Introduction

Introduction to Computer Vision: CS 566

Computer Sciences

University of Wisconsin-Madison

Instructor: Mohit Gupta

Typically We Would Talk About…

Computer Vision

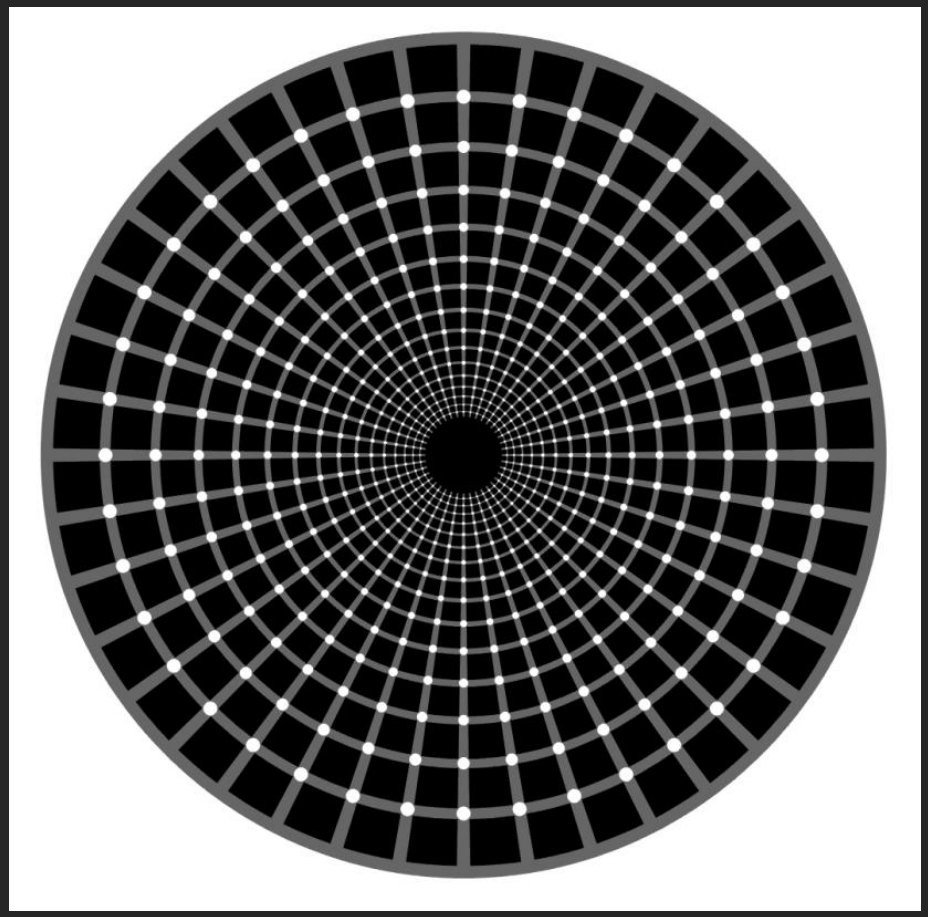
Successes

But First, Let's Talk About…

Human Vision

"Failures"

Optical Illusions



What are optical illusions?

Perception: I see 

Light (Sensing)

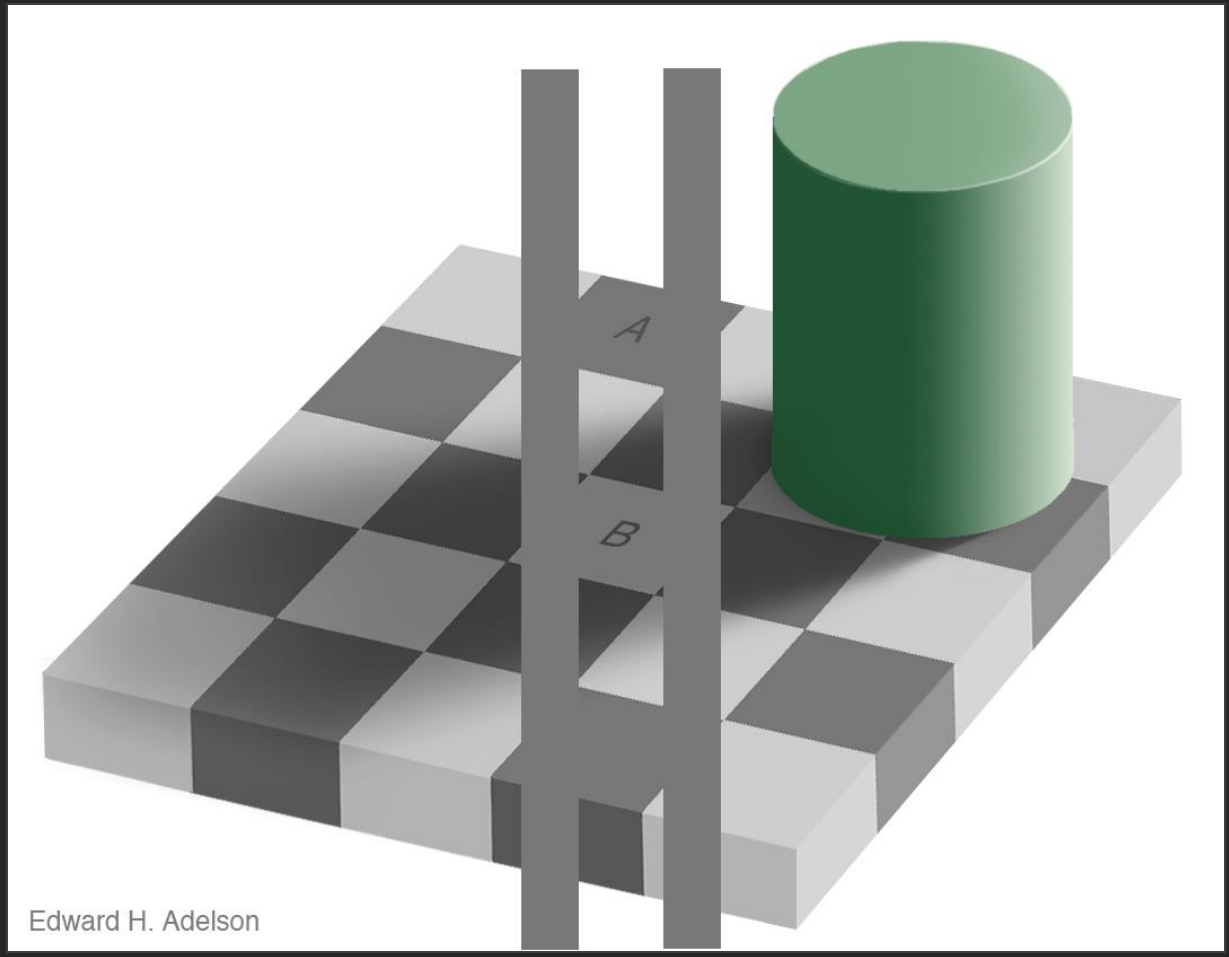
Truth: But this is an  !

Oracle

Optical Illusion in Nature

Image Courtesy: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter19/graphics/infer_mirage_road.jpg

A Brightness Illusion



Why study optical illusions?

- Studying how brain is fooled teaches us how it works

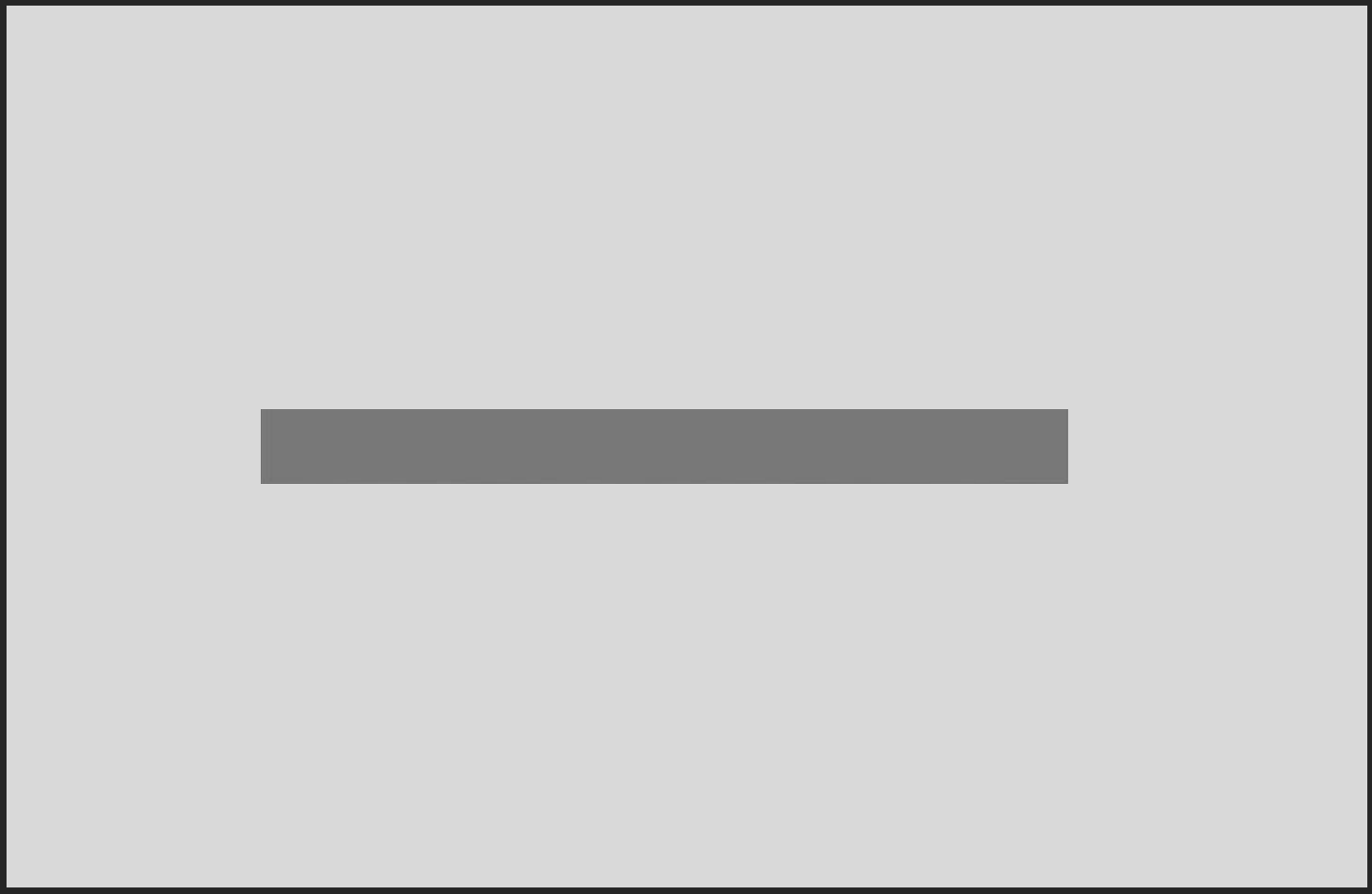
  "Illusions of the senses tell us the truth about perception" [Purkinje]

- It makes us happy ☺ : *Al Seckel*

Different kinds of illusions

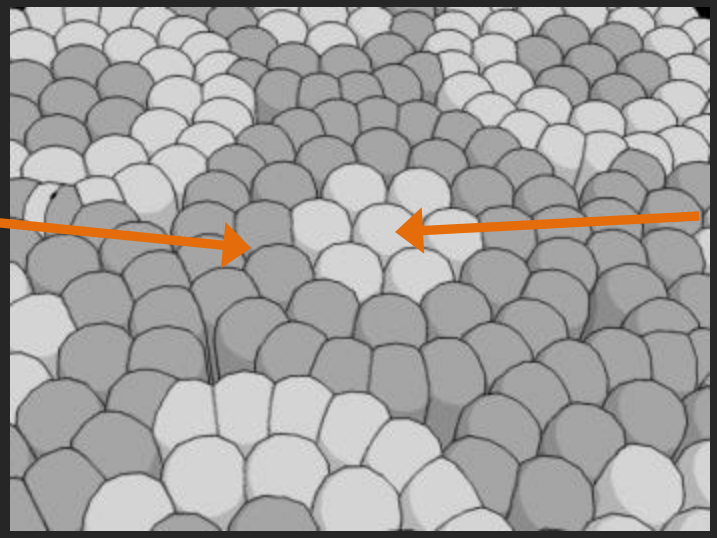
- Brightness and Contrast Illusions
- Color Illusions
- Perspective Illusions
- Relative Motion Illusions
- Illusions of Expressions

Simultaneous Contrast Illusions



Low-level Vision Explanation

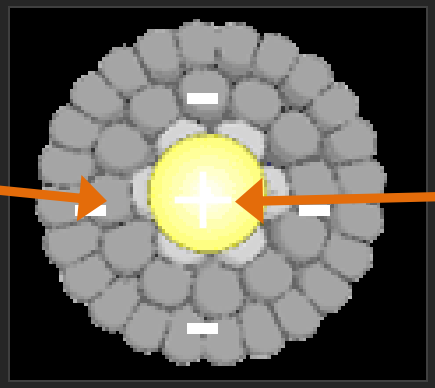
Negative
Photo-receptors



Positive
Photo-receptors

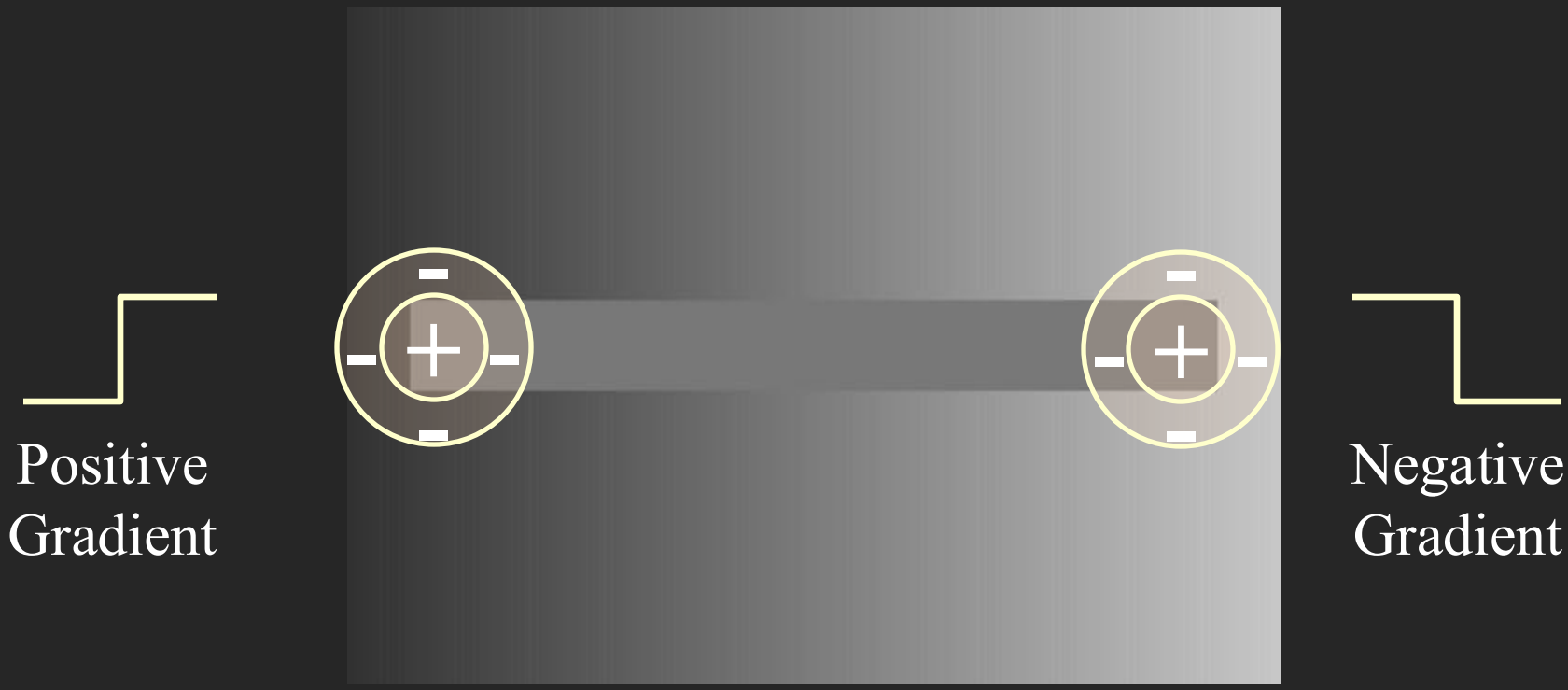
Receptive Fields in the Retina

Inhibitory
Light



Excitatory
Light

Low-level Vision Explanation



High-level Vision Explanation: Context

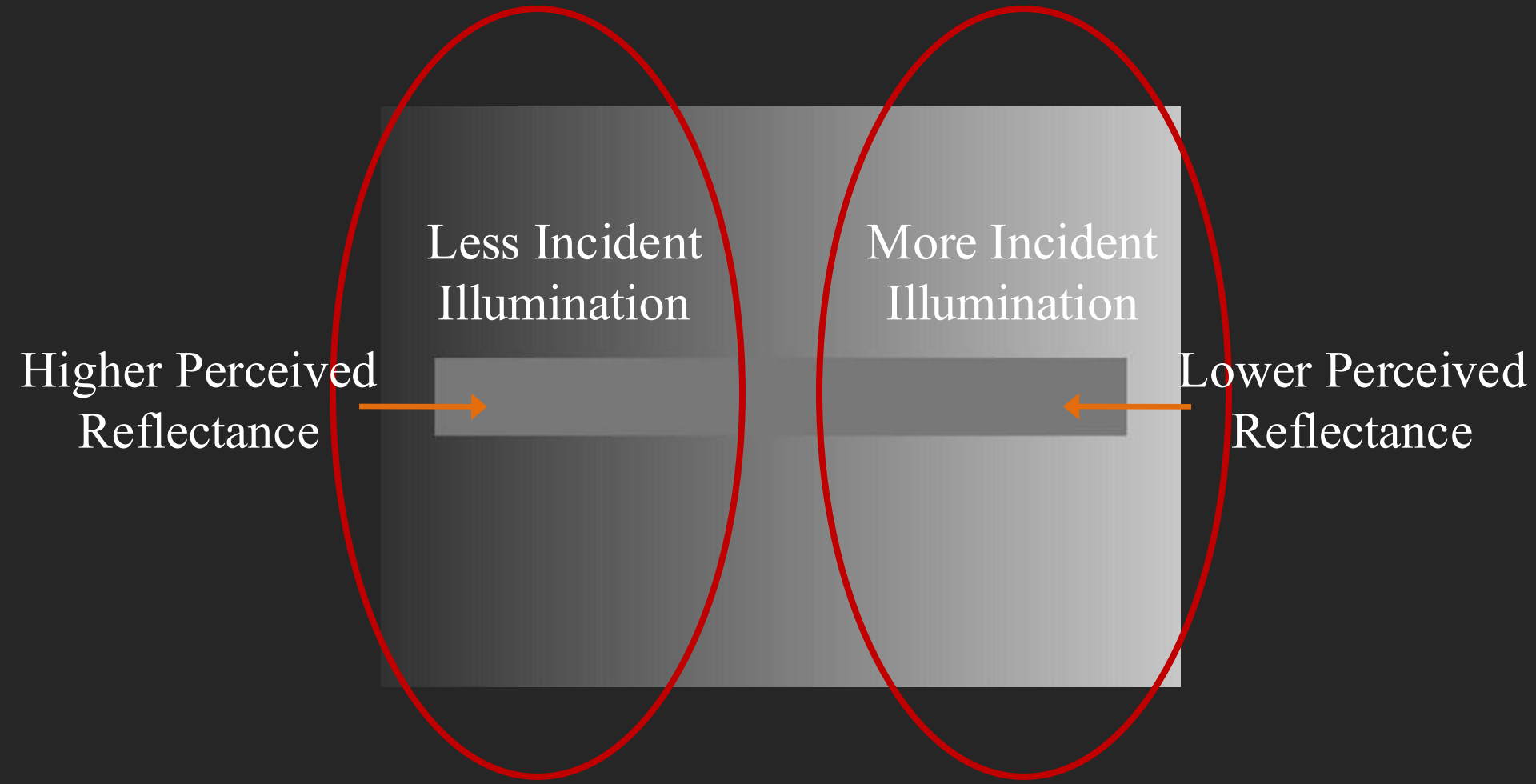
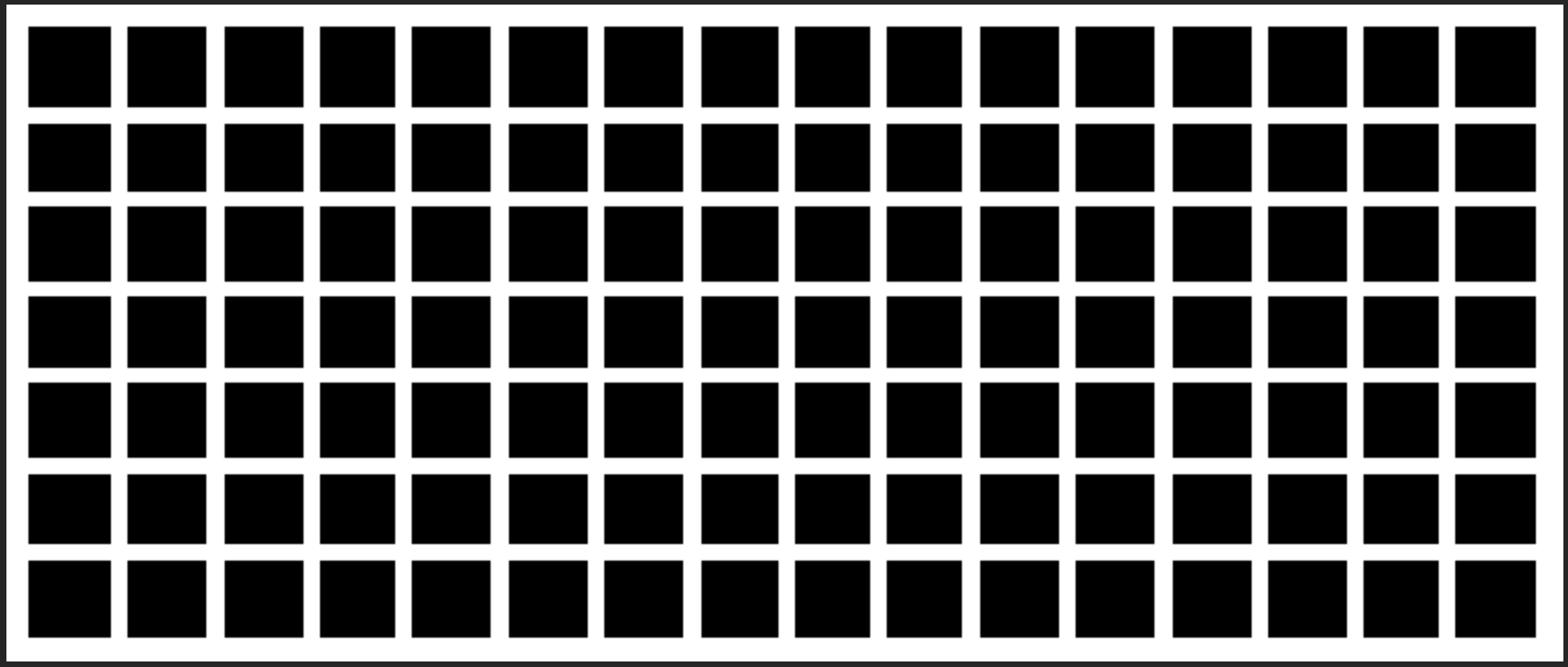
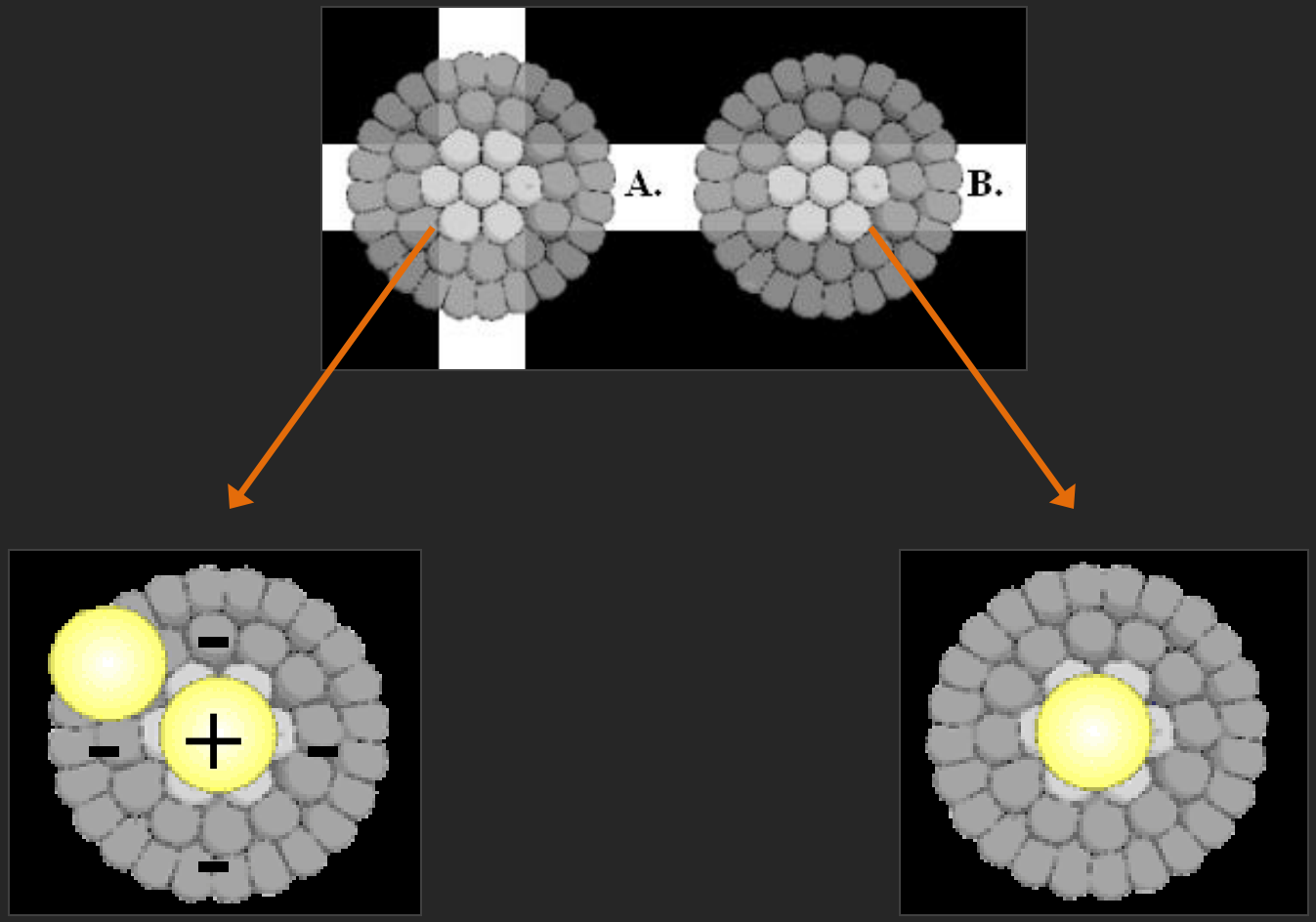


Image Intensity = Object Brightness * Incident Illumination

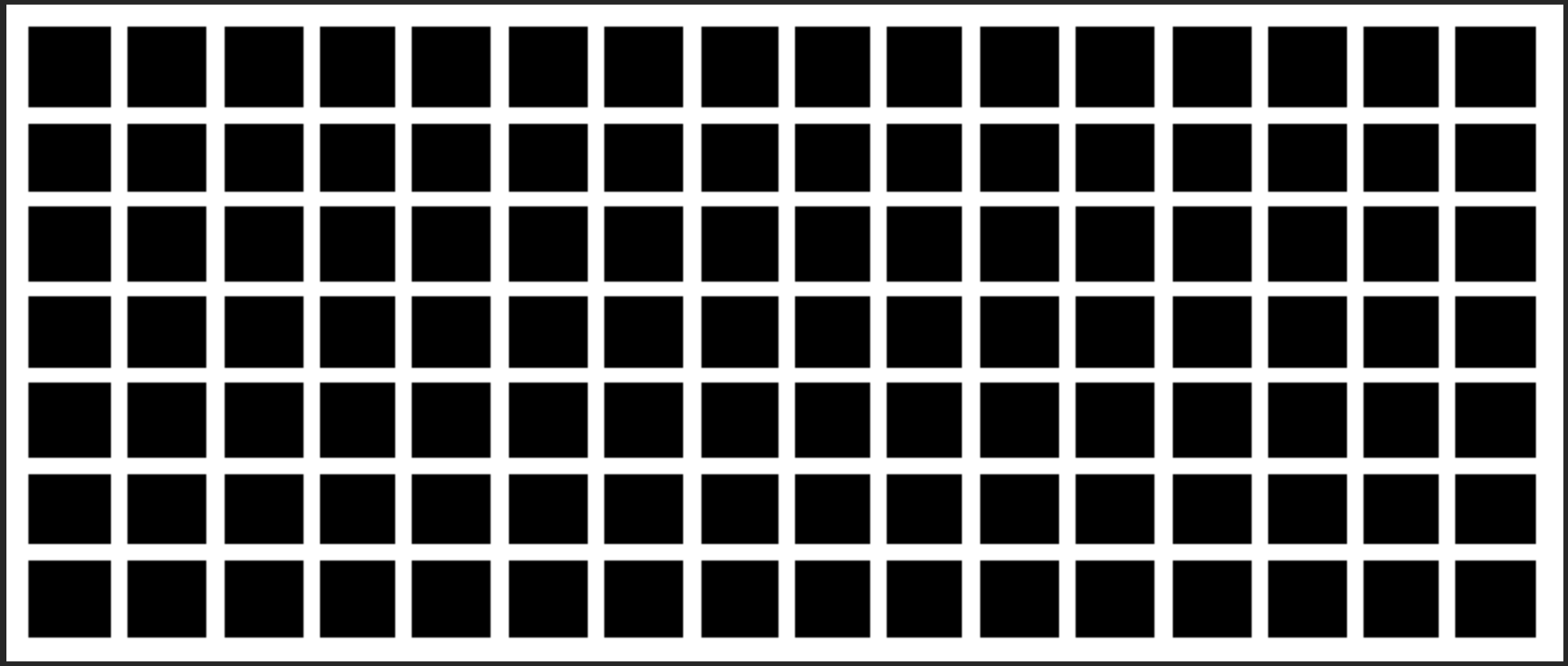
The Hermann grid illusion



The Hermann grid: Low level Explanation

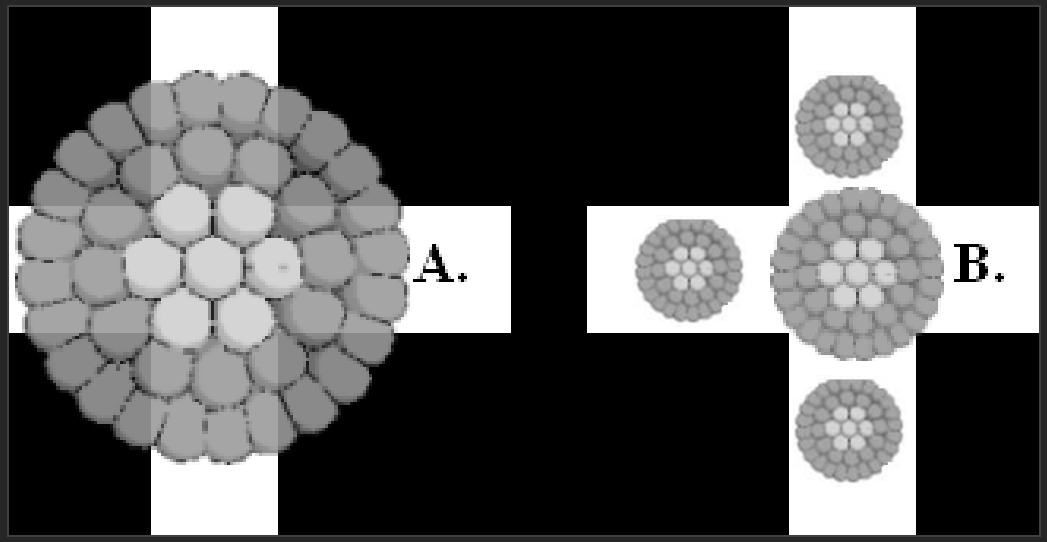


The Hermann grid illusion



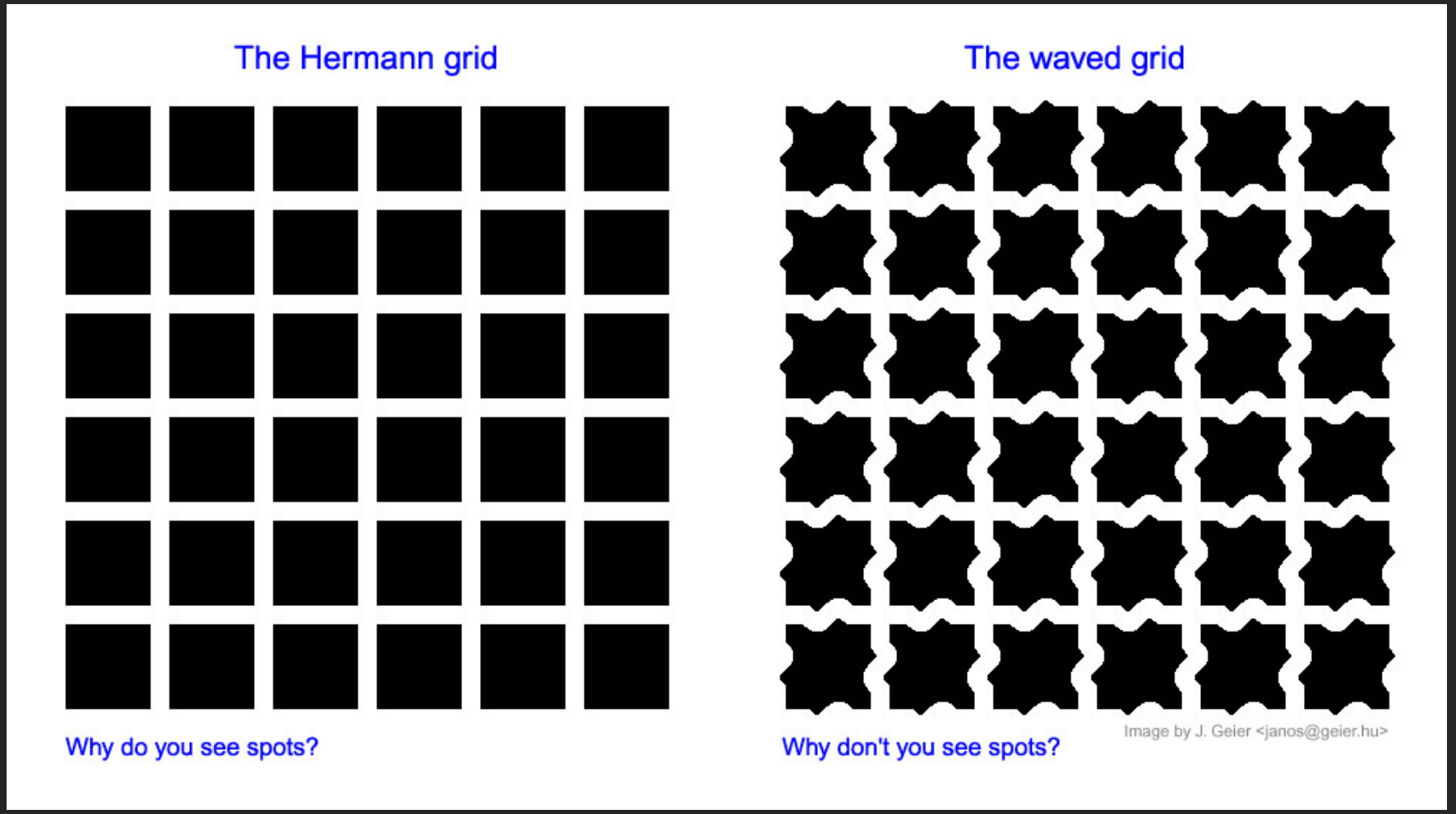
Focus on one intersection

Why does the illusion disappear?

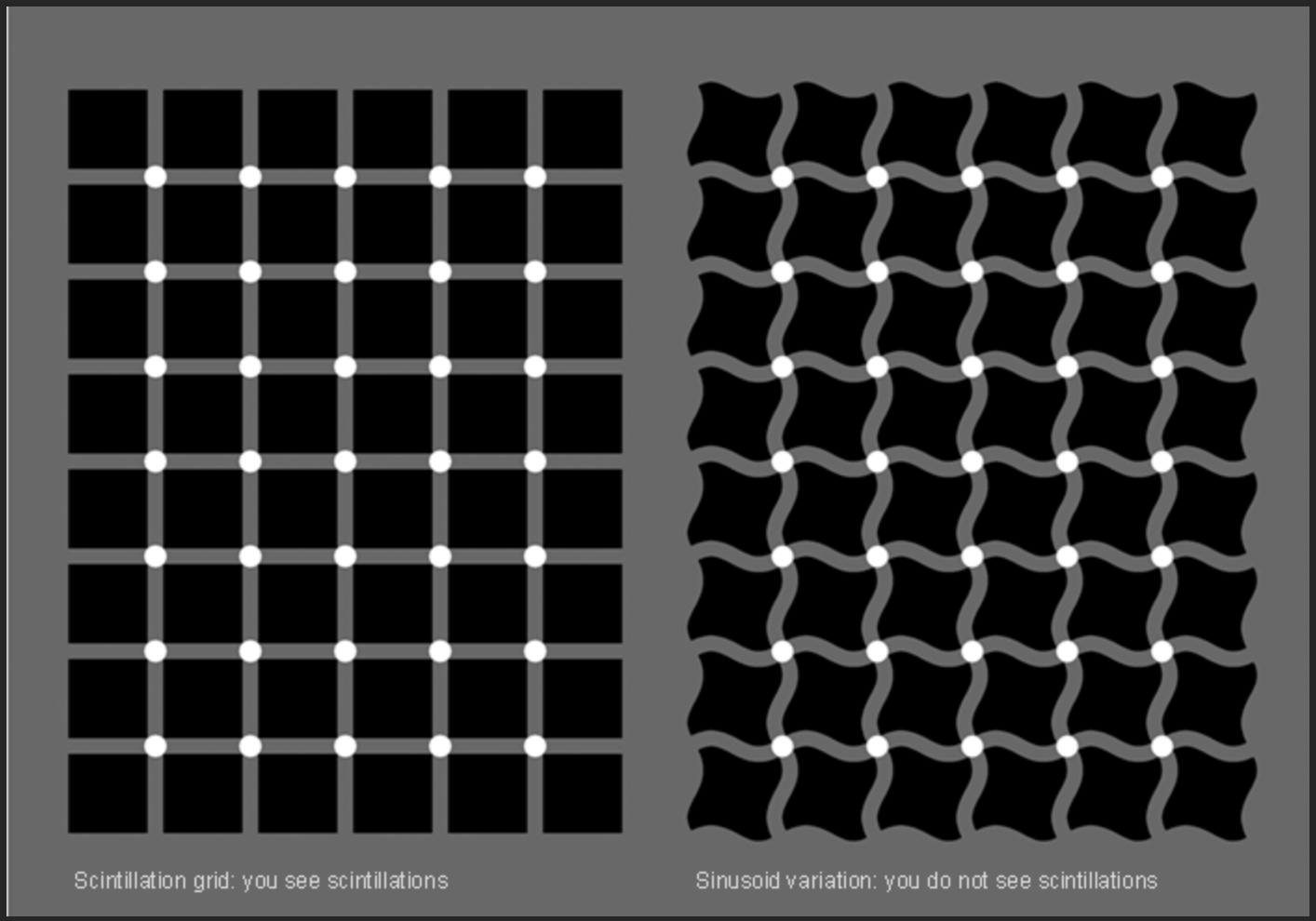


Receptive fields are smaller near the fovea (center) of the eye

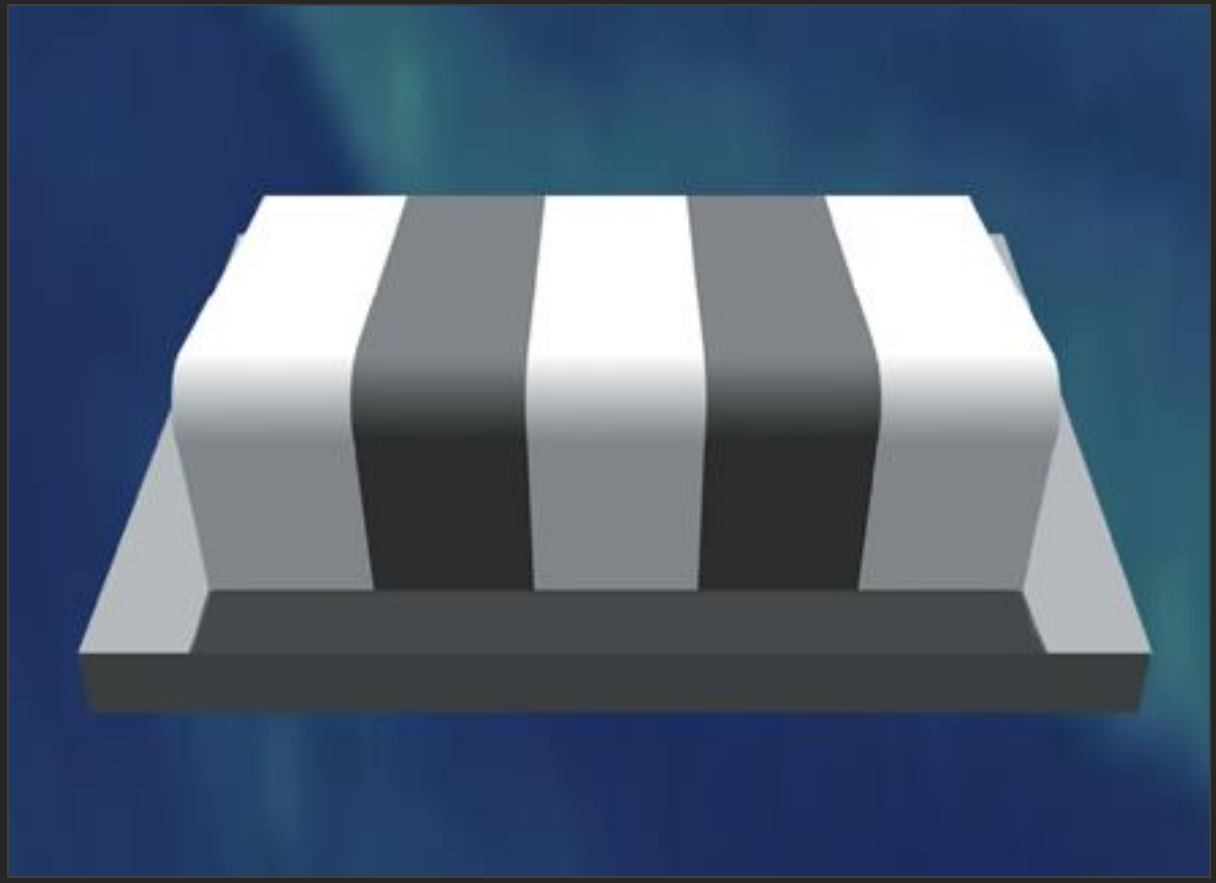
The Waved Grid: No illusion!



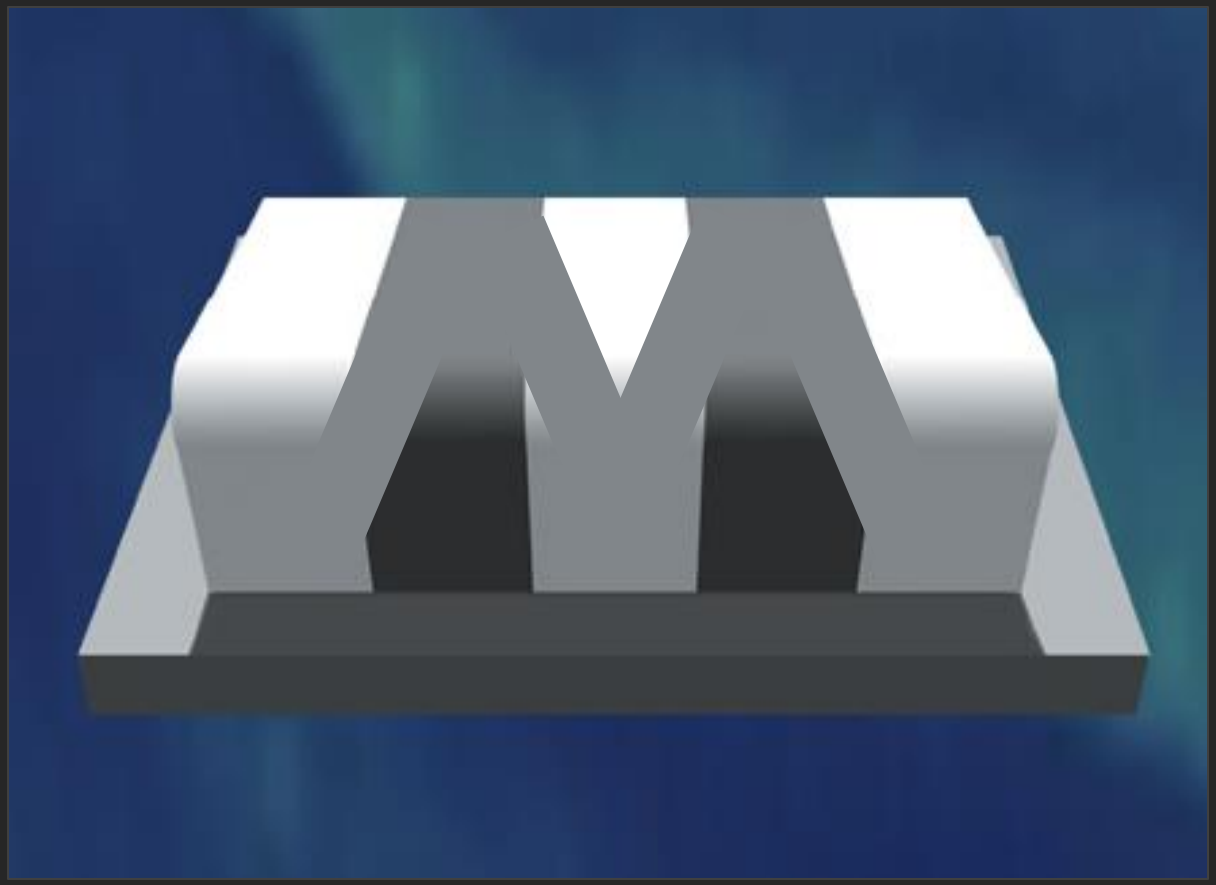
Scintillating Grids: Straight and Curved



Where is the illusion?

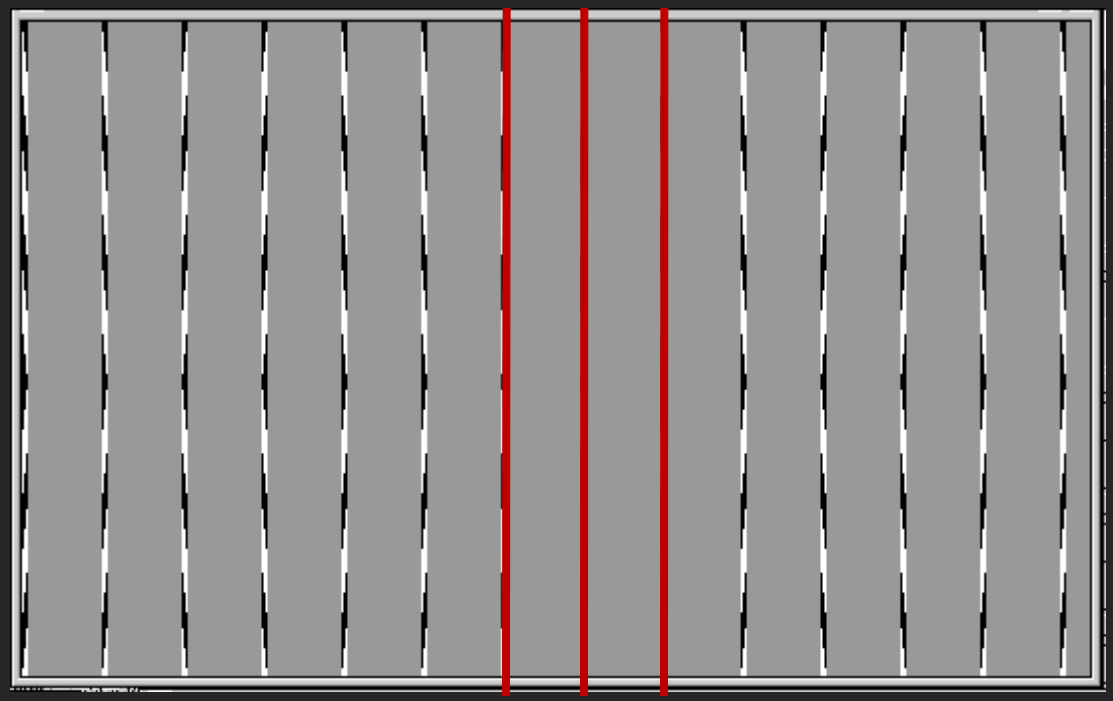


Where is the illusion?

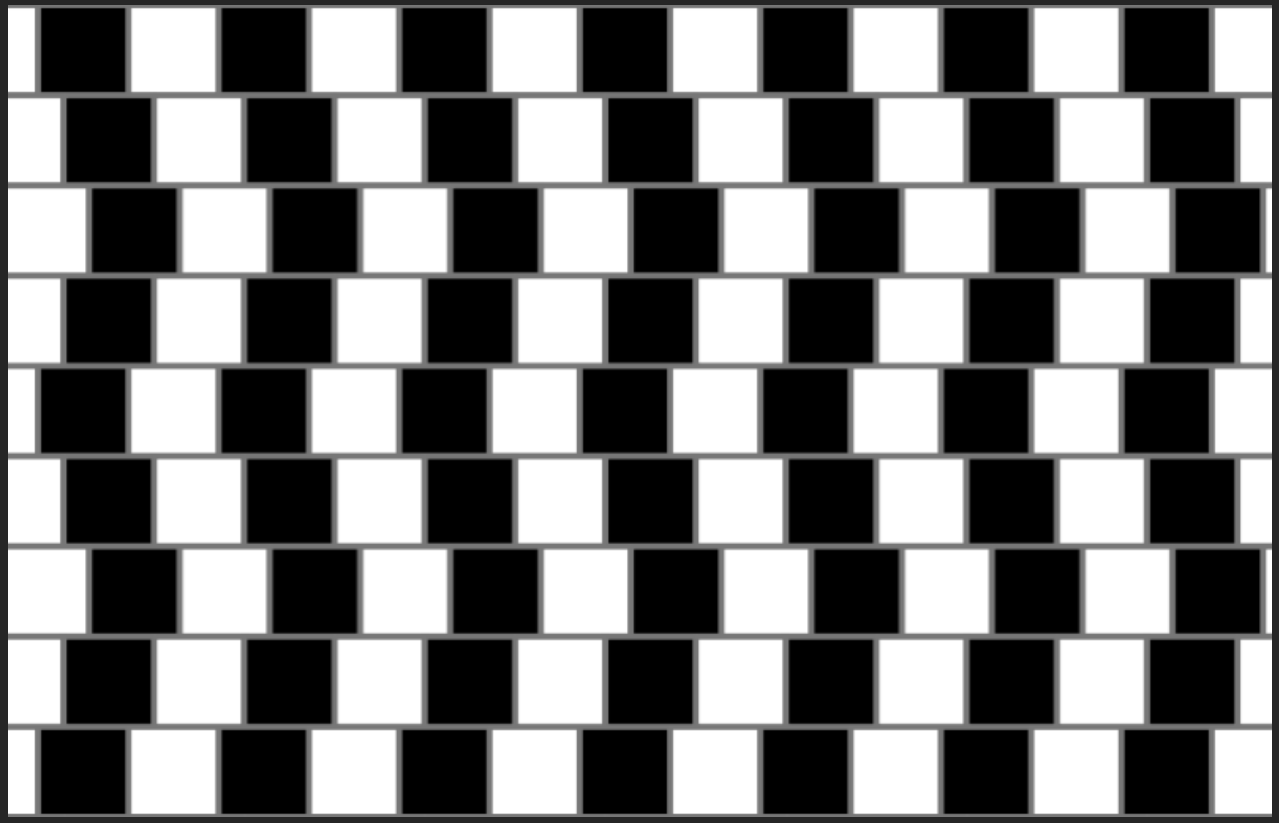


Twisted Cord Illusions

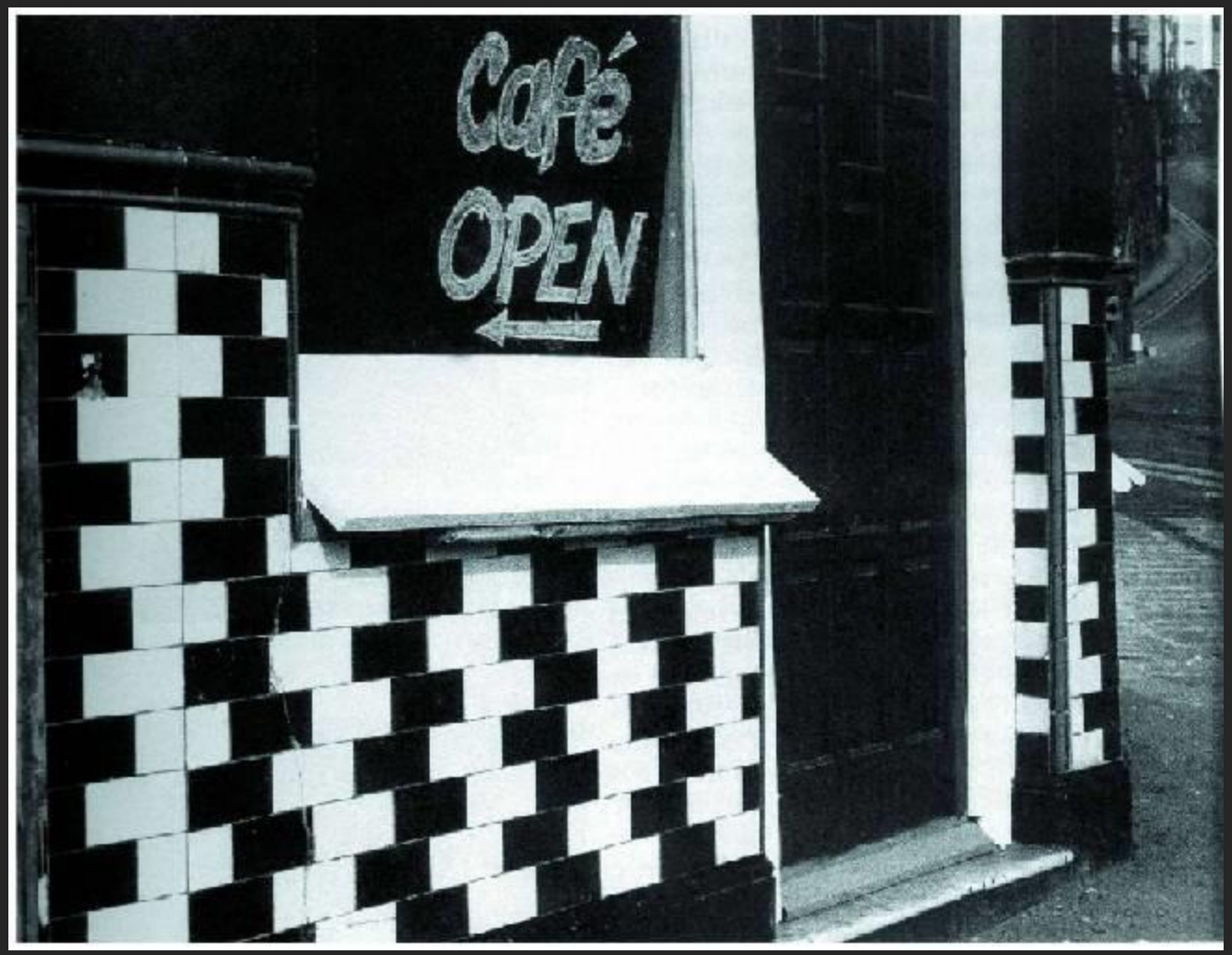
Are the lines parallel? Straight?



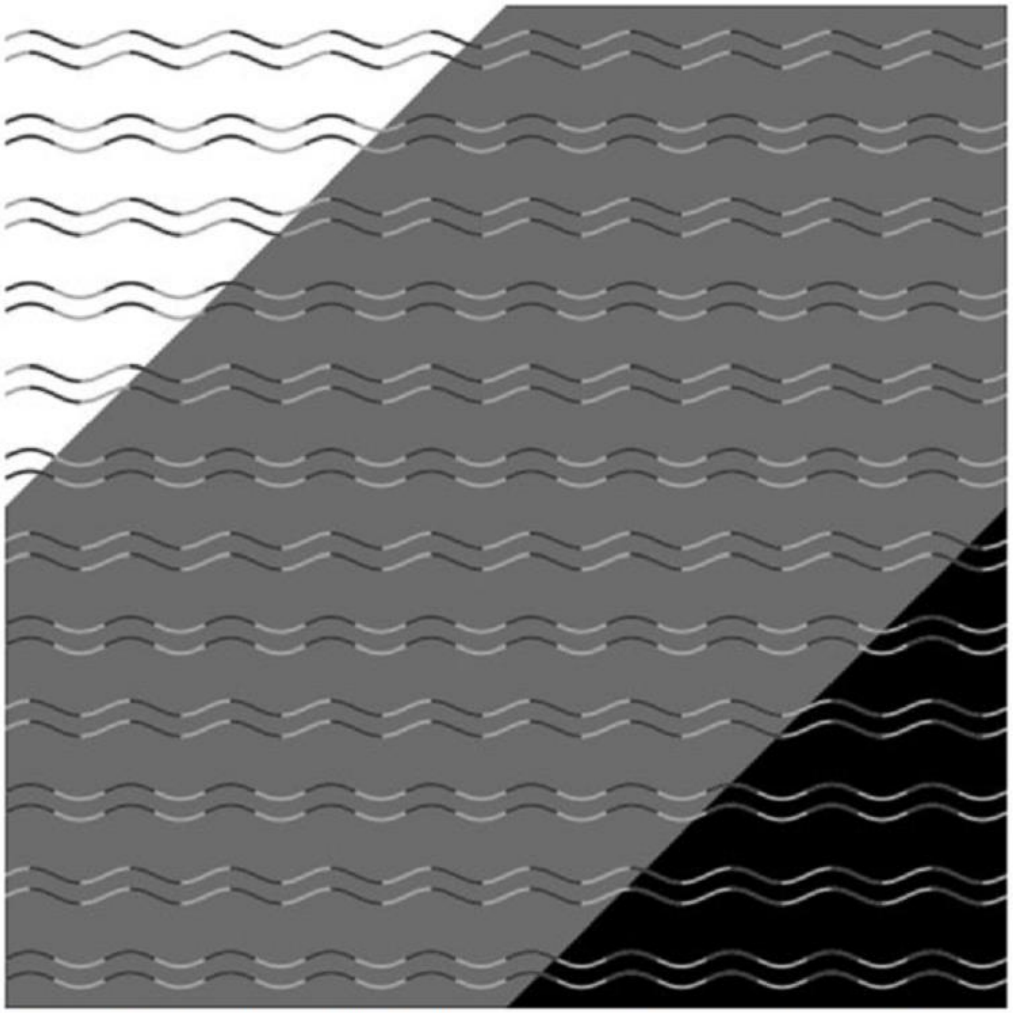
Café Wall Illusion



Café Wall Illusion



A New Arrival…



Curvature blindness illusion. All of the lines crossing the image are identical in shape, but half of them appear "zig-zagged" against the grey background

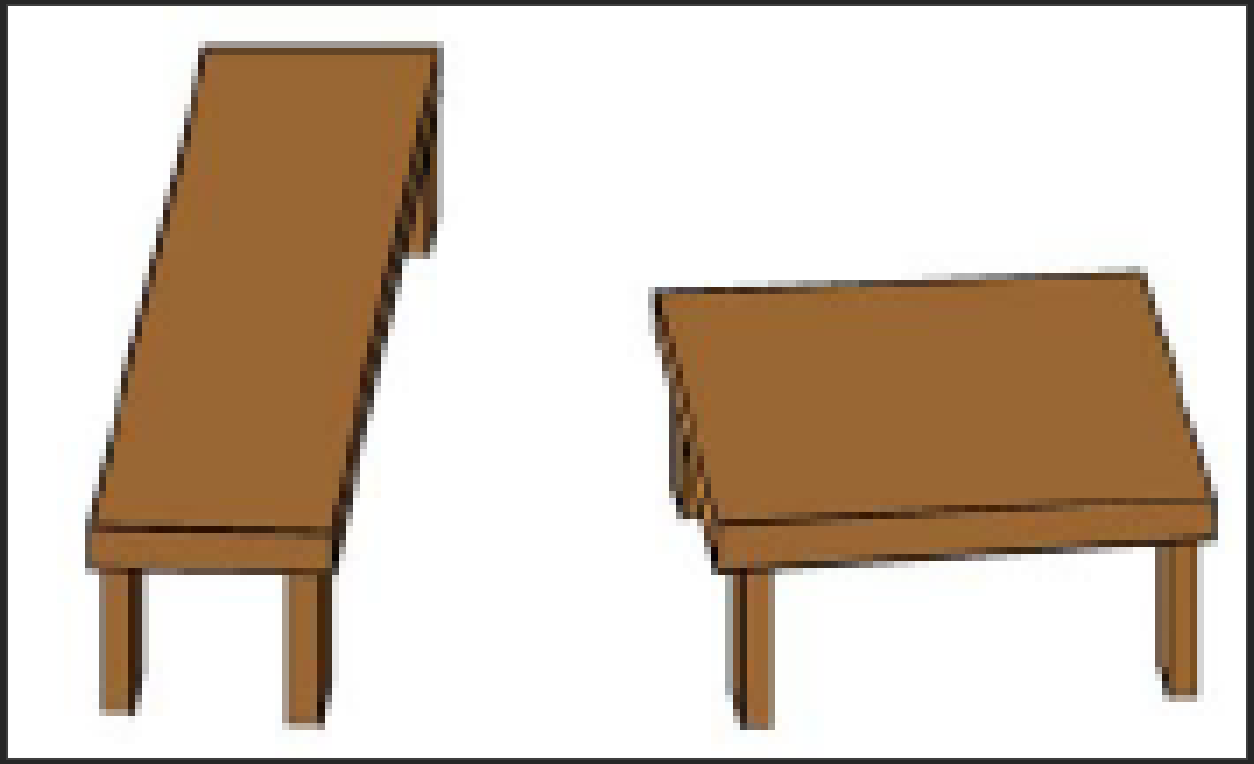
Image taken from Takahashi (2017) iPerception

Illusions involving perspective

Illusions: Forced Perspective

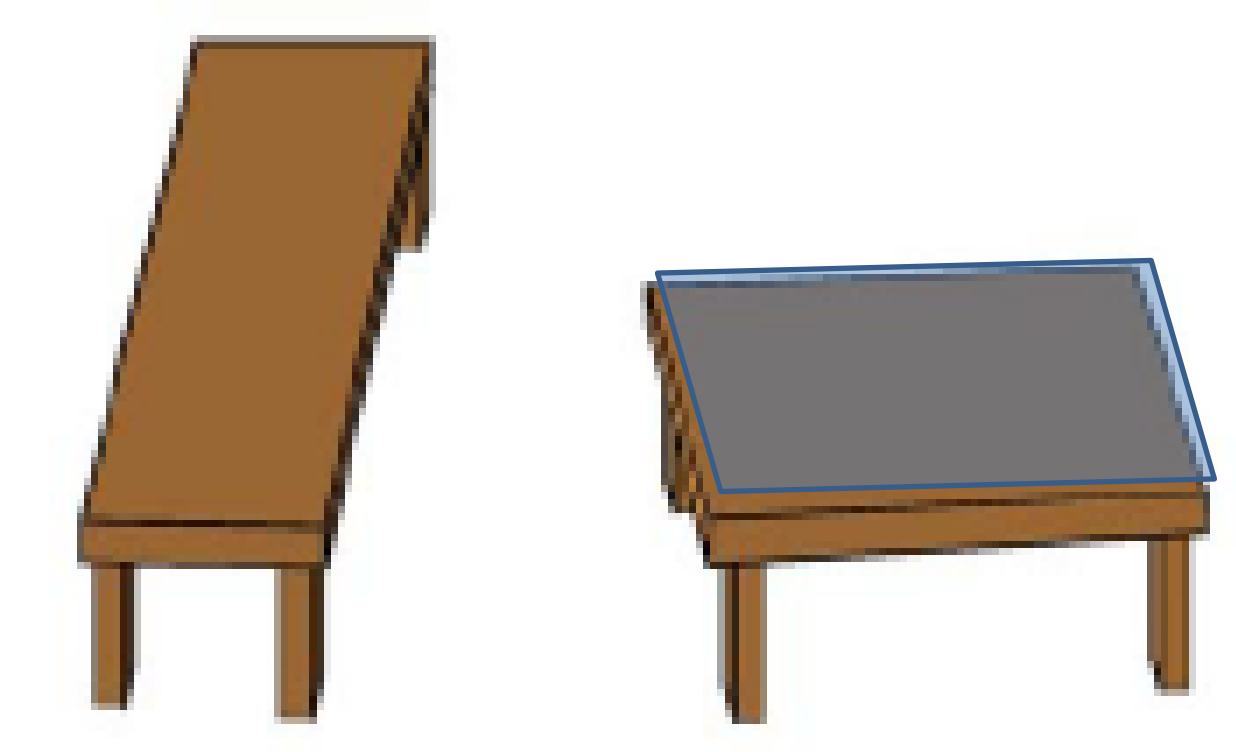
These two people are of the same height!

Shepard's table-top illusion



Which is bigger?

Shepard's table-top illusion

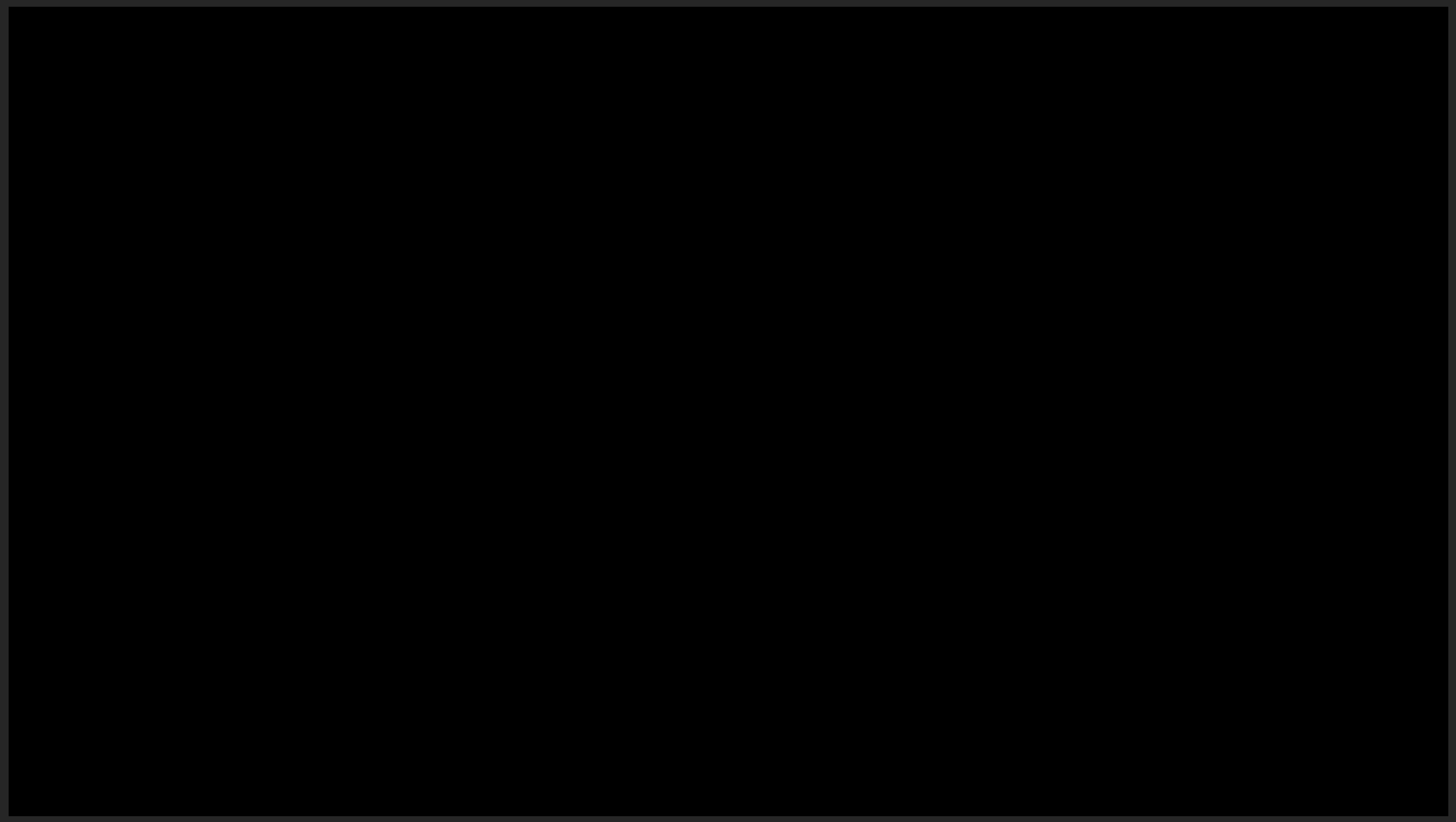


Which is bigger?

Impossible Arrow: Always Right!

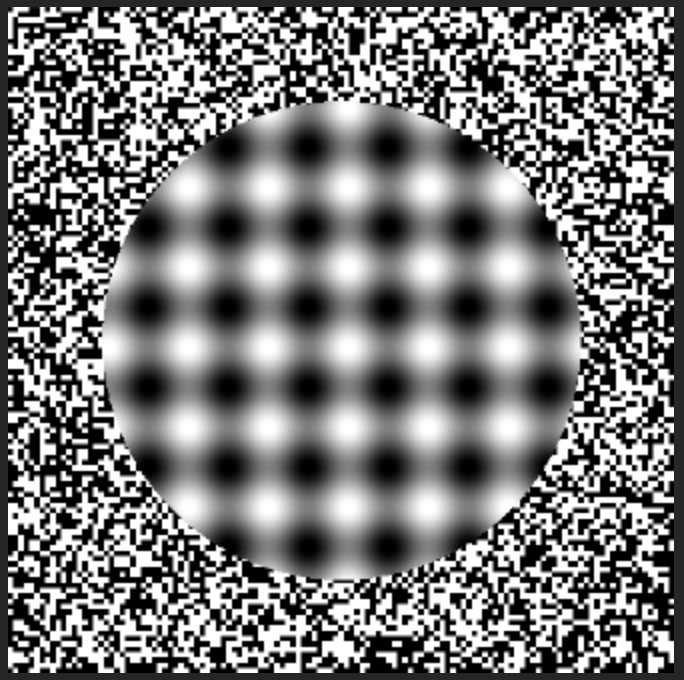
Kokichi Sugihara

Shape Shifting Tubes (Kokichi Sugihara)

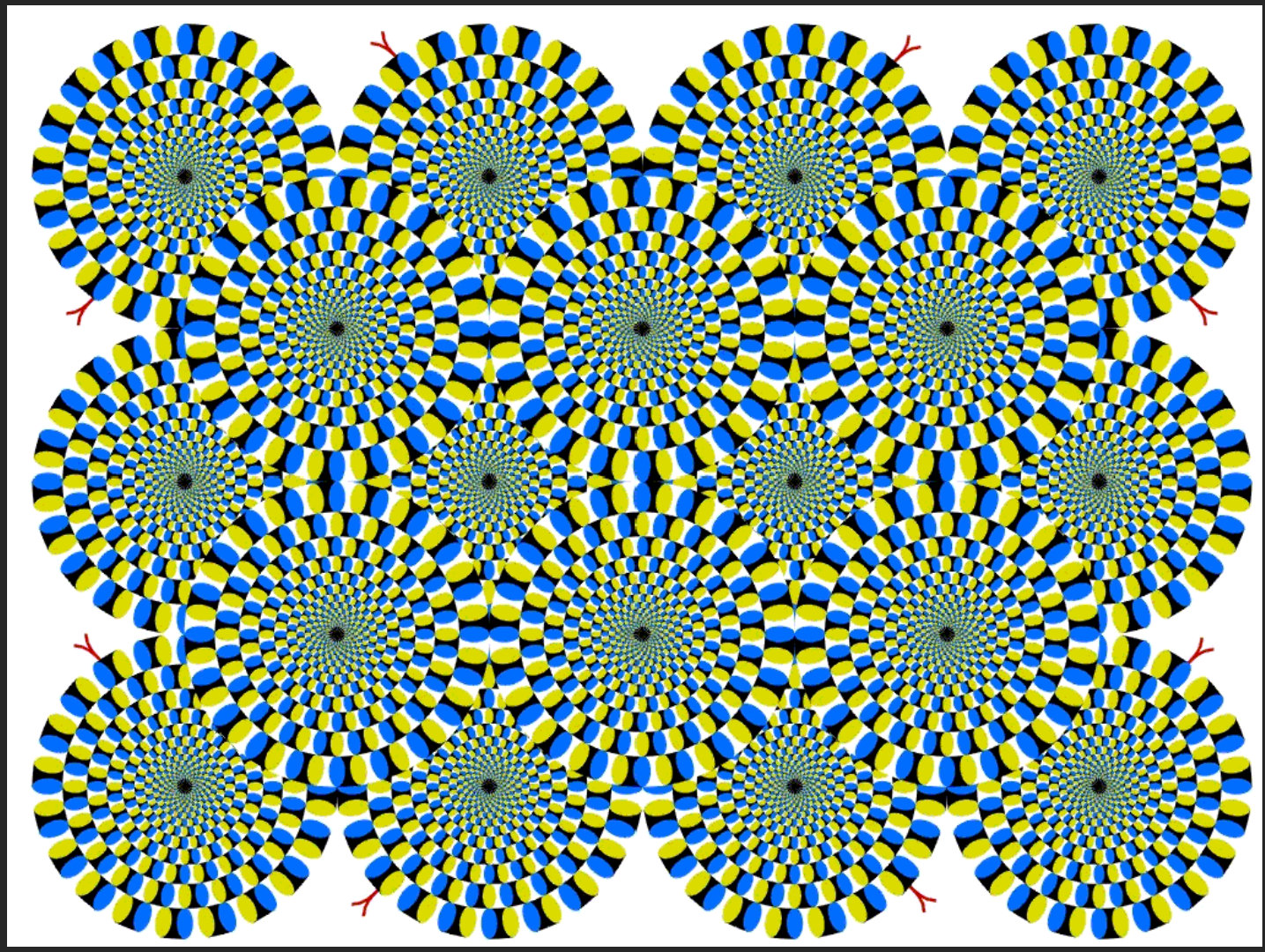


Relative Motion Illusions

Out of Focus Illusion



Spinning Wheel Illusion



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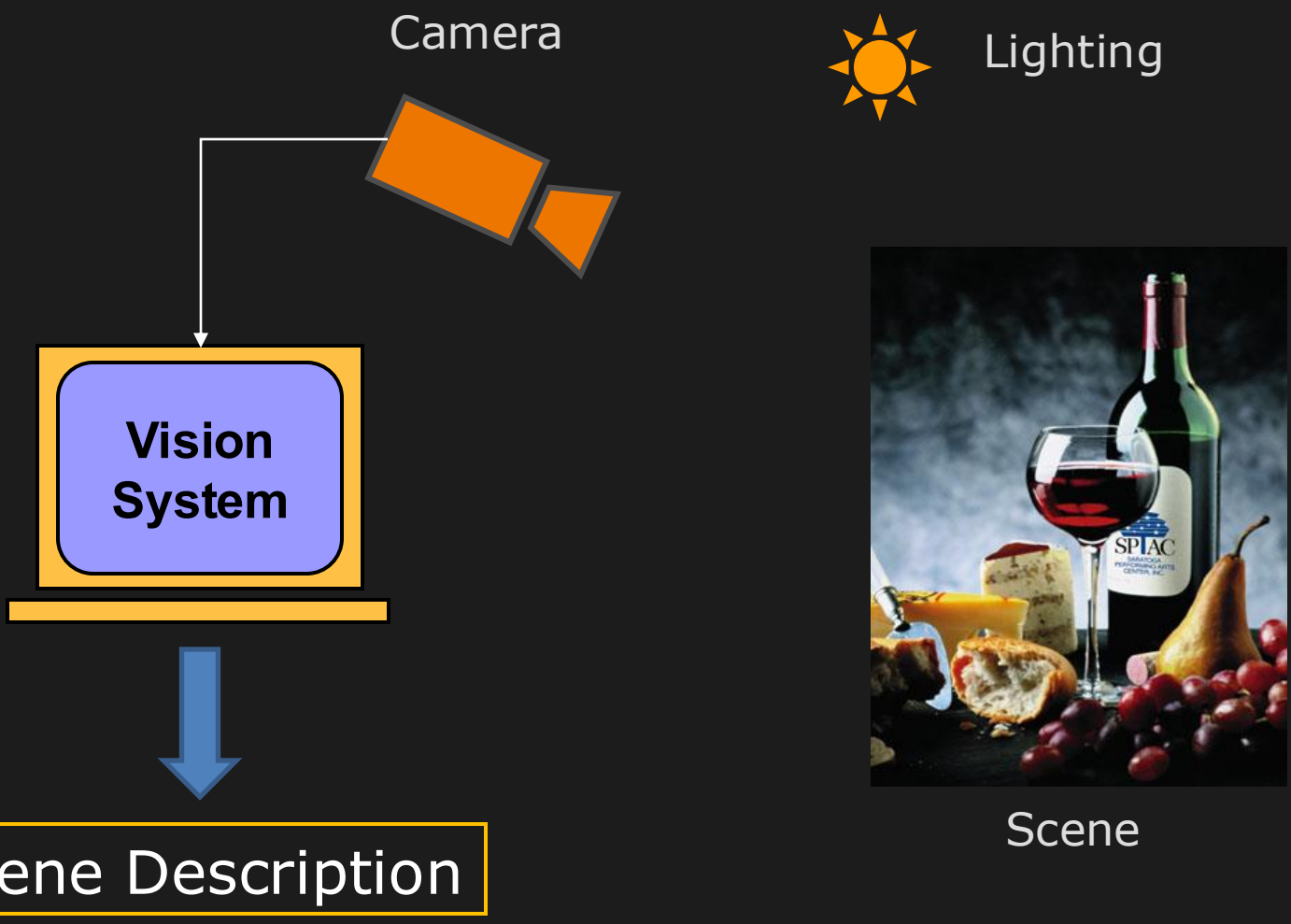
- It makes us happy ☺ : *Al Seckel*

  Click

What is Computer Vision?



But, What Really is Computer Vision?

Vision is

… automating human visual processes

… an information processing task

… inverting image formation

… inverse graphics

… really useful!

What is Vision Used For?

Industrial Inspection

What is Vision Used For?

Industrial Inspection

What is Vision Used For?

I.5

Optical Character Recognition (OCR): Book Digitization

What is Vision Used For?

ATA 010

Optical Character Recognition (OCR): Reading License Plates

What is Vision Used For?

Biometrics: Iris Recognition

What is Vision Used For?

Security: Object Detection and Tracking

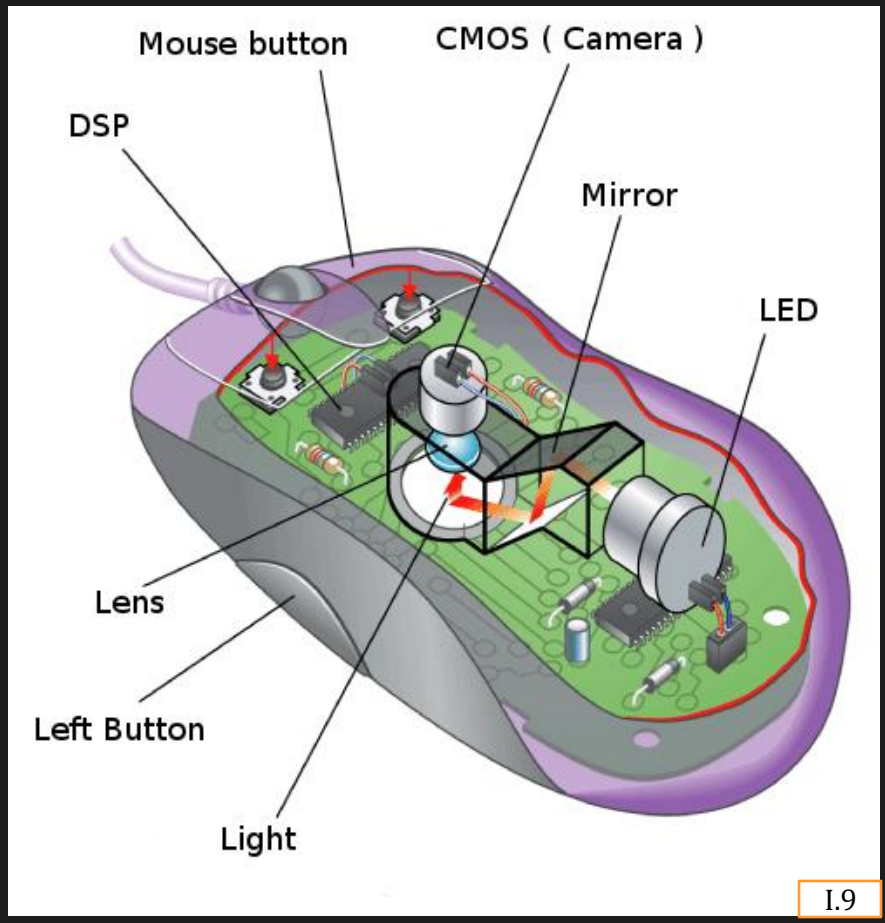
What is Vision Used For?

Biometrics: Face Detection and Recognition

What is Vision Used For?

Intelligent Marketing: Vending Machine with Face Detection

What is Vision Used For?



Human Computer Interaction: Optical Mouse

What is Vision Used For?

Entertainment and Gaming: Kinect

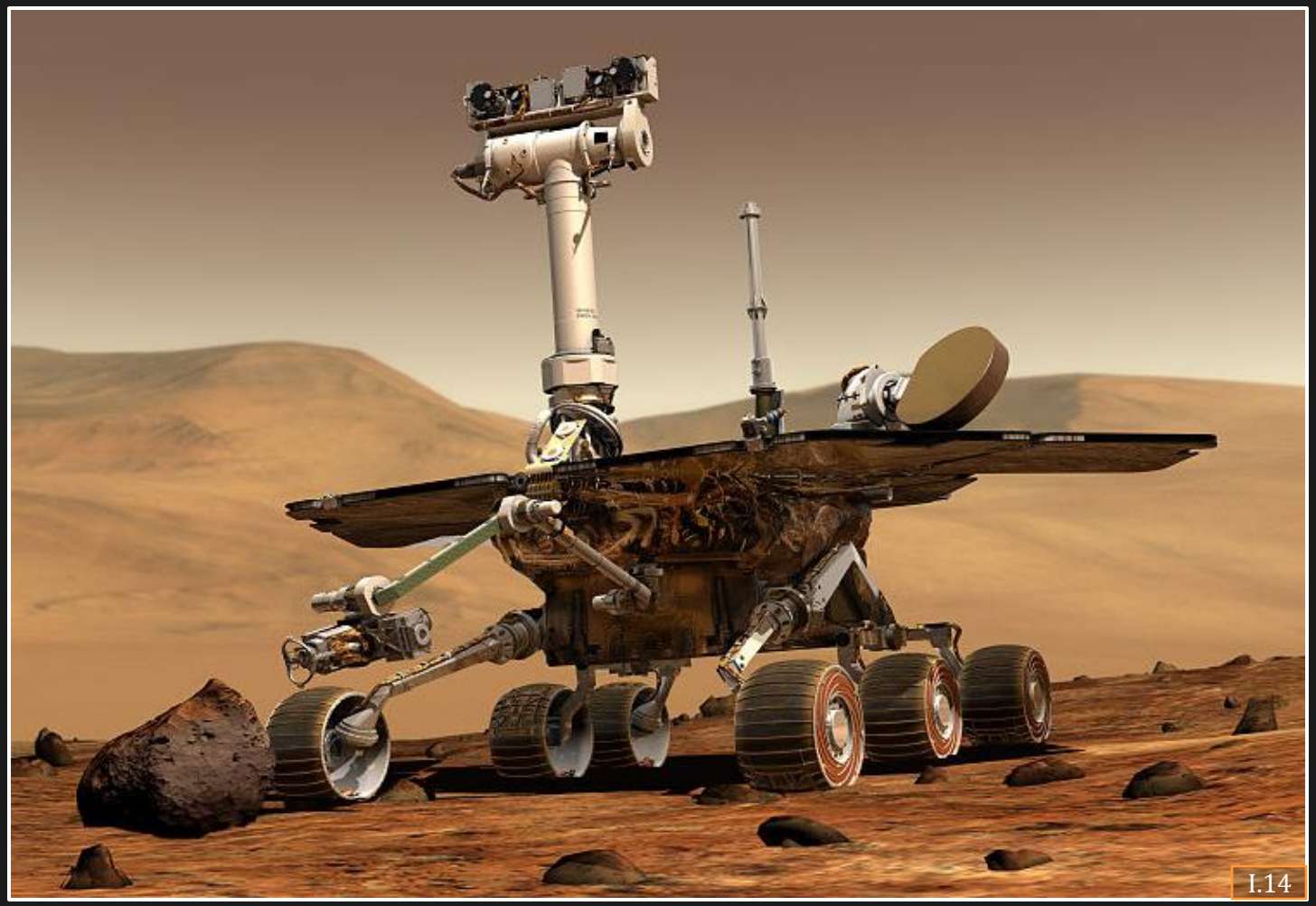
What is Vision Used For?

Human Computer Interaction: Gesture-based UI

What is Vision Used For?

Visual Effects: Motion and Performance Capture

What is Vision Used For?



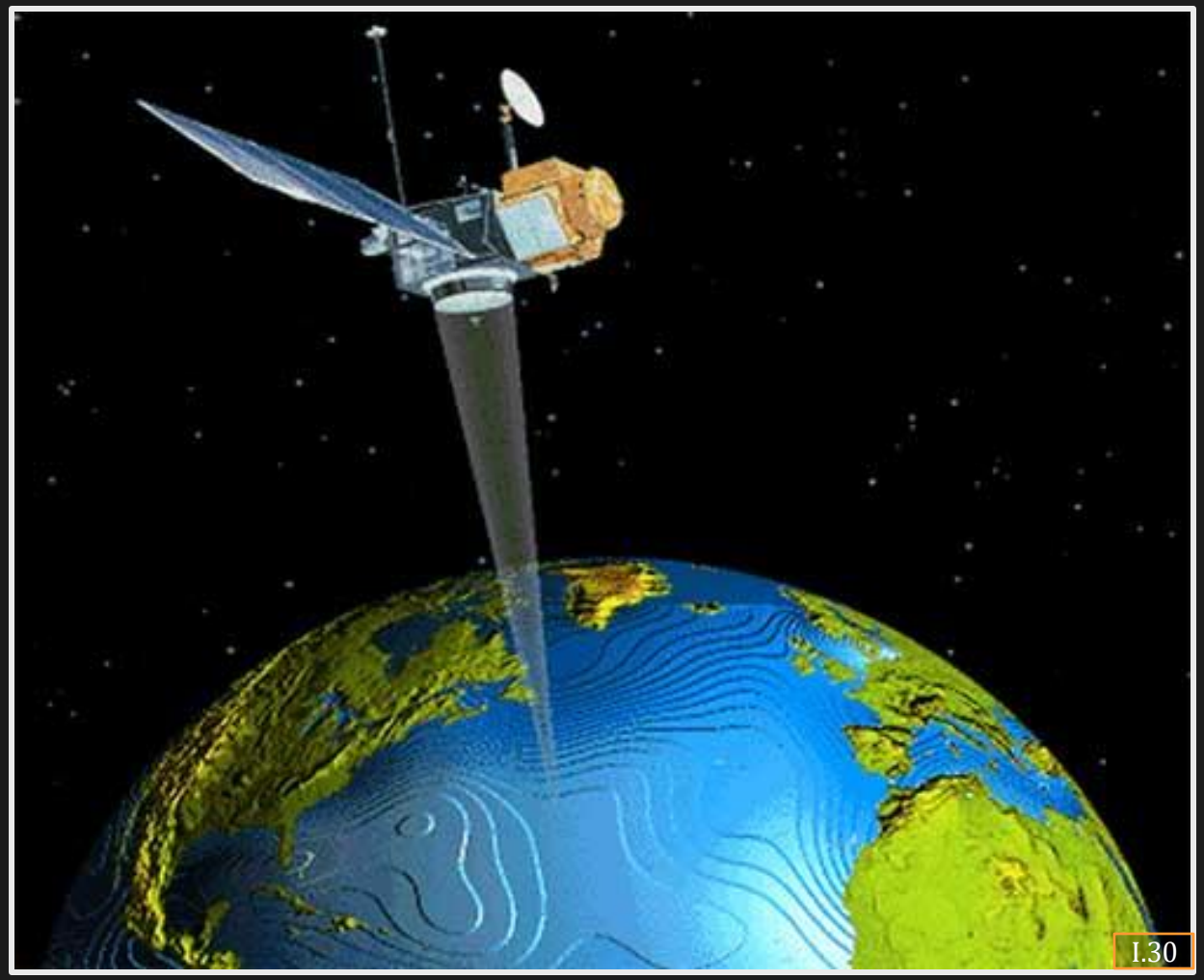
Autonomous Navigation: Space Exploration

What is Vision Used For?

I.15

Autonomous Navigation: Driverless Car

What is Vision Used For?

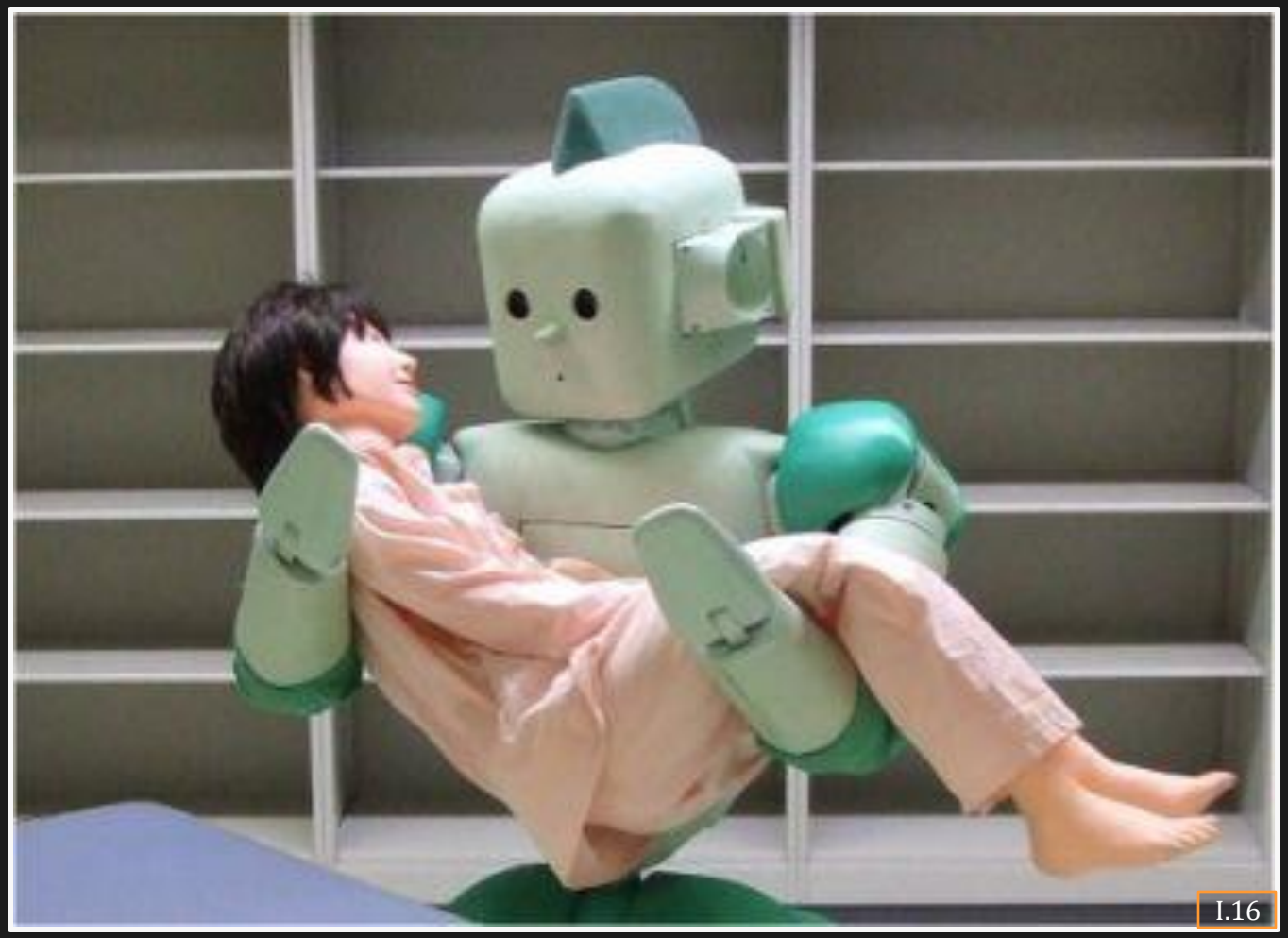


Remote Sensing

What is Vision Used For?

Medical Image Analysis

What is Vision Used For?



Humanoid Robots: Healthcare and Assistance

Images Are Interesting

But When You Look Close…

157	159	159	104	104	115	128	131	133	133	132	131	132	130	129	118	132	158	156	153	190	144	117	126	120	81
159	165	153	101	103	113	126	129	130	130	126	124	127	128	127	120	122	158	159	154	160	190	121	118	67	47
162	154	154	98	101	114	124	127	130	132	144	159	155	132	123	119	119	148	154	150	140	185	161	60	48	45
141	132	158	93	98	110	121	125	122	129	143	172	191	188	143	105	117	148	140	145	142	153	105	44	49	71
100	130	157	93	99	110	120	116	116	129	138	163	191	205	211	130	107	153	98	133	147	107	44	47	81	151
87	130	157	92	97	109	124	111	123	134	139	175	194	201	207	205	126	151	74	114	160	57	49	63	141	163
93	131	159	92	98	112	132	108	123	133	162	180	183	192	196	205	184	151	138	199	195	54	47	119	161	156
96	134	164	95	97	113	147	108	125	142	156	171	173	178	184	181	186	191	206	203	161	44	84	158	159	155
95	137	165	95	95	111	168	122	130	137	145	139	144	139	145	179	193	203	194	158	95	49	135	160	157	155
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81	115	175	104	116	87	78	69	84	56	140	124	158	170	143	173	150	76	90	68	148	153	146	148	186	196
69	108	172	107	103	87	82	54	83	105	93	107	153	166	132	162	153	68	87	97	157	149	141	179	204	206
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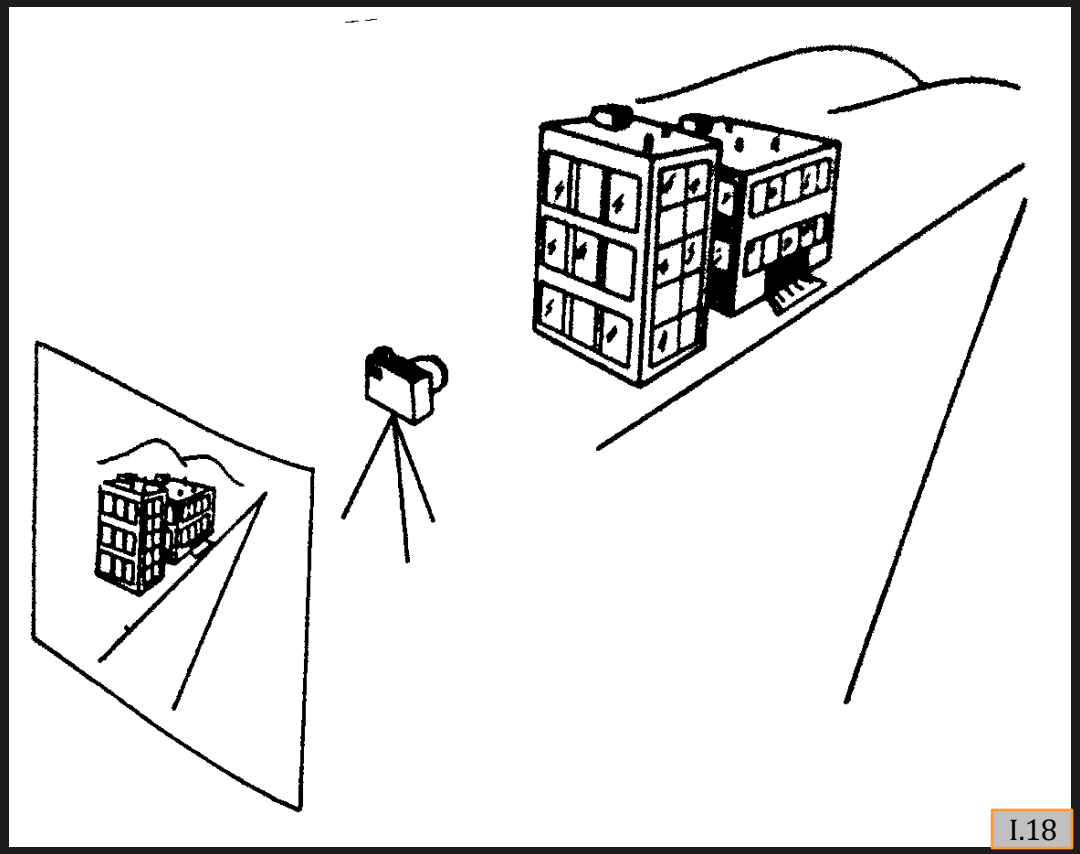
107	121	177	89	50	64	60	103	114	66	56	90	120	140	149	169	201	194	100	148	134	155	208	120	99	99

Vision Deals with Images

An Image is an Array of Pixels

A Pixel has Values:

- Brightness
- Color
- Distance
- Material
- …



Human Vision is Impressive!

You can:

- Recognize people and objects
- Navigate around obstacles
- Understand mood in the scene

What you see isn’t always what you get!

What do we do?

REINVENT!

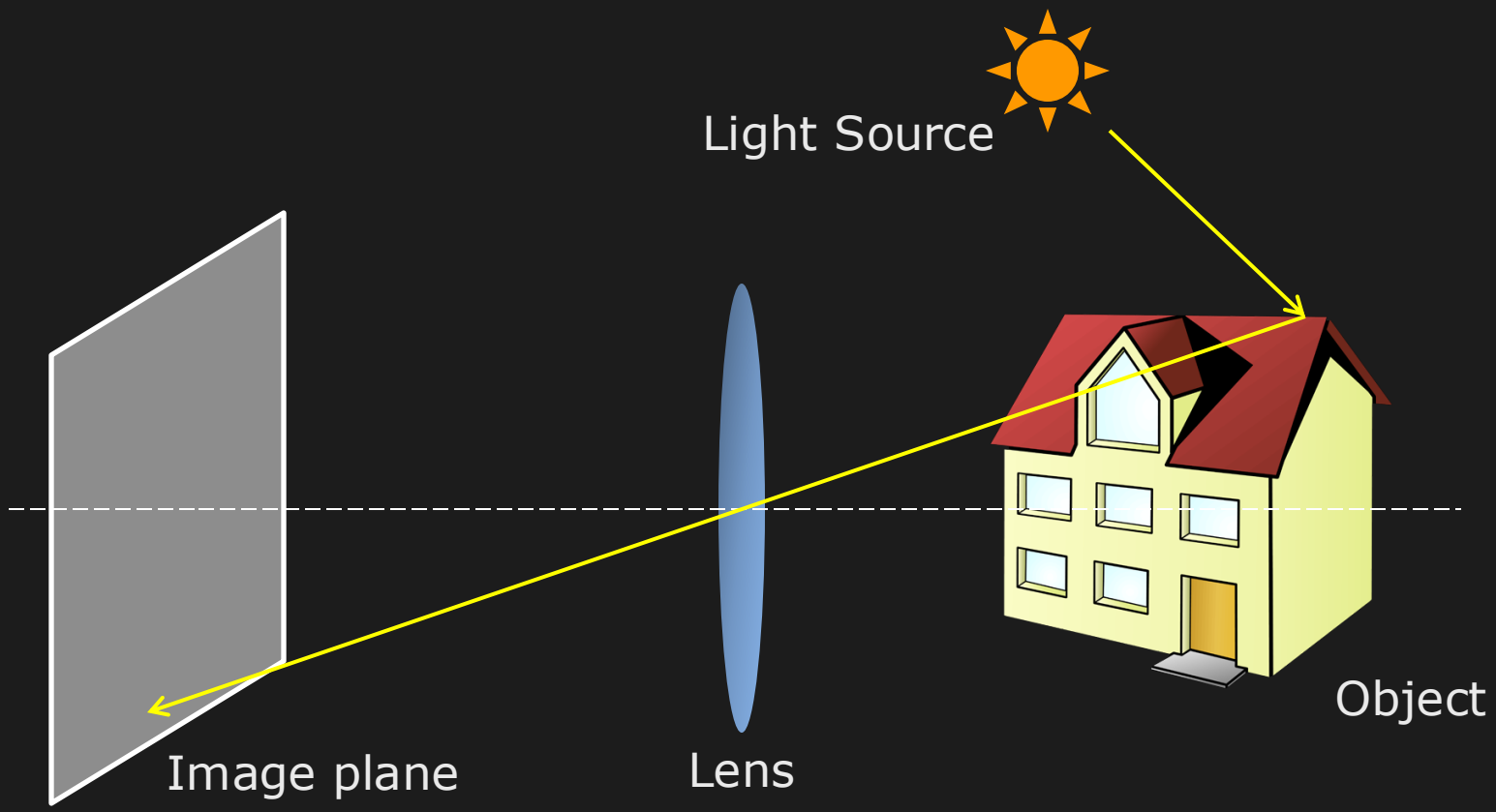
Vision Research

- Vision is a Hard Problem
- Vision is Multi-Disciplinary
- Considerable Progress Has Been Made
- Many Successful Real-World Applications

Syllabus Overview

Image Formation and Optics

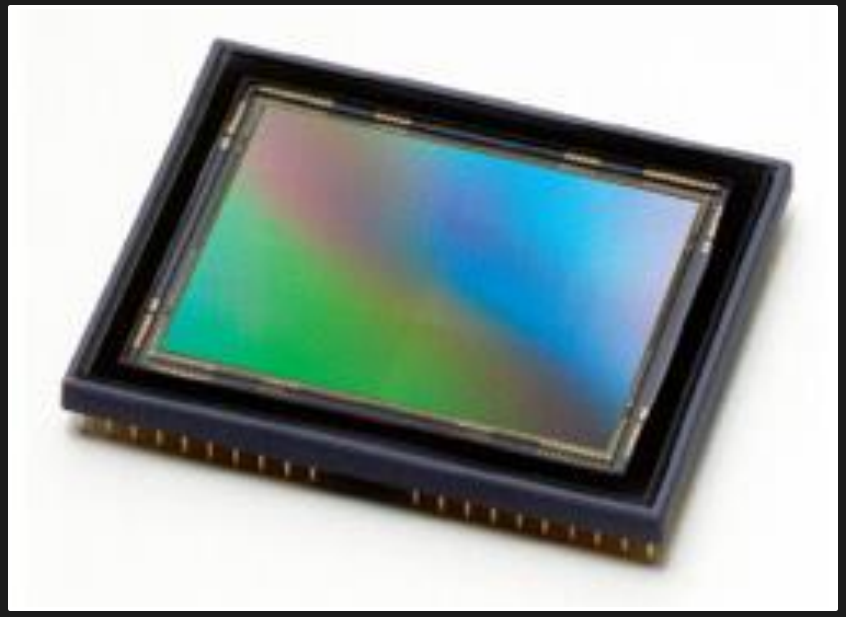
Where do Images Come From?



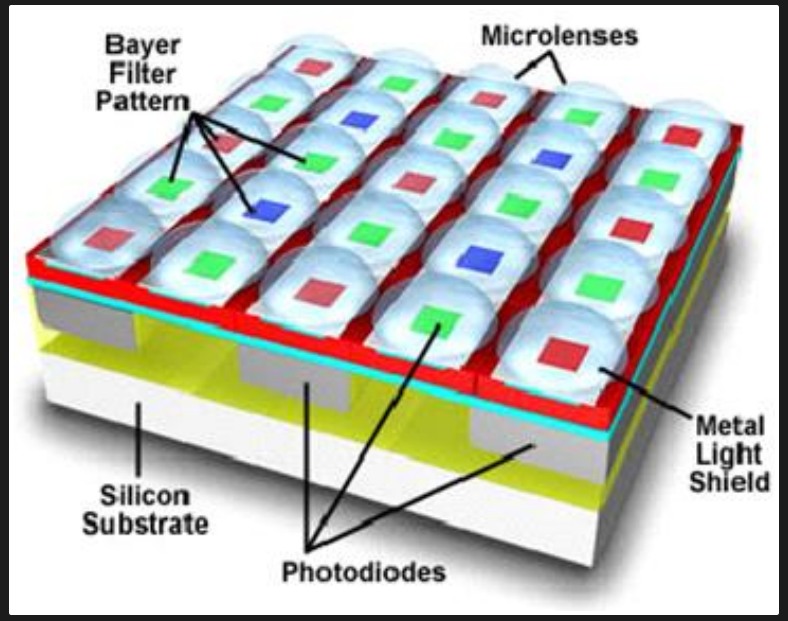
Projection of 3D world on a 2D Plane

Image Sensors

Convert Optical Images to Electrical Signals



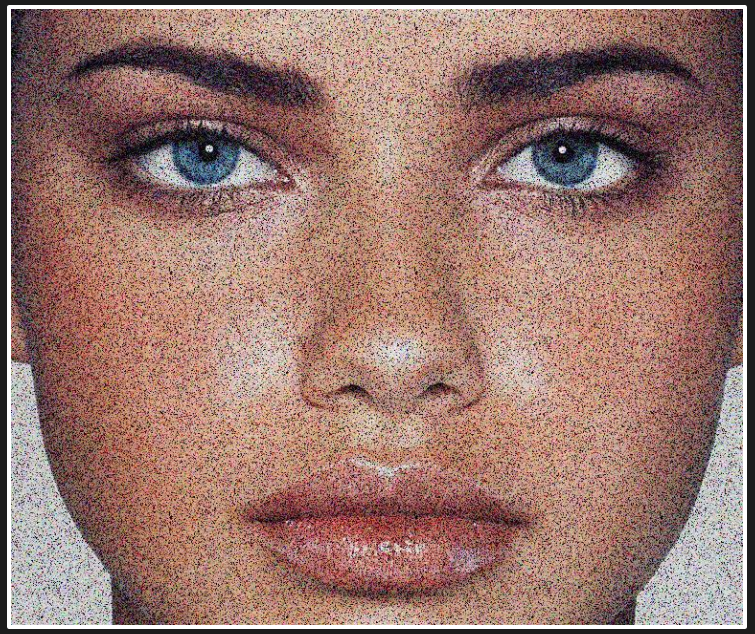
Consumer Image Sensor



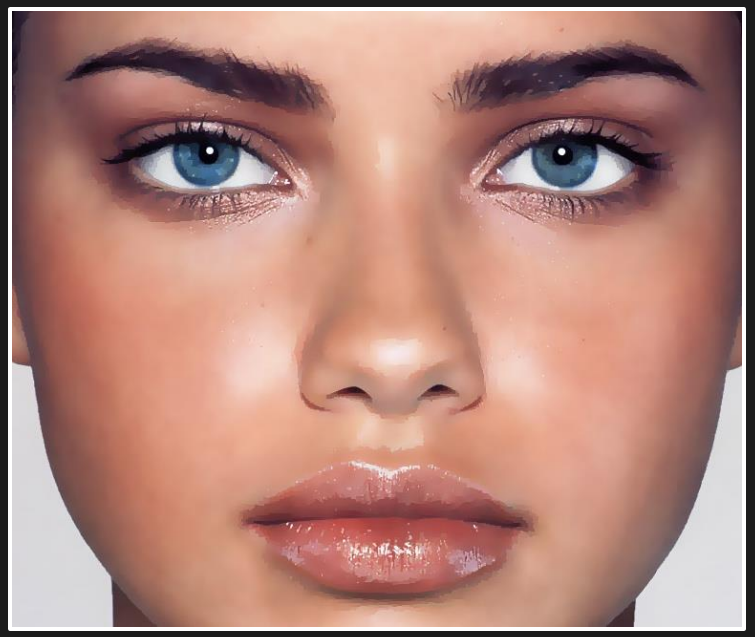
Typical Structure of Image Sensor

Image Processing

Transform Image to New One that is More Useful



Input Image



Edge-Preserved Smoothing

Edge and Corner Detection

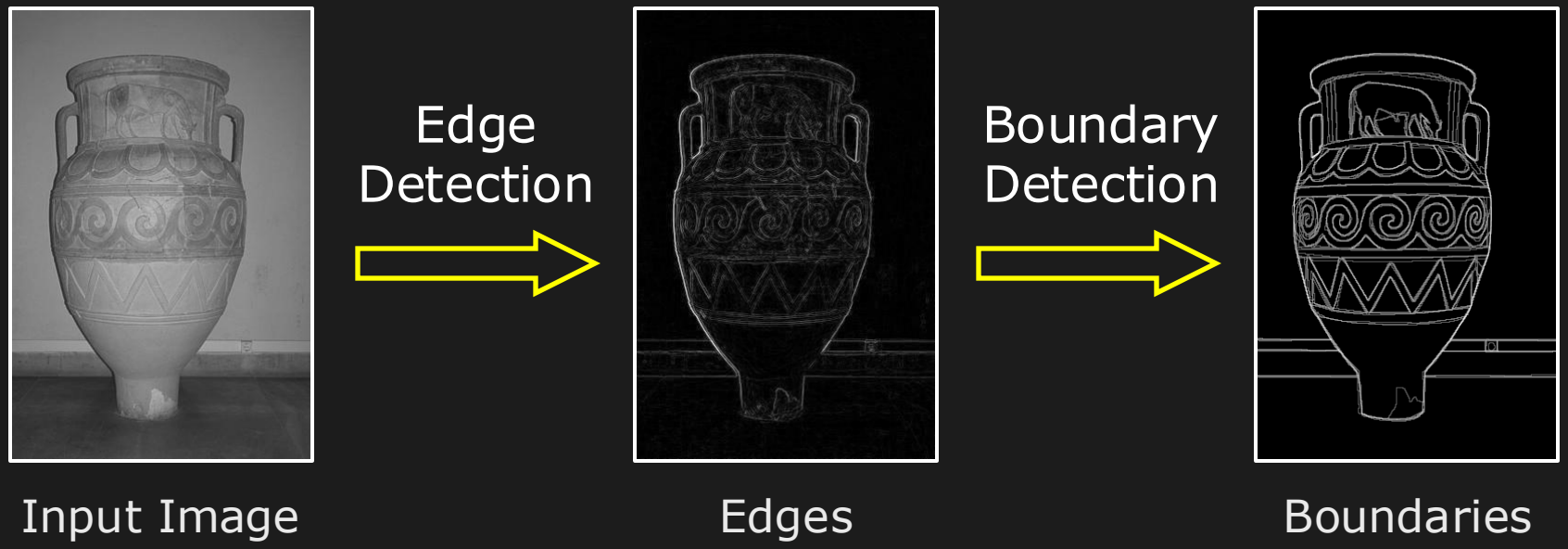
Detecting Intensity Changes in the Image

Input Image

Edges

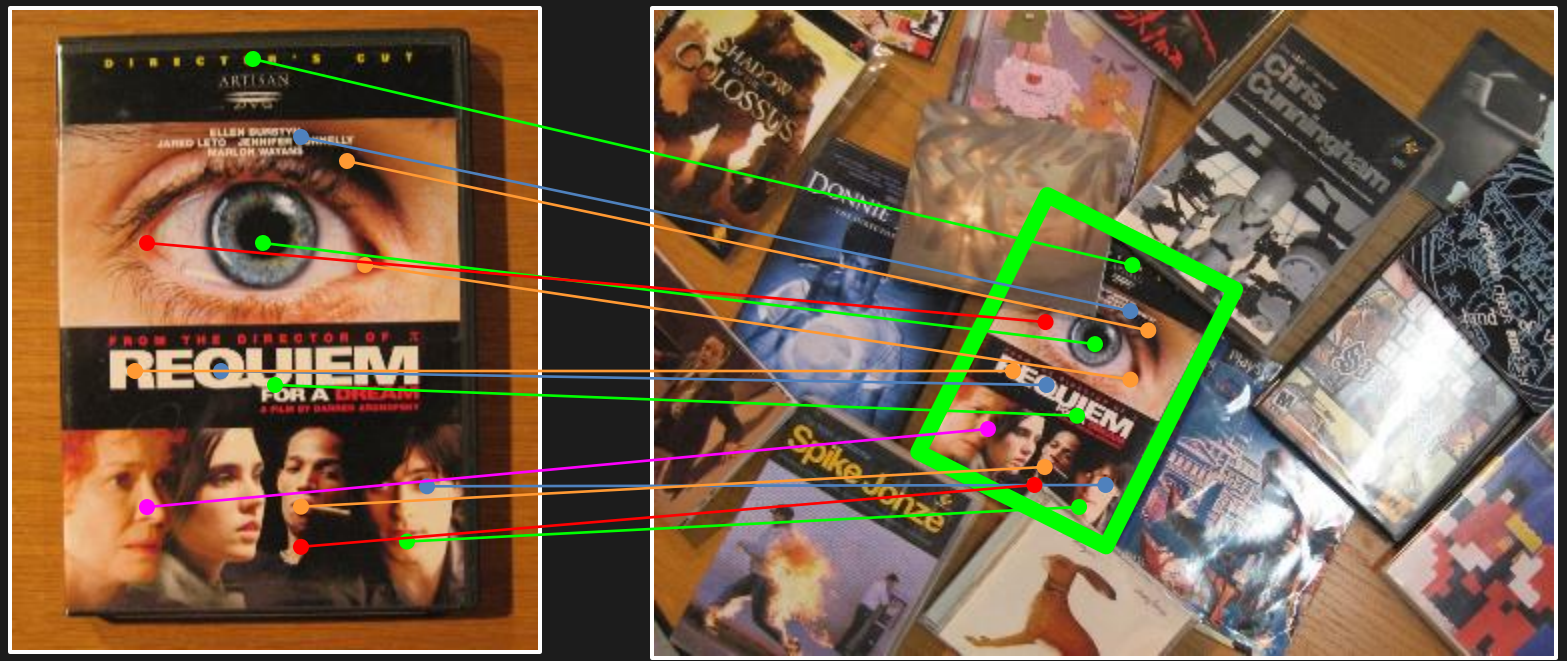
Boundaries from Edges

Finding Continuous Lines from Edge Segments



2D Recognition using Features

Matching using “Interesting Points”



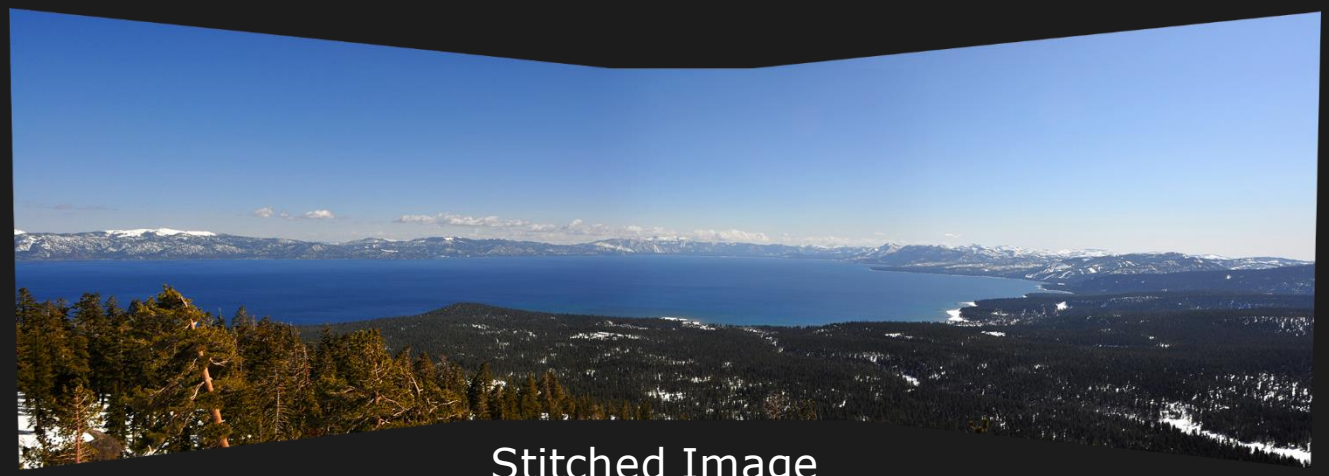
Object in Database

Input Image and Detected Object

Image Alignment and Stitching

Combine multiple photos to create a larger photo

Source Image 1 Source Image 2 Source Image 3



Stitched Image

Face Detection

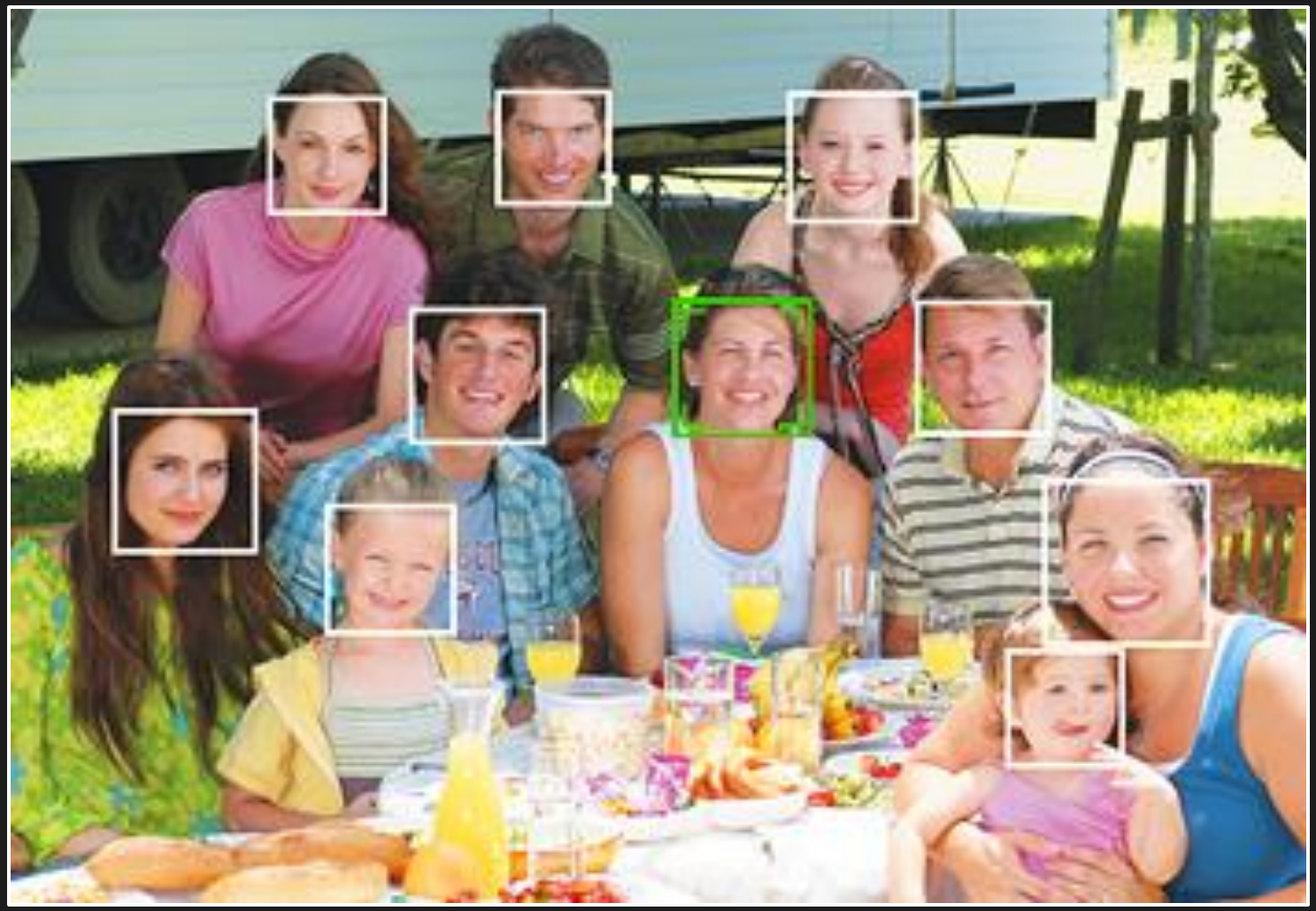


Image Segmentation

Group pixels with similar visual characteristics.

Input Image

Segmented Image

Convolutional Neural Networks

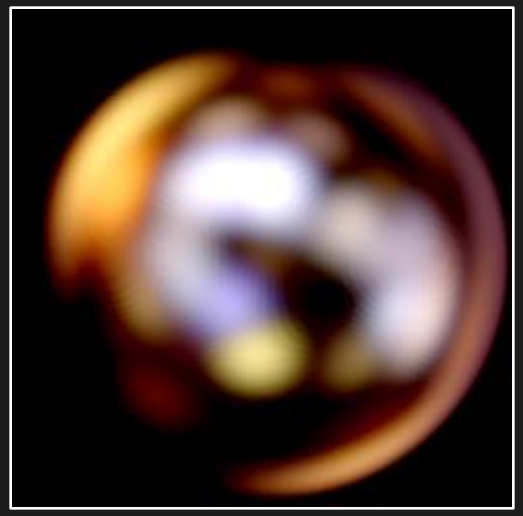
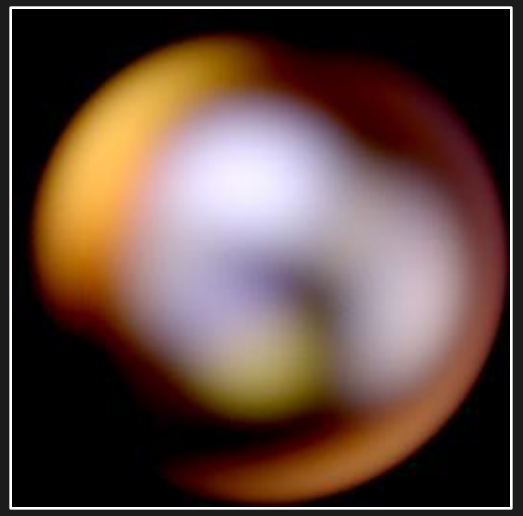
[Karpathy 2014]

Syllabus – Part I

- Image Formation and Sensing
- Image Processing I and II
- Edge and Corner Detection
- Boundary Detection and Hough Transform
- SIFT and 2D Recognition
- Image Alignment and Stitching
- Face Detection
- Segmentation
- Convolutional Neural Networks

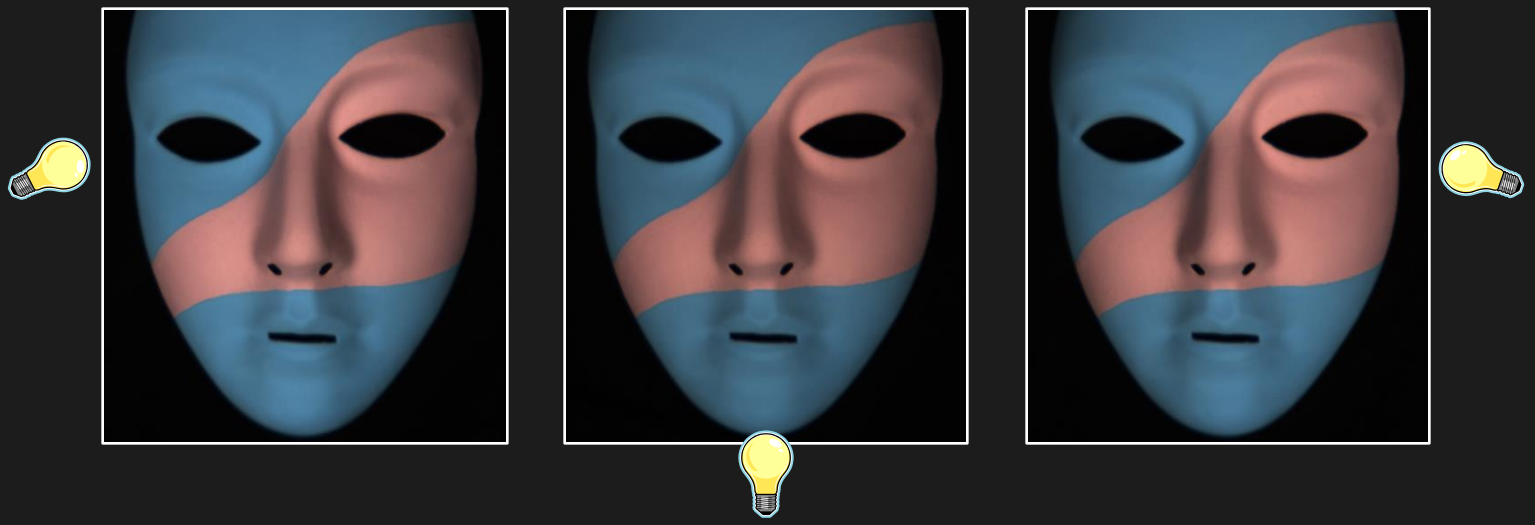
Reflectance and Color

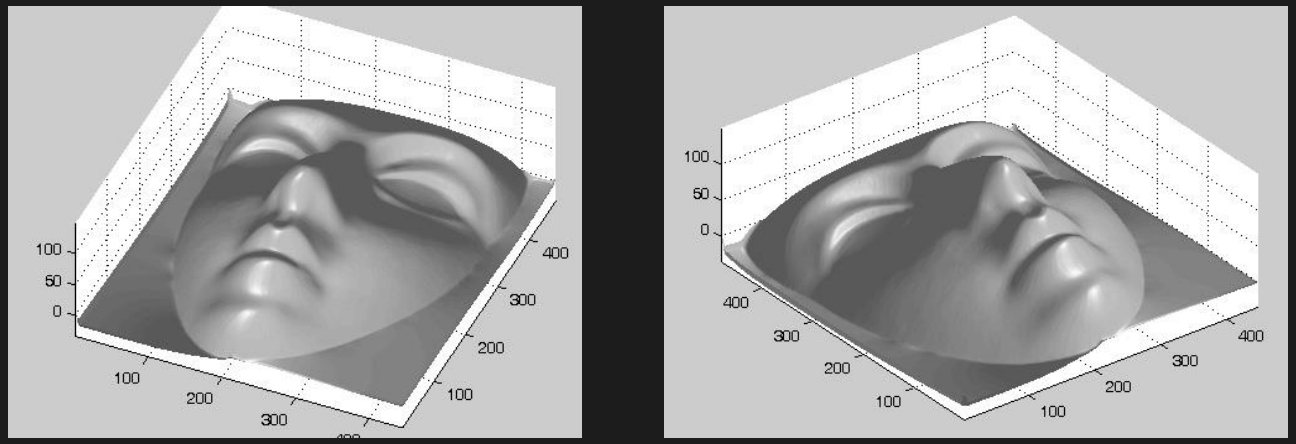
Why do these Spheres Look Different?

Photometric Stereo

3D Shape from Images under Different Lighting





Estimated Shape

Shape from Focus and Defocus

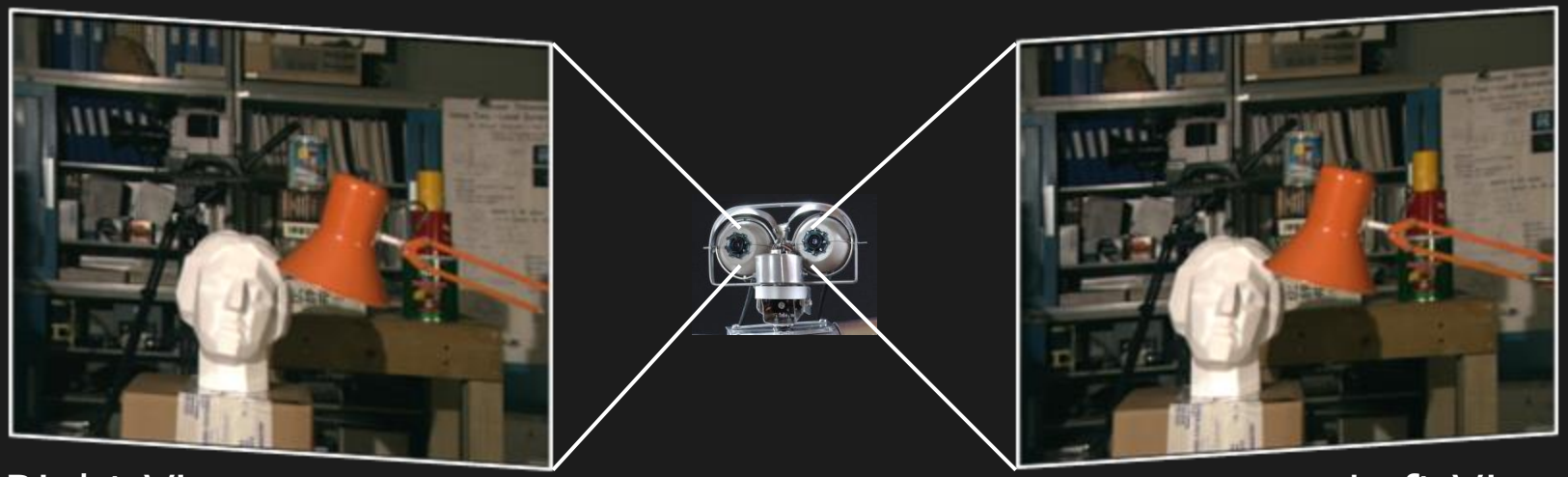
Near-Focus Image

Far-Focus Image

Estimated Depth Map

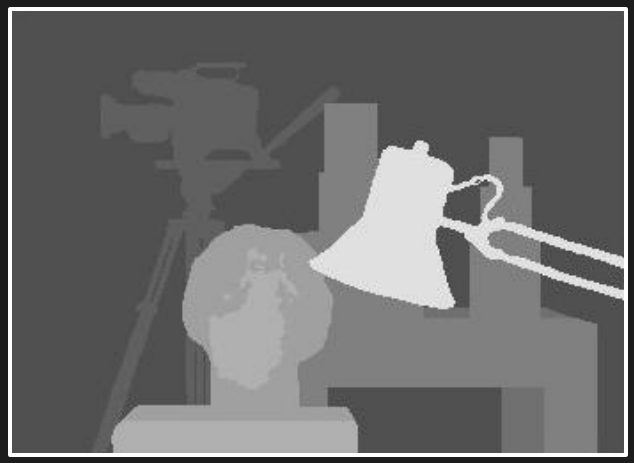
Binocular Stereo

Computing Depth using Two Views



Right View

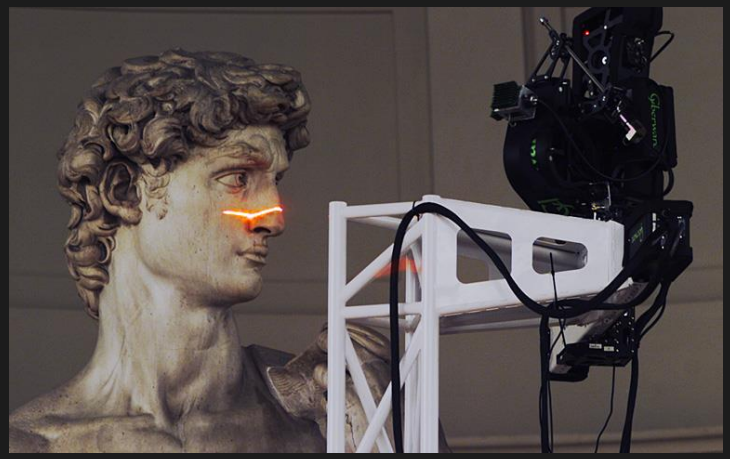
Left View

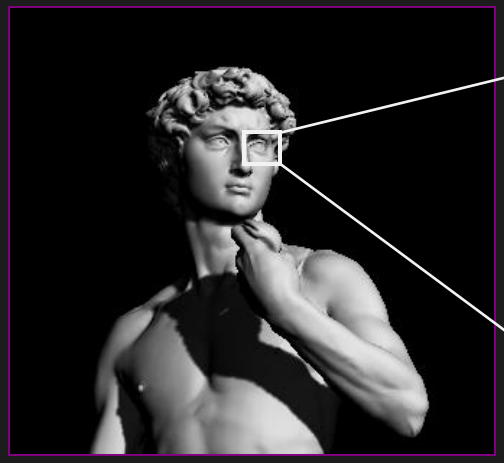


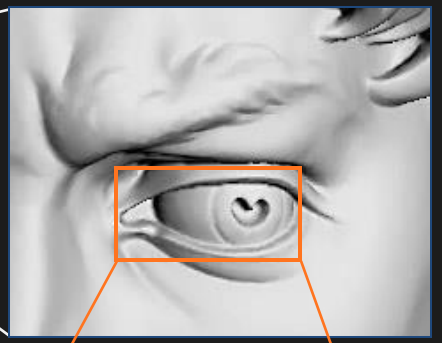
Estimated
Depth Map

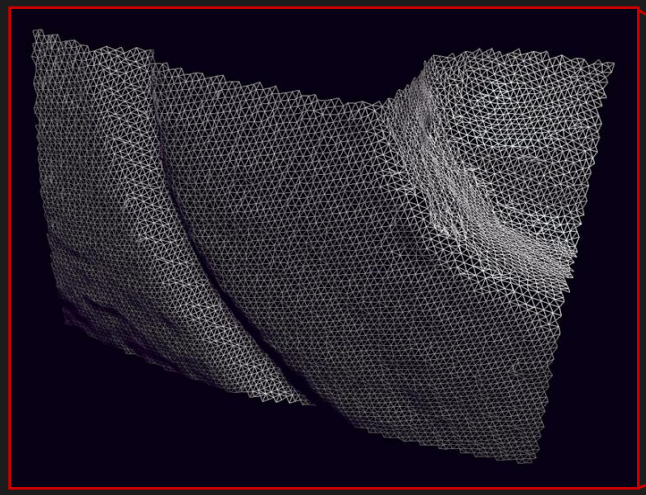
Shape from Structured Light

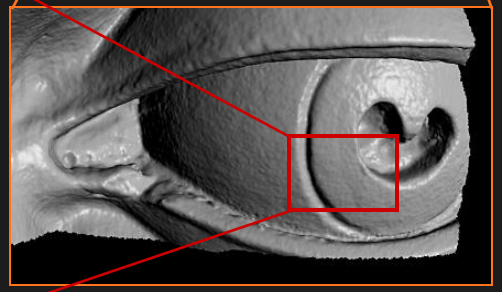
Using Patterned Lighting to Recover Shape











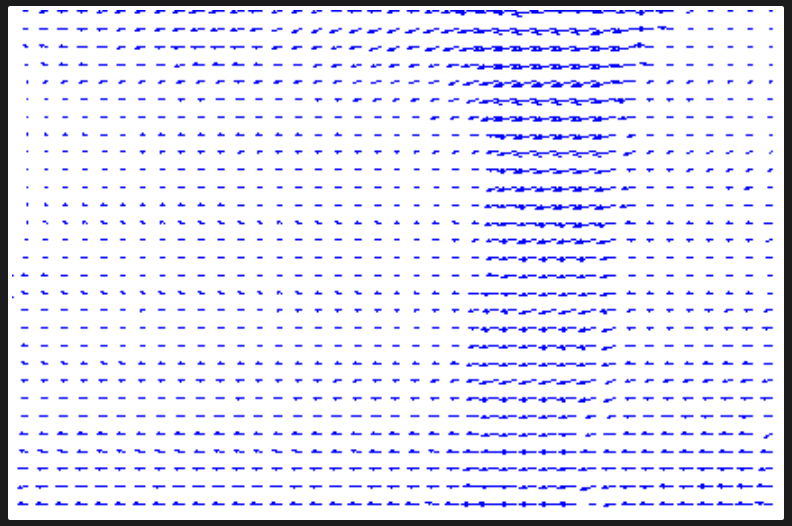
Motion and Optical Flow

Determining the Movement of Scene Points

Frame 1

Frame 2

Frame 3



Estimated Motion

Object Tracking

Determining the Movement of Objects in Videos

Syllabus – Part II

- Radiometry
- Photometric Stereo
- Depth from Focus and Defocus
- Camera Calibration
- Uncalibrated Stereo
- Motion and Optical Flow
- Object Tracking
- Structured Light Methods
- Modern Computational Cameras

Course Logistics

http://pages.cs.wisc.edu/~mohitg/courses/CS566/

Lectures

Instructor

Mohit Gupta
Email: mohitg@cs.wisc.edu
Office Hours: Tuesdays, 11:00 AM – 12:00 PM
Online on Zoom

Classes (online on Zoom, synchronous)

Tues, Thur --- 9:30 AM – 10:45 AM

Teaching Assistants

Eric Brandt (elbrandt@wisc.edu)

Office hours:
Mondays and Thursdays, 12pm-1pm, via Canvas Zoom Page

Sungjin Cheong (sungjin.cheong@wisc.edu)

Office hours:
Wednesdays and Fridays, 12pm-1pm, in-person in MH B2562

Course Prerequisites

- Fundamentals of Linear Algebra
- Fundamentals of Calculus
- Statistics
- Python

Grading

- 5 Programming Assignments 55%

- Python programming assignments.
- All assignments must be done individually.
- Total of 7 late days. 20% penalty per late day thereafter.
- More information on course website.

Academic Honesty Policy

Unless specifically authorized by the instructor, all assignment are to be done by the student working alone.

Final Project

- Research Oriented: 35% Grade
- Be creative. Originality will have the highest weight.
- Four milestones:
  - Proposal (due 30th Sep) (5%)
  - Mid-Term Report (due October 30th) (5%)
  - Presentations (December 2-11) (10%)
  - Project Webpage (Due: December 11) (15%)
- Done in teams of 2-4
- Start early!

Class Quizzes

- 10% Grade

  - Multiple choice questions (10-15 per quiz)
  - Meant to Check Your Understanding
  - Done Offline, Due 2 days (48 hours) After the Class
  - Full grades for participating, correctness not evaluated!

About the Slides

https://fpcv.cs.columbia.edu/

Course Reading

Computer Vision: Algorithms and Applications (Vision)
Szeliski, R., Springer [PDF Available Online - http://szeliski.org/Book]

Computer Vision: A Modern Approach (Vision)
Forsyth, D and Ponce, J., Prentice Hall

Robot Vision (Vision)
Horn, B. K. P., MIT Press

A Guided Tour of Computer Vision (Vision)
Nalwa, V., Addison-Wesley Pub

Digital Image Processing (Image Processing)
González, R and Woods, R., Prentice Hall

Optics (Optics)
Hecht, E., Addison Wesley

Eye and Brain (Human Vision)
Gregory, R., Princeton University Press

Animal Eyes (Biological Vision)
Land, M. and Nilsson, D., Oxford University Press

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I.1 http://www.daveltd.com/photo/macro/eyes/jalene/beautiful-right-eye.jpg

I.2 http://www.automation.com/images/article/omron/MVWP3.jpg

I.3 http://www.qualitydigest.com/june06/Images/ARTICLES/3DMEASURE/3-D-Header.jpg

I.4 http://seetech-corp.com/engineering/wp-content/uploads/2011/07/SEETECH-3d-laser-build-inspection-technology.jpg

I.5 http://www.ionaudio.com/downloads/booksaver_2011_overview.pdf

I.6 http://www.qualitydigest.com/june06/Images/ARTICLES/3DMEASURE/3-D-Header.jpg

I.7 http://www.computing.dundee.ac.uk/staff/jessehoey/teaching/vision/barca2_fd.jpg

I.8 http://ngm.nationalgeographic.com/2002/04/afghan-girl/mccurry-photography

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I.14 http://en.wikipedia.org/wiki/File:NASA_Mars_Rover.jpg

I.15 http://sfcitizen.com/blog/wp-content/uploads/2012/09/rsf.jpg

I.16 http://nxtbot.com/blog/wp-content/uploads/2006/03/riman.jpg

I.17 http://www.sciencephoto.com/image/307062/530wm/P3320434-Brain_anatomy,_MRI_scan-SPL.jpg

I.18 Adapted from V. Nalwa, "A Guided Tour of Computer Vision."

I.19 http://1x.com/photo/23656/portfolio/8197

I.20 Adapted from "Scientific American," November 1999.