Modeling 3D scenes and image formation of these scenes

- A description of the 3D stimulus (light field and plenoptic function)
- Running code to create quantified 3D scenes
- Calculating image formation and cone excitation from these scenes (ISETBio, sceneEye)

YouTube videos

https://youtu.be/0Ix0lKGxZ1w

https://youtu.be/fUQXOf8l7DI

https://scarlet.stanford.edu/~brian/talks/2020-AO-Meeting-Wandell.pdf

Scene spectral radiance in the world

Gershun (1936)

Ray intensities: L(x,y,z,α,β,λ,θ)

- Position (x,y,z)
- Azimuth and elevation (α, β)
- Wavelength (λ)
- Polarization (θ)

Light field at the eye (plenoptic function)

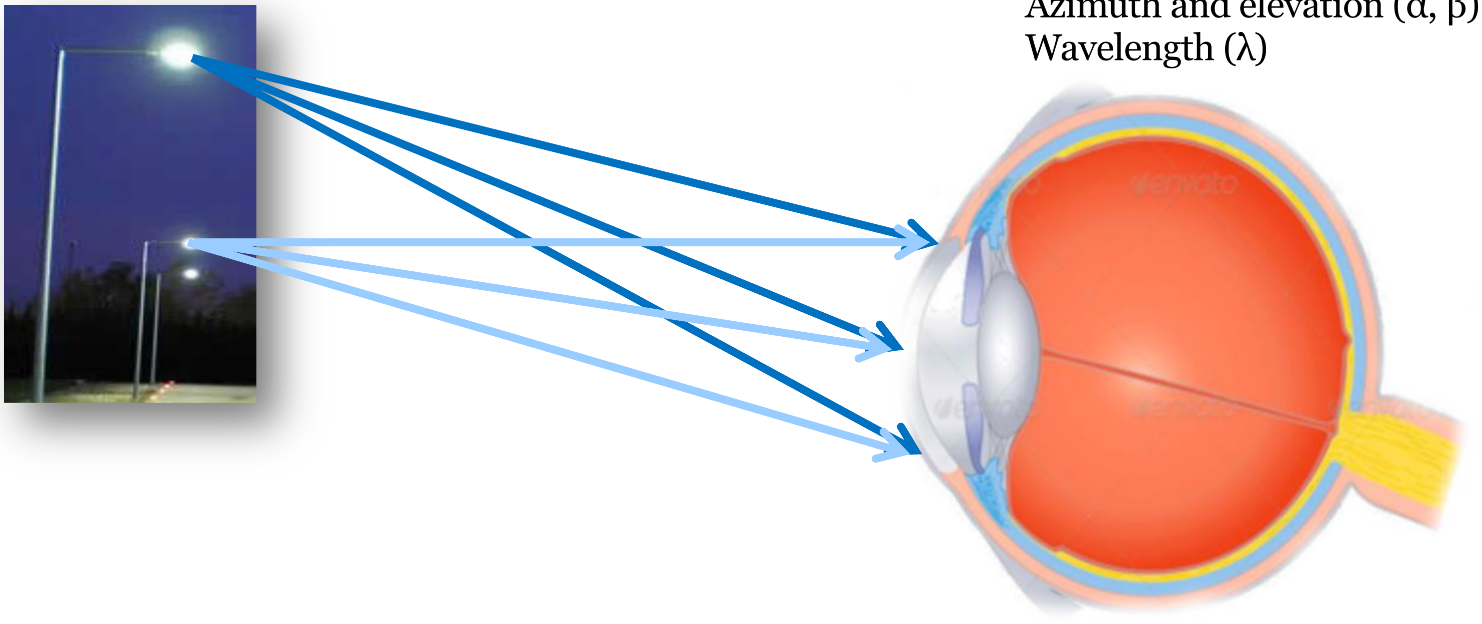
(Adelson and Bergen, 1991)

Ray intensities: L(u,v,α,β,λ)

Position (u,v)

Azimuth and elevation (α, β)

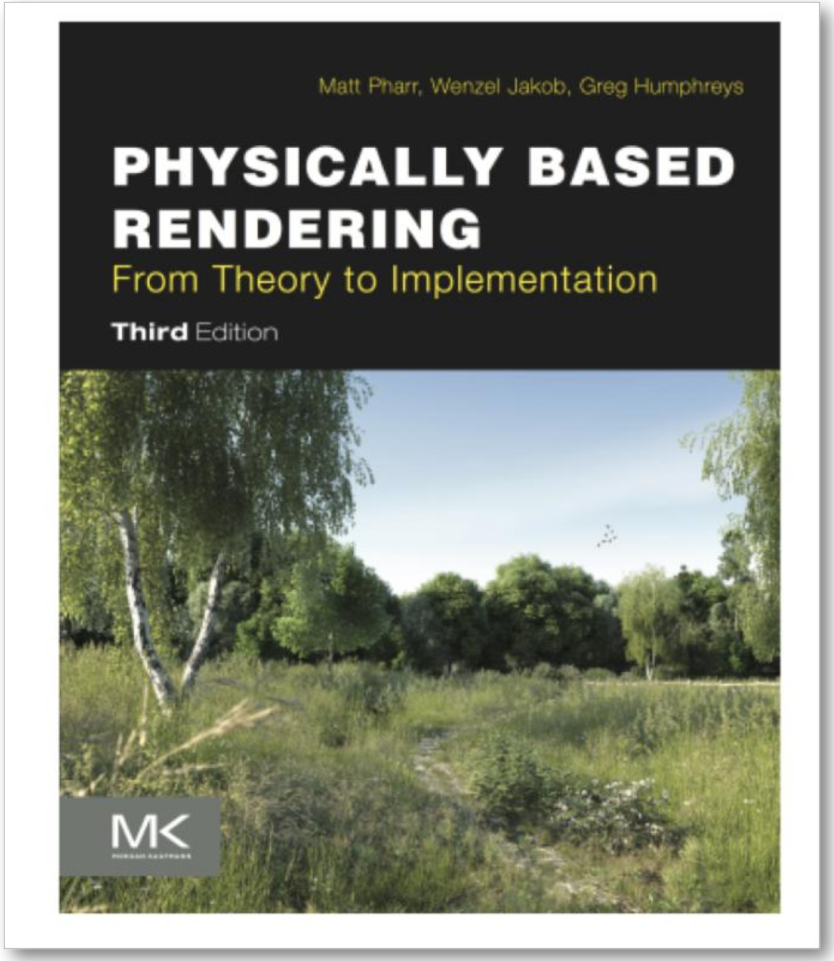
Wavelength (λ)

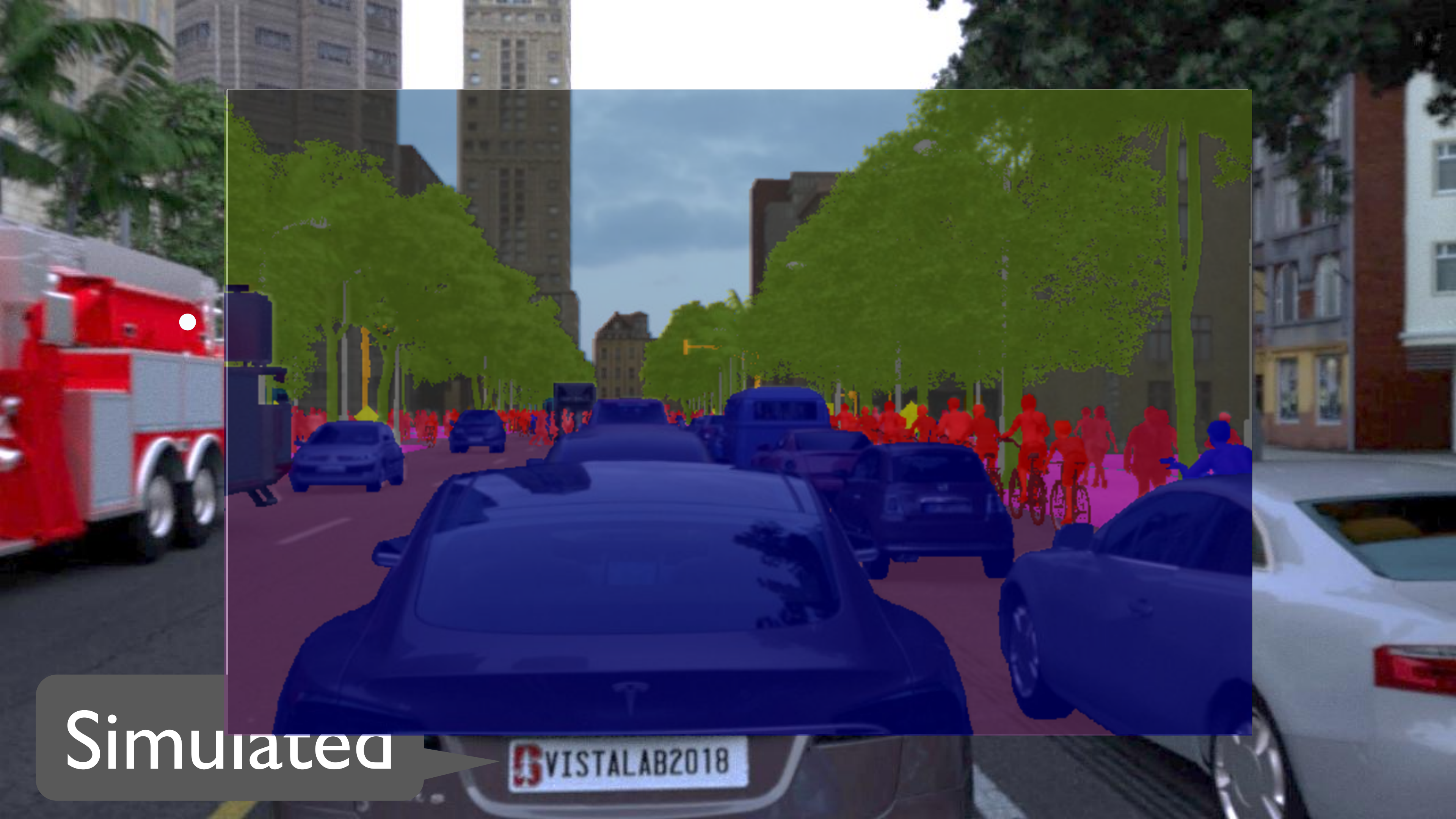


Scene creation: Quantitative computer graphics is a necessary component

- Progress in computer graphics enables us to create synthetic and yet highly realistic input data.

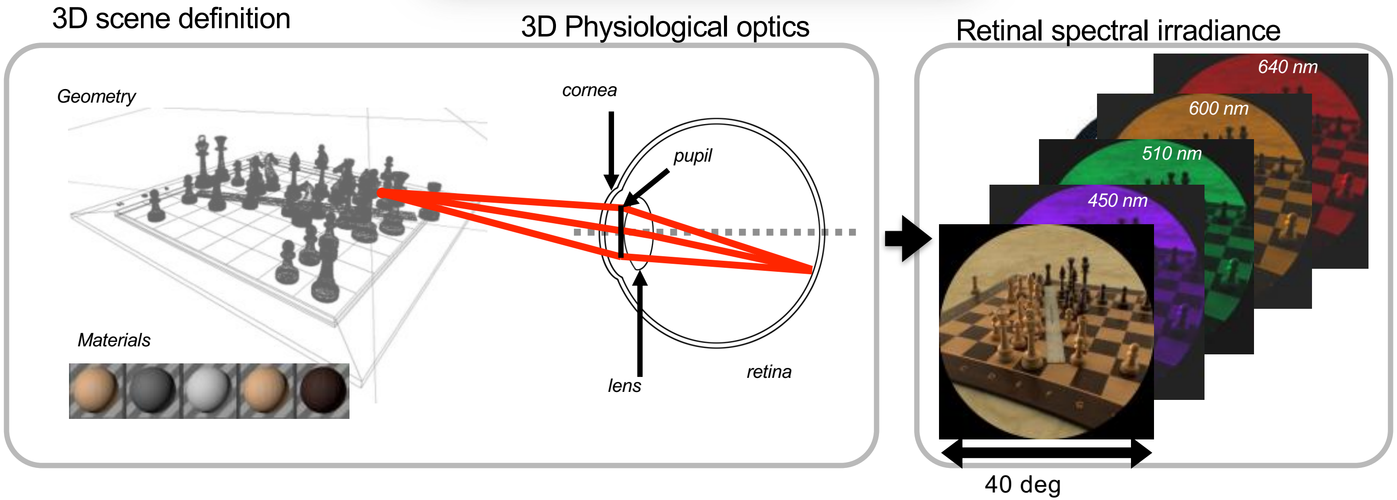
- We want simulations with meaningful units; quantitative computer graphics




Simulated
VISTALAB2018

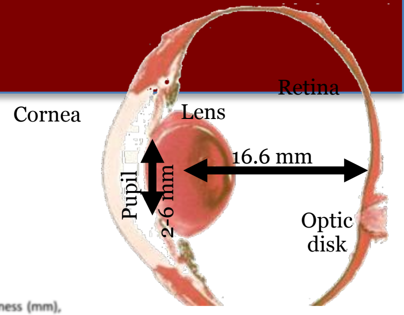
ISET3D extension to incorporate human optics

OPEN ACCESS
Article | October 2019
Ray tracing 3D spectral scenes through human optics models
Trisha Lian; Kevin J. MacKenzie; David H. Brainard; Nicolas P. Cottaris; Brian A. Wandell
+ Author Affiliations
Journal of Vision October 2019, Vol.19, 23. doi:https://doi.org/10.1167/19.12.23



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

3D Eye Models



- Aspheric surfaces and curved retina
- Wavelength-dependent index of refraction for ocular media
- Generic
- "Navarro Eye" [Escudero-Sanz & Navarro 1999]
  - Accommodation-dependent
- Compatible with other models

Table A1

Navarro eye model (Escudero-Sanz & Navarro, 1999).

Surface	Radius (mm)	Ocular media (to next surface)	Index of refraction (at 550 nm)	Conic constant	Thickness (mm), (to next surface)
Cornea anterior	7.72	Cornea	1.377	−0.26	0.55
Cornea posterior	6.50	Aqueous	1.339	0	3.05
Lens anterior	10.20	Lens	1.422	−3.1316	4.00
Lens posterior	−6.00	Vitreous	1.337	−1.0	16.3203
Retina	−12				

Table A2

Arizona eye model (Schwiegerling, 2004).

Surface	Radius (mm)	Ocular media (to next surface)	Index of refraction (at 550 nm)	Conic constant	Thickness (mm), (to next surface)
Cornea anterior	7.8	Cornea	1.377	−0.25	0.55
Cornea posterior	6.50	Aqueous	1.337	−0.25	2.97
Lens anterior	12.0	Lens	1.420	−7.518749	3.767
Lens posterior	−5.224557	Vitreous	1.336	−1.353971	16.713
Retina	−13.4				

Table A3

Le Grand full theoretical eye (Artal, 2017; Atchison & Smith, 2005).

Surface	Radius (mm)	Ocular media (to next surface)	Index of refraction (at 550 nm)	Conic constant	Thickness (mm), (to next surface)
Cornea anterior	7.8	Cornea	1.379	0	0.55
Cornea posterior	6.50	Aqueous	1.339	0	3.05
Lens anterior	10.20	Lens	1.422	0	4.00
Lens posterior	−6.00	Vitreous	1.337	0	16.5966
Retina	−13.4				

Eye models differ – and sometimes significantly

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

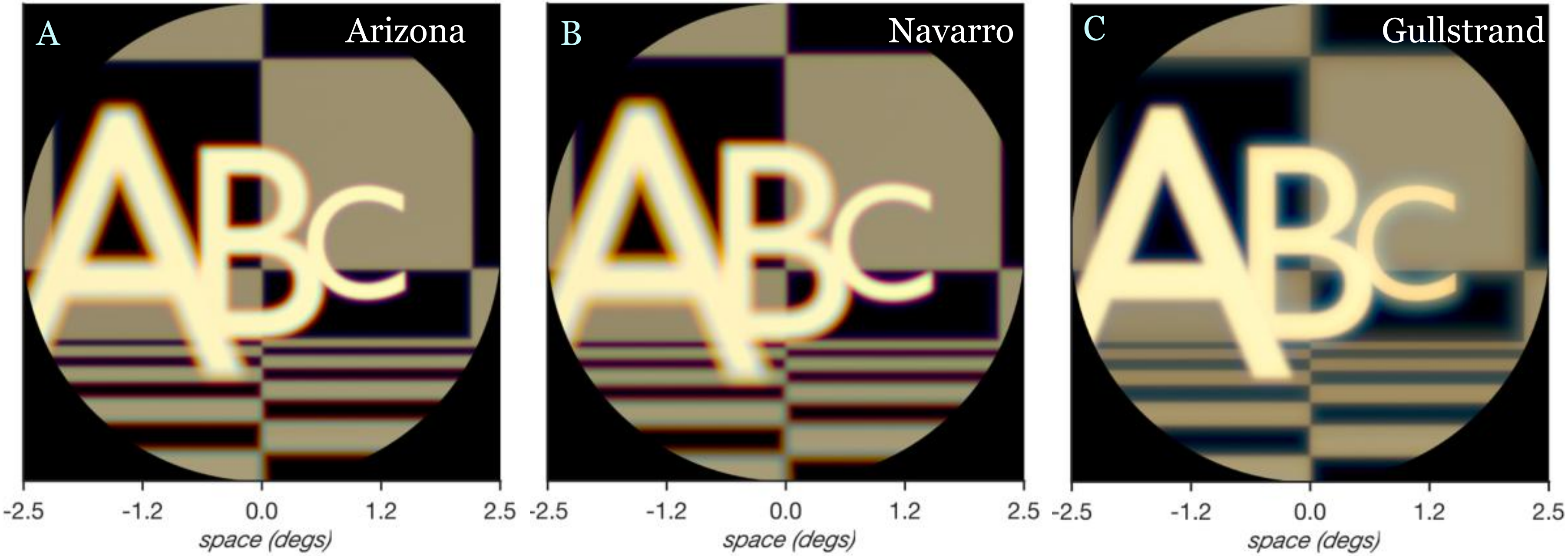
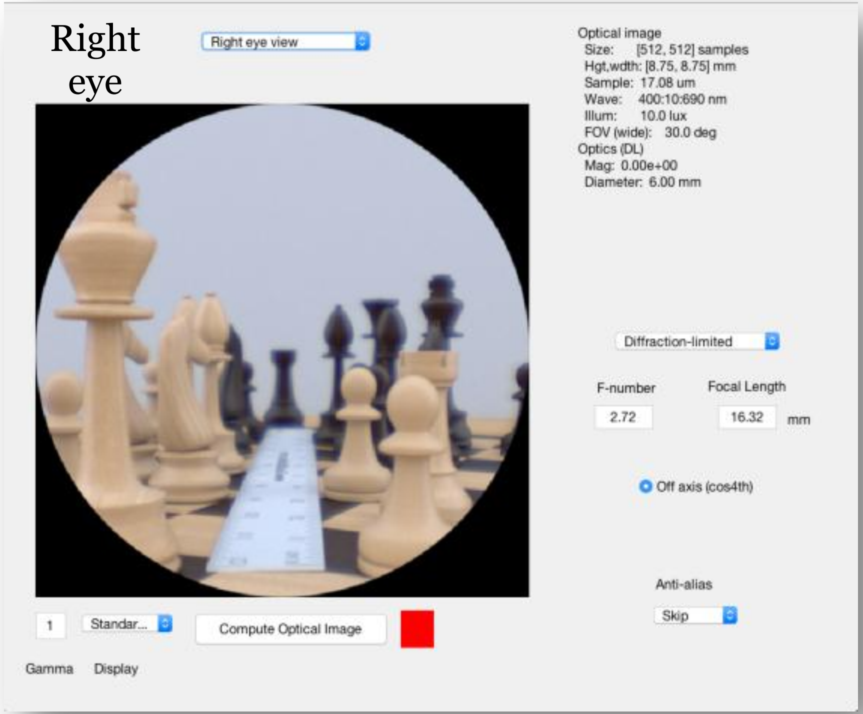
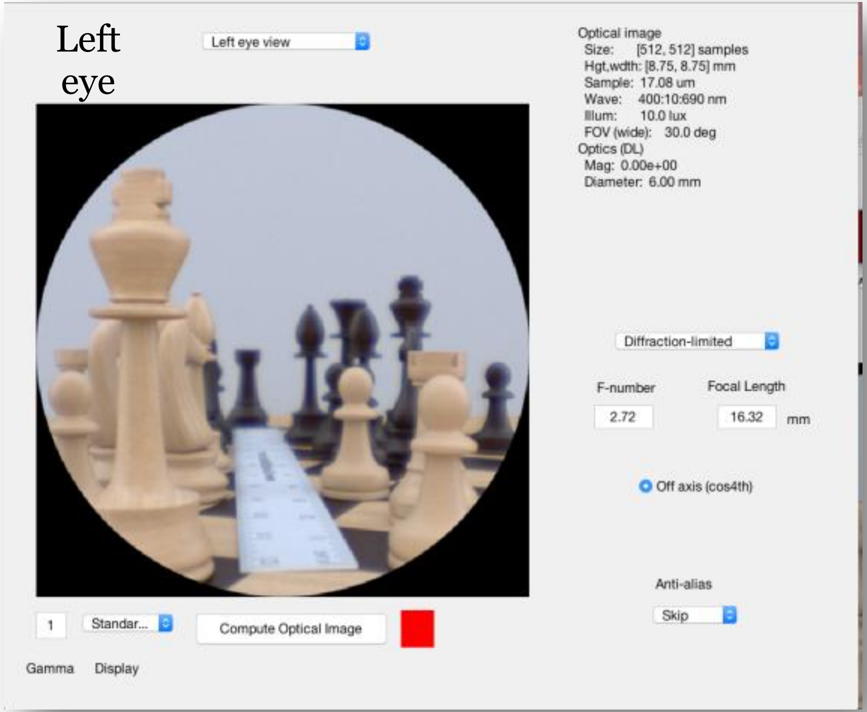


Image formation (optics) models and quantitative graphics

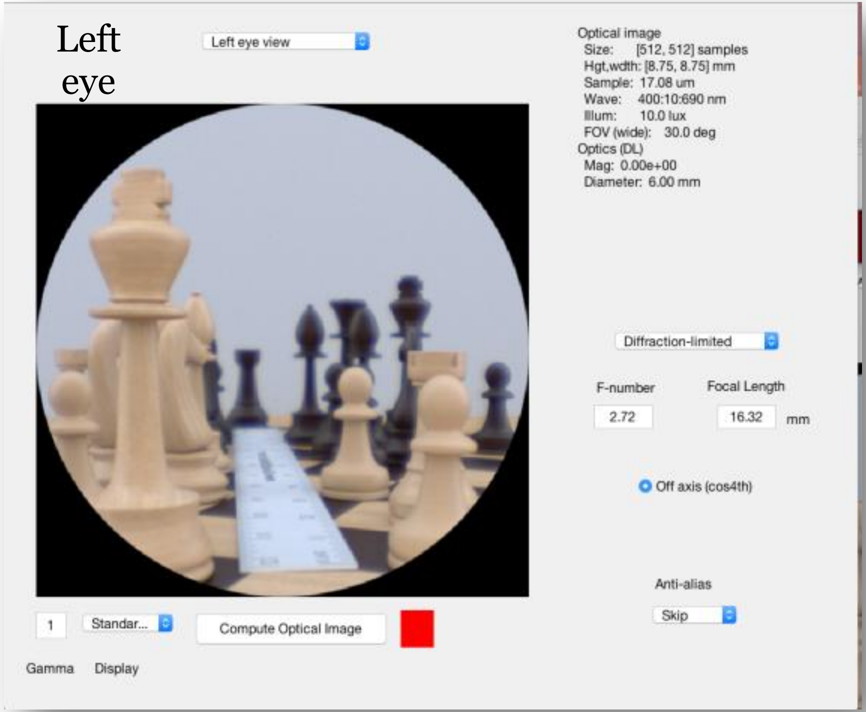
Stereo pairs are straightforward to compute

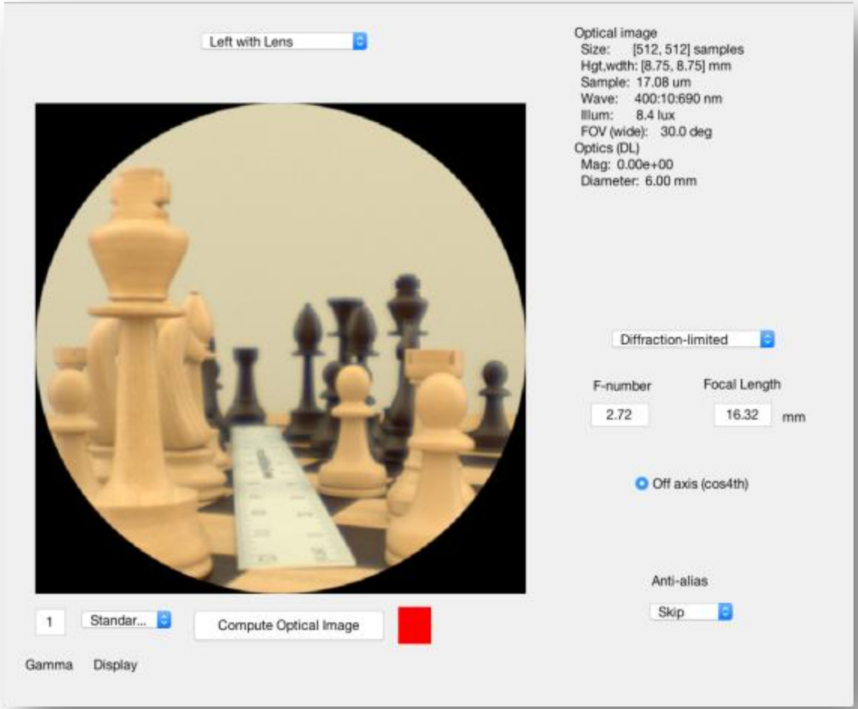




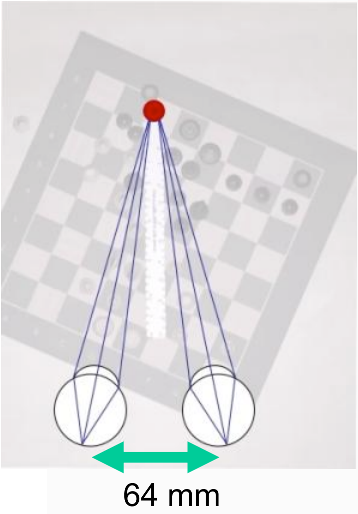
Natural images - Image formation (optics) models and quantitative graphics

Inert pigments (e.g. lens transmission)





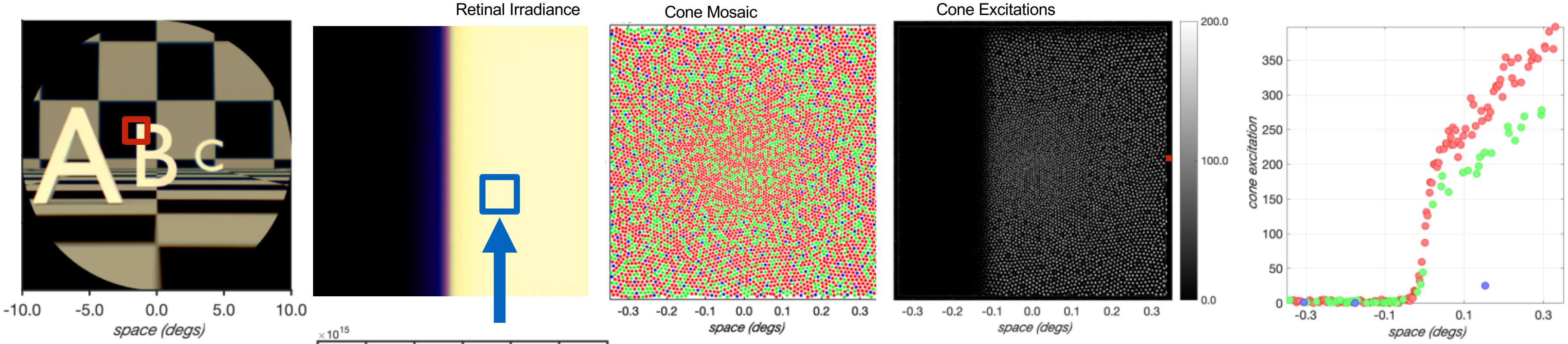
Vergence and Accommodation



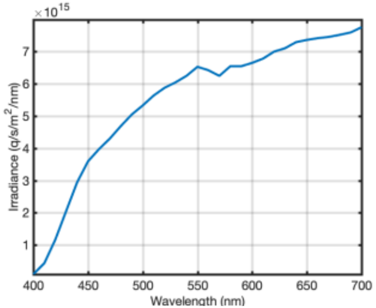
1.66 D (Left)

1.66 dpt (Right)

Calculating Cone Response



Eye movements



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.

AO Breakout illustration of the code

Let's look at and run some code

```
%% AO Breakout
%
% ISET3D Render using a fisheye lens
%
% We read in the PBRT file and render it through a pinhole.  Then we render
% the same data through a fisheye lens.
%
% Dependencies:
%    ISET3d, ISETCam, JSONio
%
%  Check that you have the updated docker image by running
%    docker pull vistalab/pbrt-v3-spectral
%    docker pull vistalab/pbrt-v3-spectral:test
%
%  You must have the chessSet PBRT scene in iset3d/data/V3
%
% ZL, BW SCIEN 2018
%
% See also
%   t_piIntro_*
%   isetlens repository

%% Initialize ISET and Docker

ieInit;
if ~piDockerExists, piDockerConfig; end

%% Read the PBRT input scene

% We input the scene and store its parameters in a recipe
thisR = piRecipeDefault('scene name','chessSet');
```

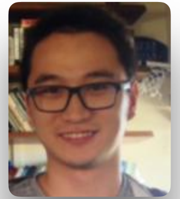
d Window

```
ading image h=180 x w=320 x 31 spectral planes.
ad 1785600 pixel elements for image.
```

ISETBio Team and Funding


Brian Wandell


Trisha Lian


Haomio Jiang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Lingqi Zhang


E.J. Chichilnisky


Fred Rieke


Joyce Farrell

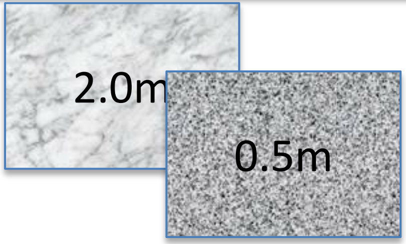

Jon Winawer

facebook research

SIMONS FOUNDATION

NIH National Eye Institute

Why ray trace? Adding convolutions across depth planes is incorrect



Two planes with identical checkerboard patterns at 0.5 m and 2 m from the eye

- Convolve and sum the two planes separately (panel A)
- For the true calculation, the occlusion blocks light from the far plane (panel B)
- The difference is significant at the edge (panel C)