave: 400:10:690 nm
Illum: 10.0 lux
FOV (wide): 30.0 deg
Optics (DL)
Mag: 0.00e+00
Diameter: 6.00 mm


F-number Focal Length
 mm

Off axis (cos4th)

Anti-alias

Gamma Display

Left with Lens



Optical image
Size: [512, 512] samples
Hgt,wdth: [8.75, 8.75] mm
Sample: 17.08 μ m
Wave: 400:10:690 nm
Illum: 8.4 lux
FOV (wide): 30.0 deg
Optics (DL)
Mag: 0.00e+00
Diameter: 6.00 mm

F-number Focal Length
 mm

Off axis (cos4th)

Anti-alias

Gamma Display

Remember: these images represent underlying spectral irradiance

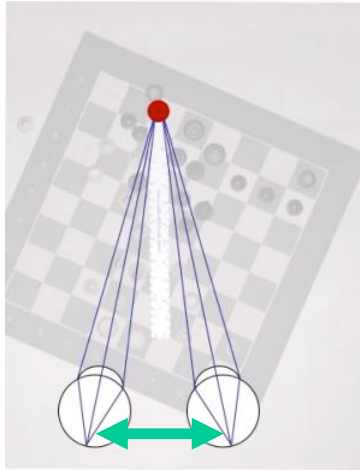
Vergence and Accommodation

Where the eye (or eyes) is looking is controlled
thisEye.set('to',loc)

1.66 D (Left)



1.66 dpt (Right)



64 mm

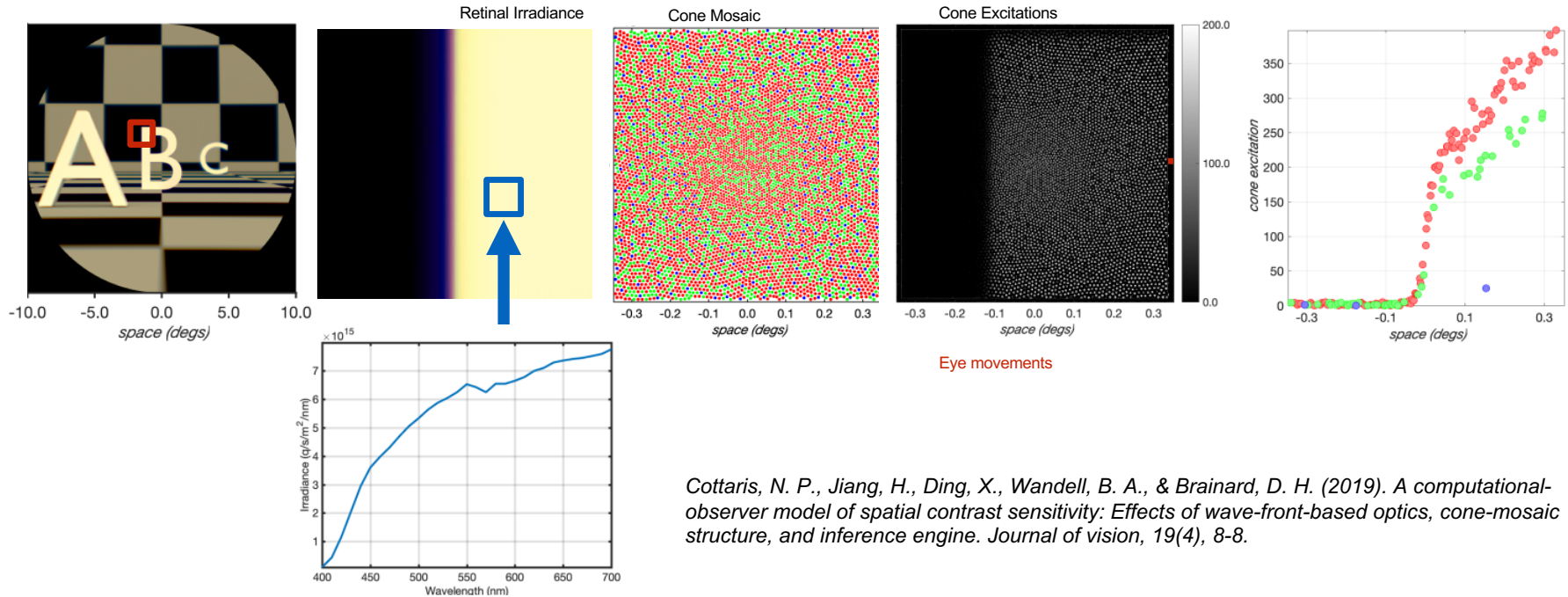
Remember: these images represent underlying spectral irradiance

Calculating cone responses and eye movements

<https://github.com/isetbio/isetbio/wiki/ISETBio-Videos>

<https://github.com/iset/isetcam/wiki/ISETCam-Videos>

GitHub wiki video pages




Cottaris, N. P., Jiang, H., Ding, X., Wandell, B. A., & Brainard, D. H. (2019). A computational-observer model of spatial contrast sensitivity: Effects of wave-front-based optics, cone-mosaic structure, and inference engine. *Journal of vision*, 19(4), 8-8.

Scenes can be quite complex and realistic

- We have more than 25 high quality scenes like these
- The geometry, reflectance, lighting and textures can be edited (ask me)
- This collection will grow and already includes HDR, inter-reflections, many types objects, materials, textures, shadows, occlusions

<- bathroom-Jul-18,12:11 >



Name: bathroom-Jul-18,12:11
(Row, Col): 512 by 512
Hgt, Wdth (,) um
Sample: um
Deg/samp:
Wave: 400:10:700 nm
DR: Inf
(max 3029, min 0.00 cd/m2)

Adjust scene size

X 1 Interp

Luminance
100.0 cd/m2

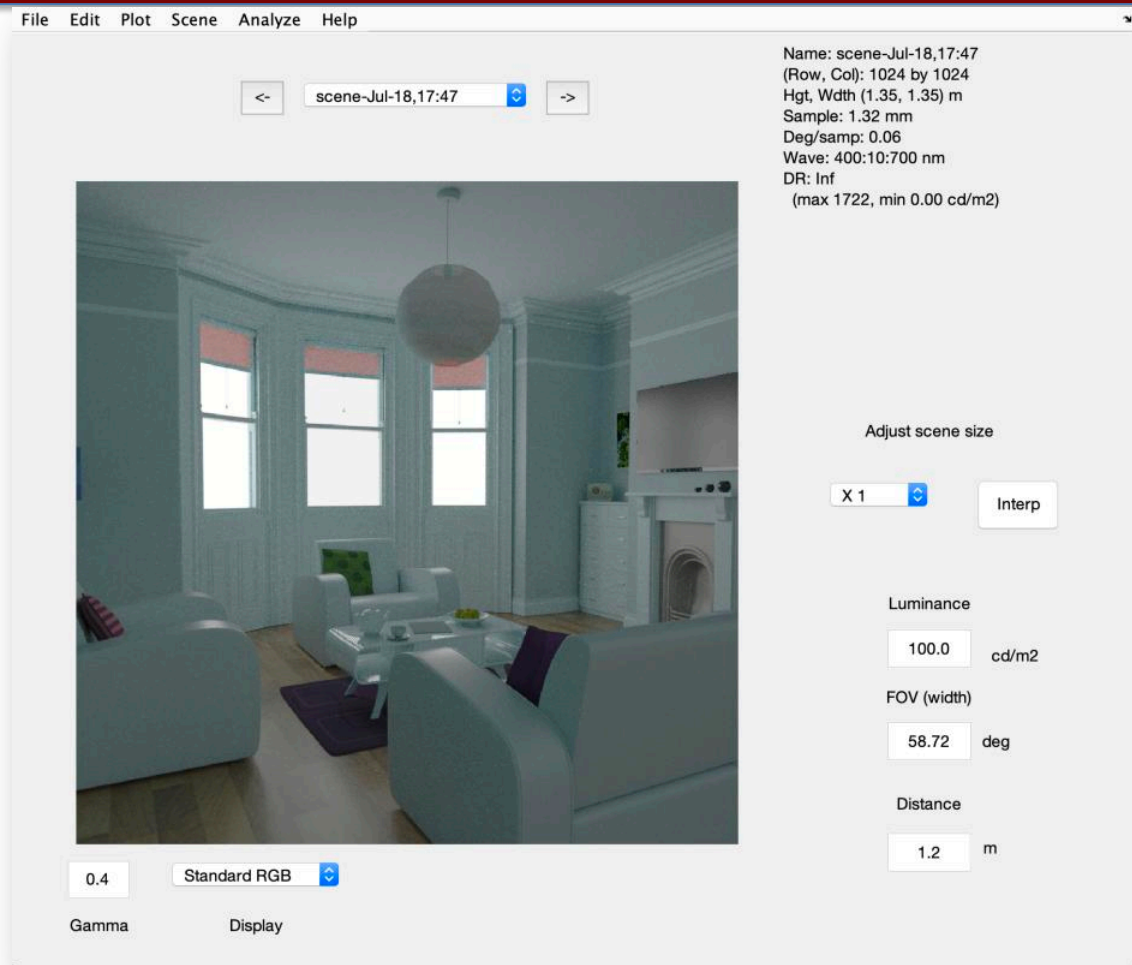
FOV (width)
deg

Distance
1.2 m

0.4 Standard RGB

Gamma Display

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File Edit Plot Scene Analyze Help

<- scene-Jul-18,12:43 >-



Name: scene-Jul-18,12:43
(Row, Col): 512 by 512
Hgt, Wdth (0.78, 0.78) m
Sample: 1.52 mm
Deg/samp: 0.07
Wave: 400:10:700 nm
DR: 114.83 dB (max 1241 cd/m2)

Adjust scene size

X 1 Interp

Luminance
100.0 cd/m2

FOV (width)
35.98 deg

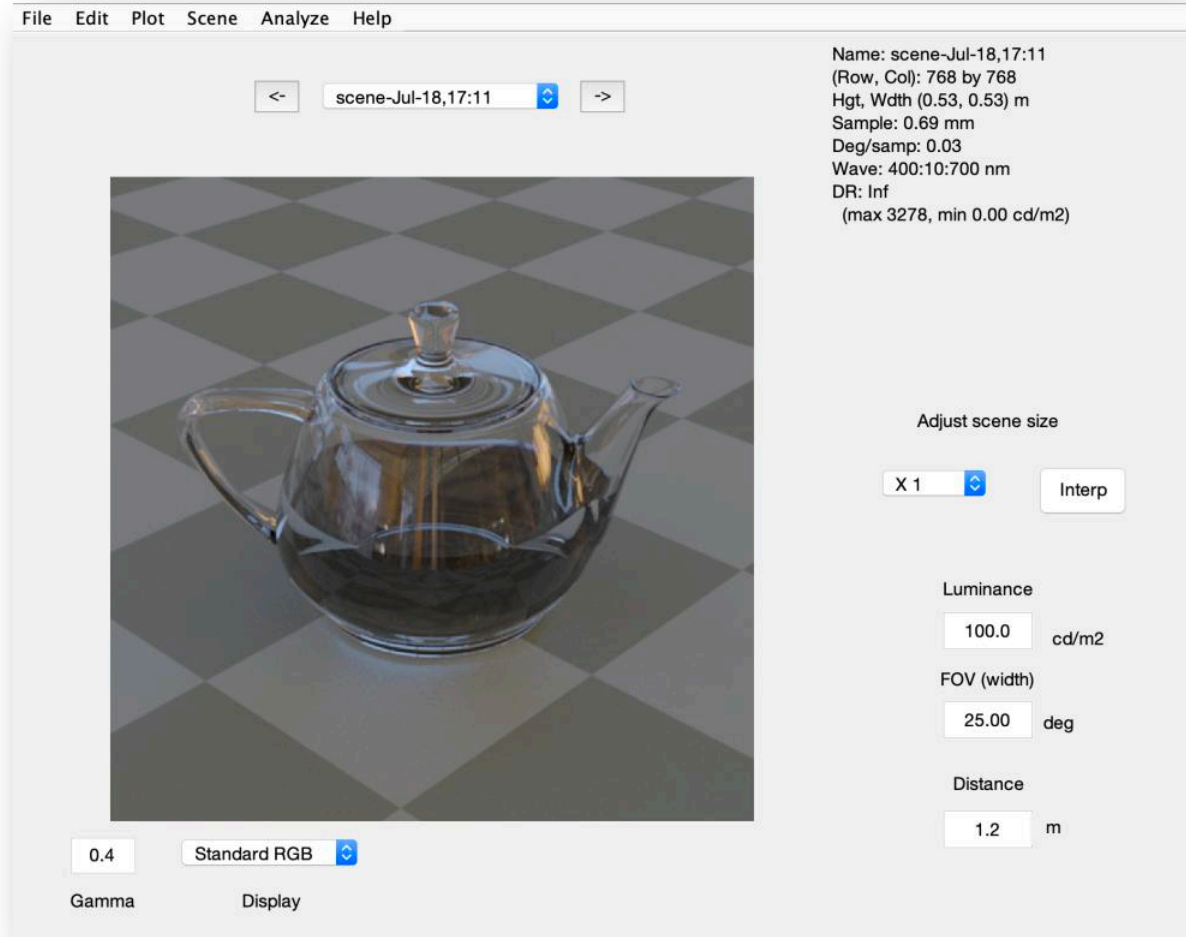
Distance
1.2 m

0.4 Standard RGB

Gamma Display

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<- scene-Jul-18,12:22 ->



Name: scene-Jul-18,12:22
(Row, Col): 512 by 512
Hgt, Wdth (1.35, 1.35) m
Sample: 2.64 mm
Deg/samp: 0.11
Wave: 400:10:700 nm
DR: Inf
(max 2933, min 0.00 cd/m2)

Adjust scene size

X 1 Interp

Luminance
100.0 cd/m2

FOV (width)
58.72 deg

Distance
1.2 m

0.4 Standard RGB

Gamma Display

ISETBio Team and Funding



Brian Wandell



Trisha Lian



Haomio Jiang



James Golden



David Brainard



Nicolas Cottaris



Xiaomao Ding



Lingqi Zhang



E.J. Chichilnisky



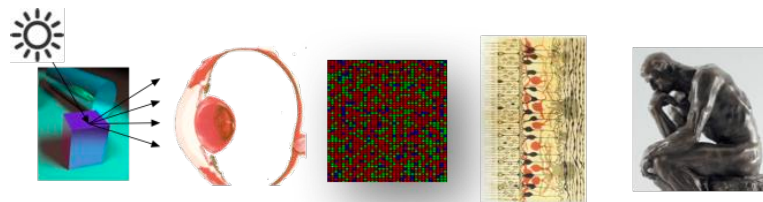
Fred Rieke



Joyce Farrell



Jon Winawer



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