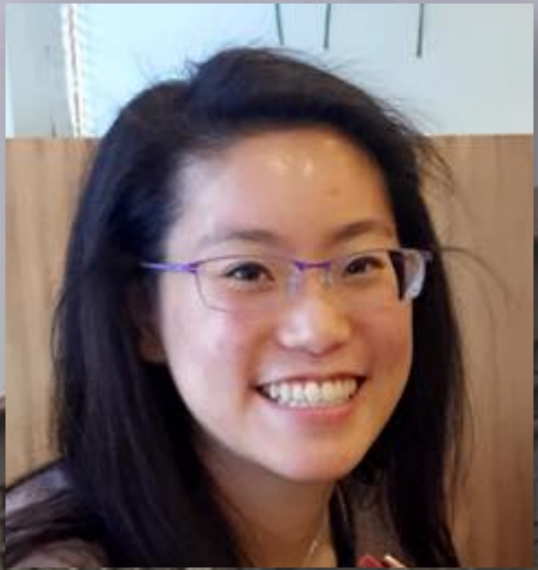
# Image Systems Engineering (Psych 221)

Psych 221 (Fall 2017)

Professor Brian Wandell
wandell@stanford.edu



Co-instructor

Dr. Joyce Farrell

Stanford, EE

Course Assistant

Trisha Lian

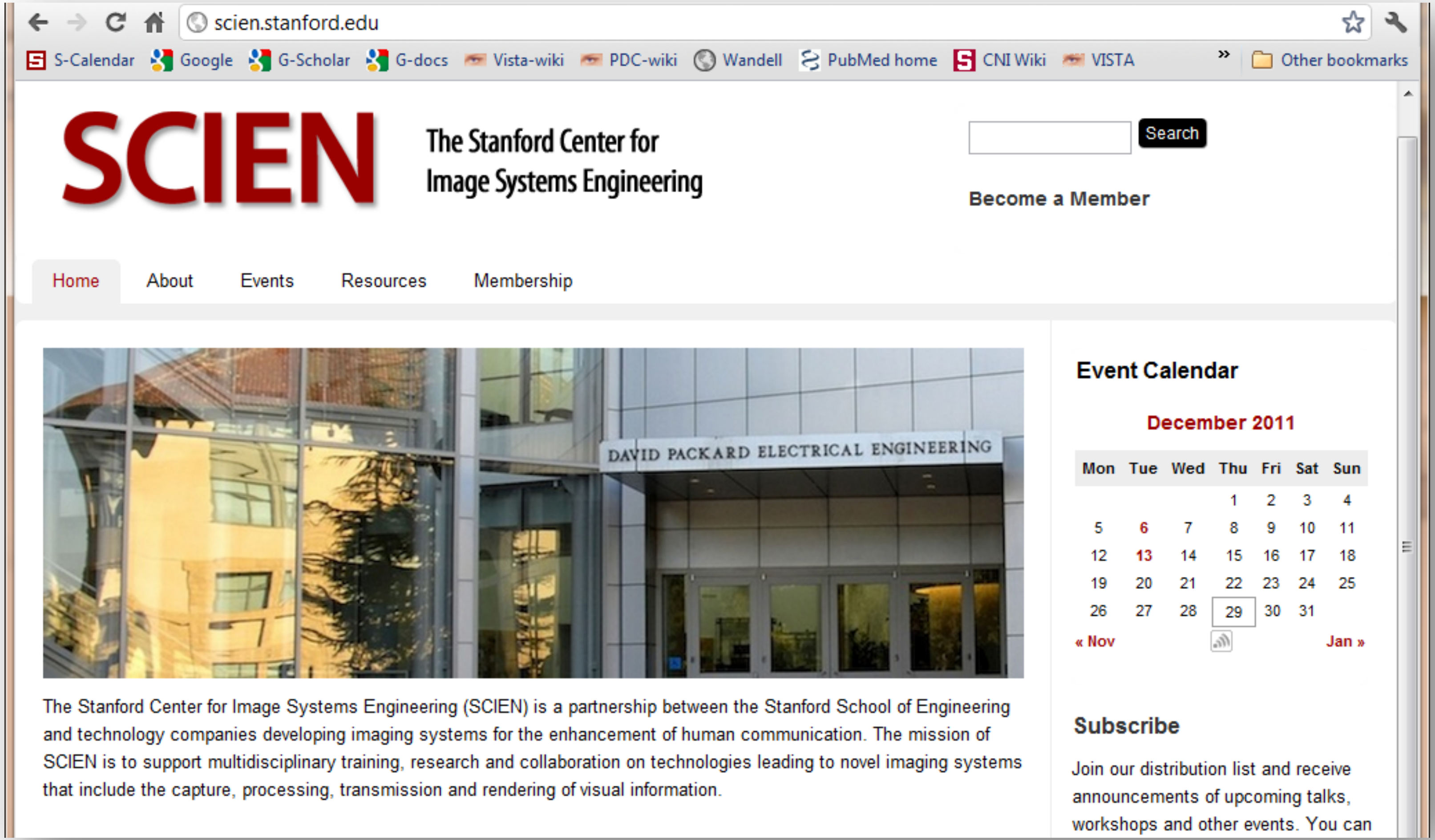
tlian@stanford.edu

# Image Systems Engineering (Psych 221)

- SCIEN – motivation and history
- Human visual perception
- What the course covers
- Course mechanics

# Image Systems Engineering

- SCIEN is an industry affiliates program that spans hardware, software and algorithms
- Faculty, students and industry colleagues work together on some of the interesting problems in imaging technologies



# Image Systems Engineering

- The SCIEN seminar series (EE 292E) is a great way to find internships and hear talks

- The SCIEN talks are recorded and available at http://talks.stanford.edu, if you have an SUNET ID.

EE292E - Seminar Series on Image Systems Engineering

**Available:** Online

**Overview**

The Stanford Center for Image Systems Engineering (SCIEN), a partnership between the Stanford School of Engineering and technology companies, hosts this seminar on developing imaging systems for the enhancement of human communication. Each week, Stanford faculty and other industry experts will discuss topics that include the capture, processing, transmission and rendering of visual information.

Upcoming guest speaker listings and an archive of past seminars can be found here: https://scien.stanford.edu/

**Enroll Now - Select a course to enroll in**

**EE292E** Autumn 2017-18 Online

REQUEST INFORMATION

| Day | Date | Time | Location |
|---|---|---|---|
| Wed | Sep 27 to Dec 06, 2017 | 4:30PM to 5:50PM PT | Online |

**Tuition Option(s):** For Credit $1,260.00

**Units:** 1 units

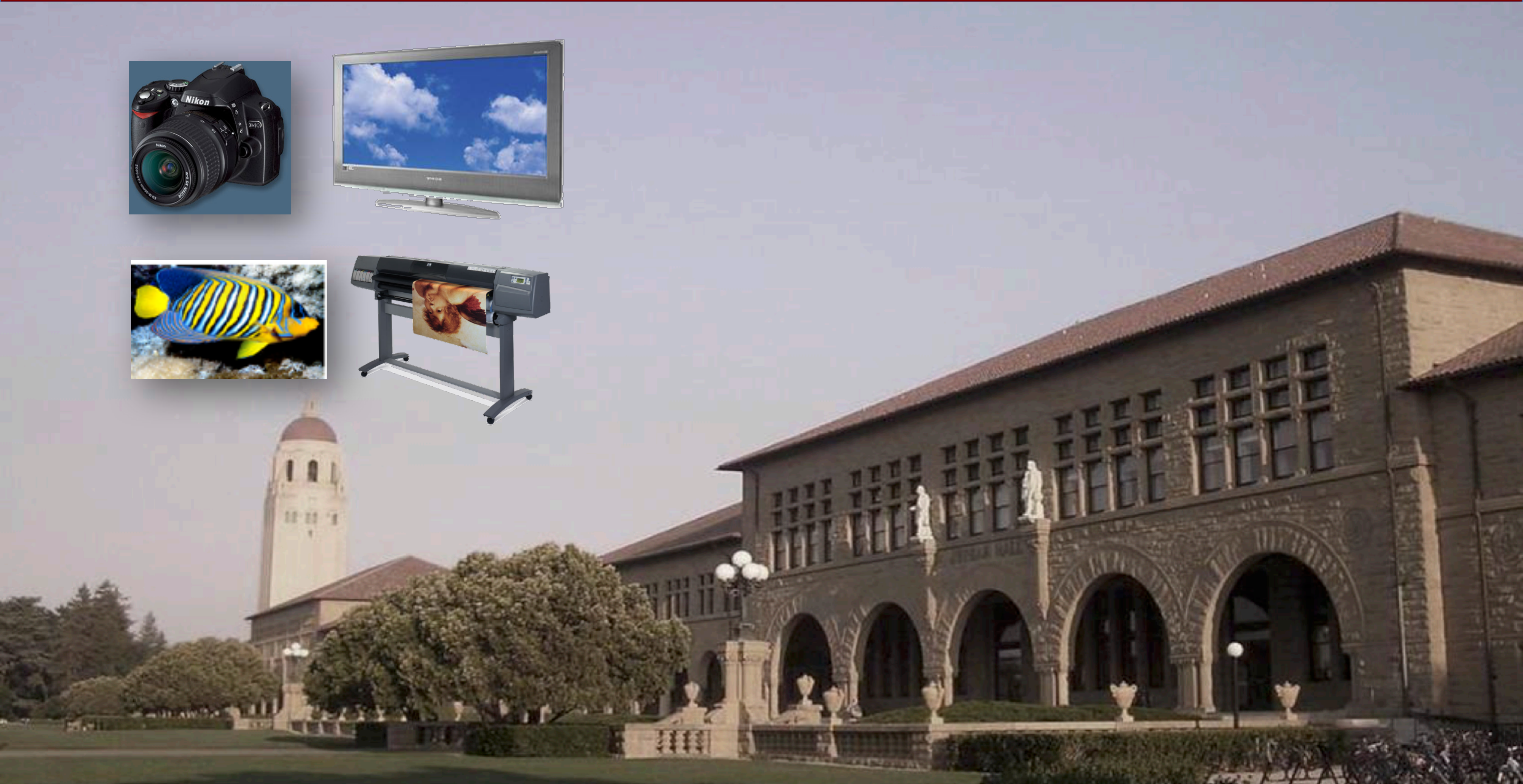
**Instructor(s):** Joyce Farrell, Bernd Girod, Brian Wandell, Gordon Wetzstein

**Enrollment Dates:** August 1 to September 11, 2017

**Course Dates**

Dates shown reflect the period for class lectures. Immediately

# Motivation for Image Systems Engineering



# Device specifications

One at a time


8 Megapixel
ISO 1600
F# 2.4-16
14 bit
5:1 optical zoom

# Device specifications

One at a time

780p
1080i
1000:1 CR
24 bit

# Device specifications


8 Megapixel
ISO 1600
F# 2.4-16
14 bit
5:1 optical zoom

*If I have this display, do I benefit from that camera?*

# Device specifications


8 Megapixel
ISO 1600
F# 2.4-16
14 bit
5:1 optical zoon

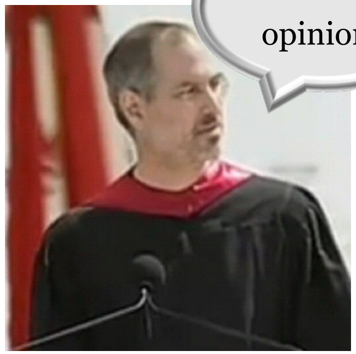
780p
1080i
1000:1 CR
24 bit

800 lux
outdoor

1440 dpi
Two-pass
Duotone
64 inch

# And where’s the consumer?

8 Megapixel
ISO 1600
F# 2.4-16
14 bit
5:1 optical zoom

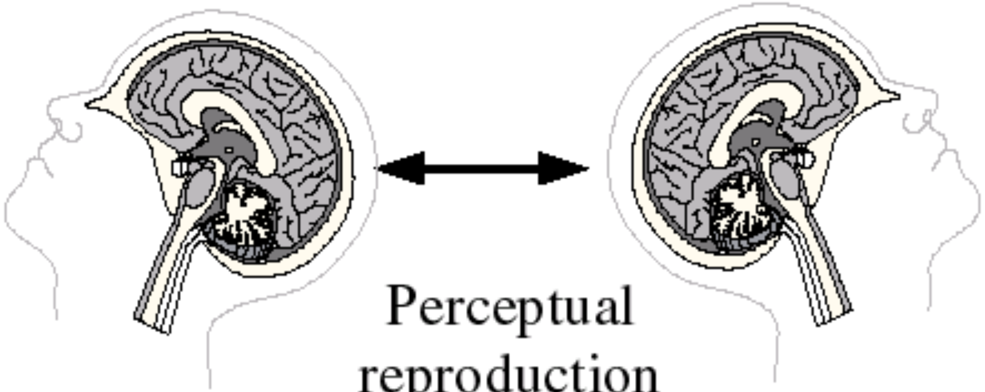




800 lux
outdoor

1440 dpi
Two-pass
Duotone
64 inch

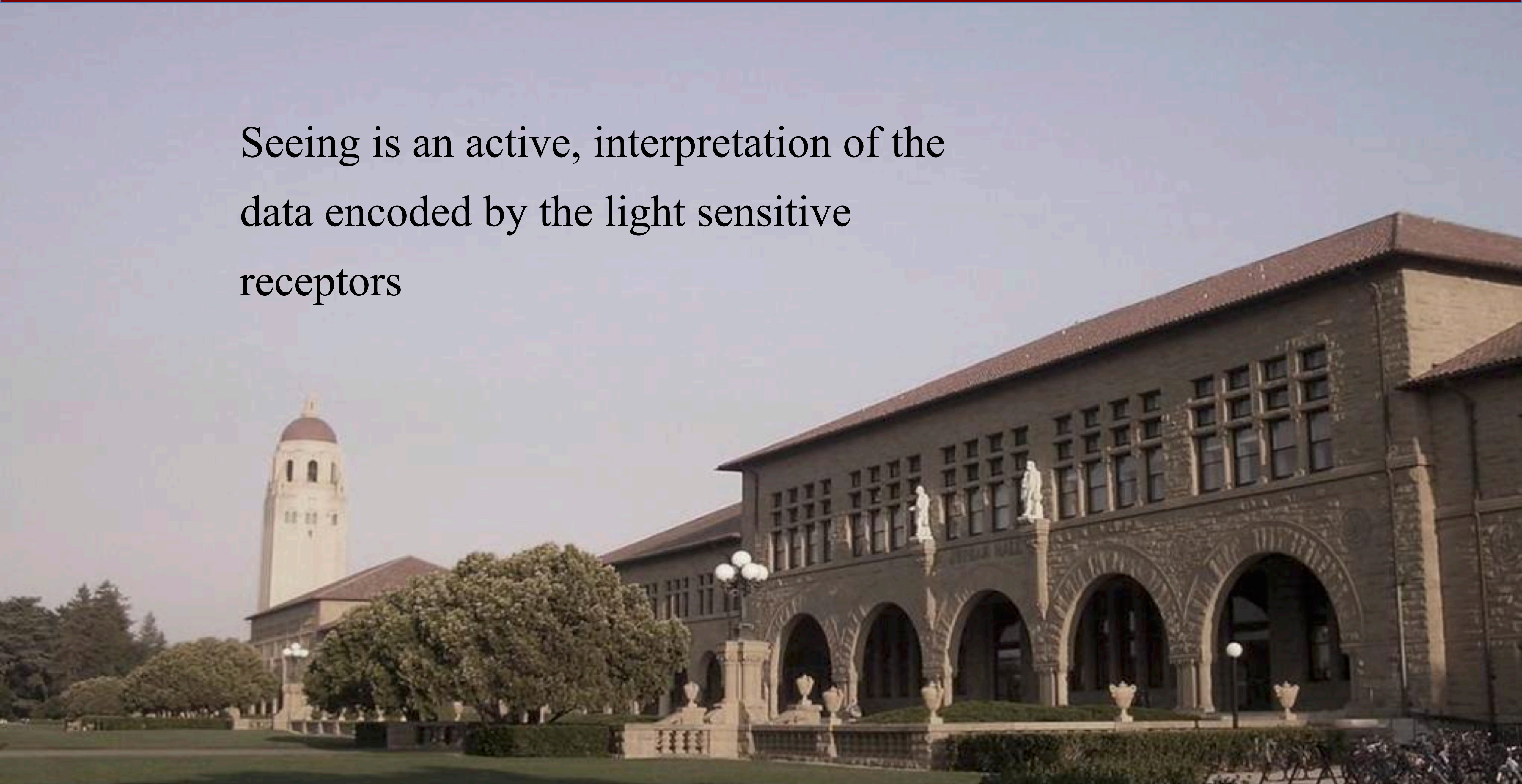
# The Image System Engineer: Analyzes the entire pipeline

# Image System Engineering: Accounts for the human observer

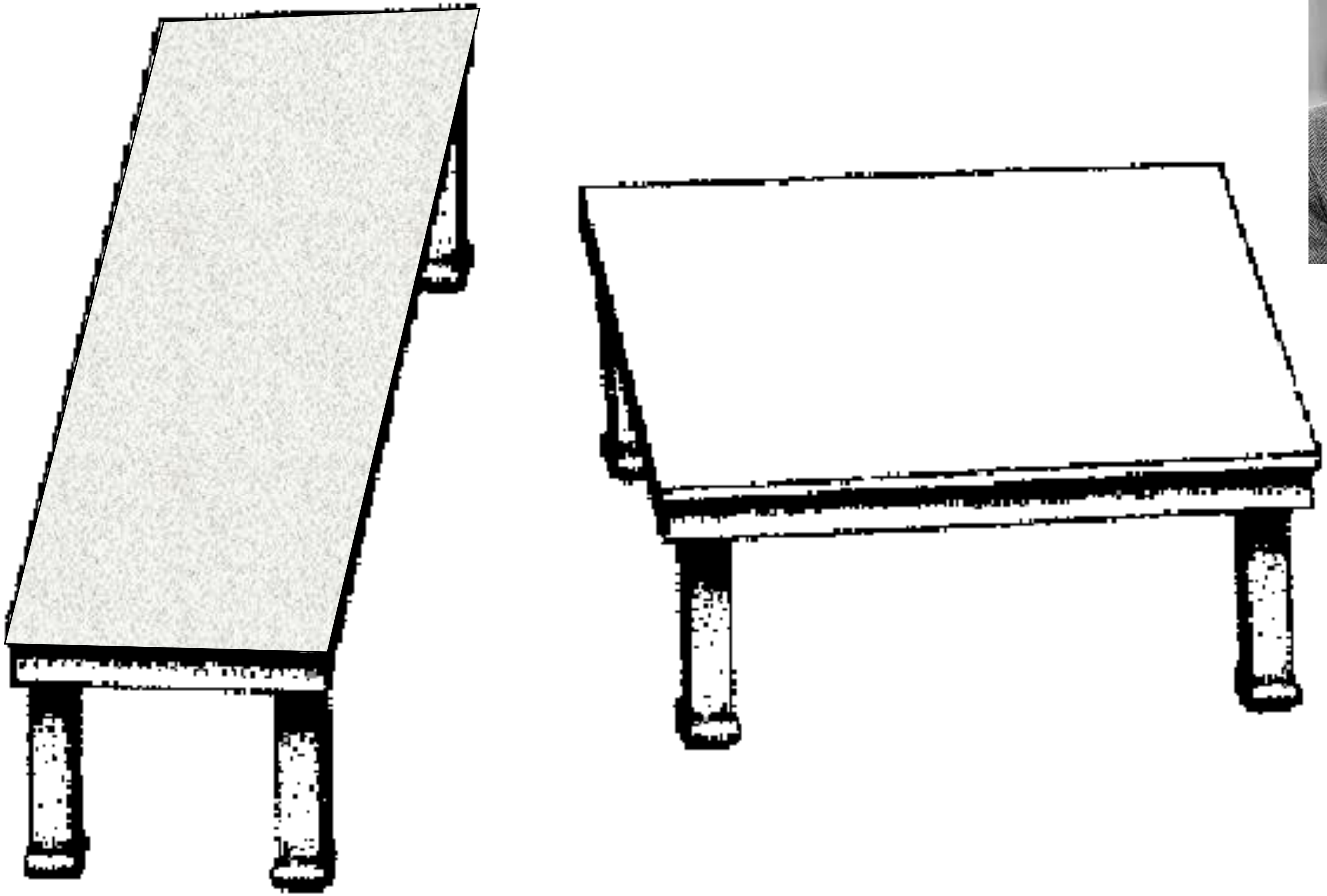
Perceptual reproduction metrics

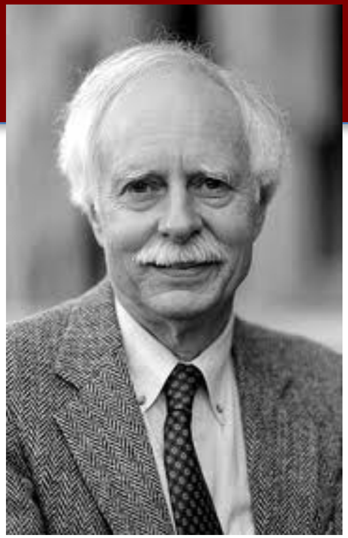
# Human visual perception



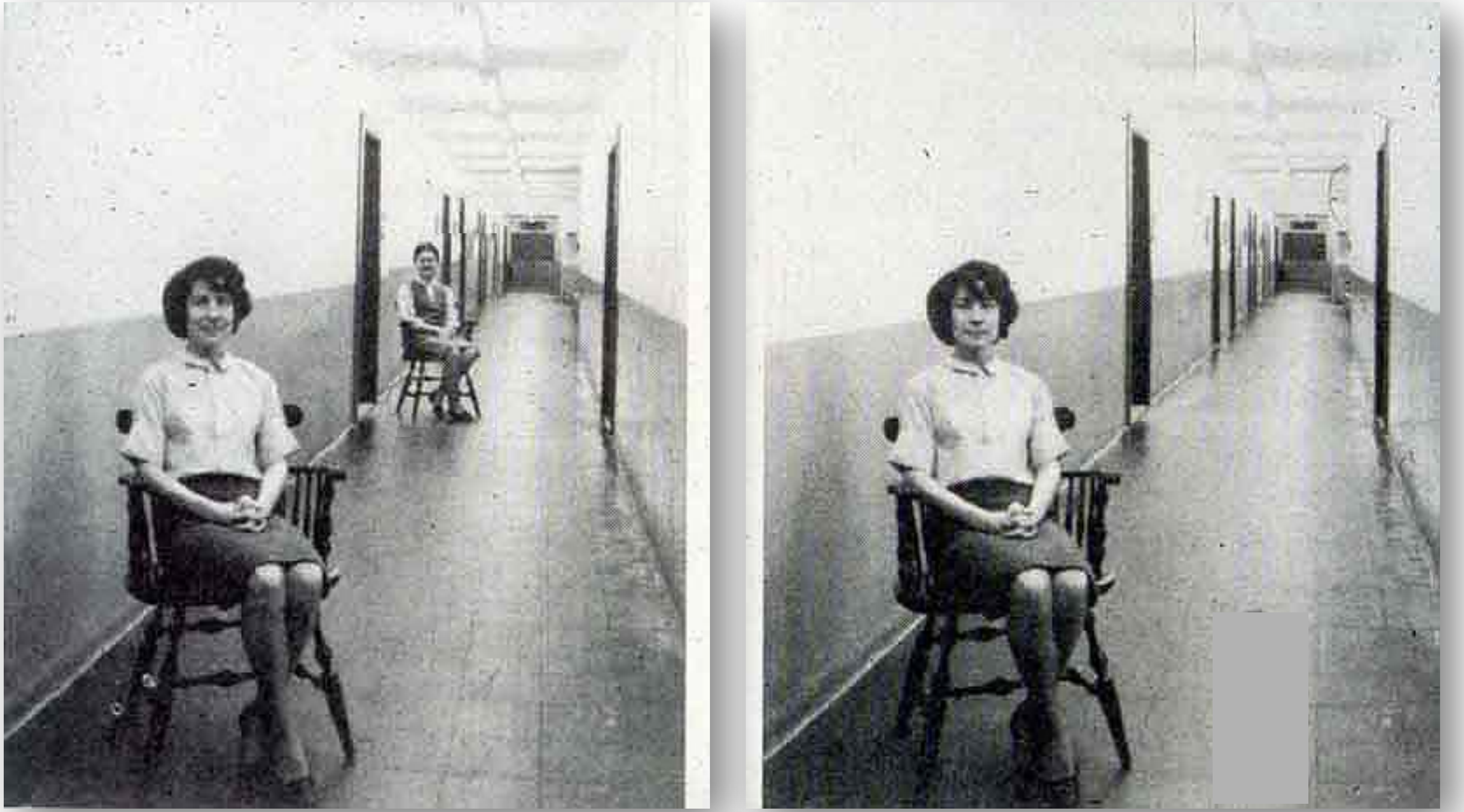
Seeing is an active, interpretation of the data encoded by the light sensitive receptors

# Turning the Tables (R.N. Shepard)





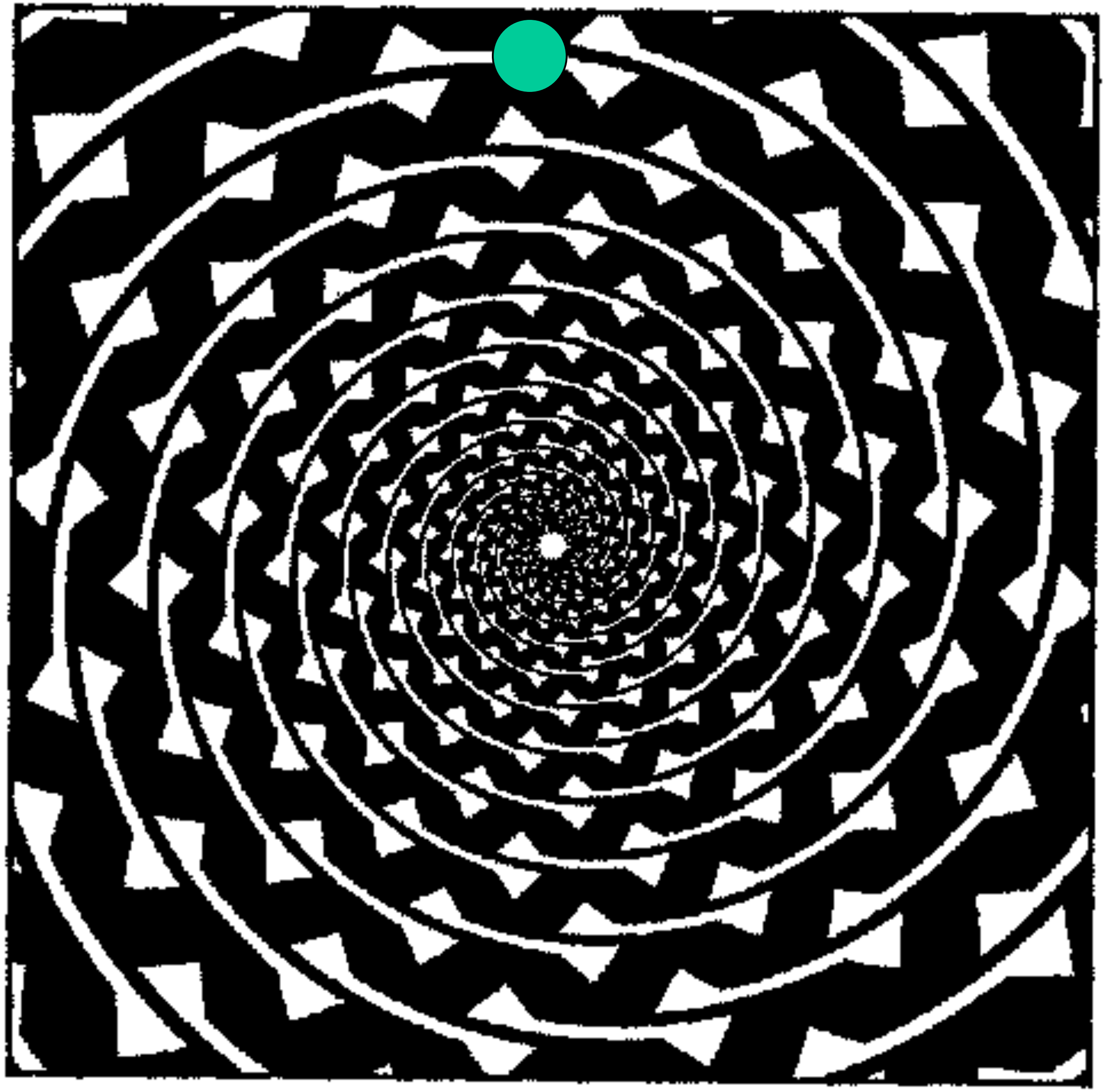
# Size constancy (E.G. Boring)



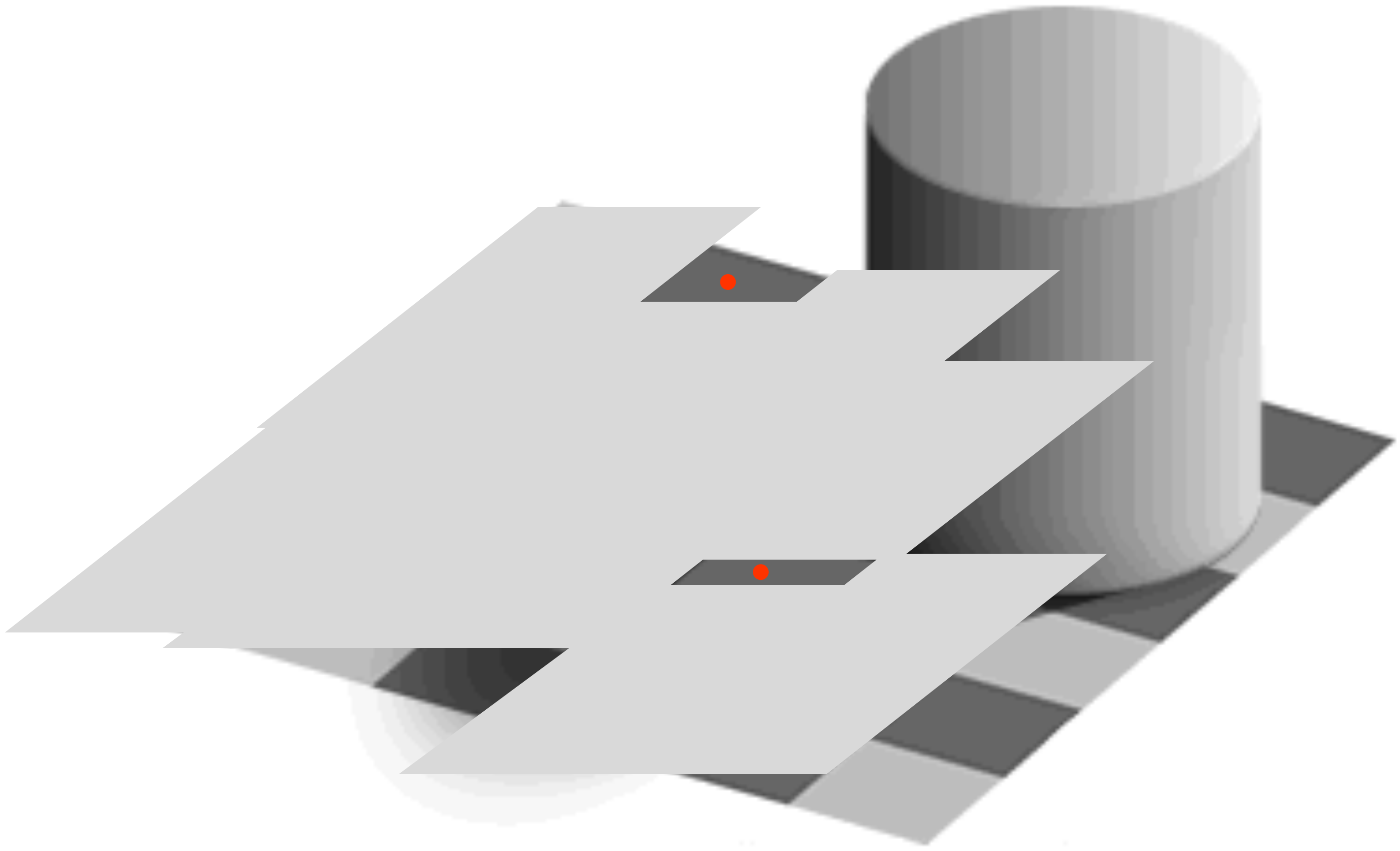
# Hollow mask illusion

Richard Gregory

# Fraser's Spiral



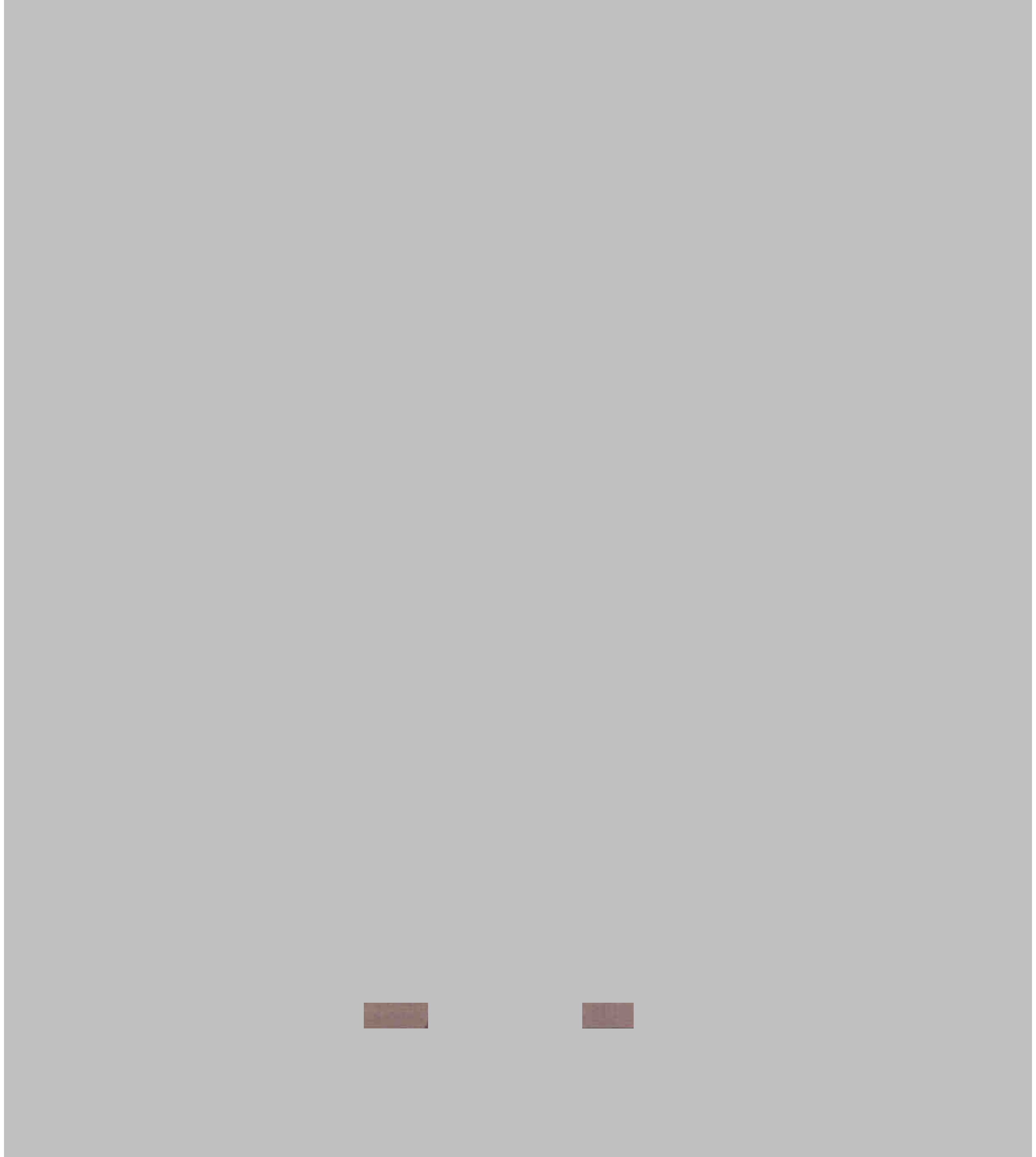
# The Perception of Lightness



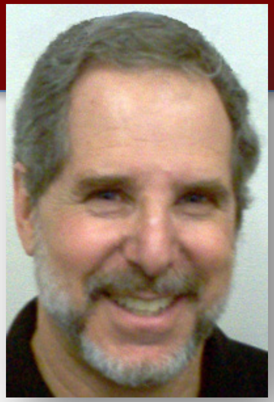
Ted Adelson

# Lightness Perception (Lotto and Purves)

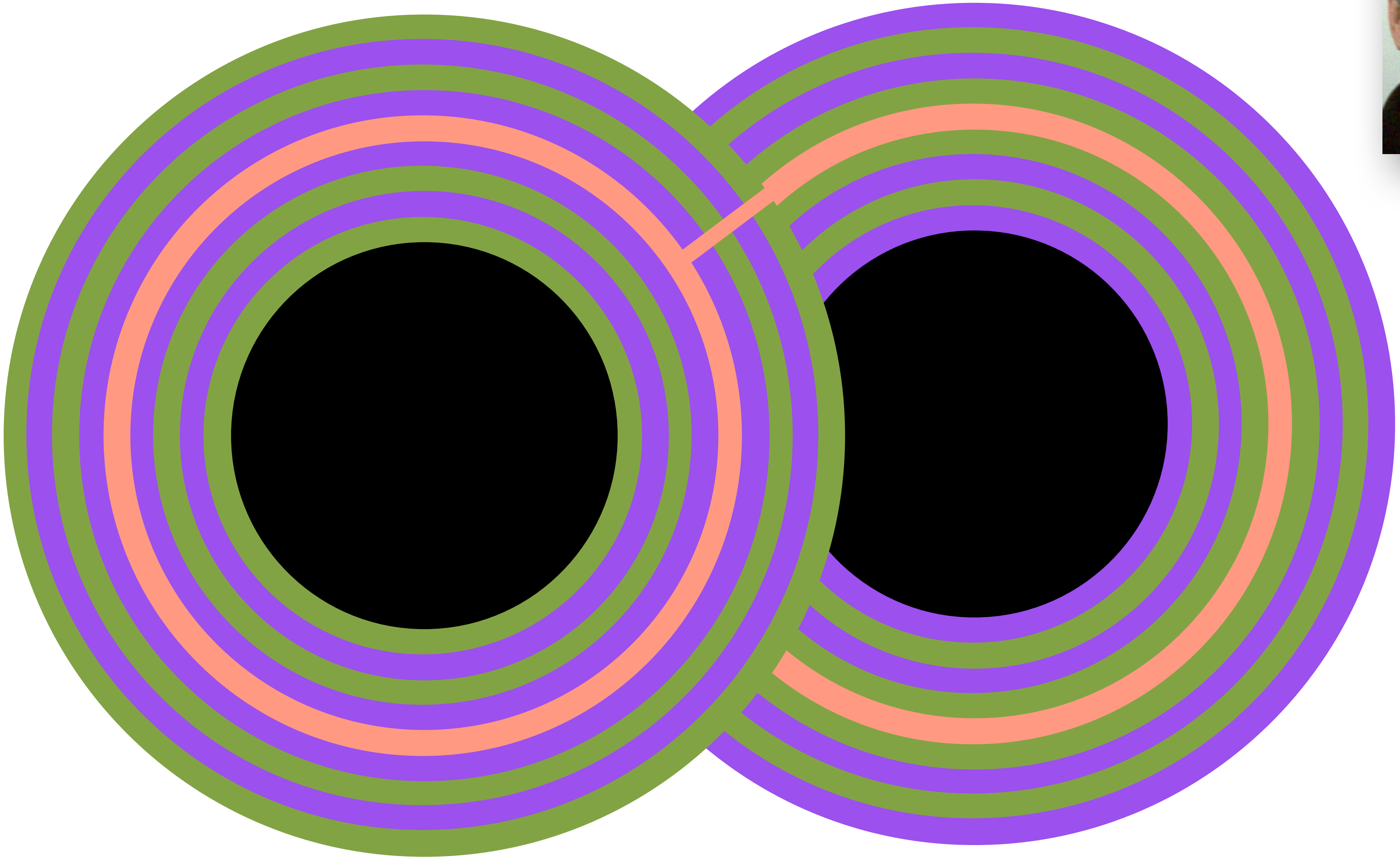
Alternative



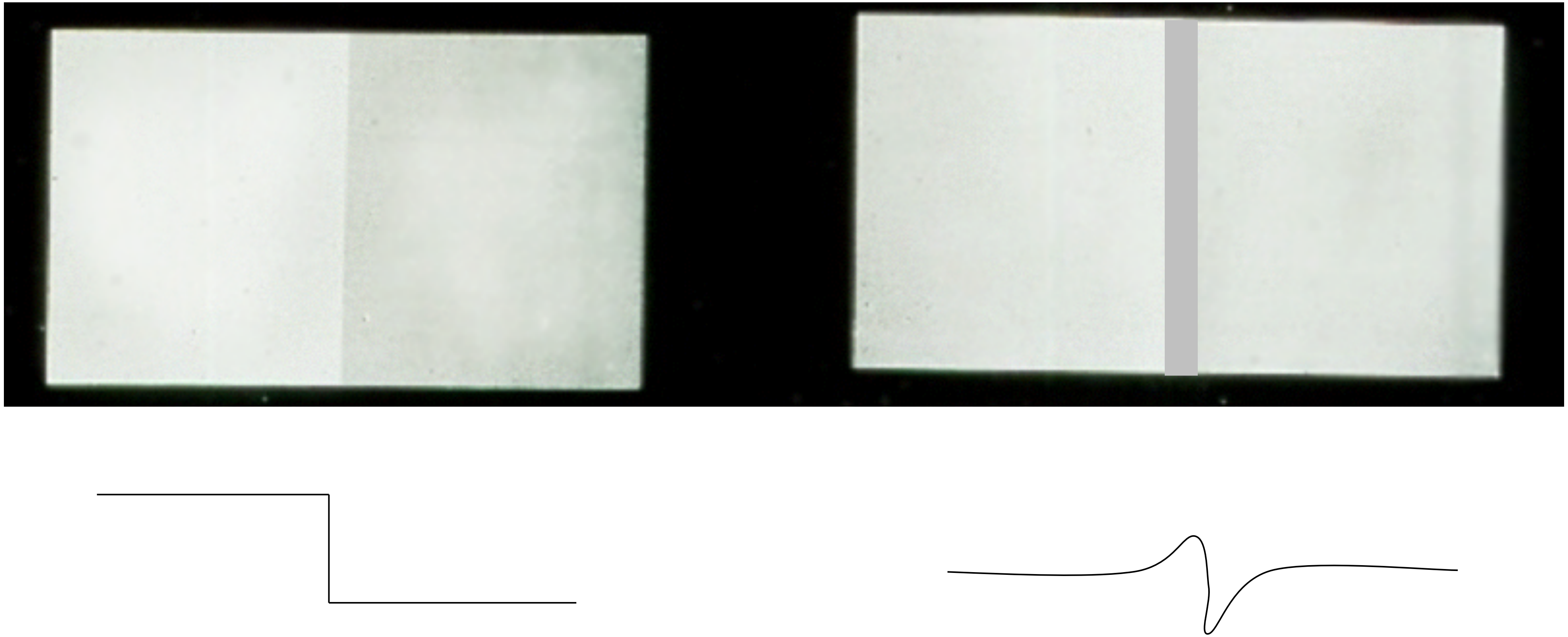
# Color Appearance Depends On The Spatial Pattern



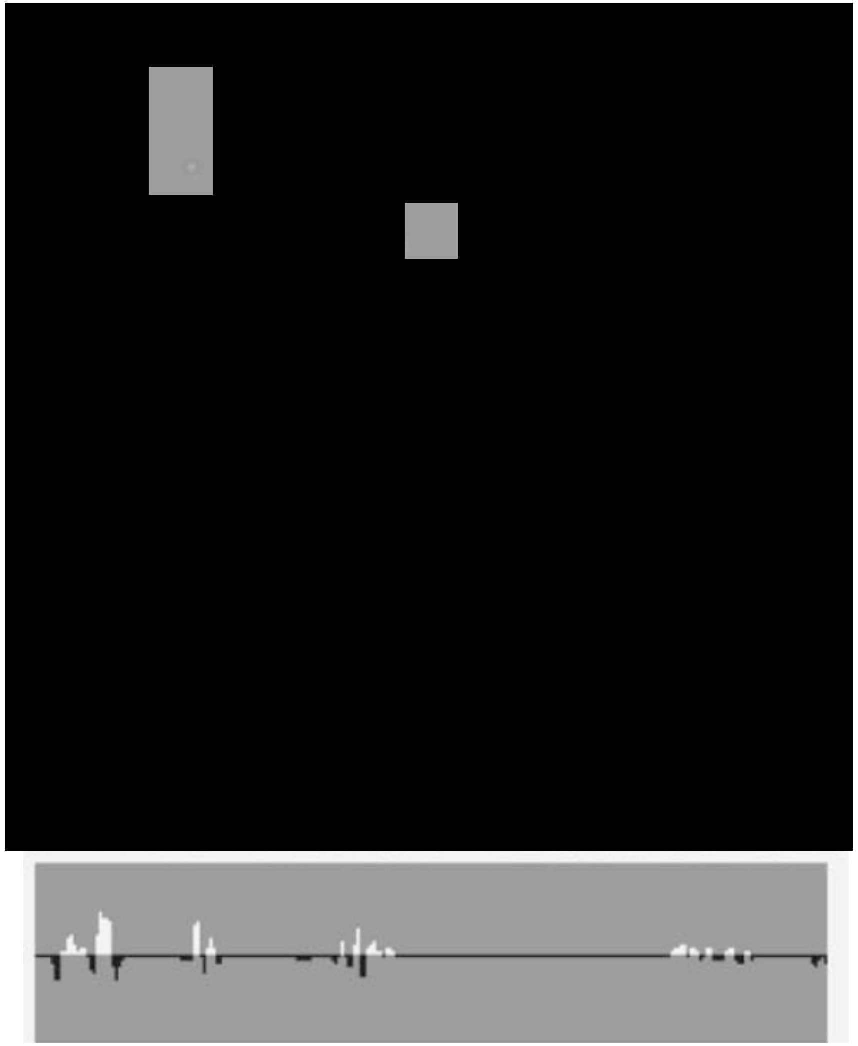
Shevell and Monnier



# Craik-O'Brien-Cornsweet Effect

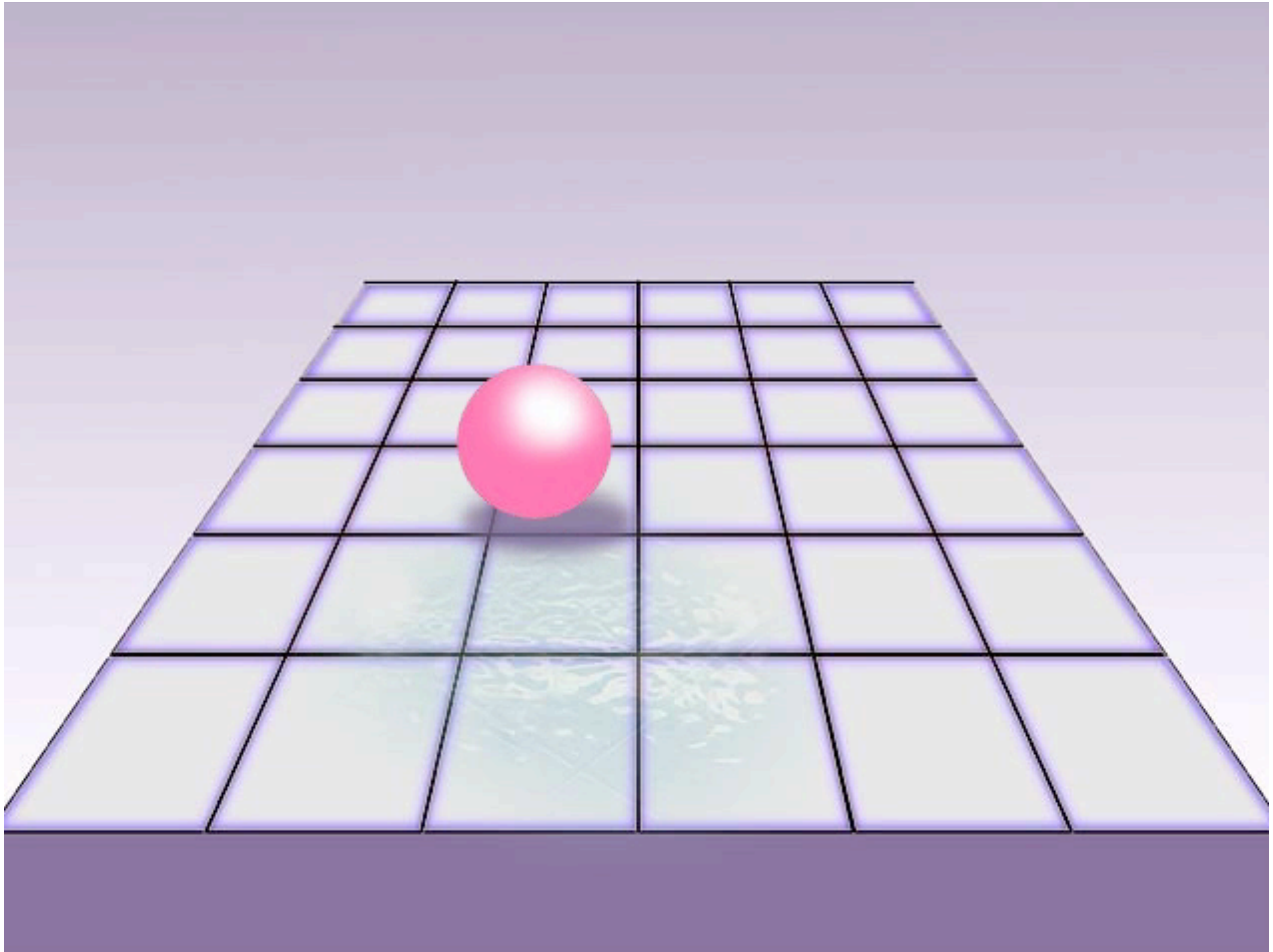


# The Visual System Interprets Data

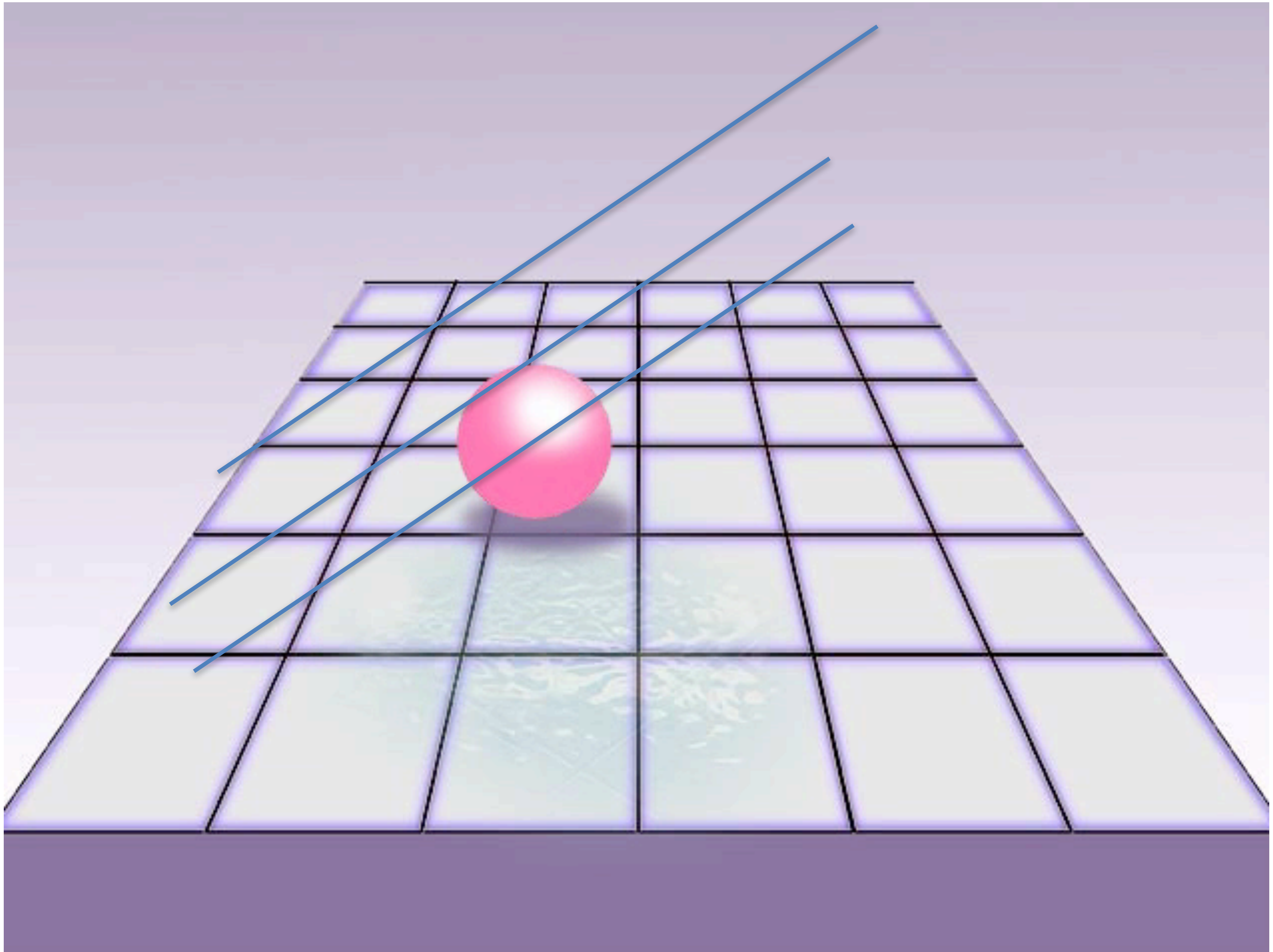



*Dakin and Bex, 2003, Proc. Roy Soc.*

# Shadows and perceived motion (Kersten)



# Shadows and perceived motion (Kersten)

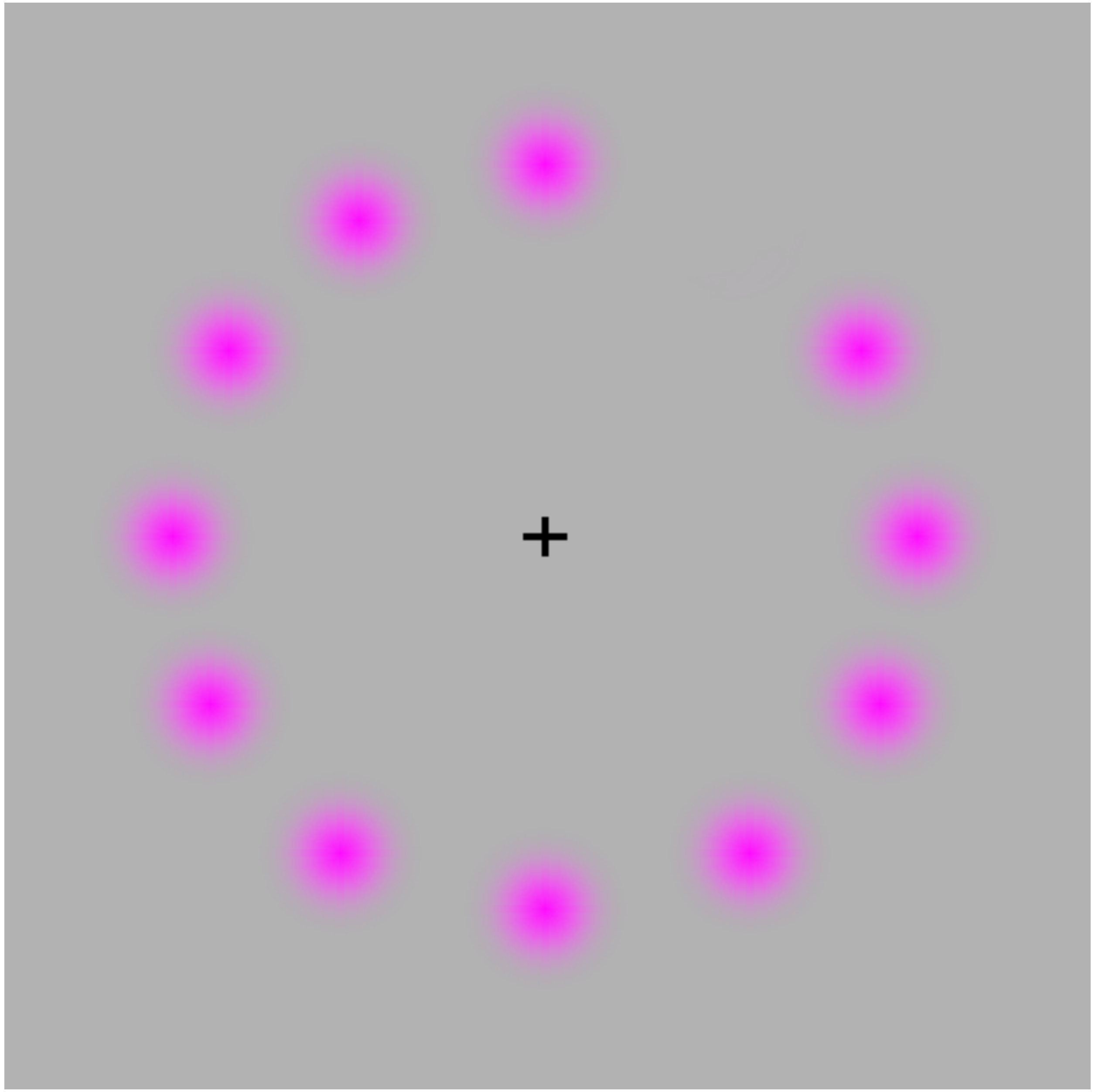


# The green dot illusion: Time-history matters

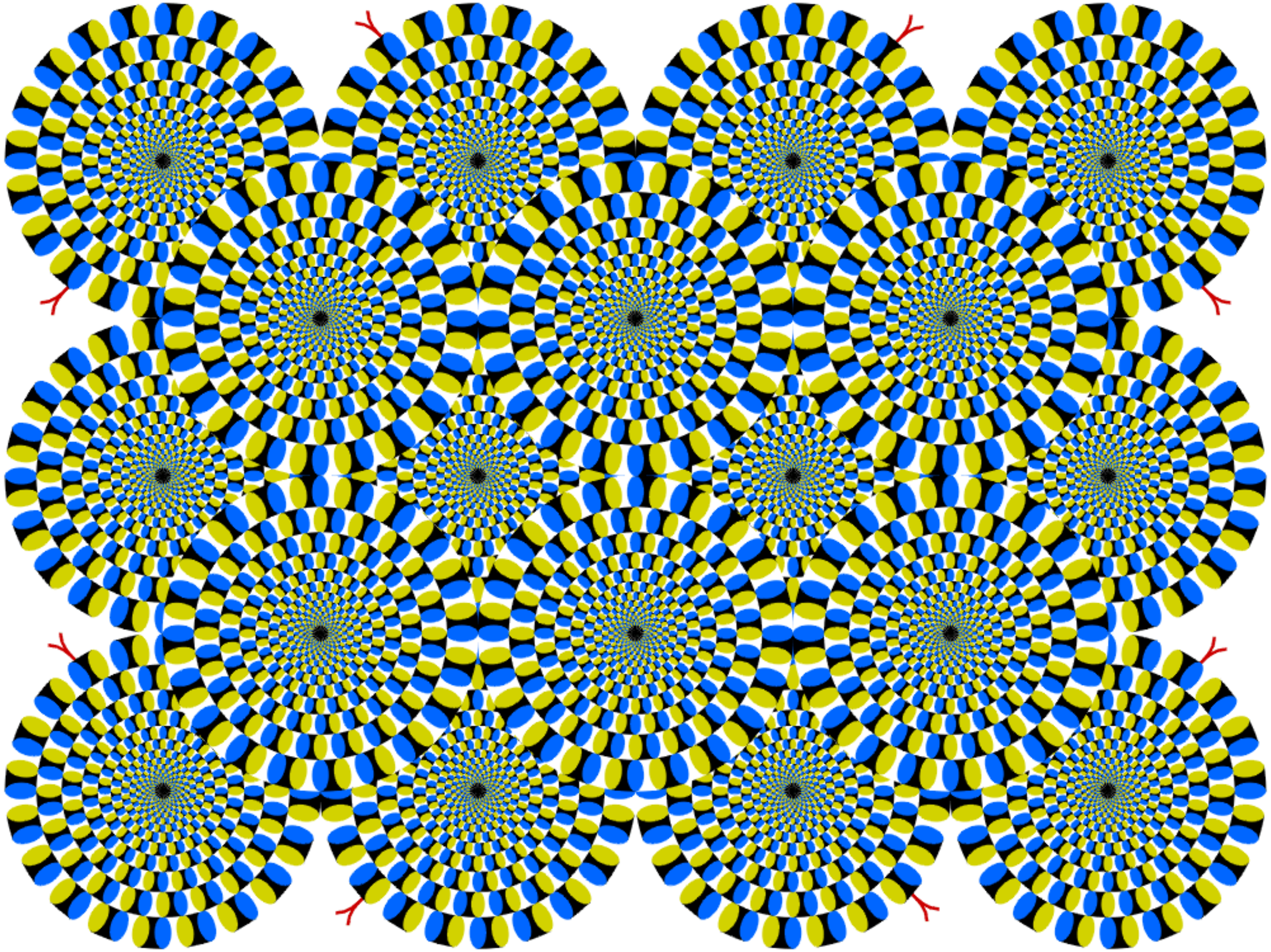
If your eyes follow the movement of the rotating pink dot, you will only see one color, pink

If you stare at the black + in the center, the moving dot turns to green.

Now, concentrate on the black + in the center of the picture. After a short period of time,  all the pink dots will slowly disappear, and you will only see a green dot rotating if you're lucky!



# Illusory Motion



# Course topics

# Scene radiance and generation

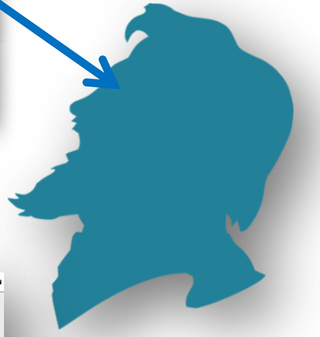
What is a light field and a plenoptic function?

What is scene radiance?

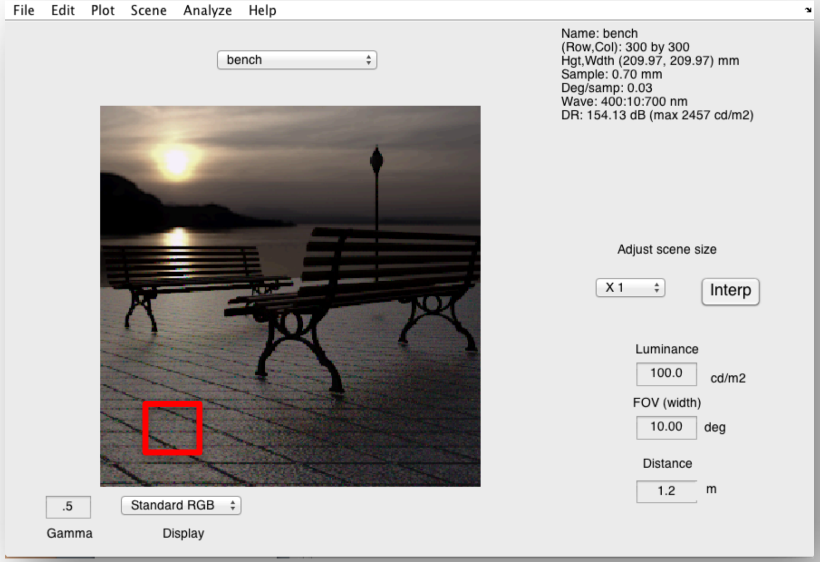
Snell's Law, F/#, Circle of confusion, diffraction, chromatic aberration, depth of field (bokeh[1])

How can I use computer graphics to generate realistic scenes and depth maps?

[1] pronounced (bow – keh)



Rendered using Blender and PBRT



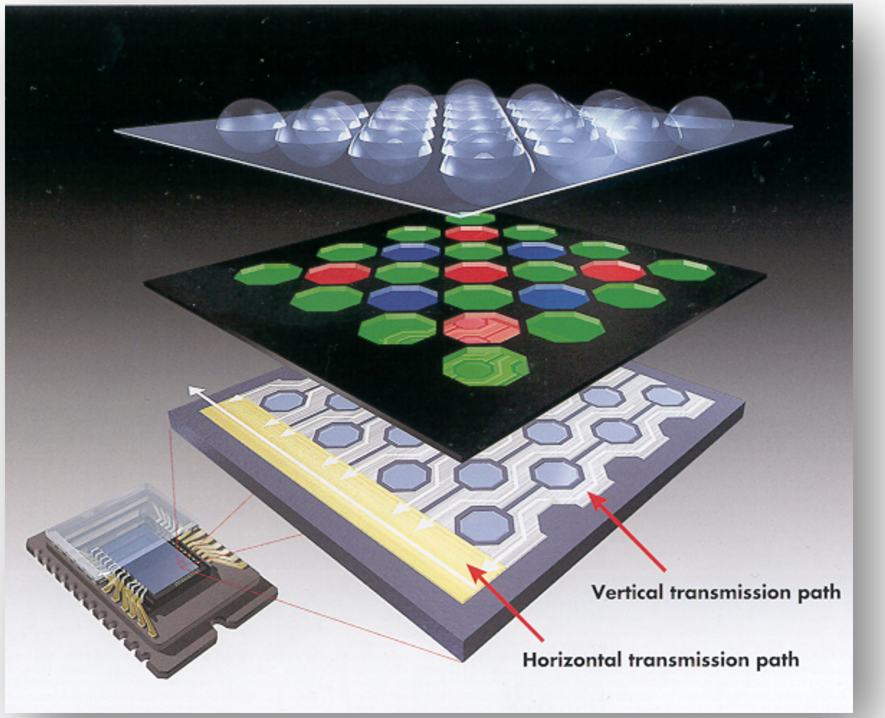
# Optics, image formation, and cameras

What are CCD and CMOS sensors?

What is the  microlens array, and what is a color filter array? Anti-aliasing filters

What are pixel sizes, fill-factors, and dynamic range?

What are camera dark noise,  quantum efficiency, fixed  pattern noise?

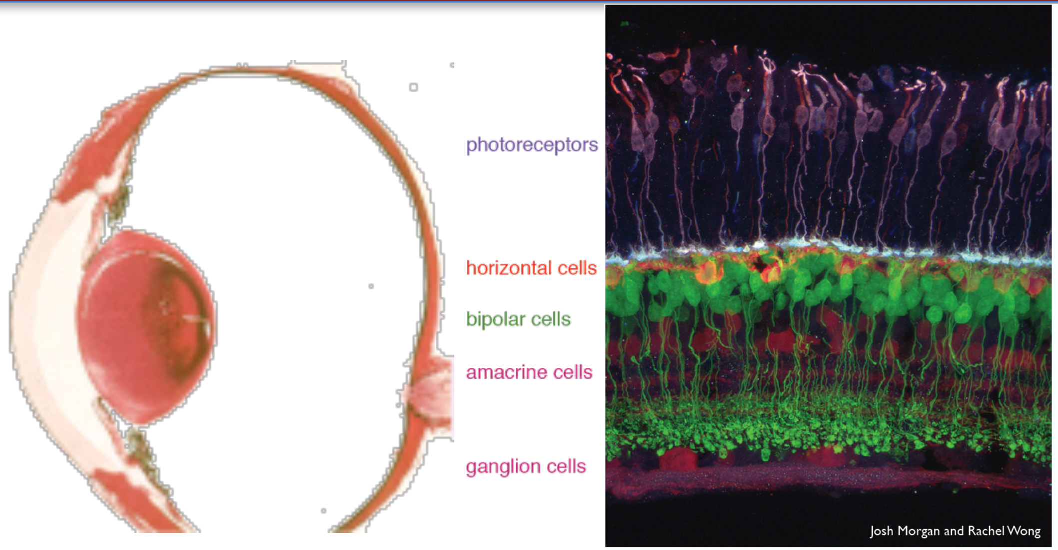



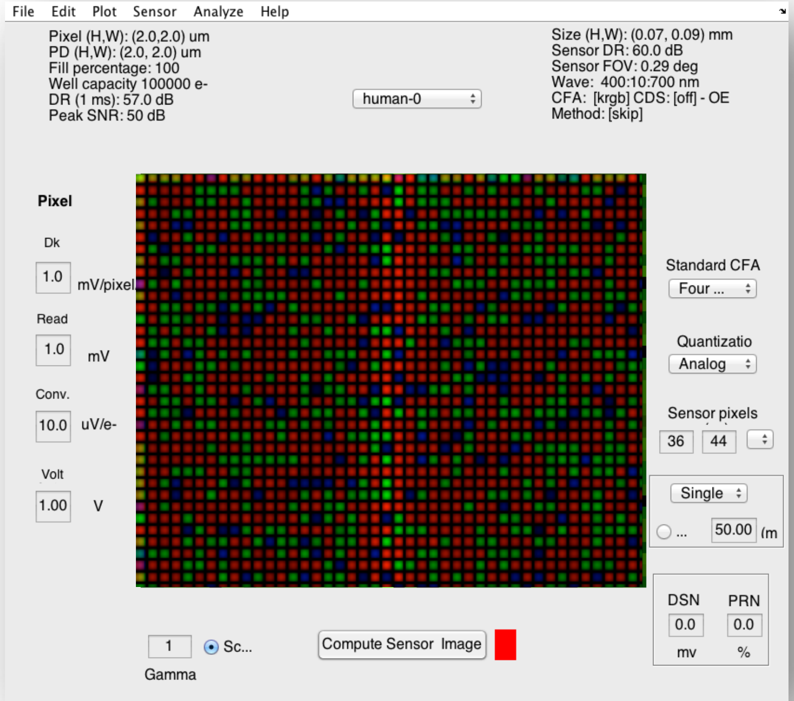
# Human retina modeling

How does the eye form images?

How do the eye's receptors encode the spectral irradiance at the retina?

How can I calculate the cone absorptions, cone photocurrent, and model retinal cell responses?



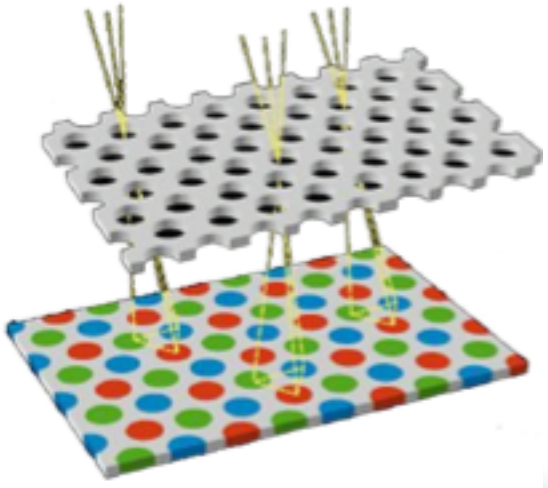
# Radiometry and color science

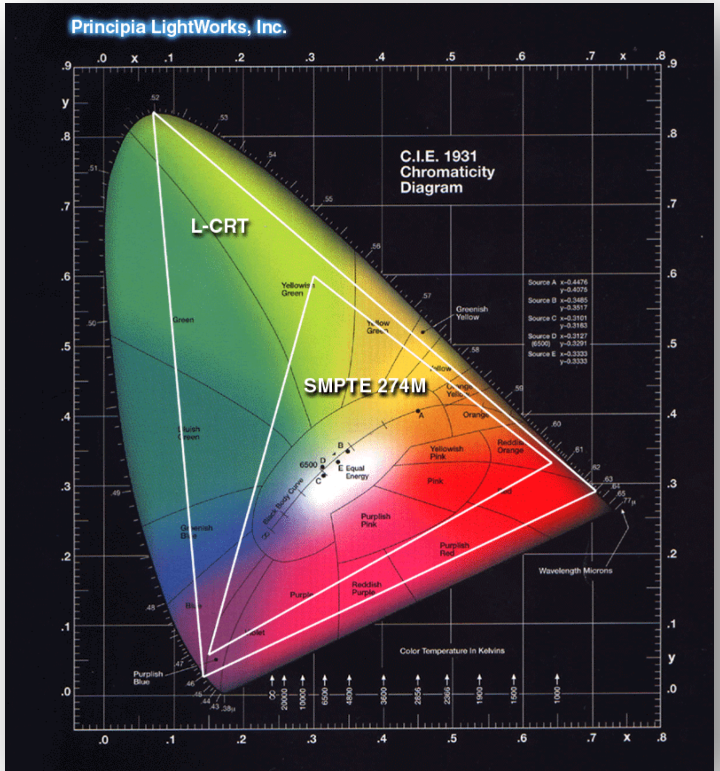
How do we measure spectral radiance and spectral irradiance?

How do we quantify colors; how do we calculate a perceived color difference?

What are CIE, xy, NTSC YIQ, YCbCr, CIELAB and CIELUV

Image processing - sensor conversion and illumination correction



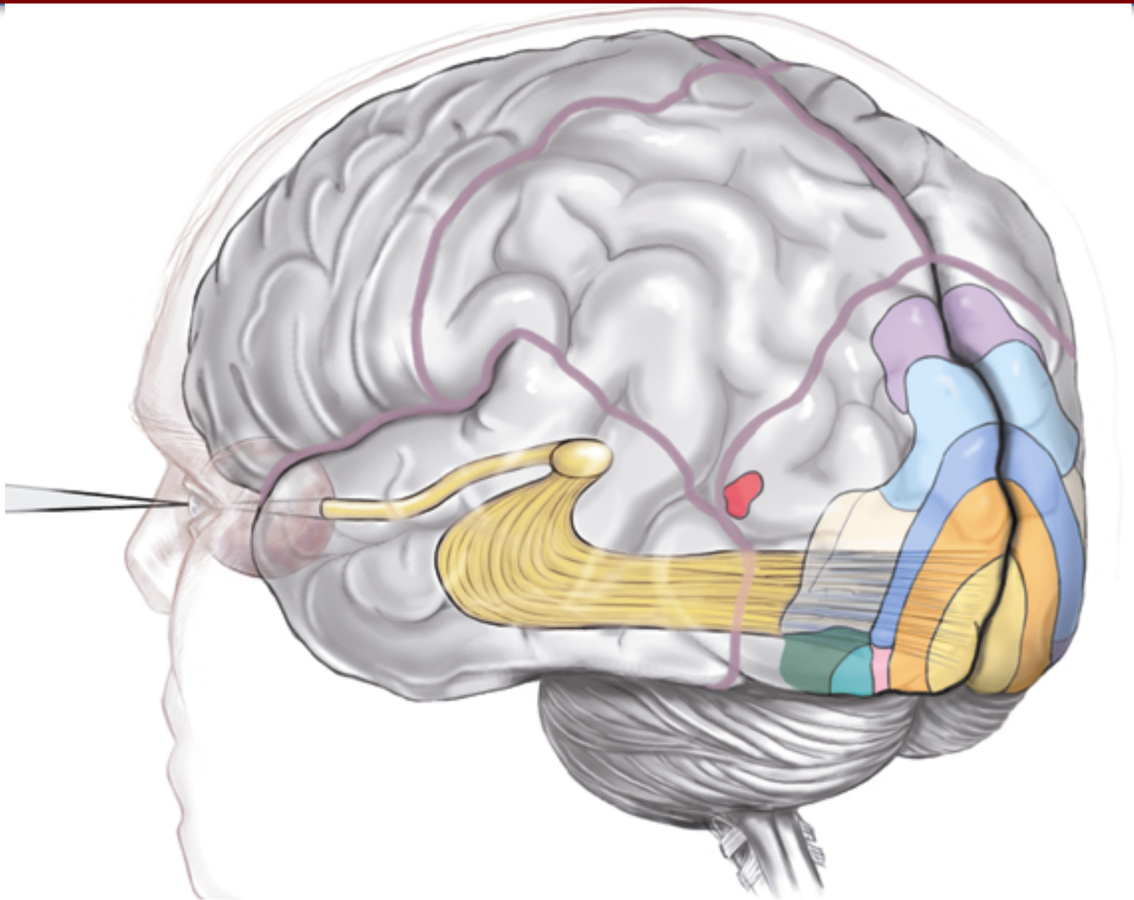


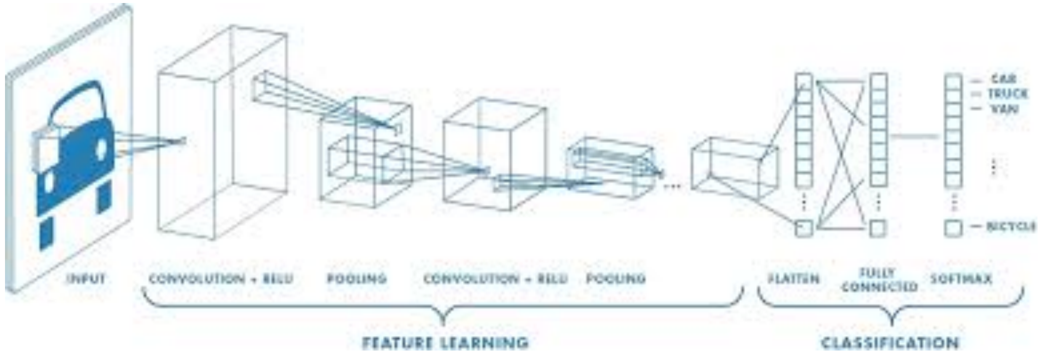
# Human spatial and temporal vision – neural networks

How do we measure and model visual pattern and temporal sensitivity?

How are multiresolution models used to summarize the human visual system?

How did the study of human vision inspire the development of Convolutional Neural Networks (CNNs)



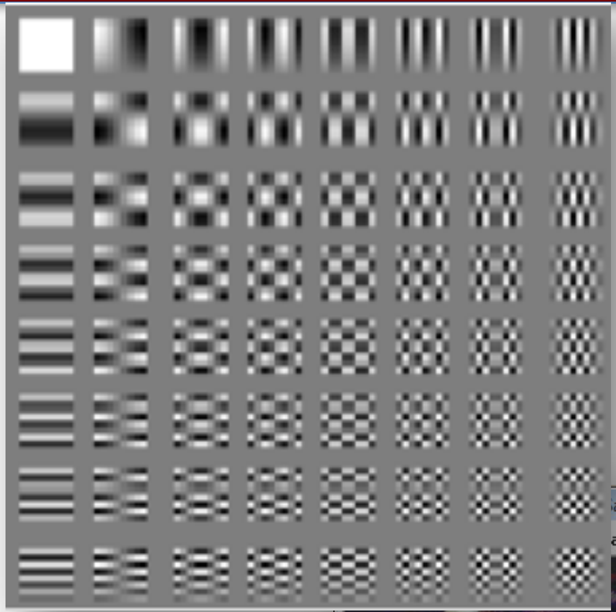


What are lossy and lossless compression?

How does JPEG use human vision principles?

What are quantization tables?

What are image pyramids, and wavelets?



# Course mechanics

Psych 221
Tuesday-Thursday 1:30PM-2:50PM

The course consists of lectures, homework, readings, and a project.

**Lectures** cover the basic ideas and provide an opportunity for discussion. Videos of lectures from past years and supplementary material are posted online at talks.stanford.edu and on my youtube channel.

**Homework** includes software and calculations related to the digital imaging pipeline.

**Projects** may include programming, measurement, or construction

**Readings**: The course textbook is Foundations of Vision (1995, Wandell). The book chapters are posted online and links can be found in the Canvas | Pages and my on my home page.

The course grade depends on **homework** (45%), a **project** (45%) and **participation** (10%)

# We use Canvas to communicate and for assignments

Stanford University

Account
Dashboard
Courses
Calendar
Inbox
Commons
Help

F17-PSYCH-221-01

*Fall 2017*

- Home
- Announcements
- Assignments
- Discussions
- Grades
- People
- Pages
- Files
- Syllabus
- Outcomes
- Quizzes
- Modules
- Conferences
- Collaborations
- Chat
- Roster Photos
- Zoom
- Settings

## Image Systems Engineering

Edit

Instructors: Professor Brian Wandell and Dr. Joyce Farrell

The course is an introduction to digital imaging systems with a particular emphasis on the role of human vision in system design. The course makes extensive use of software simulation to model digital image systems components and the human visual system. Finally, the course illustrates how image systems simulations can be useful in industrial vision applications and neuroscience.

The content includes lectures, weekly homework, and a final course project. Some background in mathematics (linear algebra) and programming (Matlab) is valuable.

The following topics are covered and software tools are introduced:

- Basic principles of optics (Snell's Law, diffraction, adaptive optics, light fields)
- Image sensors (CMOS, CCD, pixel electronics)
- Color science, metrics, and calibration (Color matching, CIE XYZ, CIELAB)
- Human vision (space, depth, motion)
- Image processing principles (Demosaicking, color balance, compression principles)
- Display technologies (LCD, OLED, CRT, HMD)
- Computational methods (Simulation, machine-learning)

**Course meeting times**
Tue, Thu 1:30 PM - 2:50 PM

**Location**
Huang Engineering Center, Room 18 (basement, next to Nvidia auditorium)

**TA Office Hours**
Trisha Lian (tlian@stanford.edu)
Tue (3:10 - 4:40 PM), Thu (3:10 - 4 PM), or by appointment
Building 420 (Jordan Hall) Room 371

PSYCH 221 | 3 units | Class # 17371 | Section 01 | Grading: Letter or Credit/No Credit | LEC
09/26/2016 - 12/09/2016

---

Stanford University

Account
Dashboard
Courses
Calendar
Inbox
Commons
Help

F17-PSYCH-221-01 › Syllabus

*Fall 2017*

- Home
- Announcements
- Assignments
- Discussions
- Grades
- People
- Pages
- Files
- Syllabus
- Outcomes
- Quizzes
- Modules
- Conferences
- Collaborations
- Chat
- Roster Photos
- Zoom
- Settings

## Course Syllabus

Jump to Today  Edit

## General

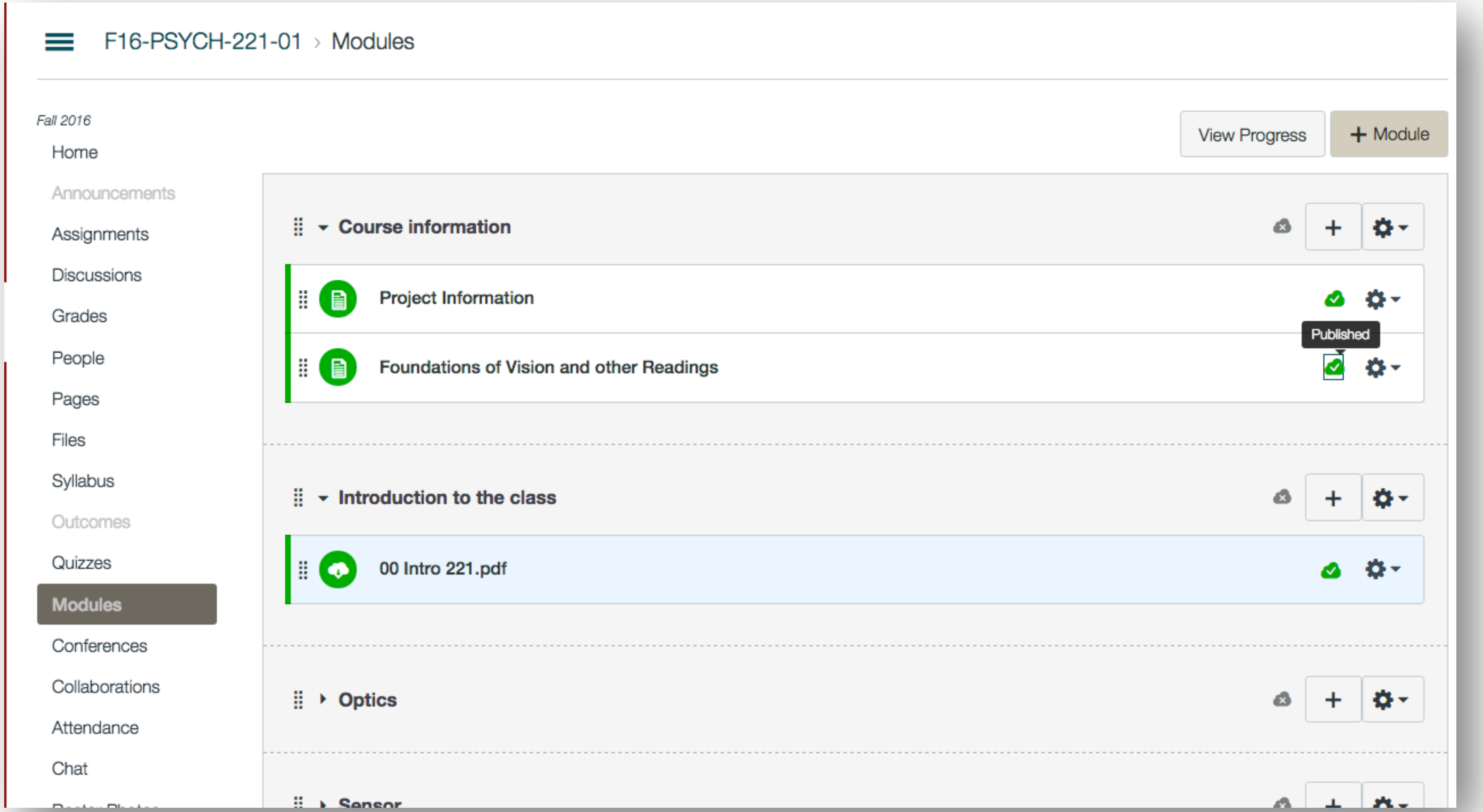
**Readings:** The course textbook Foundations of Vision (1995, Wandell) is online
**Grading:** Homework counts for 50% of your grade; the project counts for 50%.
**Homework:** Students are asked to answer weekly problem sets. These are either short answer questions or small programming problems in Matlab using the image systems' engineering toolbox (ISET). The toolbox and tutorials can be run from any computer running Matlab 7.0 or higher.
**Project:** Project suggestions and opportunities will be explained in class. Projects from previous years can be browsed here.

### Lecture schedule

| Day | Topic | Tutorials | Homework due by midnight* | Chapters | Videos | Notes |
|---|---|---|---|---|---|---|
| Tues 9/26 | Course overview | | | | | |
| Thurs 9/28 | Image formation: basic principles | | | | ISET video | |
| Tues 10/3 | Defocus, Depth of field, light field camera, linear systems | hwImageFormation.mlx hwImageFormationHuman.mlx | HW 1 Available | Chapters 1-3 | Ray tracing and light fields | |
| Thurs 10/5 | Adaptive optics and human optics | | | | | |
| Tues 10/10 | CCD and CMOS Sensors, Rolling and Global Shutter, 3T pixel, Pixel response model, CFAs, HDR pixels | | HW 1 Due HW 2 Available | | | |
| Thurs 10/12 | Sensor calibration and modeling (ISET) | hwSensorEstimation.m hwMetricsMTF.m | | | | Joyce |
| Tues 10/17 | Novel sensor designs (Triple well, Pixim) | | HW 2 Due HW 3 Available | | | |

# The “Modules” on Canvas have the main sequence of events

The lecture slides, video tutorials, and software for the course will be available through the Modules page.



# Projects: Imaging industry continues to innovate with cameras and displays


Multiple lens


RGB-depth


Light field

360 Surround Video



VR, AR and MR HMDs

# Projects: Innovation is speeded by simulation

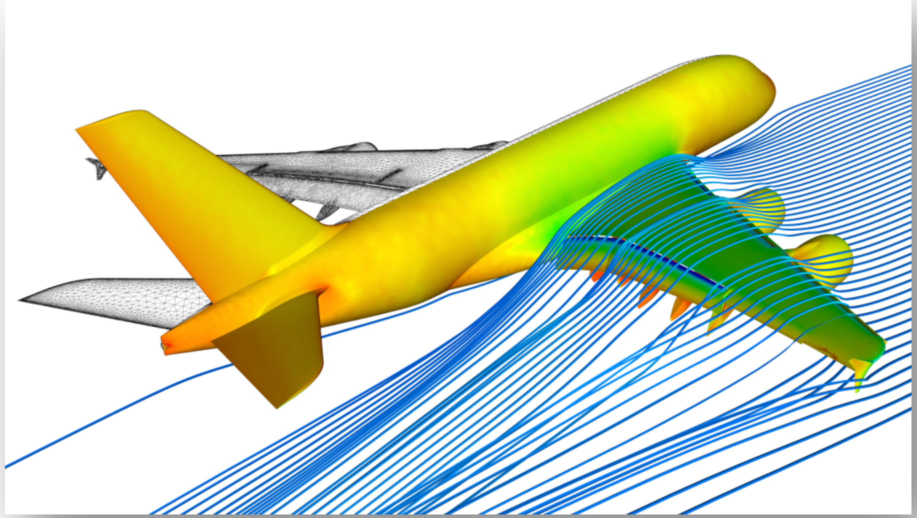
- Device development relies very heavily on physical prototyping
- Simulation could significantly reduce development time
- Simulation could enable testing more ideas, enhancing innovation

[Thanks to Brian Cabral, Facebook, @SCIEN 2016]

# Projects: Image systems simulation

Simulation is important in many mature industries

ECU (Electronic Control Unit) Simulation for Automobiles



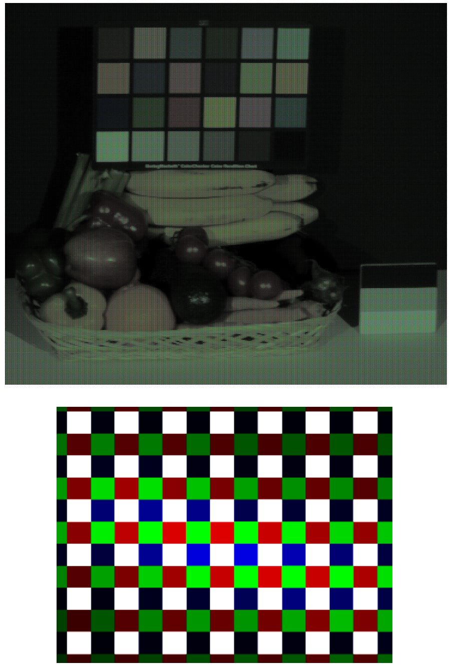
Numerical flow simulation on an Airbus A380


Magnetic resonance simulations

# Projects: Image systems simulation

Four examples of soft prototyping using image systems simulation methods

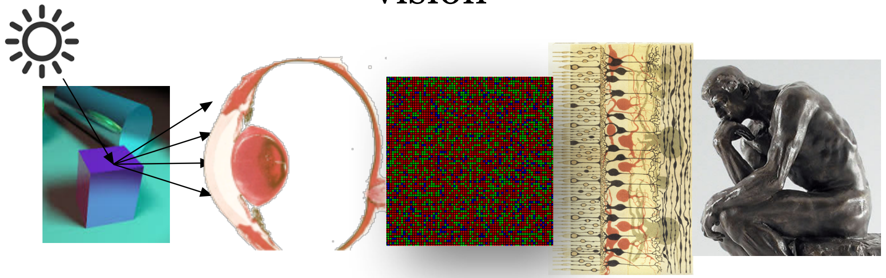
Learning the image processing pipeline for a novel sensor



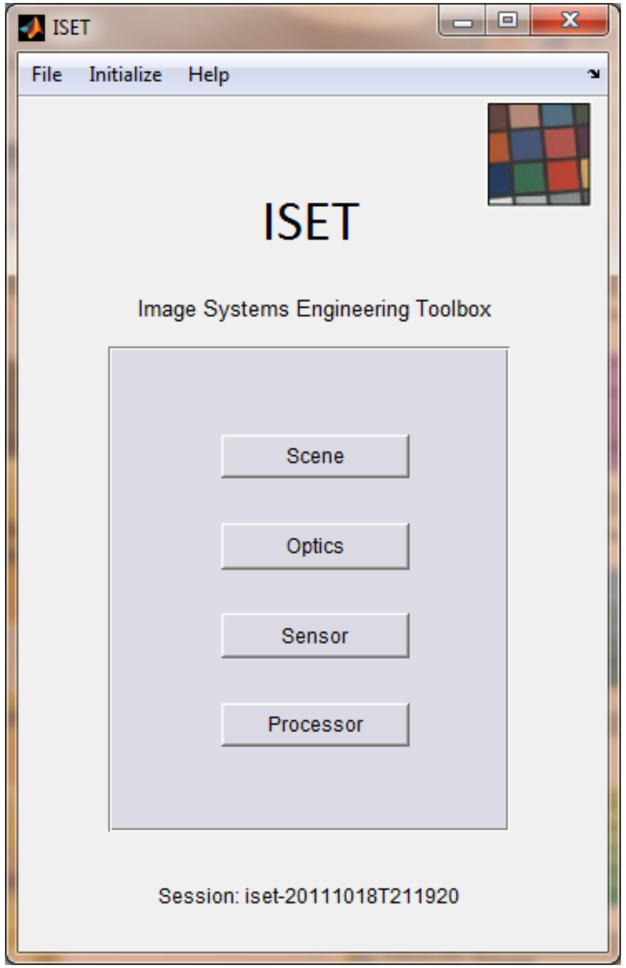
Camera designs for VR

Machine learning for autonomous vehicles

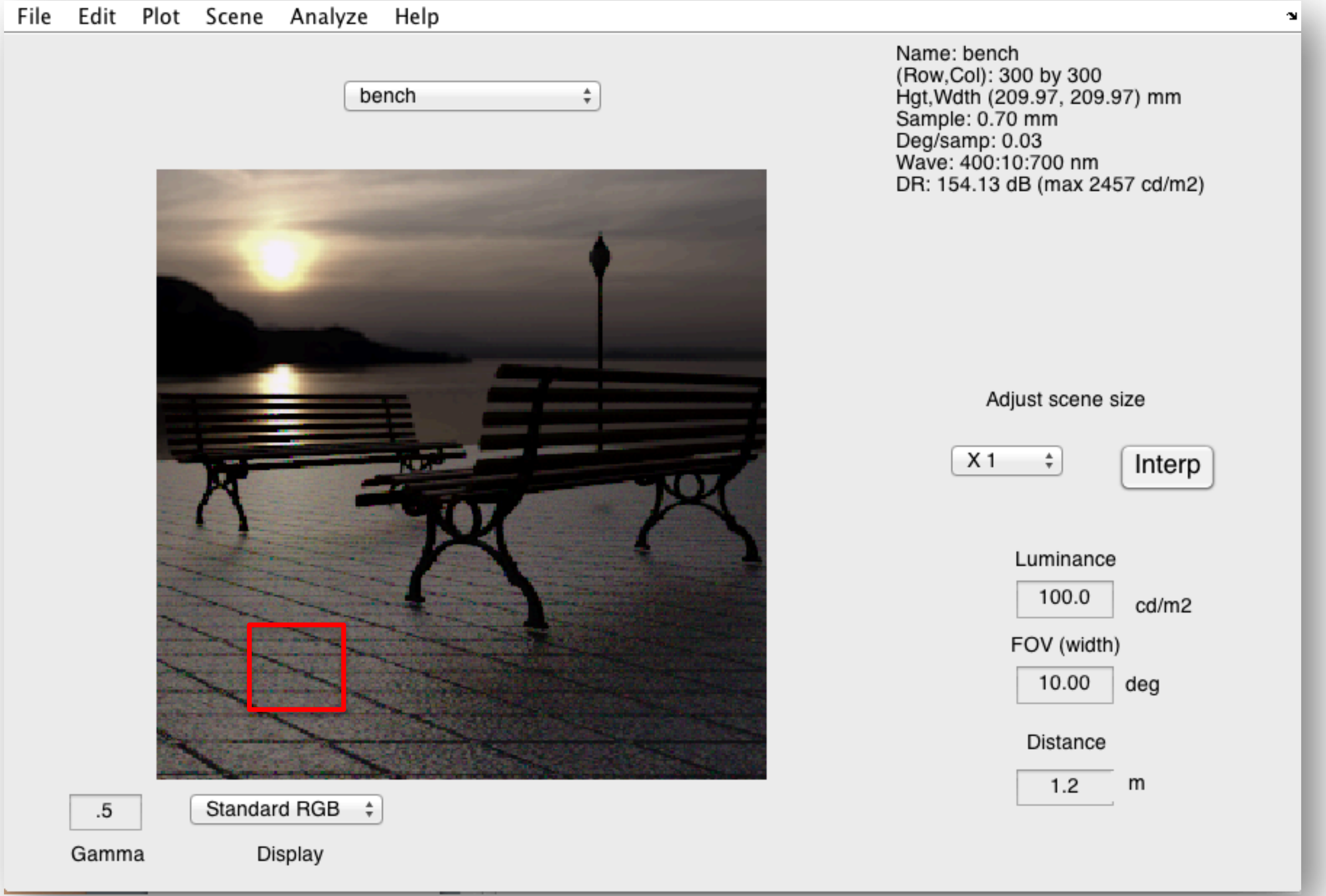

Modeling human vision



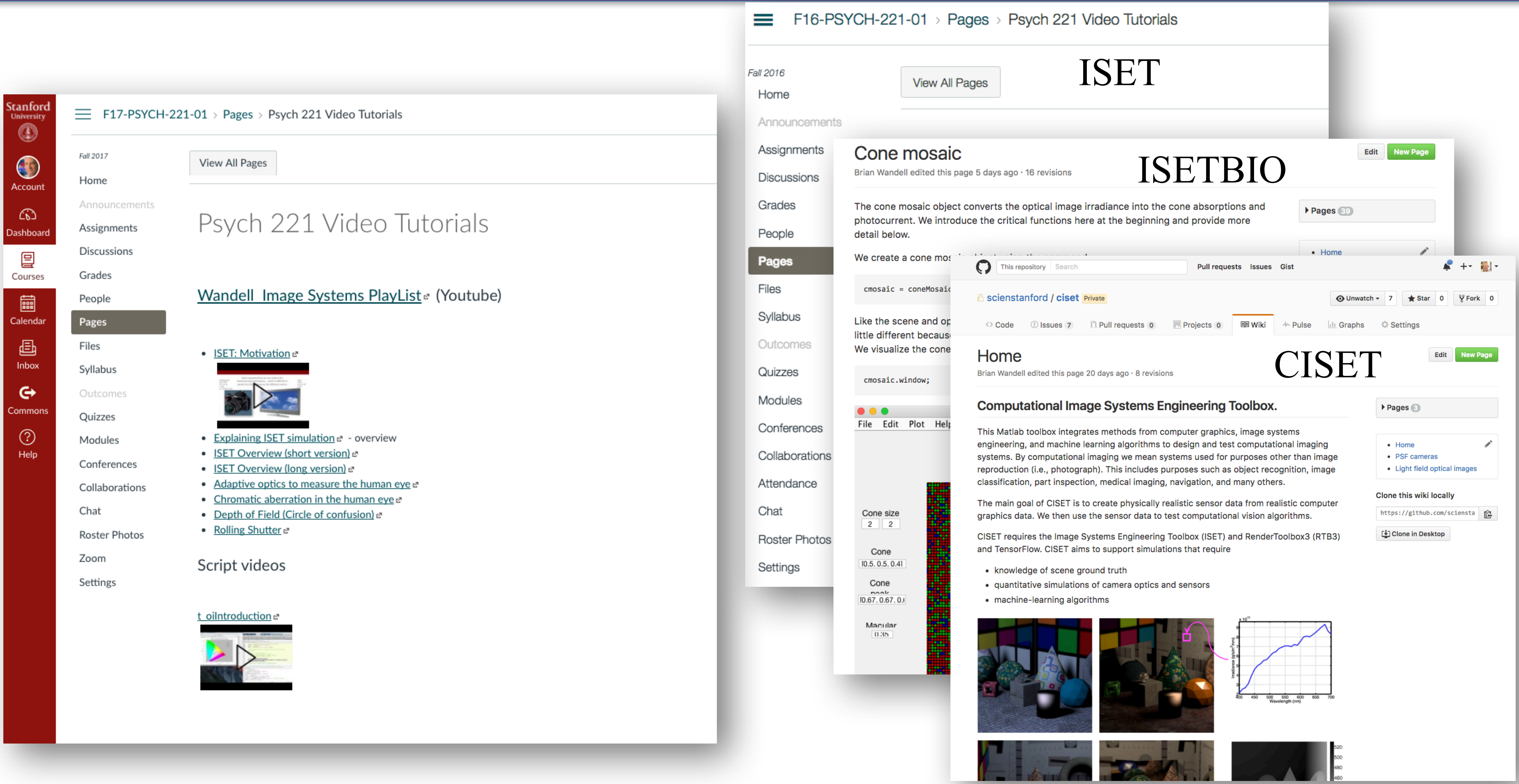
# Software tools for image systems simulation




## Simulated scene radiance calculated using PBRT



# Software tutorials and toolboxes for different projects



# About ISET tutorials

A page with many tutorial scripts

http://imageval.com/wiki/doku.php?id=tutorials

There are about 100 tutorials

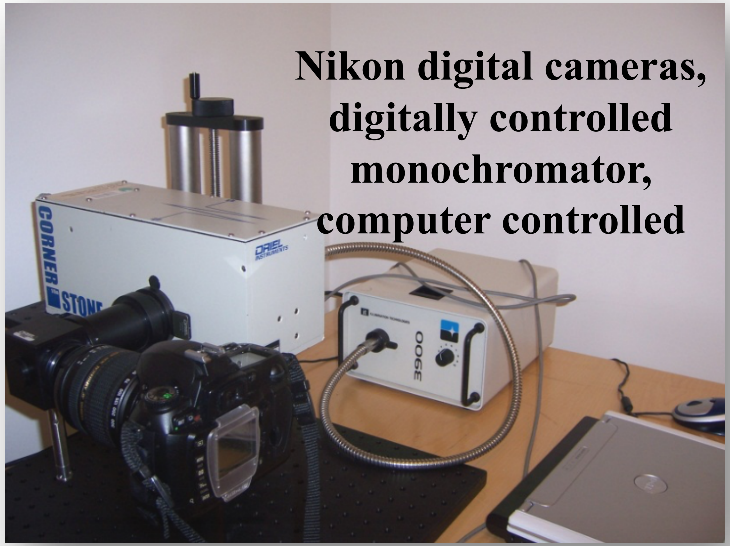
An example scene introductory script

http://imageval.com/Scripts/scene/t_sceneIntroduction.html

We are trying to produce online video tutorials as well on my YouTube Channel in the Image Systems Playlist

# SCIEN Lab (070, Packard)

Building, calibrating, evaluation





Large format printer

Photometer

# Project Suggestions Wiki Page (Software)

[Link to Project Suggestions Page]

- Cell phone image processing pipeline modeling and experiments
- Machine-learning and camera properties
- Stereo image pair database
- Stereo algorithm assessment
- More …

## Projects Fall 2017

### Modeling a cell phone camera pipeline

The good folks at Google wrote a paper describing how they make high quality images on a cell phone camera. The paper is included on our Canvas web-site.

Burst photography for high dynamic range and low-light imaging on mobile cameras. Hasinoff et al., ACM Trans. Graph. Vol. 35, No 6. Article 192 (2016).

For some of the projects, we can divide up different parts of the image processing pipeline described in this paper and simulate the expected results using the ISET tools. The critical simulation concerns the acquisition of many brief images, alignment of these images, and combining the results into a high quality result. Let's see how far we can get in doing an assessment of their burst photography design with software simulation tools.

### Camera properties and machine-learning algorithm performance

There are two thoughts about image sensors and machine-learning algorithms. One group of people thinks that the algorithms will run across any type of camera. Another group thinks that changing the camera optics and sensor may have an impact on the algorithm performance.

It is likely that the truth is somewhere in between. Some optics and sensor changes will have an impact on some types of algorithms. But we are not aware of any systematic studies that have examined how changing out camera parameters will influence the performance of convolutional neural nets (CNNs).

We can use the ISET tools in this class to simulate images obtained by cameras with optics and sensors. Those of you who are interested or skilled in machine-learning for image classification or object detection can create a project to evaluate how well a CNN trained for one camera will generalize to images obtained from a different camera.

### Depth from Stereo Images

#### Database of synthetic stereo images

The Middlebury Stereo dataset is a collection of stereo images with "ground truth" disparities or depth maps. Researchers and students have used datasets that are part of this collection to compare different methods for estimating depth from stereo images. The depth maps are inherently noisy due to that they are empirically measured using range-sensing devices or structured lighting

This project will use our lab software to create a new database of synthetic stereo camera images and associated depth maps. You can modify the scene properties of a scene, position the cameras in the scene, modify the baseline distance separating two cameras, and modify properties of the optics and sensors in the two cameras.

#### Stereo algorithm assessment

As a related project, a cooperating group might run depth estimation algorithms that are already published on the web (see, for example,

# What’s next?

1. Sign up for the class on Axess

2. Go to the class web-page on Canvas and look around

3. Start doing the readings (online, FOV-2,3)

4. Download ISET and the Psych 221 homework live scripts