

Simulation technologies for image systems engineering

Brian A. Wandell

Stanford Center for Image Systems Engineering (SCIEN)

Wu Tsai Neurosciences Institute (WTNI)

Stanford Center for Cognitive and Neurobiological Imaging (CNI)

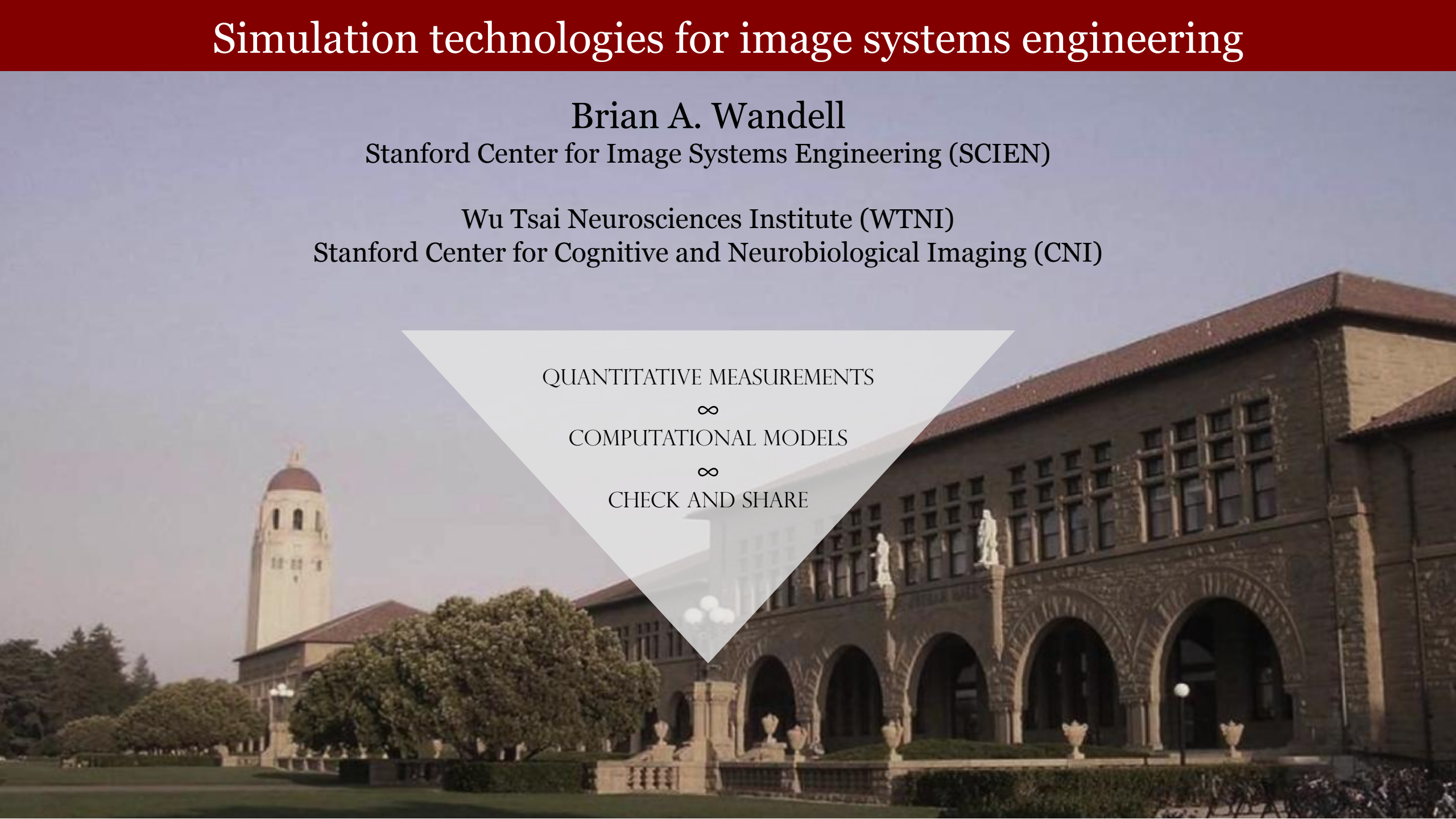
QUANTITATIVE MEASUREMENTS

∞

COMPUTATIONAL MODELS

∞

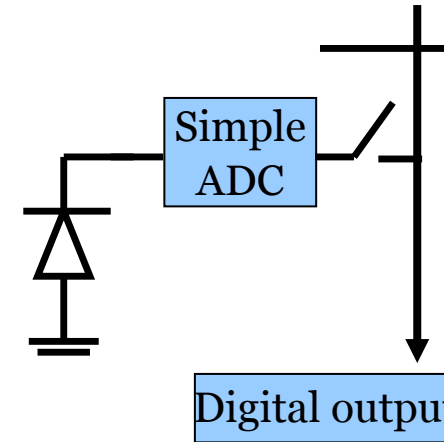
CHECK AND SHARE



The Programmable Digital Camera project

- In the mid 1990s, I was fortunate to strike up a good relationship with Abbas El Gamal, who was just returning to Stanford from industry.
- At that time industry was beginning the shift to CMOS imagers from CCD, and Abbas was trying out new ideas
- We coordinated our groups closely over a period of about six or eight years, to try to understand the pros and cons of various circuit designs for CMOS imagers

Digital pixel sensor (DPS)



Imaging systems simulation (ISETCam)

The Image Systems Engineering Toolbox for cameras (**ISETCam**) provides an extensive software environment that engineers and scientists use to simulate and predict the imaging systems performance.



Optics



Sensor



Display

Imaging Systems Engineering Toolbox (ISET)

More than 500 users in
80 companies,
9 research institutes,
65 universities,
in 24 countries

Open Source

<https://github.com/iset/isetcam>



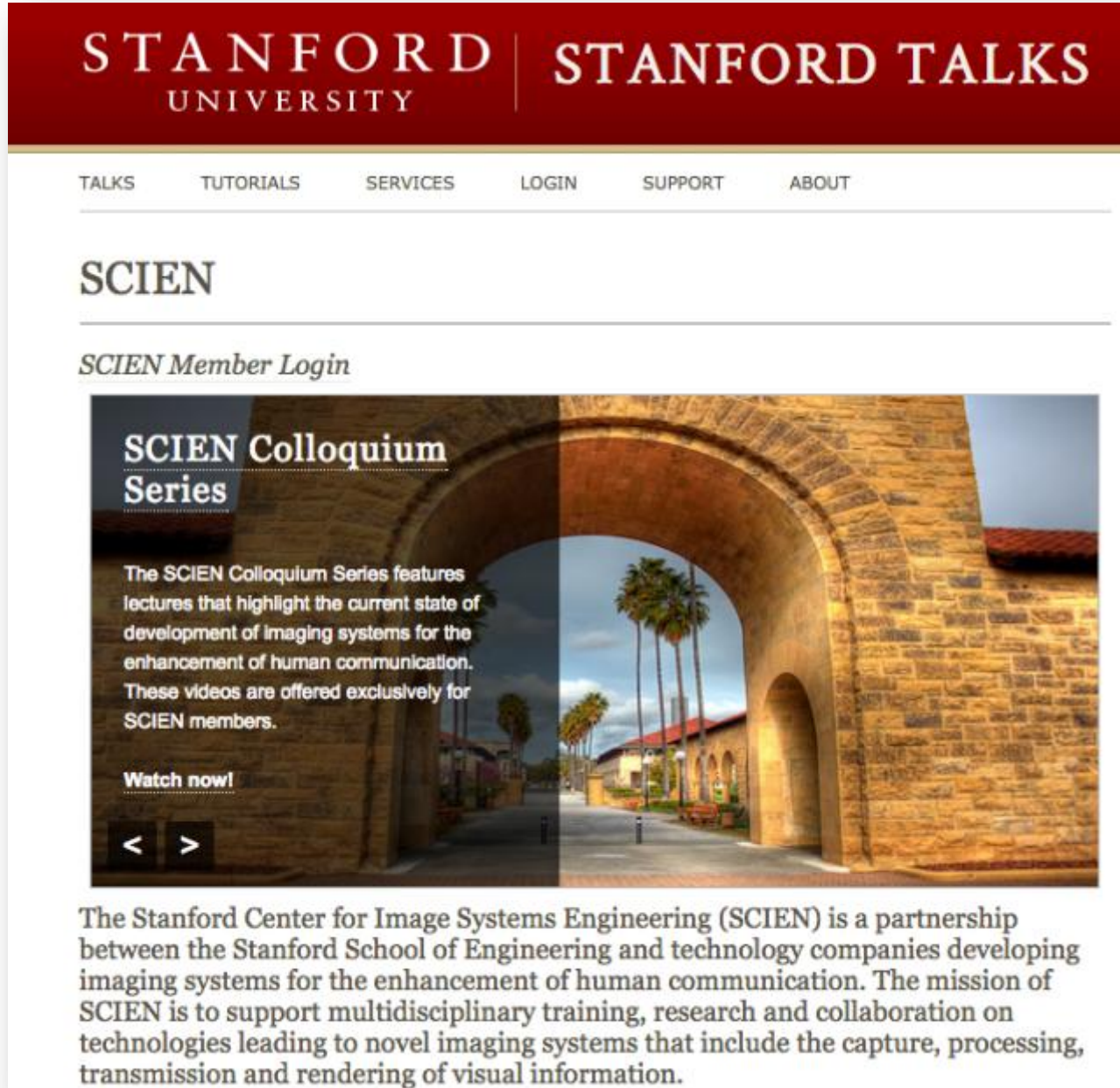
SCIEN

The Stanford Center for
Image Systems Engineering

The Stanford Center for Image Systems Engineering (SCIEN) is a **partnership** between the Stanford School of Engineering and technology companies developing imaging systems for the enhancement of human communication



Stanford's Center for Image Systems Engineering (SCIEN)



STANFORD UNIVERSITY | STANFORD TALKS

TALKS TUTORIALS SERVICES LOGIN SUPPORT ABOUT

SCIEN

SCIEN Member Login

SCIEN Colloquium Series

The SCIEN Colloquium Series features lectures that highlight the current state of development of imaging systems for the enhancement of human communication. These videos are offered exclusively for SCIEN members.

Watch now!

< >

The Stanford Center for Image Systems Engineering (SCIEN) is a partnership between the Stanford School of Engineering and technology companies developing imaging systems for the enhancement of human communication. The mission of SCIEN is to support multidisciplinary training, research and collaboration on technologies leading to novel imaging systems that include the capture, processing, transmission and rendering of visual information.

- Weekly seminar series of academics and new technology companies
- More than 300 talks are recorded and available to everyone at Stanford and our industrial affiliates
- Annual workshops on developing imaging technologies

Dr. Joyce Farrell



Prof. Bernd Girod Prof. Gordon Wetzstein

Stanford Center for Image Systems Engineering

Camera Phone Image Quality

December 7, 2006

High Dynamic Range Imaging

September 10, 2009 to September 11, 2009

Mobile Visual Search

December 3, 2009

3D Imaging

January 27, 2011 to January 28, 2011

The Stanford Symposium on Biomedical Imaging

April 5, 2012 to April 6, 2012

Entertainment Technology in the Internet Age (2013)

June 18, 2013 to June 19, 2013

The Workshop on Light Field Imaging: February 12, 2015

February 12, 2015

ETIA 2015 Entertainment in the the Internet Age

June 16, 2015 9:00 am to June 17, 2015 5:15 pm

Workshop on Cinematic VR and Immersive Storytelling

May 19, 2016

Workshop on Medical VR and AR

April 5, 2018

Workshop on the Future of Medical Imaging: Sensing, Learning and Visualization

April 4, 2019 8:30 am to 6:00 pm



Dr. Joyce Farrell



Panel Discussions

Interactive demos
Research projects, clinical
applications and startup



Prof. Bernd Girod Prof. Gordon Wetzstein

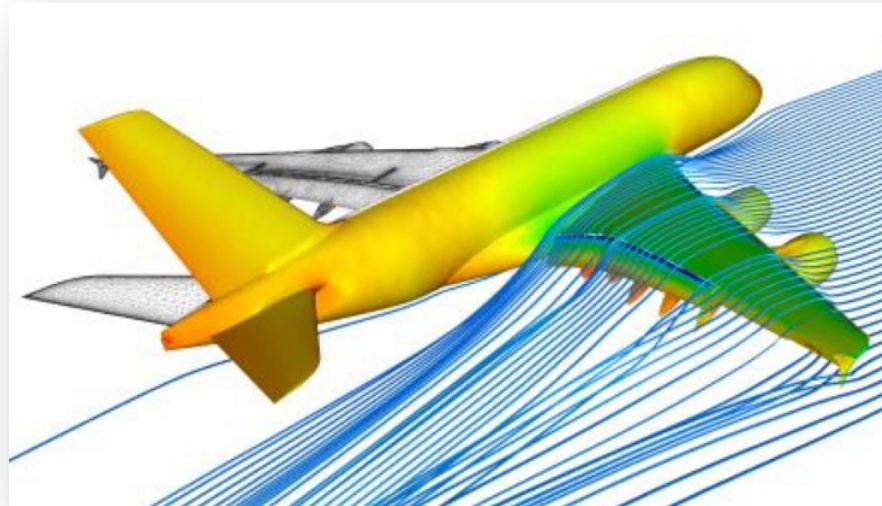


The main idea now: Image systems simulation

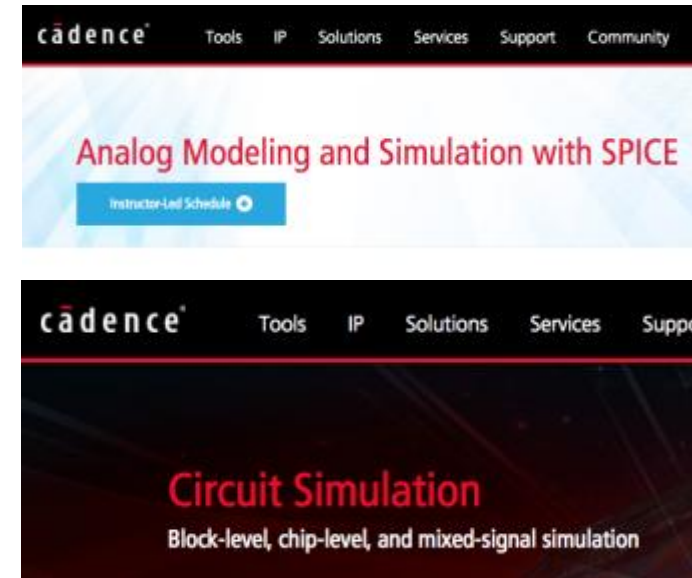
System simulation is important in many mature industries



ECU (Electronic Control Unit) Simulation for Automobiles



Numerical flow simulation on an Airbus A380



Integrated circuitry

First and main point

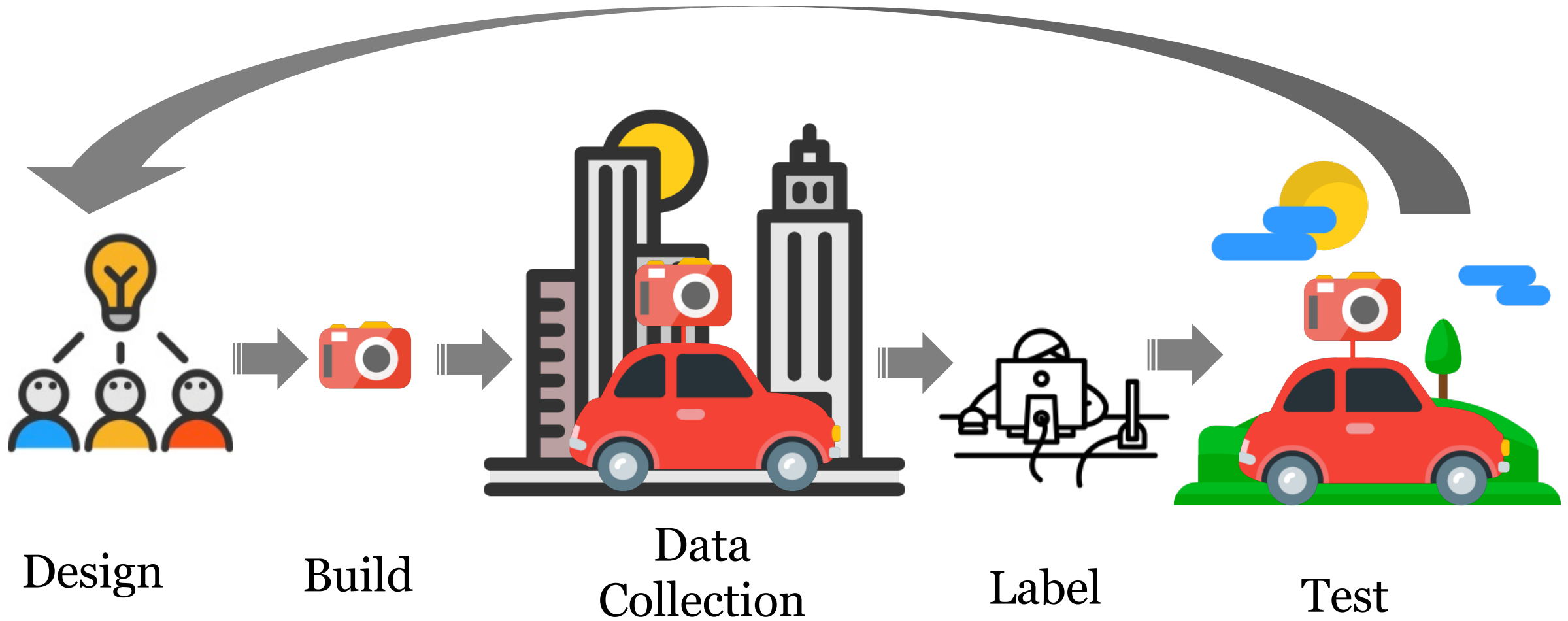
Image systems simulation software that is trusted by key stakeholders in industry and academia can be useful – perhaps necessary - to speed the development of next generation image sensors, camera arrays and displays.

Illustrating the case for image systems simulation

- Image systems simulation I: Camera design and machine-learning applications
- Image systems simulation II: Display design and perceptual image quality



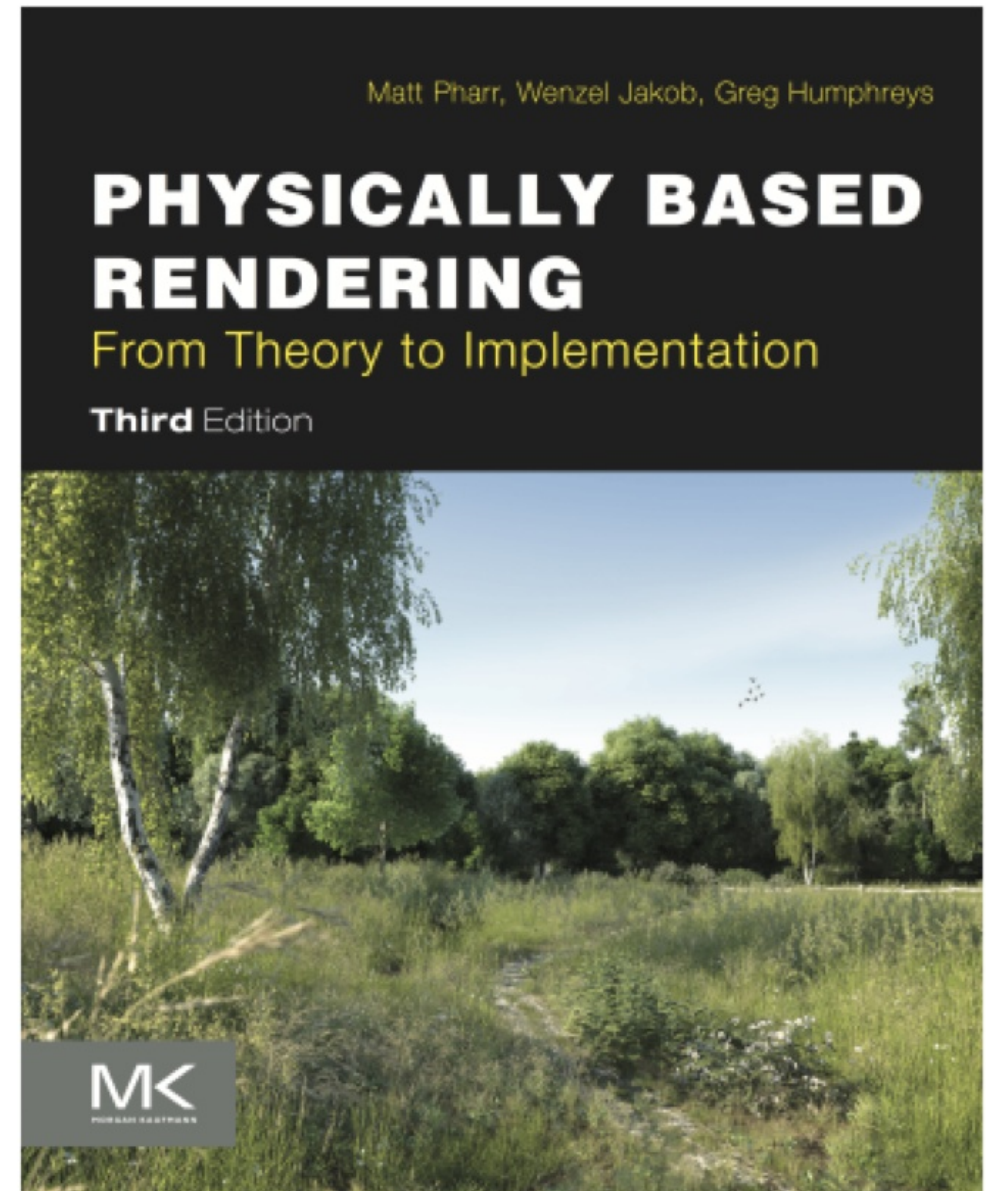
Camera design for automotive machine-learning





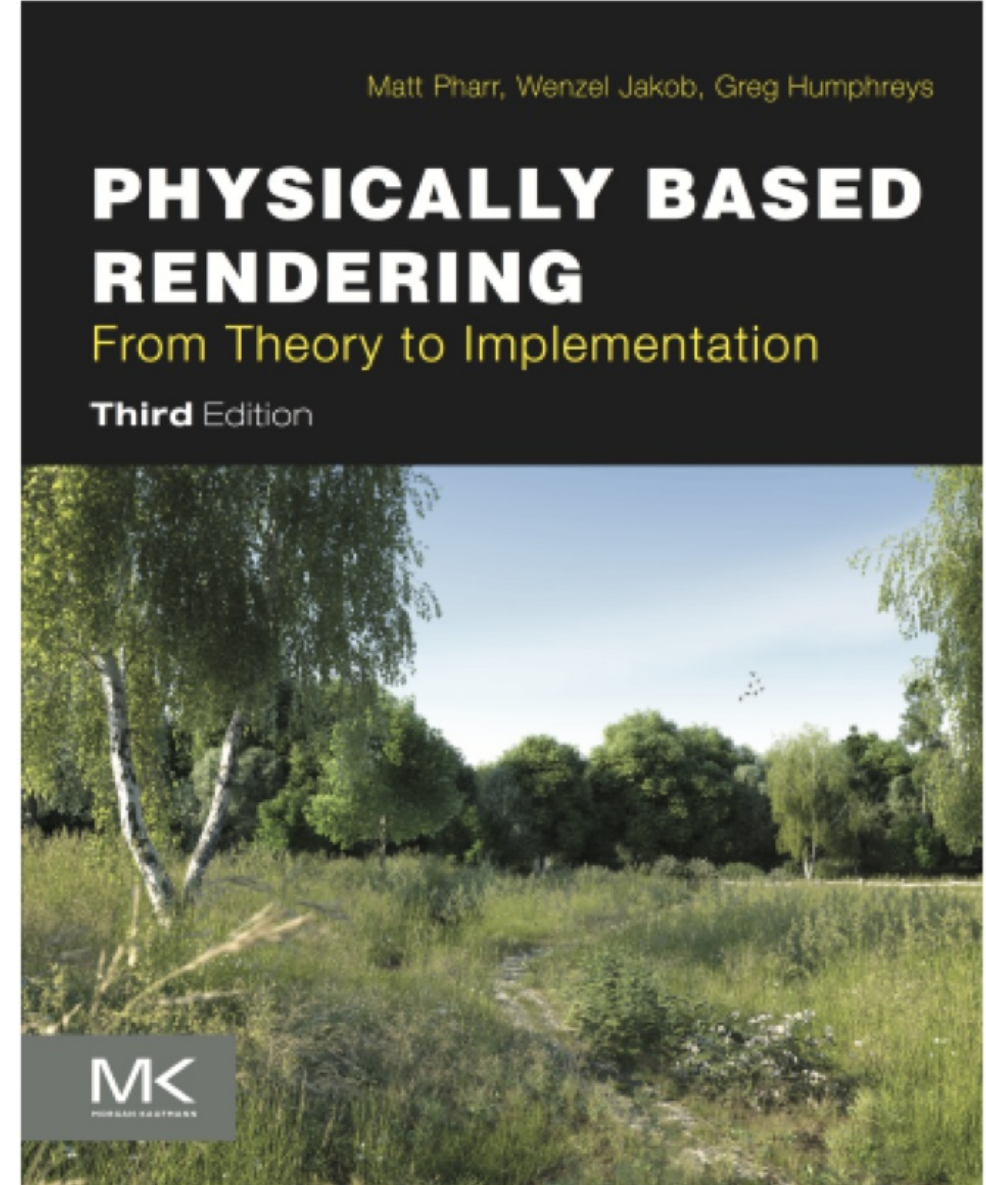
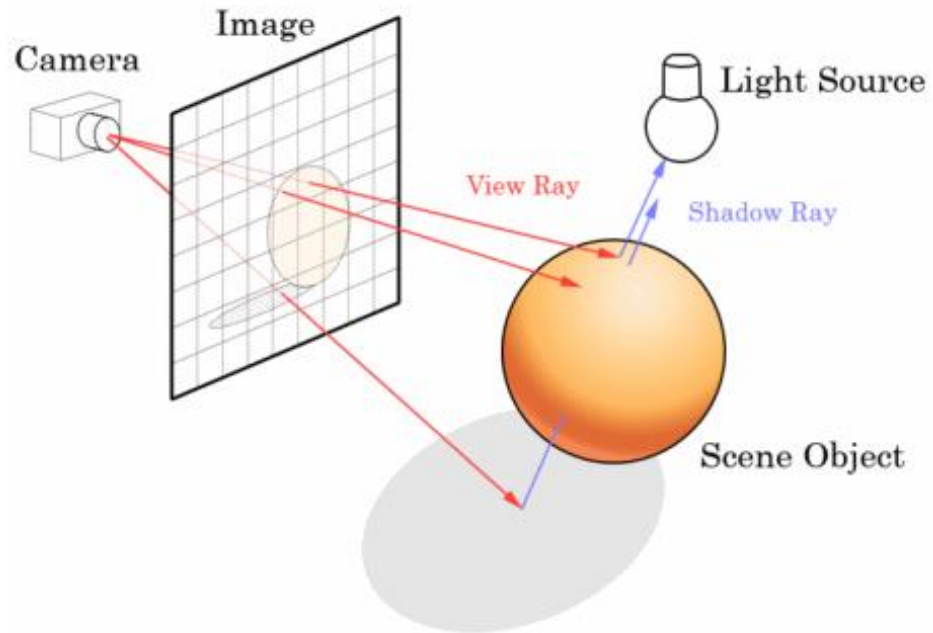
Scene creation: Quantitative computer graphics is a necessary component

- Progress in computer graphics enables us to create synthetic and yet highly realistic input data.
- We want simulations with meaningful units; quantitative computer graphics



Tools for modeling shapes, lights, materials, geometry

PBRT using ray tracing from the sensor through a camera model into the scene, incorporating physical models of optics, surfaces and lights



Rasterization is excellent for many purposes, but not physically accurate

- No physical quantities (e.g., spectral radiance, irradiance)
- Pinhole, not real optics
- Bag of tricks for visual appeal

High quality
rasterization –
hand-edited
(800 x 421)
(Unity)



- Attempts to be physically accurate
- Incorporate lens and microlens models
- Produces complex visual effects

Ray traced –
(712 x 395)
(PBRT)



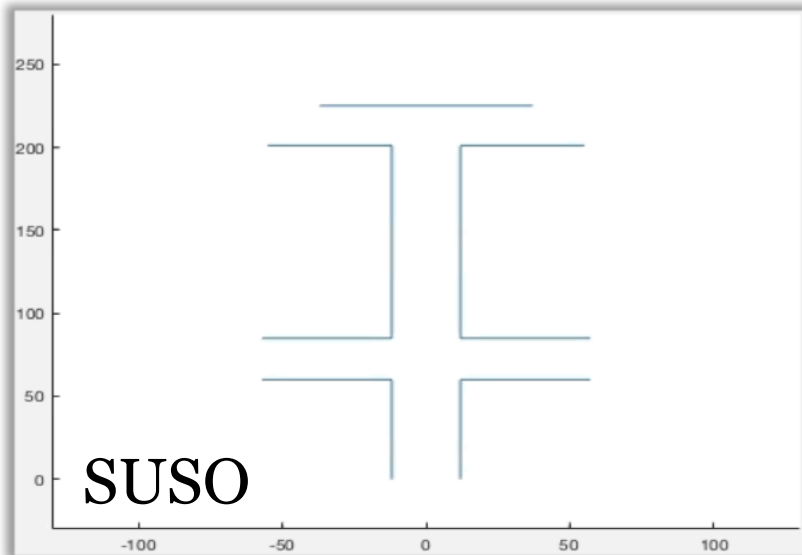
Asset curation

**Set Pivot Point to
Move object freely**

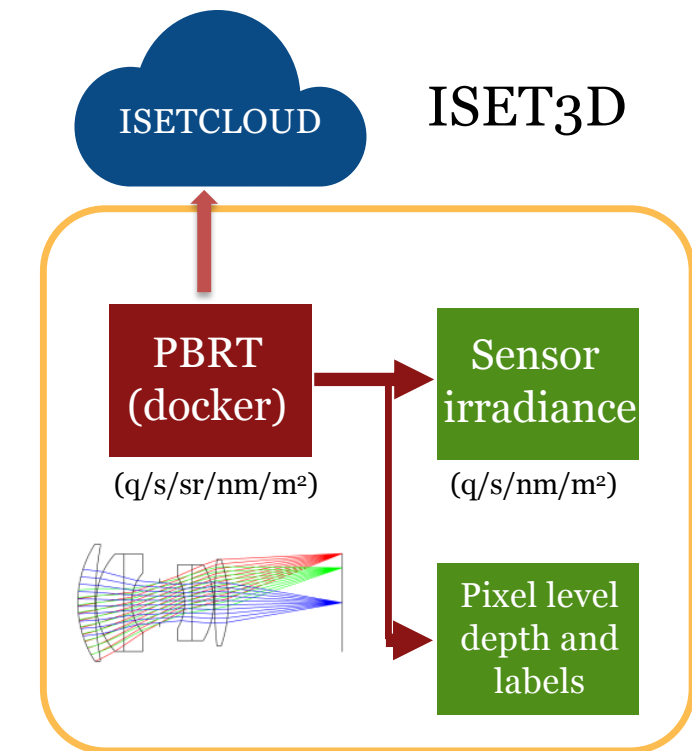


Scene generation is essential

- Traffic flow (Position, orientation, speed of cars, trucks, pedestrians) is **randomly** generated with SUMO by given **parameters**.
- Appearance of the vehicles are **randomly** according to car color popularity.
- Buildings and other static objects are **randomly** sampled from the database (Flywheel) and designed to place along side of the road reasonably(SUSO) by given **parameters**.
- Camera and lighting parameters are established by given **parameters**



SUMO is an open source, highly portable, microscopic and continuous road traffic simulation



Asset management and curation for scene generation is essential

Flywheel cloud database with SDK

Assets:

Recipe.json:

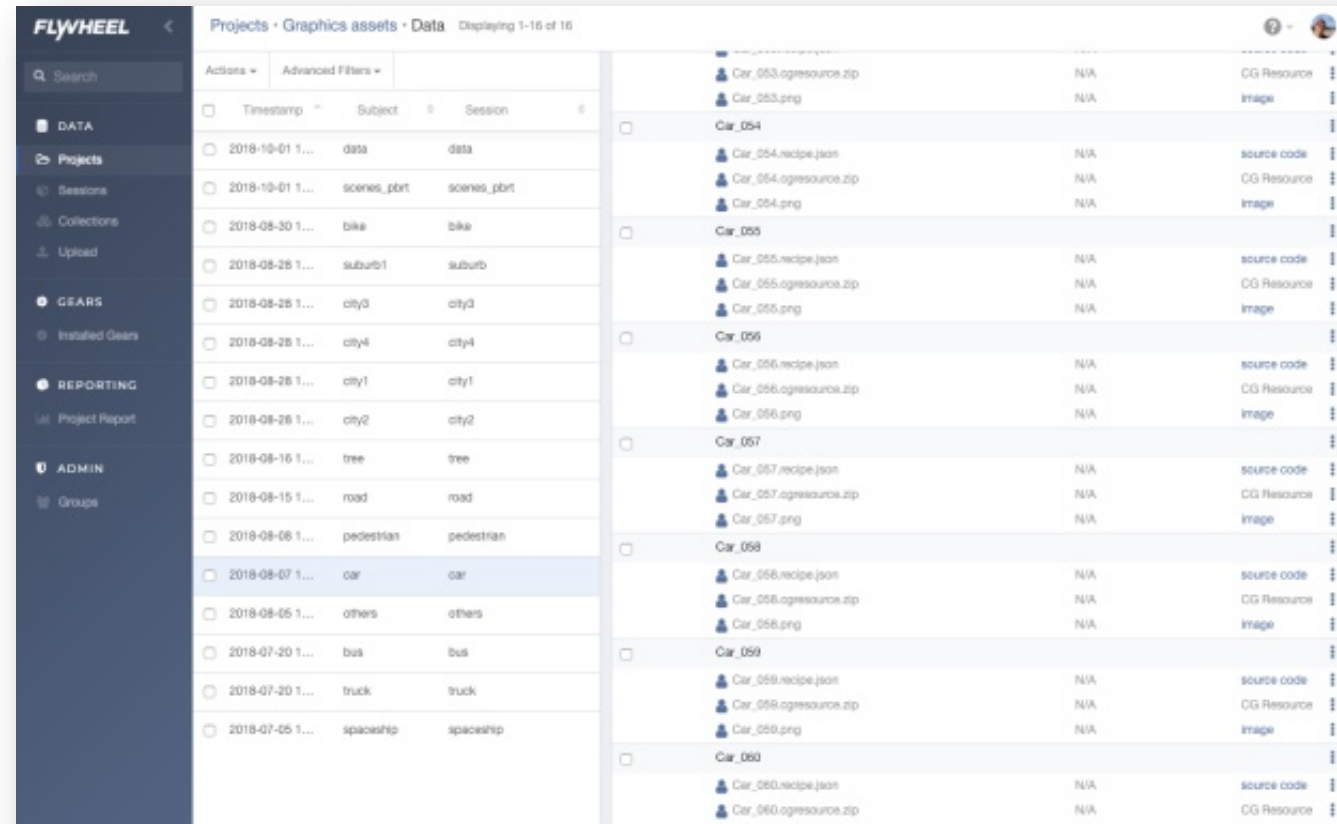
Contains material, geometry, texture pointer information.

CgResource:

Brdfs of material, texture files, geometry(point, triangle vertices, faces).

Png File:

For preview.



The screenshot displays the Flywheel cloud database interface. The left sidebar contains navigation options: DATA, Projects, Sessions, Collections, Upload, GEARS (Installed Gears), REPORTING (Project Report), ADMIN (Groups), and Search. The main content area shows a table of assets with columns for Actions, Timestamp, Subject, and Session. The table is filtered to show 1-16 of 16 items. The selected row is '2018-08-07 1... car car'. The right panel shows the details for 'Car_054', including a list of assets: Car_054.recipe.json (source code), Car_054.cgresource.zip (CG Resource), and Car_054.png (Image).

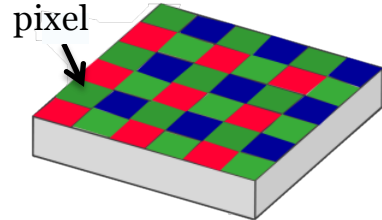
Actions	Timestamp	Subject	Session
<input type="checkbox"/>	2018-10-01 1...	data	data
<input type="checkbox"/>	2018-10-01 1...	scenes_pbrt	scenes_pbrt
<input type="checkbox"/>	2018-08-30 1...	bike	bike
<input type="checkbox"/>	2018-08-28 1...	suburb1	suburb
<input type="checkbox"/>	2018-08-28 1...	city3	city3
<input type="checkbox"/>	2018-08-28 1...	city4	city4
<input type="checkbox"/>	2018-08-28 1...	city1	city1
<input type="checkbox"/>	2018-08-28 1...	city2	city2
<input type="checkbox"/>	2018-08-16 1...	tree	tree
<input type="checkbox"/>	2018-08-15 1...	road	road
<input type="checkbox"/>	2018-08-08 1...	pedestrian	pedestrian
<input checked="" type="checkbox"/>	2018-08-07 1...	car	car
<input type="checkbox"/>	2018-08-05 1...	others	others
<input type="checkbox"/>	2018-07-20 1...	bus	bus
<input type="checkbox"/>	2018-07-20 1...	truck	truck
<input type="checkbox"/>	2018-07-05 1...	spaceship	spaceship

Asset Name	Source Code	CG Resource	Image
Car_054			
Car_054.recipe.json	N/A		source code
Car_054.cgresource.zip	N/A	N/A	CG Resource
Car_054.png	N/A		Image
Car_055			
Car_055.recipe.json	N/A		source code
Car_055.cgresource.zip	N/A	N/A	CG Resource
Car_055.png	N/A		Image
Car_056			
Car_056.recipe.json	N/A		source code
Car_056.cgresource.zip	N/A	N/A	CG Resource
Car_056.png	N/A		Image
Car_057			
Car_057.recipe.json	N/A		source code
Car_057.cgresource.zip	N/A	N/A	CG Resource
Car_057.png	N/A		Image
Car_058			
Car_058.recipe.json	N/A		source code
Car_058.cgresource.zip	N/A	N/A	CG Resource
Car_058.png	N/A		Image
Car_059			
Car_059.recipe.json	N/A		source code
Car_059.cgresource.zip	N/A	N/A	CG Resource
Car_059.png	N/A		Image
Car_060			
Car_060.recipe.json	N/A		source code
Car_060.cgresource.zip	N/A	N/A	CG Resource

Imaging sensors will be re-designed for machine perception

Sensors for evaluation

Sensor A

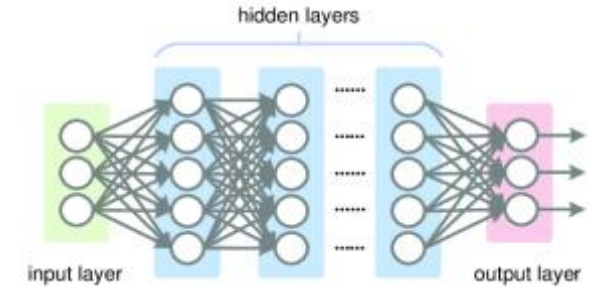


Sensor B

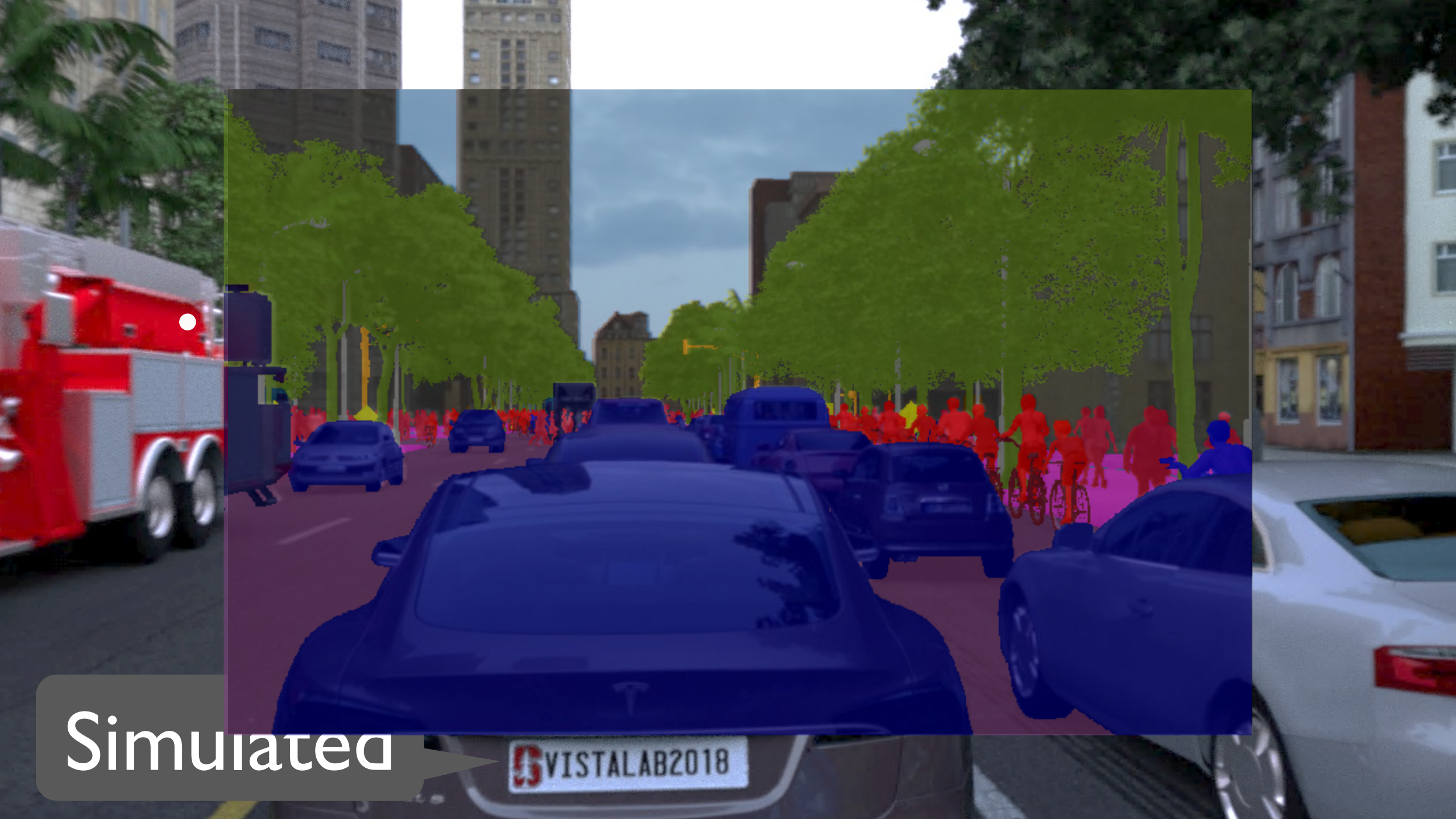
Parameter	Value
Optical Format	1/3 inch
Active Imager Size	4.51 mm(H) x 2.88 mm(V)
Active Pixels	752H x 480 V
Pixel Size	6 um x 6 um
Color Filter Array	RGGB Pattern
Full Resolution	752 x 480
Frame Rate	60fps
Dark Noise	1.0mV/pixel/second
Read Noise	1.0 mV

Parameter	Value
Optical Format	1/3 inch
Active Imager Size	4.51 mm(H) x 2.88 mm(V)
Active Pixels	1504H x 960 V
Pixel Size	3 um x 3 um
Color Filter Array	RGGB Pattern
Full Resolution	1504 x 960
Frame Rate	60fps
Dark Noise	1.0mV/pixel/second
Read Noise	1.0 mV

CNN models



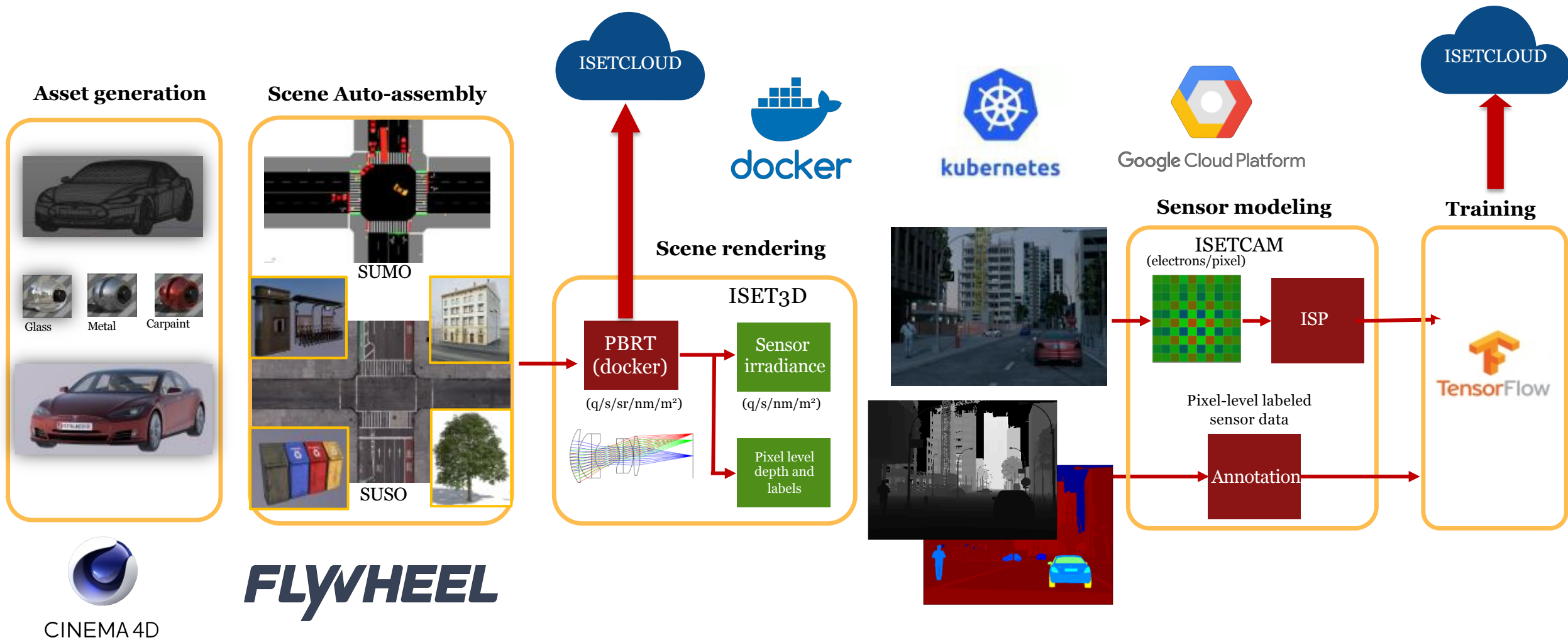
Parameter	Value
Feature Extrator	faster_rcnn_resnet101
Num of Layers	101
First stage features stride	16
First stage nms iou threshold	0.7
First stage max proposals	300
Optimizer	momentum_optimizer
Regularizer	l2_regularizer
Score converter	SOFTMAX



Simulated

VISTALAB2018

ISETAuto: Simulation System Overview



Second point

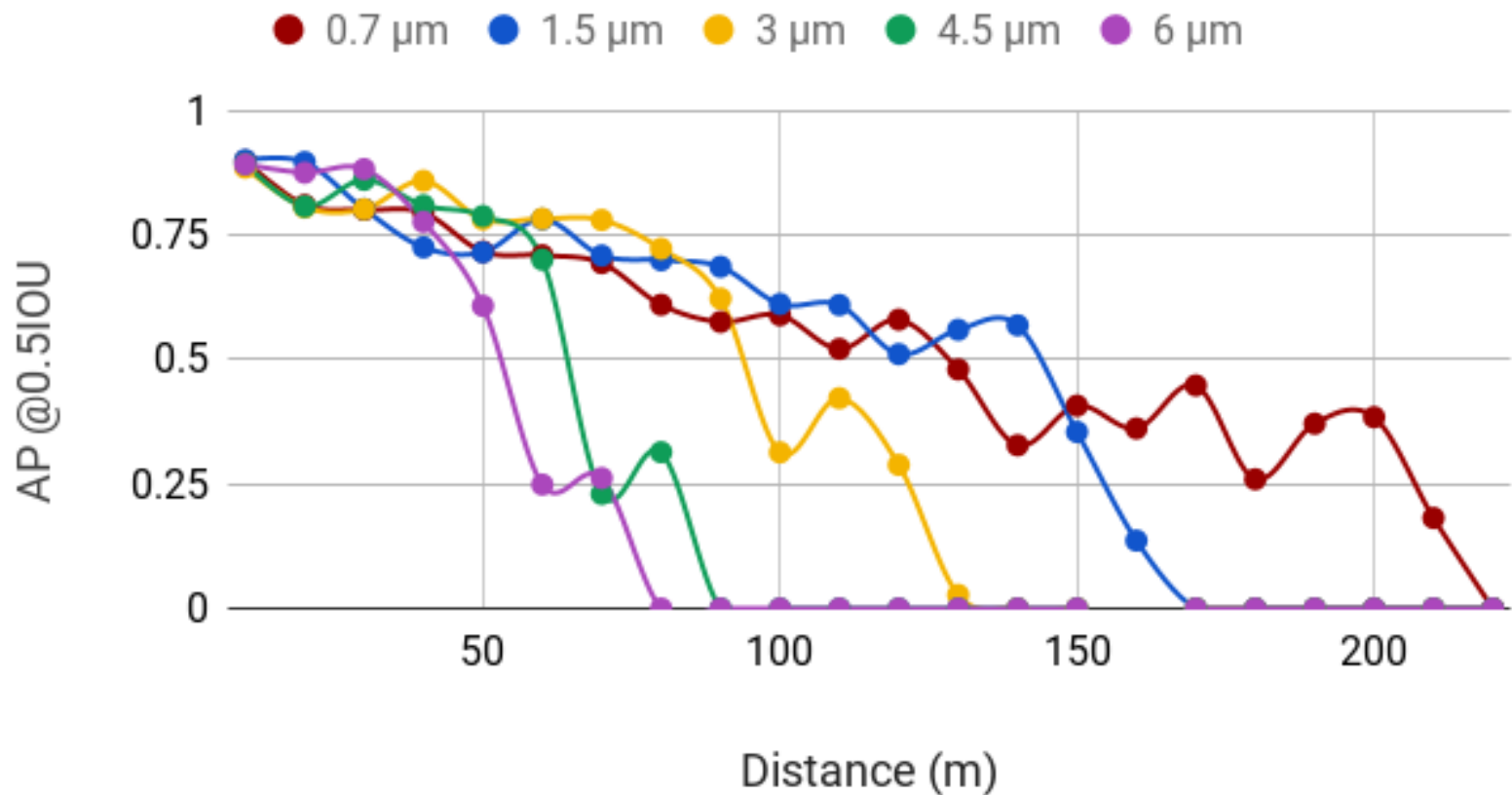
Image systems simulation software involves skills that are beyond the capabilities of most academic labs and many commercial ventures (particularly startups).

To speed progress, we might build and share consensus (validated) tools

Meaningful performance metrics computed from simulation

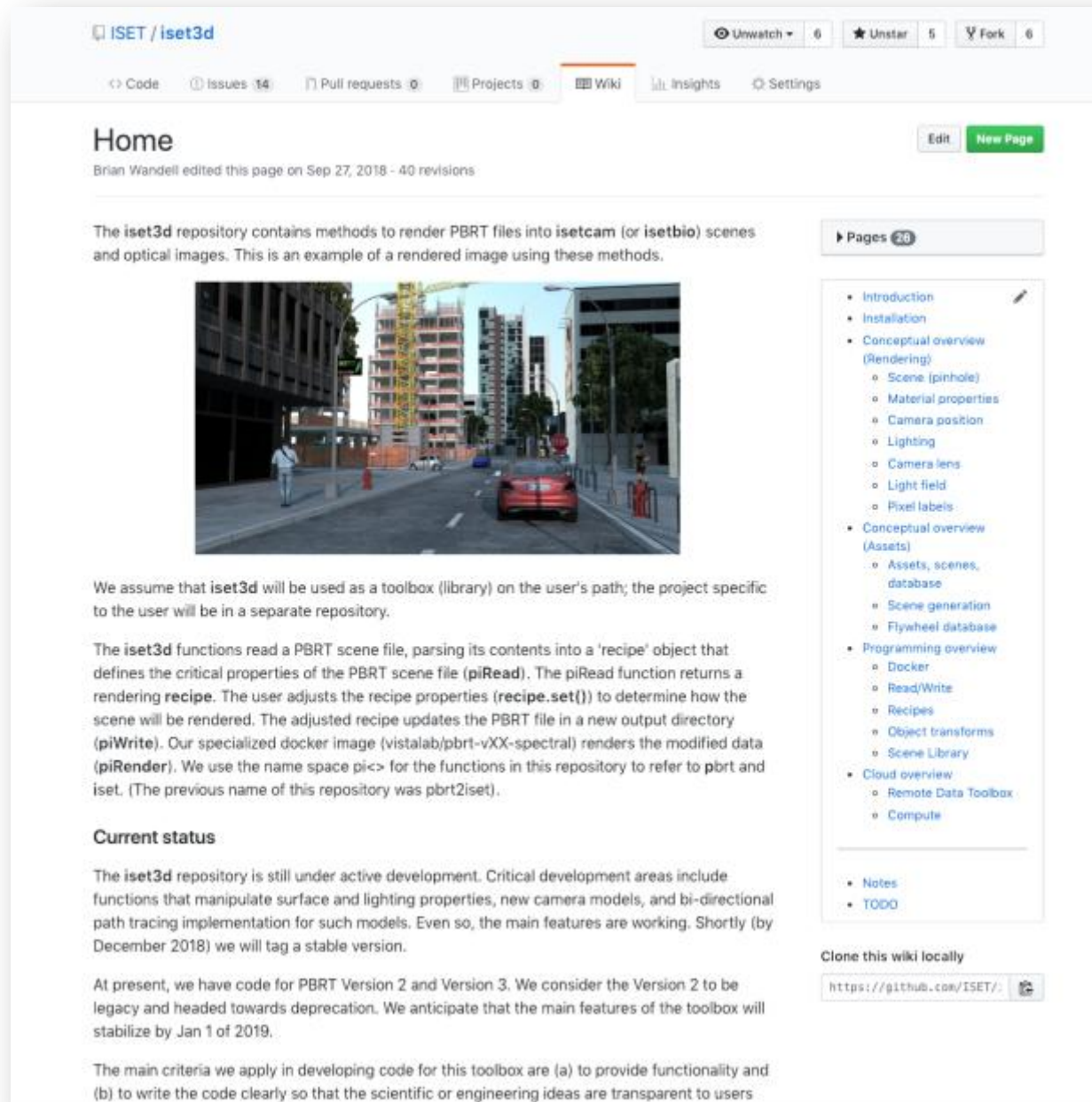
- This analysis simulates average precision of a CNN (ResNet) measuring with cameras with different pixel sizes
- The loss of visibility depends on pixel size, systematically
- The simulation includes meaningful units
- The performance of the 1.5 μm and 0.7 μm pixels similar to the performance of current LIDAR detectors

Automobile localization as a function of distance and pixel size



Part I: Simulation for camera design in automotive machine-learning

- A purely empirical approach for camera design for automotive application is impractical.
- We created an end-to-end system to automate the generation of physically accurate natural scenes and sensor images for network training and evaluation.



ISET / iset3d


Unwatch 6 Unstar 5 Fork 6

Code Issues 14 Pull requests 0 Projects 0 Wiki Insights Settings

Home

Brian Wandell edited this page on Sep 27, 2018 - 40 revisions

The `iset3d` repository contains methods to render PBRT files into `isetcam` (or `isetbio`) scenes and optical images. This is an example of a rendered image using these methods.



We assume that `iset3d` will be used as a toolbox (library) on the user's path; the project specific to the user will be in a separate repository.

The `iset3d` functions read a PBRT scene file, parsing its contents into a 'recipe' object that defines the critical properties of the PBRT scene file (`piRead`). The `piRead` function returns a rendering `recipe`. The user adjusts the recipe properties (`recipe.set()`) to determine how the scene will be rendered. The adjusted recipe updates the PBRT file in a new output directory (`piWrite`). Our specialized docker image (`vistalab/pbrt-vXX-spectral`) renders the modified data (`piRender`). We use the name space `pi<>` for the functions in this repository to refer to `pbrt` and `iset`. (The previous name of this repository was `pbrt2iset`).

Current status

The `iset3d` repository is still under active development. Critical development areas include functions that manipulate surface and lighting properties, new camera models, and bi-directional path tracing implementation for such models. Even so, the main features are working. Shortly (by December 2018) we will tag a stable version.

At present, we have code for PBRT Version 2 and Version 3. We consider the Version 2 to be legacy and headed towards deprecation. We anticipate that the main features of the toolbox will stabilize by Jan 1 of 2019.

The main criteria we apply in developing code for this toolbox are (a) to provide functionality and (b) to write the code clearly so that the scientific or engineering ideas are transparent to users

Pages 28

- Introduction
- Installation
- Conceptual overview (Rendering)
 - Scene (pinhole)
 - Material properties
 - Camera position
 - Lighting
 - Camera lens
 - Light field
 - Pixel labels
- Conceptual overview (Assets)
 - Assets, scenes, database
 - Scene generation
 - Flywheel database
- Programming overview
 - Docker
 - Read/Write
 - Recipes
 - Object transforms
 - Scene Library
- Cloud overview
 - Remote Data Toolbox
 - Compute

Notes
TODO

Clone this wiki locally

<https://github.com/ISET/>

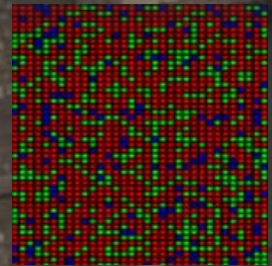
Third point

The demand for camera sensors in cars will drive innovation;

The automotive industry may find image systems simulation tools are helpful in setting the requirements and speeding innovation

Illustrating the case for image systems simulation

- Image systems simulation I: Camera design and machine-learning applications
- Image systems simulation II: Display design and perceptual image quality



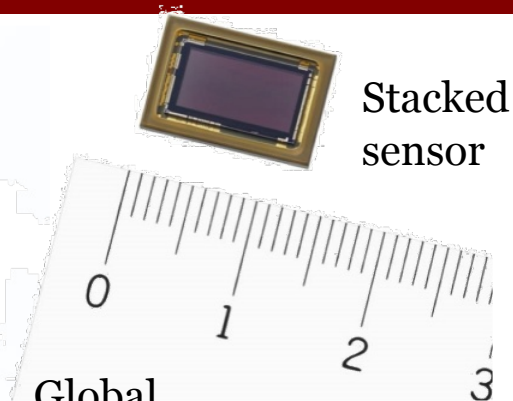
Physiological optics

Photo transduction

Imaging industry innovates – cameras and sensors



Multiple lens

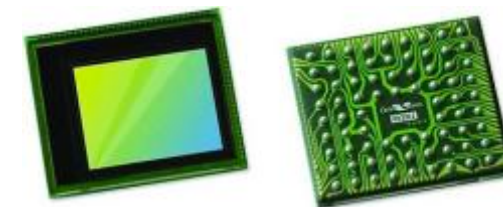
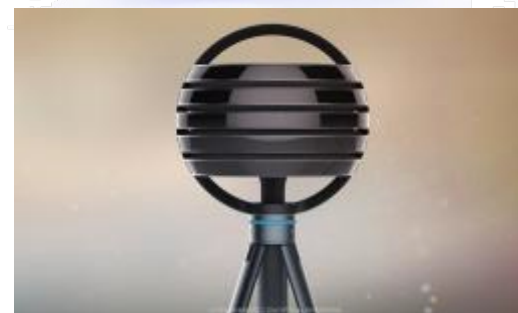


Stacked sensor

Global shutter



RGB-depth



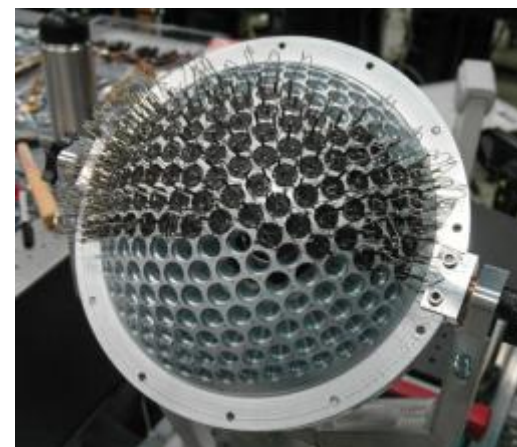
Dual pixel autofocus



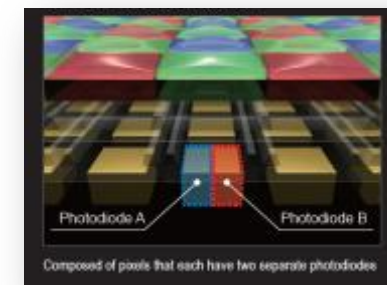
Light field



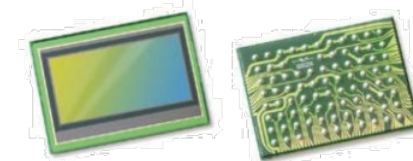
360 Surround Video



Massive resolution



RCCC automotive



Imaging industry innovates –displays for AR/MR/VR

Head-mounted form factors



Samsung Gear(a)



Cardboard (b)



Oculus(c)



HTC Vive (d)



LG (e)



Playstation VR (PSVR) (f)



Hololens (g)

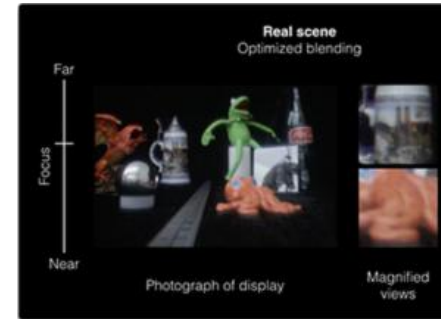


Meta (h)



Moverio BT200 (i)

Multi-focal planes

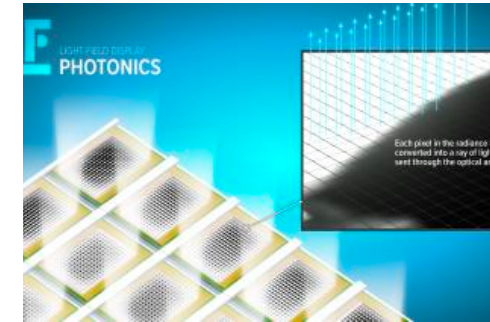


Minn., UCB, Dolby

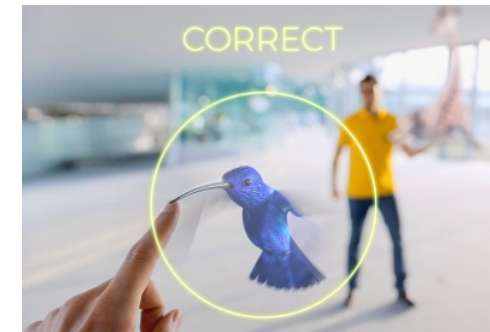


Oculus

Light field



FOVI 3d



CREAL 3d

Advancing display simulation for image quality metrics

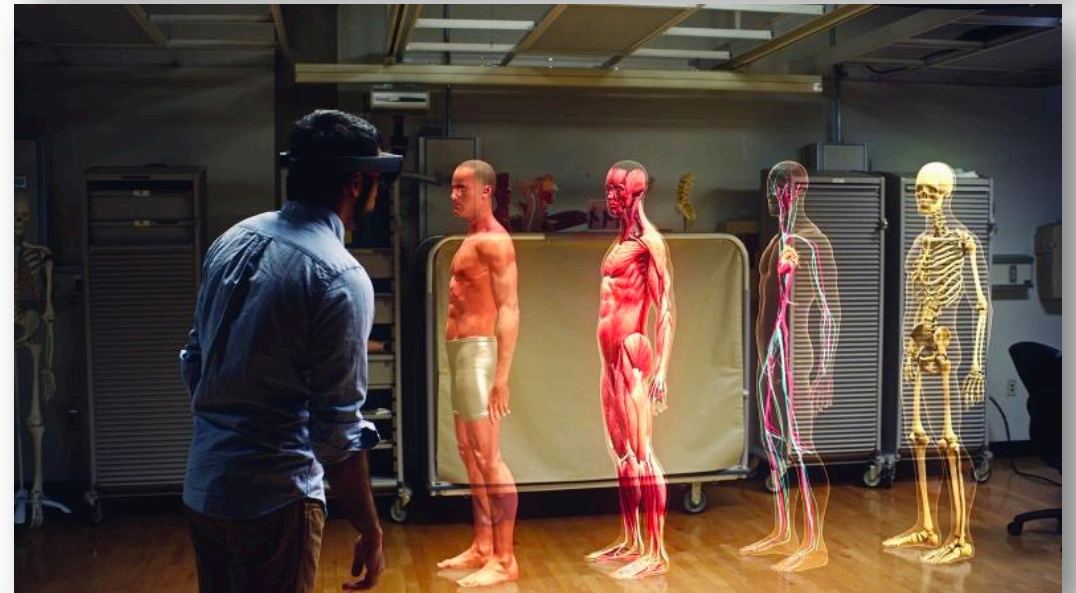
- Current image quality metrics work on the classic model of display technology
 - Images are controlled by RGB input
 - Quality is measured using these input referred values: the **ideal RGB** input vs. the **actual RGB** values delivered by a camera or algorithm
- For example, the image quality metric, SSIM, which has been cited more than 20,000 times and was awarded a Television Emmy, uses this approach

SSIM, PSNR, MS-SSIM



Next generation displays cannot be evaluated using RGB values

- Image quality metrics for the next generation of displays requires a new approach because ...
- Rendered images are mixtures of the display photons and natural image photons (mixed reality)
- The displays include transparent elements at multiple focal planes (multi-focal) or emit rays at multiple angles (light field), so there is no 'RGB' input



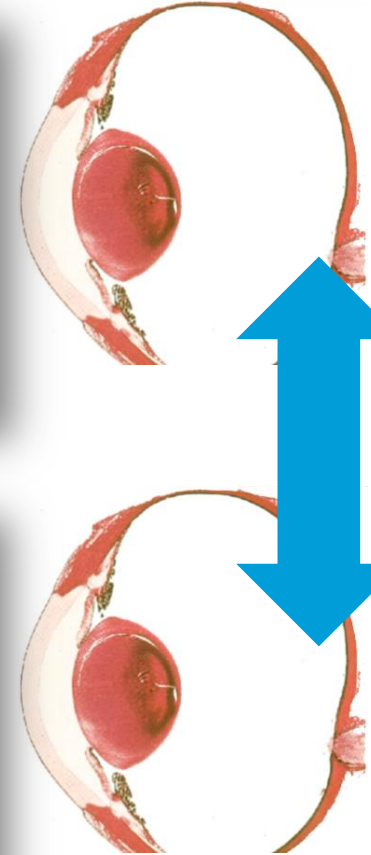
Advancing display simulation for image quality metrics

- A better framing: calculate metrics quality using the photons absorbed by the photoreceptors
- Many advantages; but we must be able to calculate the photoreceptor excitations!

Ideal RGB



Actual RGB



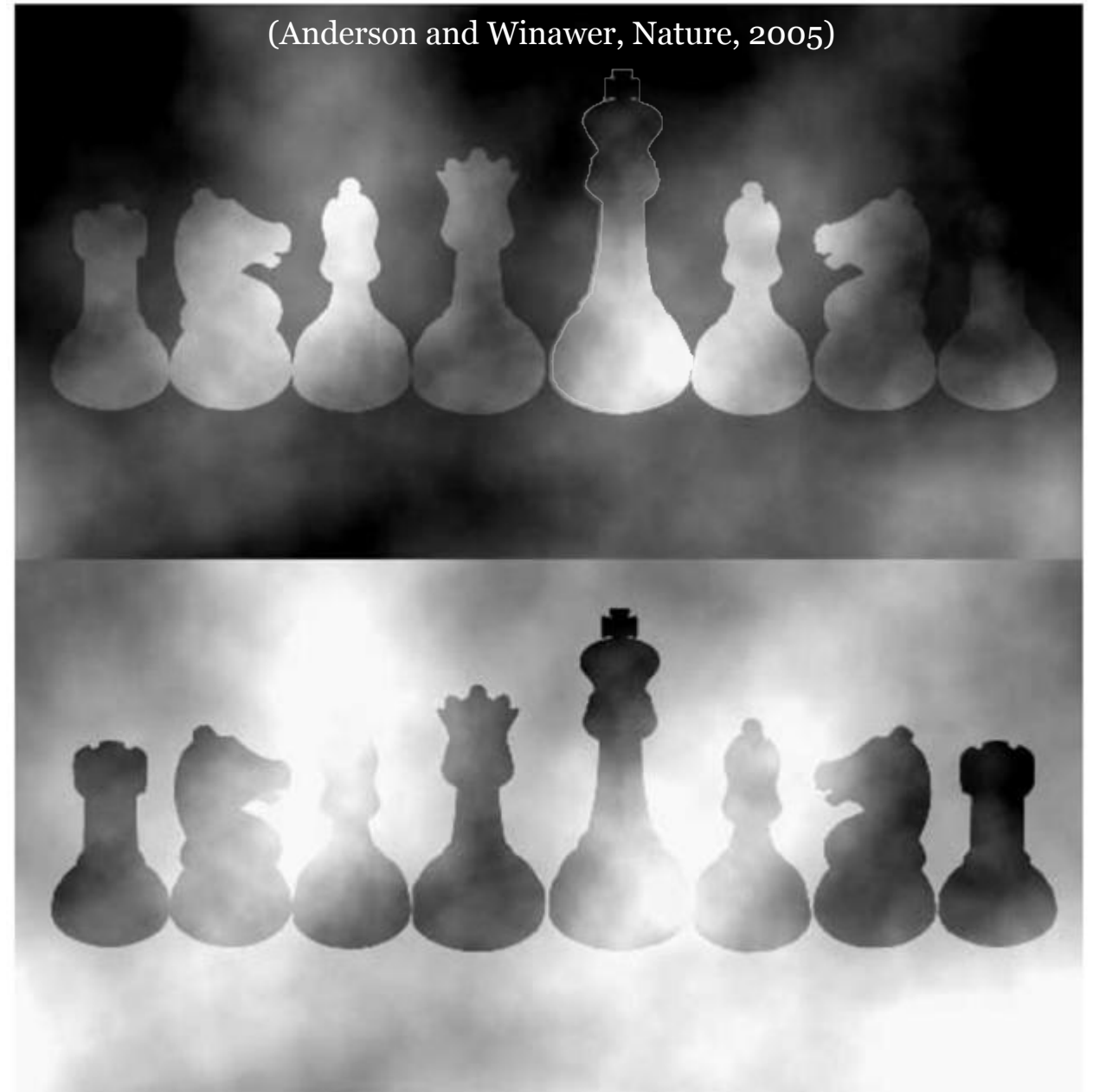
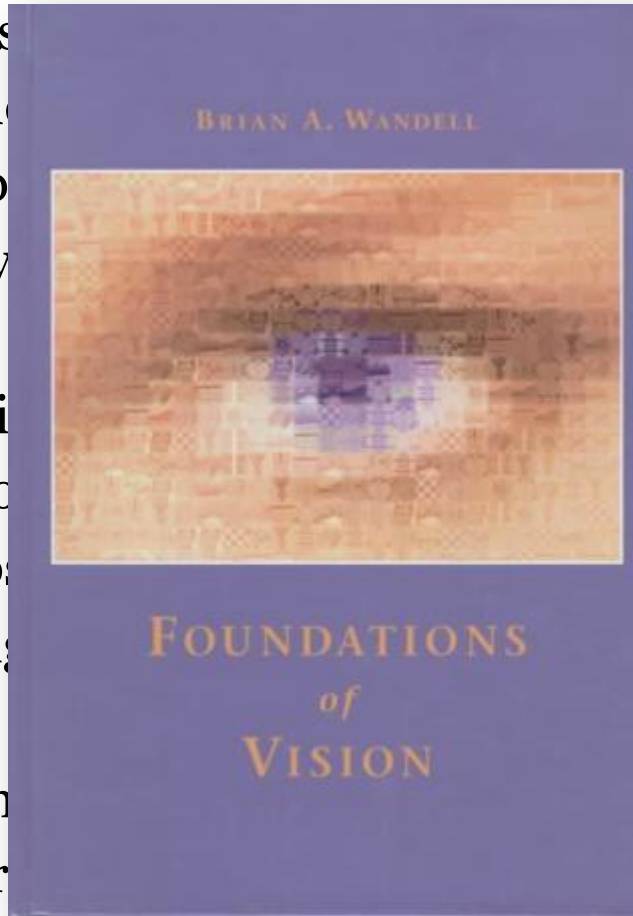
Compare here

Fourth point

Image systems simulation of the human eye can be the basis of a next generation of image quality metrics to guide insight for designing advanced displays and camera rigs

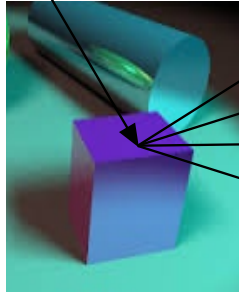
Vision and computation

- Even so, the process of visual perception is carried out by the brain.
- The visual system has a great potential in developing intelligent machines.
- Vision is an important part of the computer industry.



The infrastructure for ISETBio conceptually matches ISETcam

Parameters and certain aspects differ, but a common infrastructure is used



Scene spectral radiance



Physiological optics

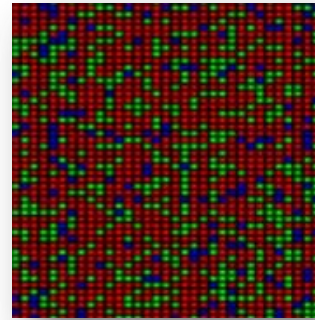


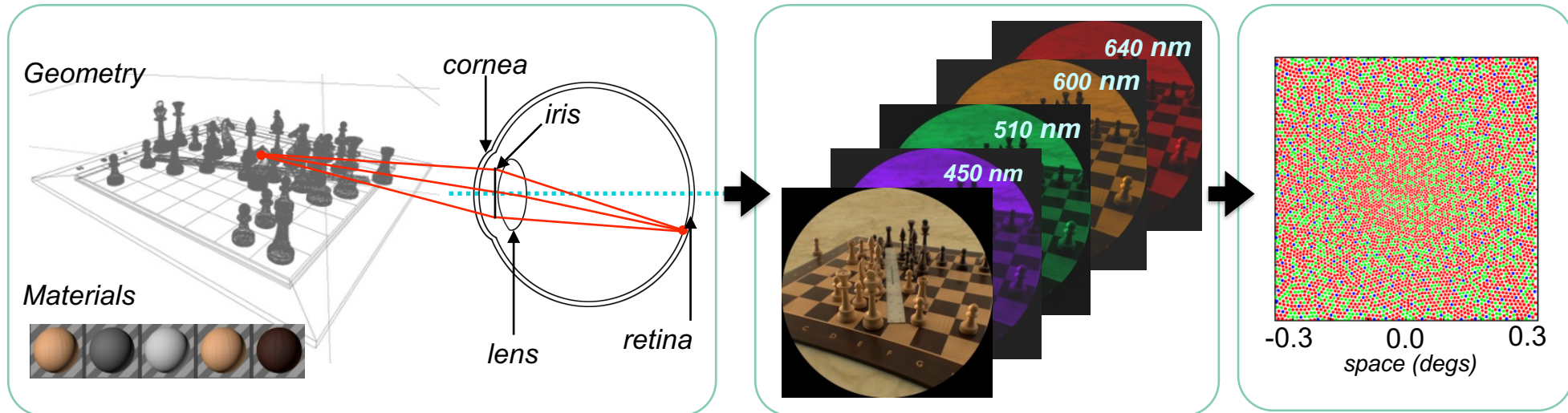
Photo transduction



Retinal processing

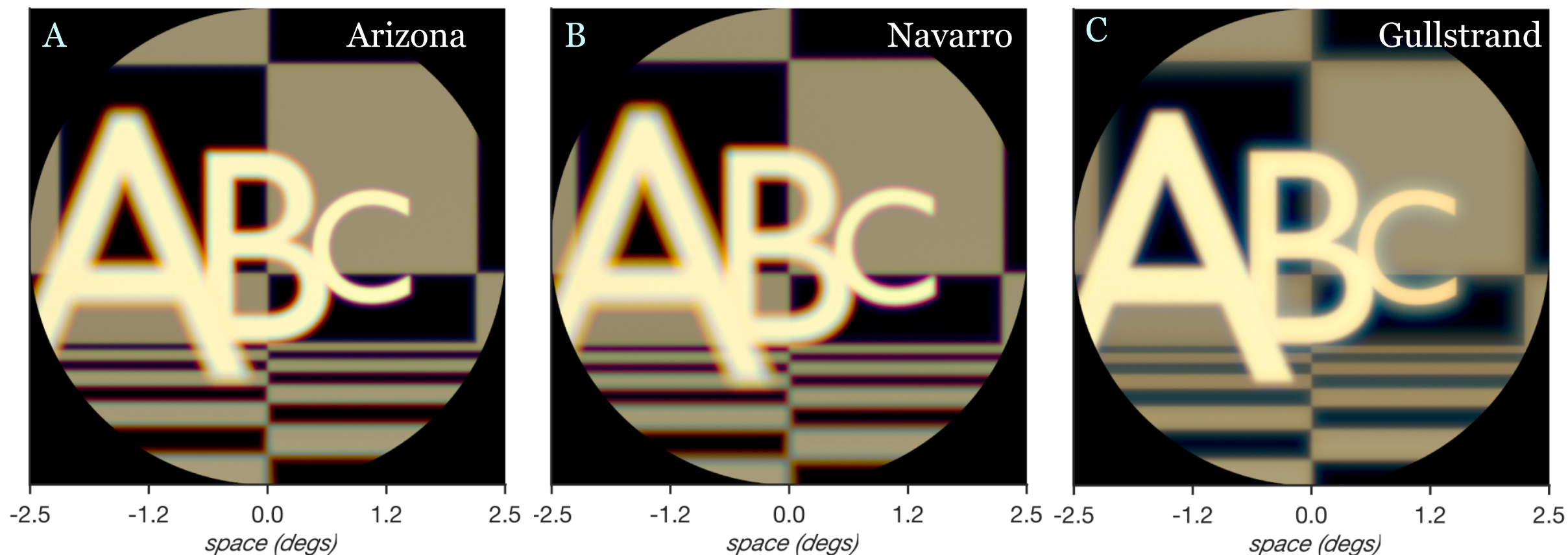


Inference



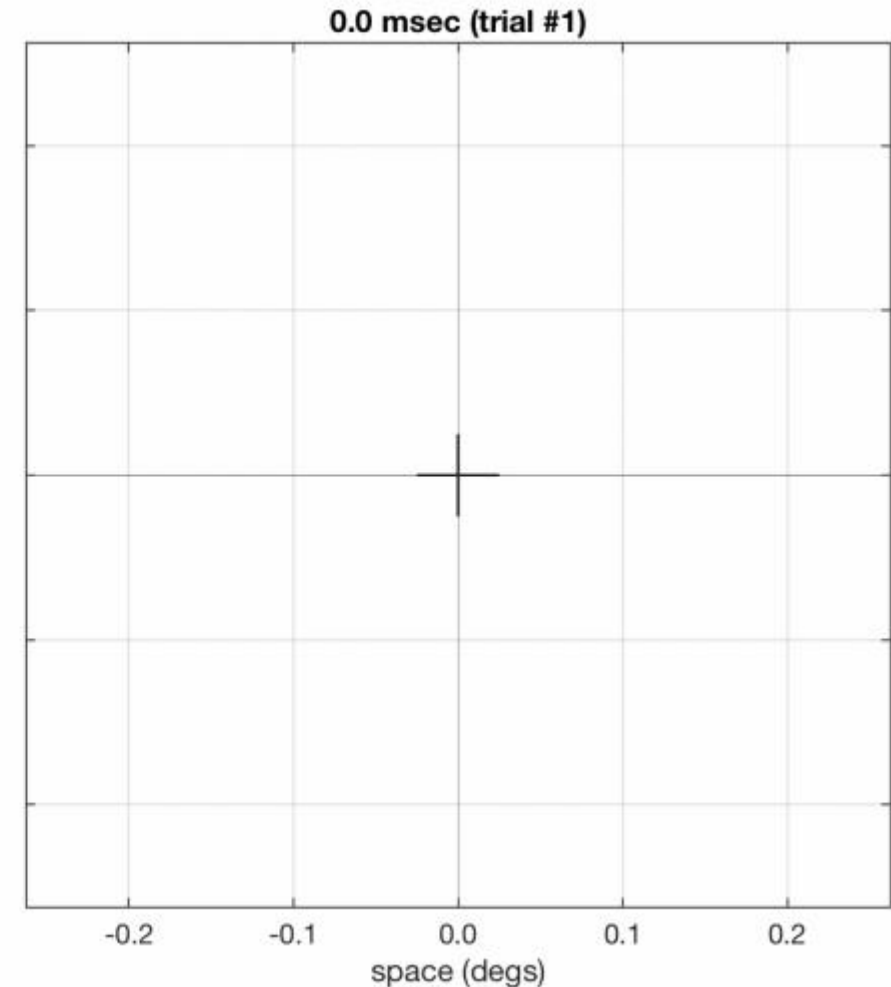
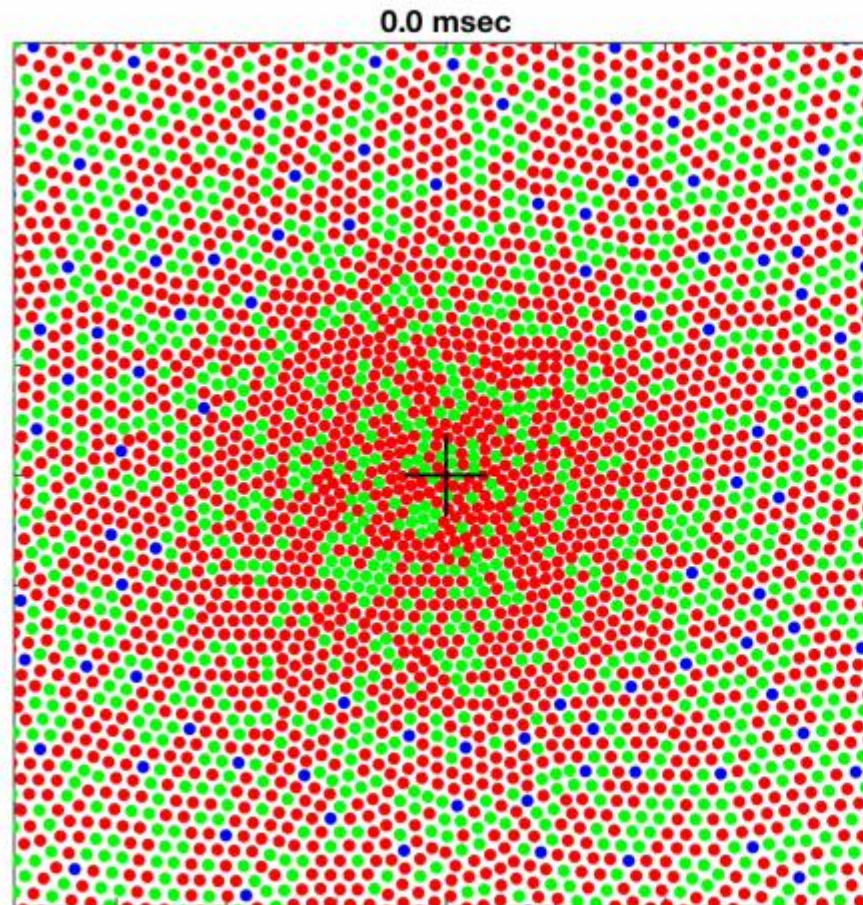
Eye models differ – and sometimes significantly

There are commonalities and differences between the major human eye models, (Lian et al. 2019, bioRxiv).



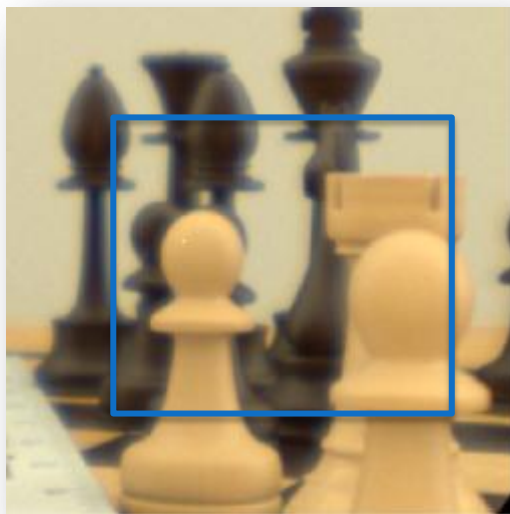
Eye movement modeling (Nicolas Cottaris)

- Uniform and space-varying cone density representations
- Cone spacing and cone aperture size vary with distance from the fovea
- Inhomogeneous cone sampling densities



Cone mosaic absorptions and eye movements

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



OS: osLinear
noise: random

Chess-left-0.5

Absorption m...
Showing absorption movie

Mosaic size (mm): 2.1 (w) x 2.1 (h)
FOV (deg): 7.00 (w) x 7.00 (h)
Aperture (um): 3.44 (w) x 3.44 (h)
Active cones: 364816
Density (cones/mm²): 84379.2
Duration: 0.5 sec (100 samps)

Cone size (um)
3.442 3.442

Pigment density
[0.5, 0.5, 0.4]

Peak
[0.67, 0.67, 0.67]

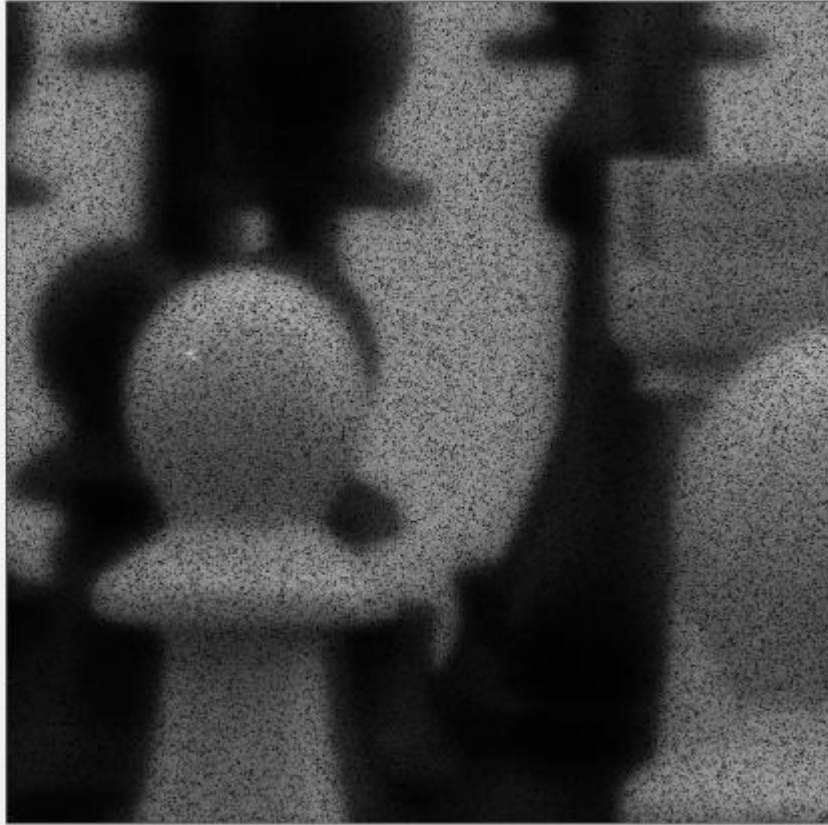
Macular density
0.35

Row Col
604 604

Integration
5.0 (ms)

Eccentricity
0.45

Blank-LMS
[0.0, 0.6, 0.3]



1
Gam


Compute cone absorptions

0.5 deg ecc

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

Inert pigments (e.g. lens transmission)

Left eye




Optical image
Size: [512, 512] samples
Hgt,width: [8.75, 8.75] mm
Sample: 17.08 μm
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



Optical image
Size: [512, 512] samples
Hgt,width: [8.75, 8.75] mm
Sample: 17.08 μm
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

Image formation (optics) models and quantitative graphics

Stereo pairs are straightforward to compute

Right eye



Optical image
Size: [512, 512] samples
Hgt,width: [8.75, 8.75] mm
Sample: 17.08 μm
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 eye



Optical image
Size: [512, 512] samples
Hgt,width: [8.75, 8.75] mm
Sample: 17.08 μm
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

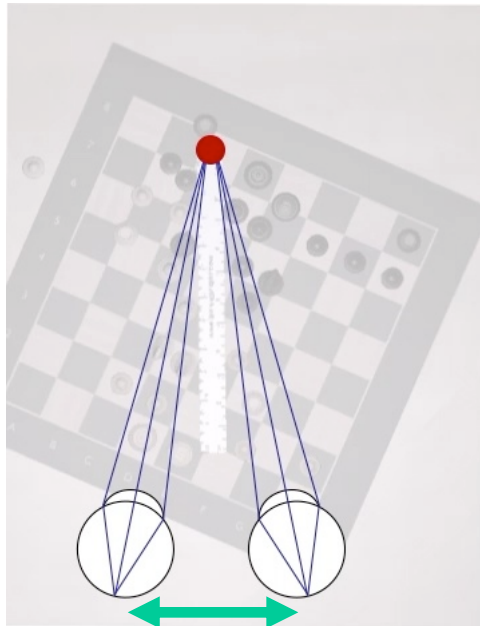
Gamma Display

Vergence and Accommodation

1.66 diopters (Left)



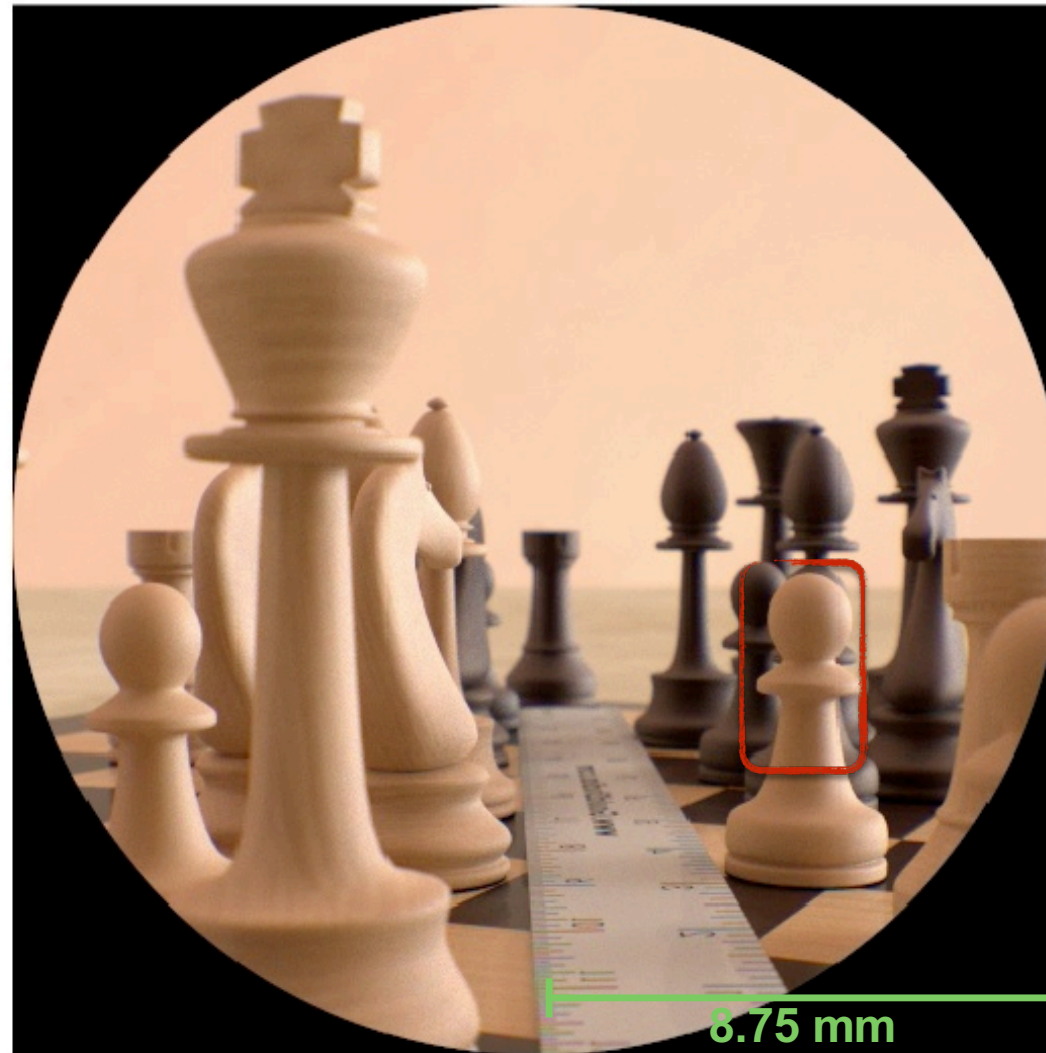
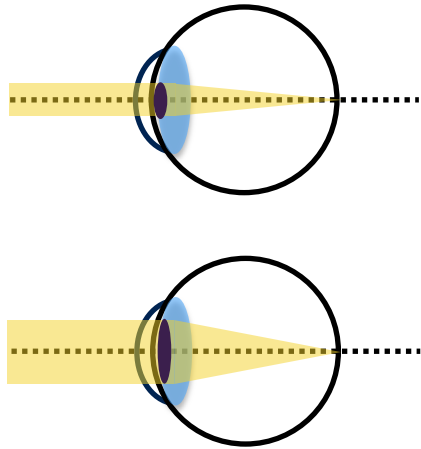
1.66 diopters (Right)



64 mm

Pupil Diameter

2.0 mm



8.75 mm

Video tutorials and data resources

Tutorials

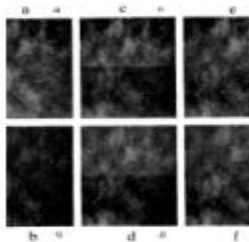
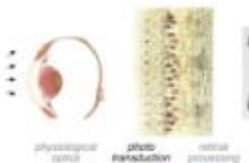


Image Systems

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

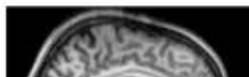
Start watching now!



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
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: Computational modeling early human vision" (09/09)
- » Brian Wandell: "Photons and Energy"
- » Fred Rieke: "Modeling Cone Responses"
- » PSYCH 204A (Fall 2014): MRI – Signal
- » PSYCH 204A (Fall 2014): MRI – The

TOPICS

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 Hypesx 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.

Fifth point

Many modern computer science methodologies could be applied to make these ideas into a useful industrial tool – database extensions, cloud-scaling, platform independence.

Building a consensus (validated) platform will be beneficial to the imaging industry

Simulation technologies for image systems engineering

Brian A. Wandell

Stanford Center for Image Systems Engineering

Wu Tsai Neurosciences Institute
Stanford Center for Cognitive and
Neurobiological Imaging

QUANTITATIVE MEASUREMENTS

∞

COMPUTATIONAL MODELS

∞

CHECK AND SHARE

