# EE 267: Introduction and Overview


Gordon Wetzstein
Stanford University

EE 267 Virtual Reality

Lecture 1

stanford.edu/class/ee267/

# vir·tu·al re·al·i·ty

vərCH(əw)əl rēˈalədē

*the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.*

vpl research

simulation & training

visualization & entertainment

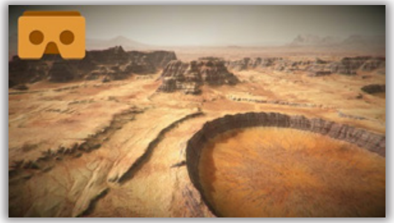
remote control of vehicles, e.g. drones

gaming

robotic surgery

architecture walkthroughs

education



virtual travel

a trip down the rabbit hole

# VR at Stanford's Medical School

photo from Stanford Medicine News

- Lucile Packard Children's Hospital: used to alleviate pain, anxiety for pediatric patients
- VR Technology Clinic: applications in psychotherapy, mental health, for people with phantom pain, …
- help train residents, assist surgeons planning operations, …

# National Academy of Engineering

“Enhance Virtual Reality” is 1 of 14 NAE grand challenges for engineering in the 21st century

image from NAE

# Exciting Engineering Aspects of VR/AR

- cloud computing
- shared experiences

- CPU, GPU
- IPU, DPU?

- compression, streaming

- sensors & imaging
- computer vision
- scene understanding


images by microsoft, facebook

- VR cameras

- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, …

- HCI
- applications

# Where We Want It To Be

image by ray ban

Personal Computer
e.g. Commodore PET 1983

Laptop
e.g. Apple MacBook

Smartphone
e.g. Google Pixel

AR/VR/MR
e.g., Apple Vision Pro

???

# A Brief History of Virtual Reality

Stereoscopes
Wheatstone, Brewster, …

VR & AR
Ivan Sutherland

Nintendo
Virtual Boy

VR explosion
Oculus, Sony, Apple, …

???

1838 | 1968 | 1995 | 2012-2024

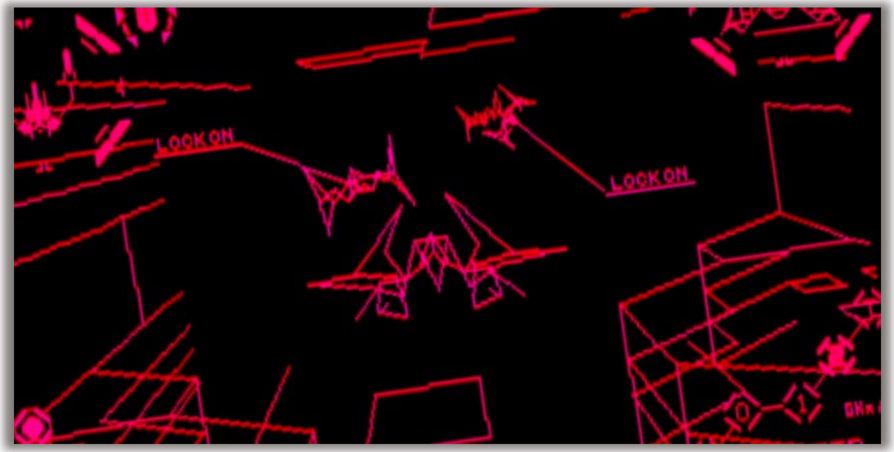
# Ivan Sutherland's HMD

- optical see-through AR, including:
    - displays (2x 1" CRTs)
    - rendering
    - head tracking
    - interaction
    - model generation
- computer graphics
- human-computer interaction

I. Sutherland "A head-mounted three-dimensional display", Fall Joint Computer Conference 1968

# Nintendo Virtual Boy

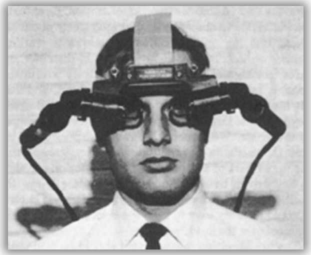
- computer graphics & GPUs were not ready yet!

Game: Red Alarm

# Where we are now

IFIXIT Apple Vision Pro - teardown



electronic / digital

1968

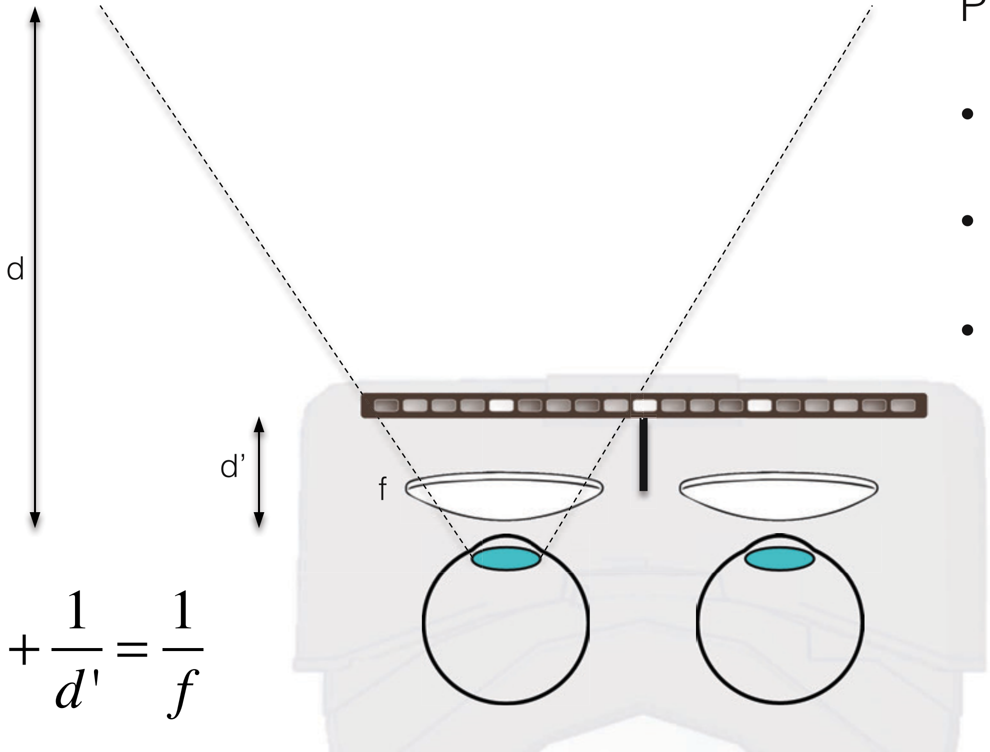
HCI / haptics

1980s

low cost, high-res, low-latency!

2000s

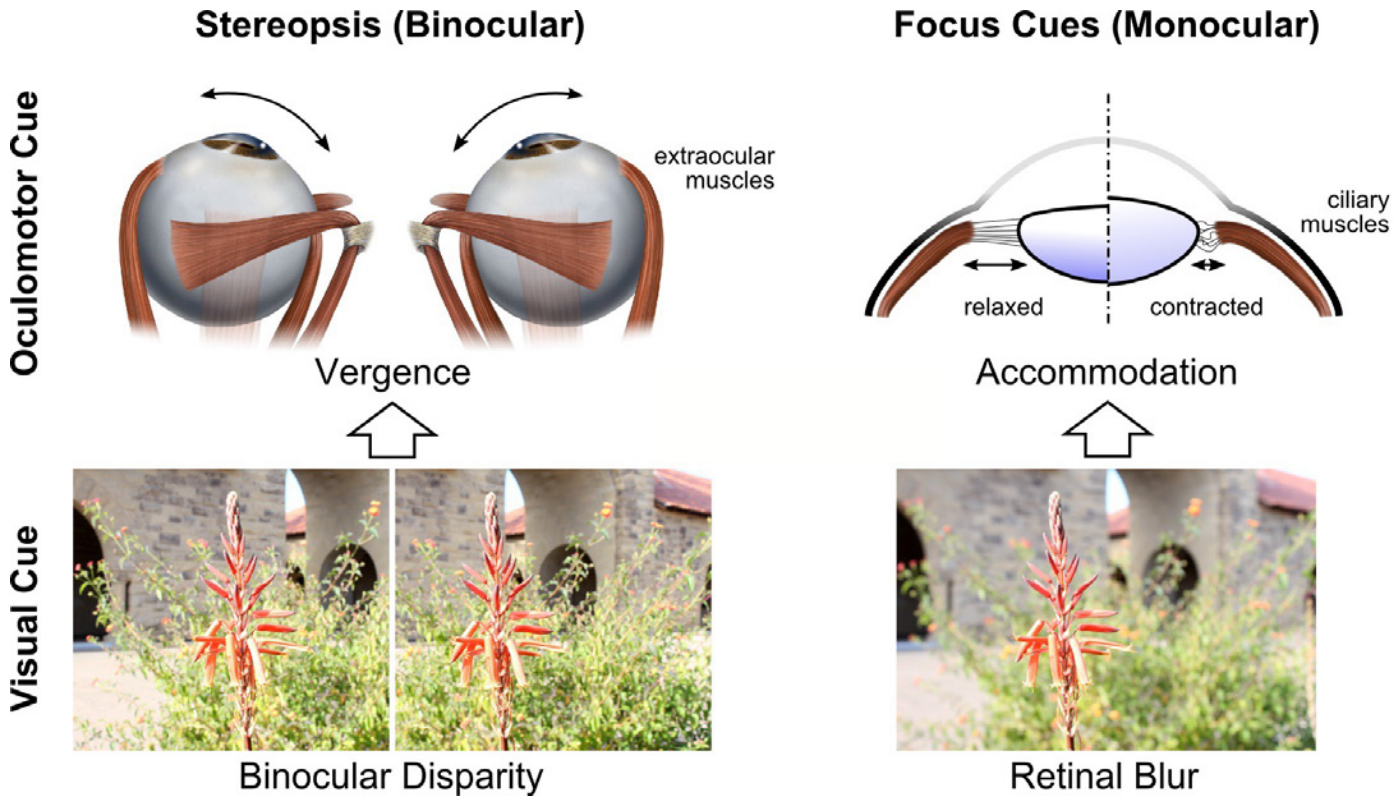
# Virtual Image

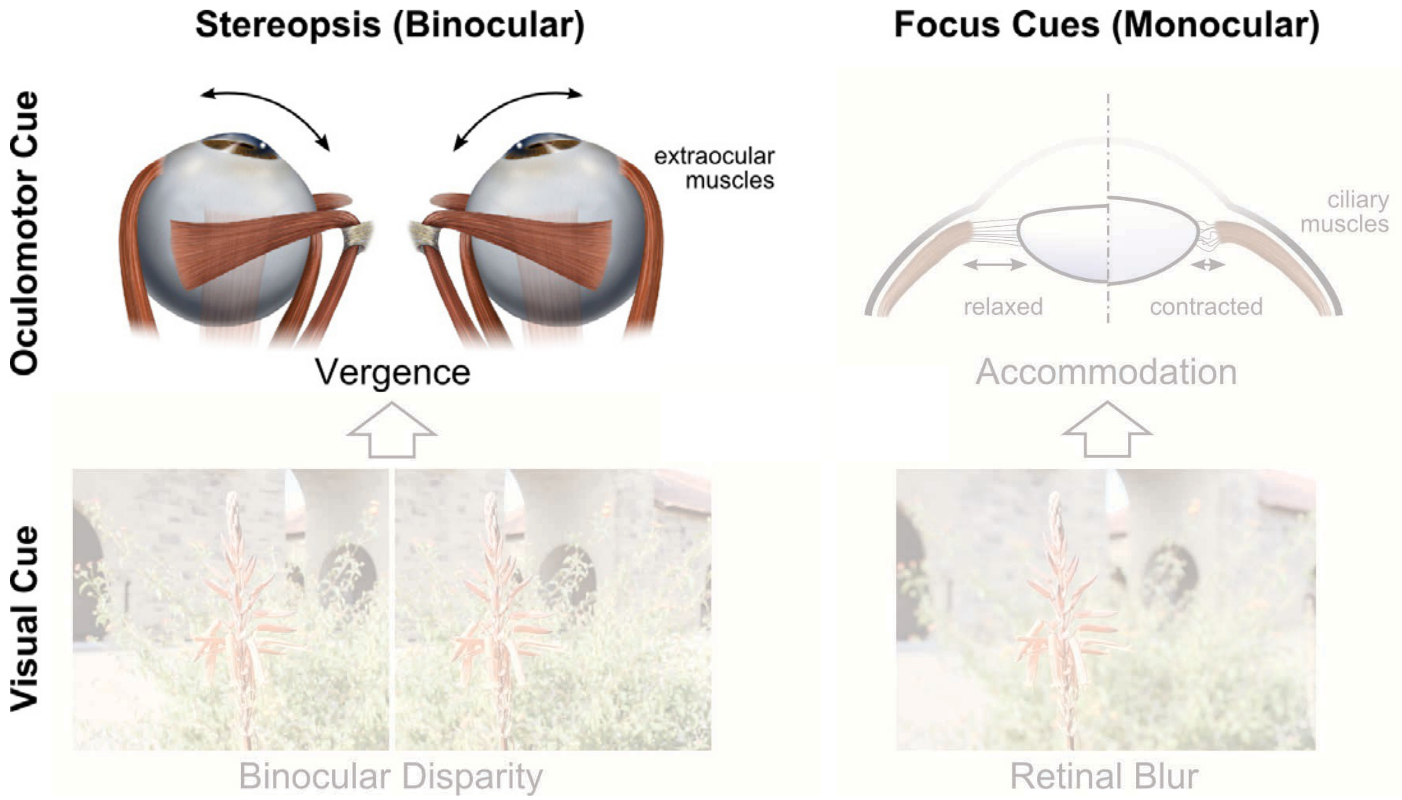



$$\frac{1}{d} + \frac{1}{d'} = \frac{1}{f}$$

Problems:

- fixed focal plane
- no focus cues ☹
- cannot drive accommodation with rendering!


Stereopsis (Binocular)
Focus Cues (Monocular)
Oculomotor Cue
extraocular
muscles
ciliary
muscles
relaxed
contracted
Vergence
Accommodation
Visual Cue
Binocular Disparity
Retinal Blur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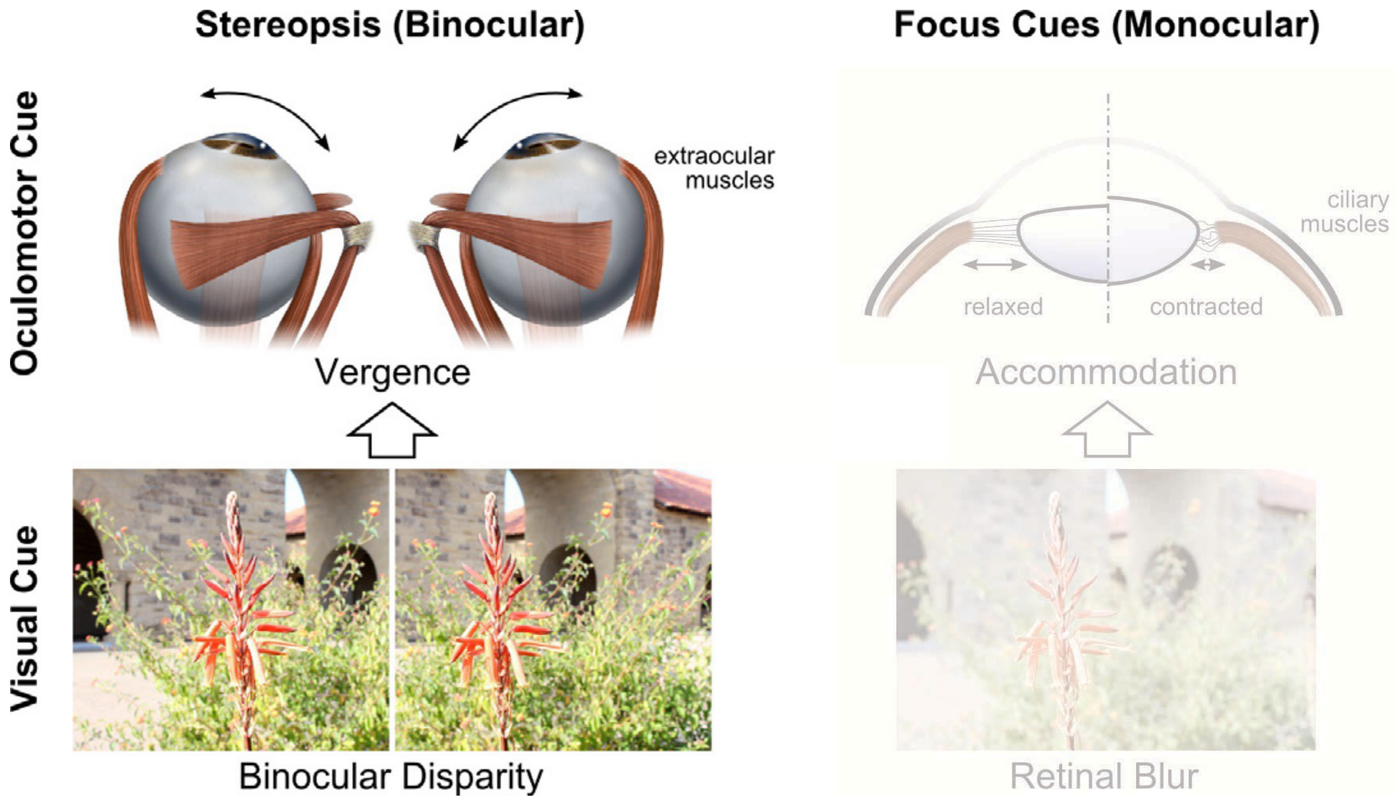
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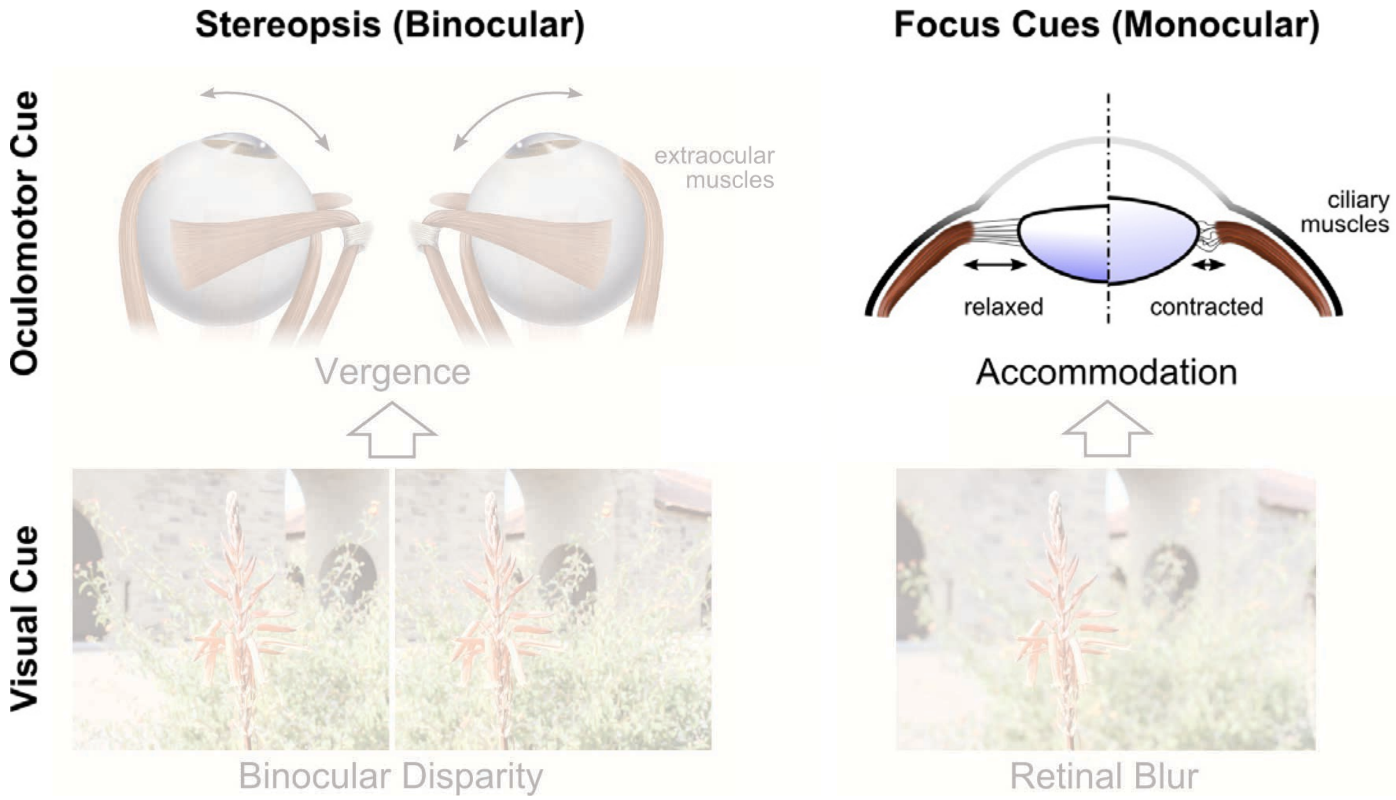

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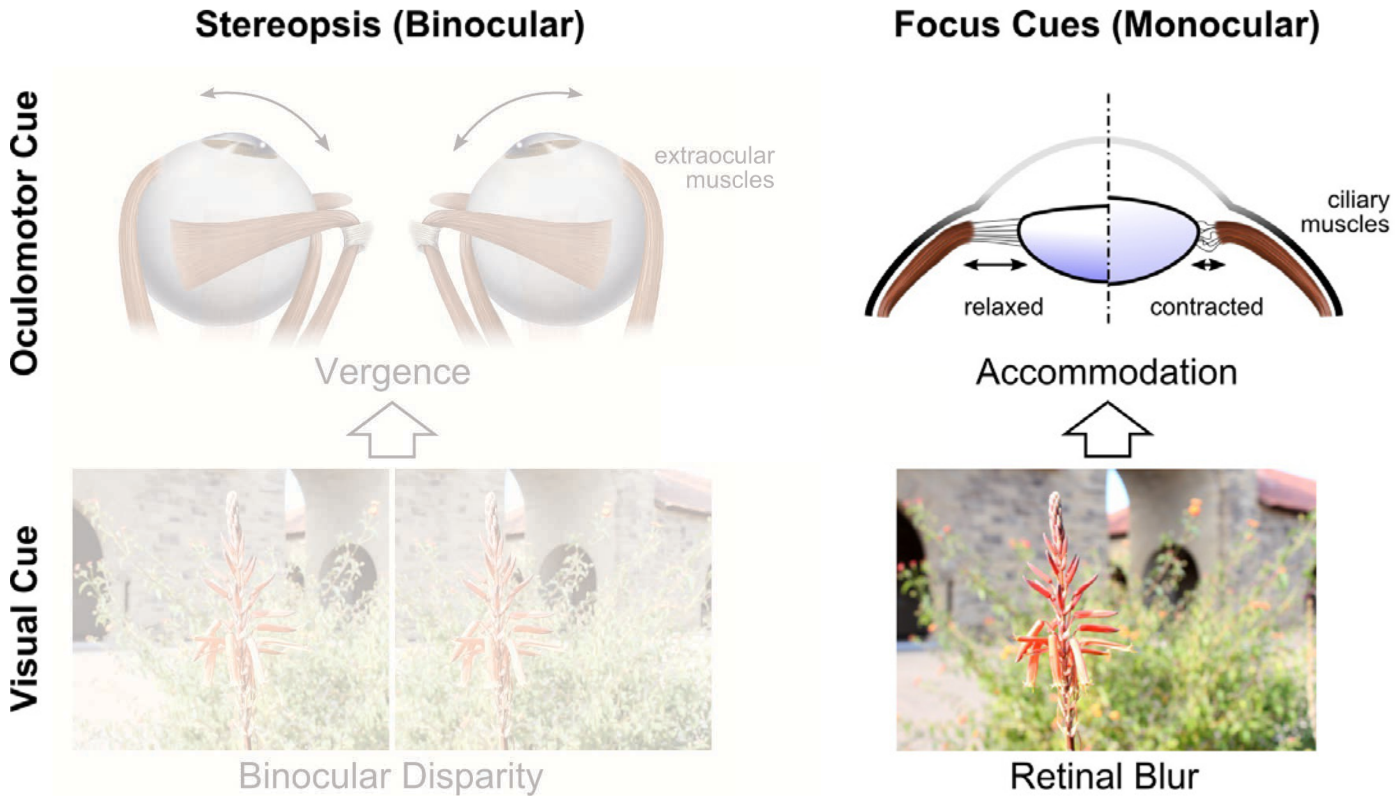

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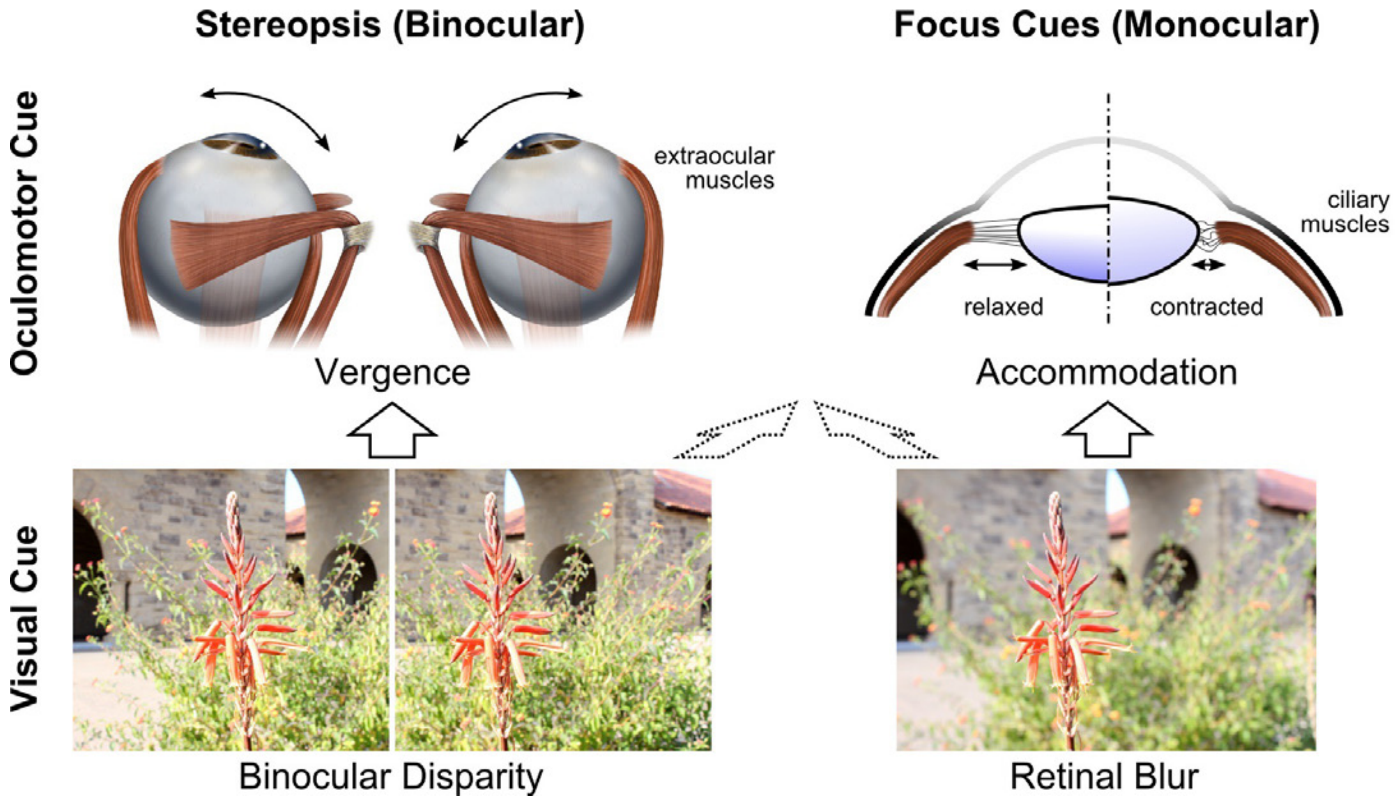
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# Mixed Reality or Pass-through VR

(not really covered in this class, but closely related)

# Apple Vision Pro (supposedly) has 14 cameras!

4x front- and side-facing for SLAM.

**<u>2x for pass through.</u>**

4x for eye & face tracking.

2x for torso tracking.

1x for gesture tracking.

1x time-of-flight sensor.

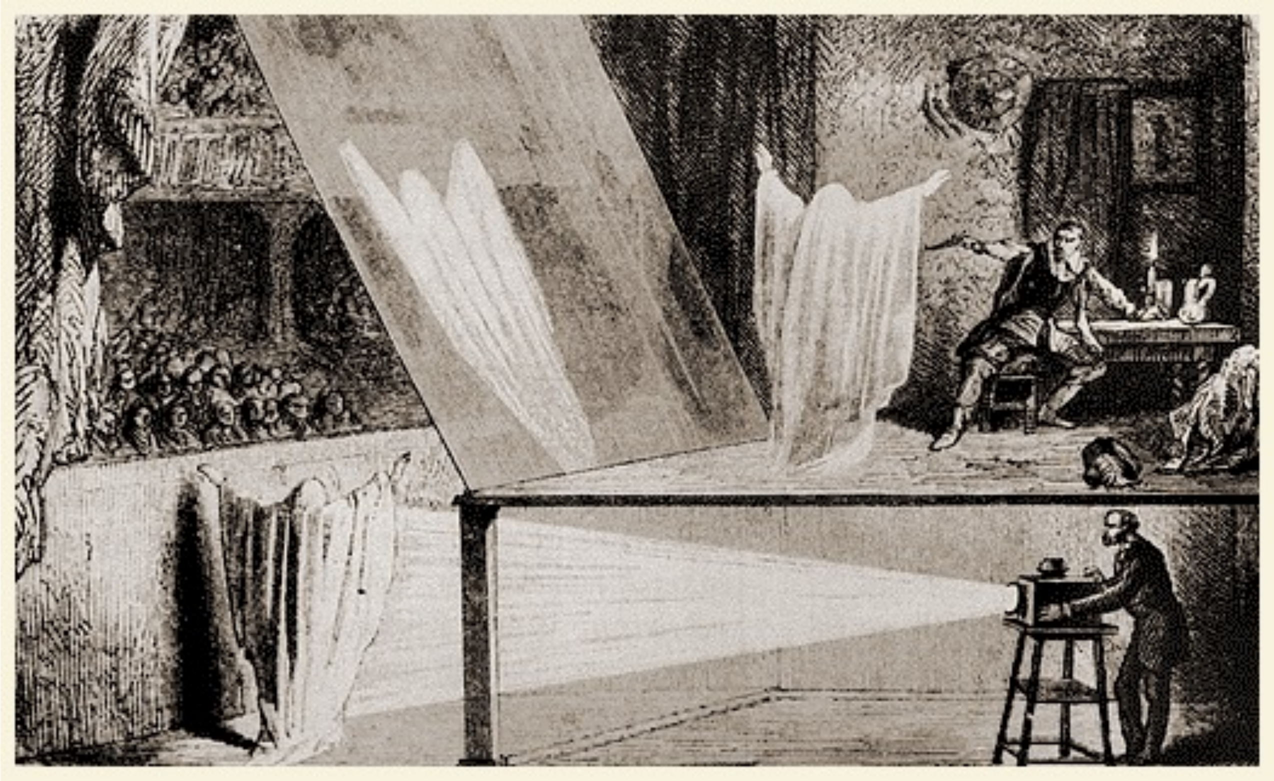
# What's Pass-through VR?

- How you see the physical environment (room, people, your body parts)
- Pass-through = video camera(s) record the scene, typically do some 3D reconstruction, then re-render on digital display for stereo vision
- Issues:
    - Resolution
    - Latency
    - Image quality (color, noise, reconstruction fidelity, …)
    - Dynamic range / contrast
    - …

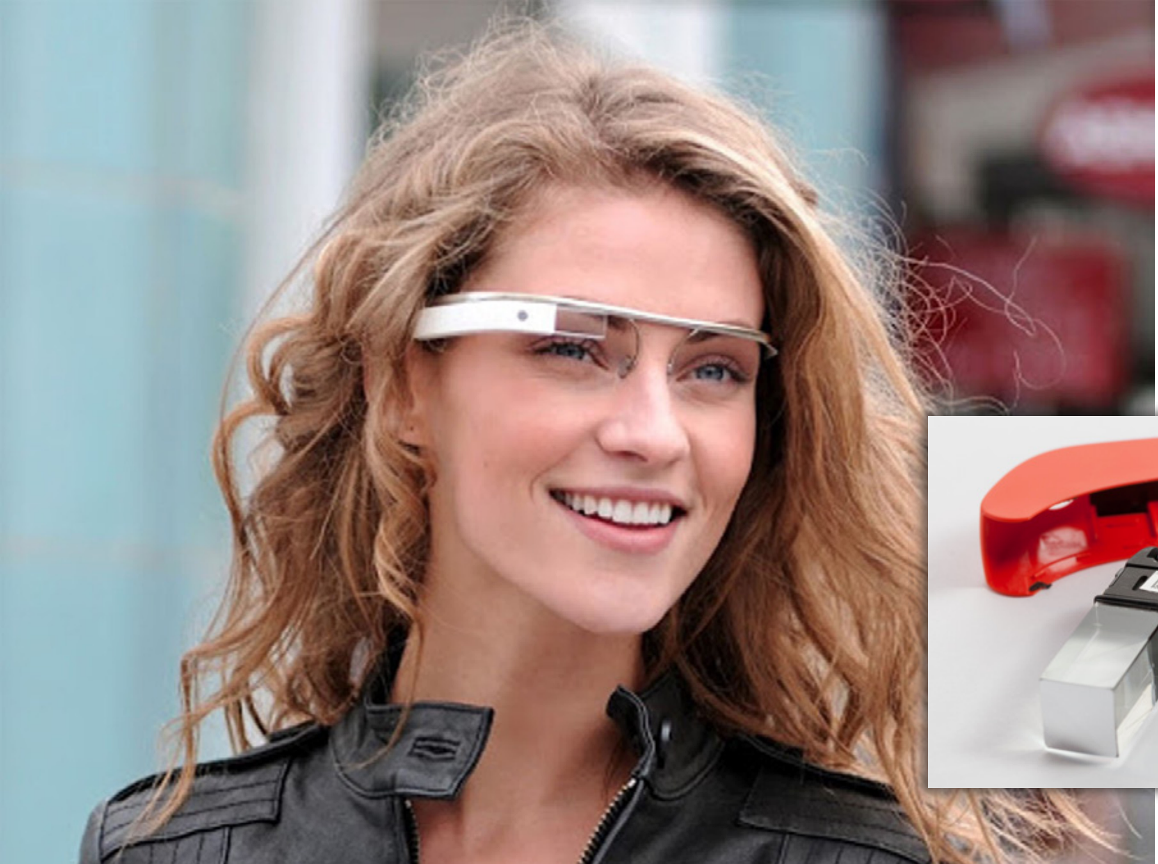
# (Optical See-through) Augmented Reality

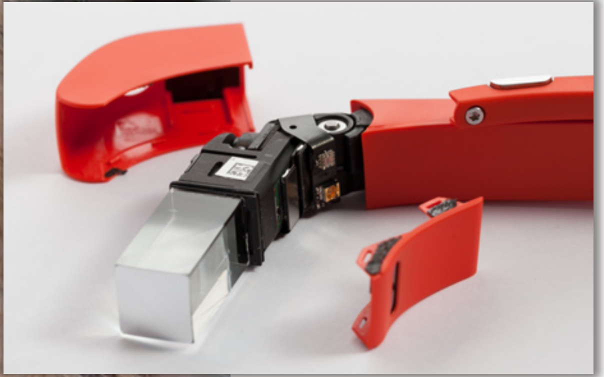
(not really covered in this class, but closely related)

# Pepper's Ghost 1862



# Google Glass





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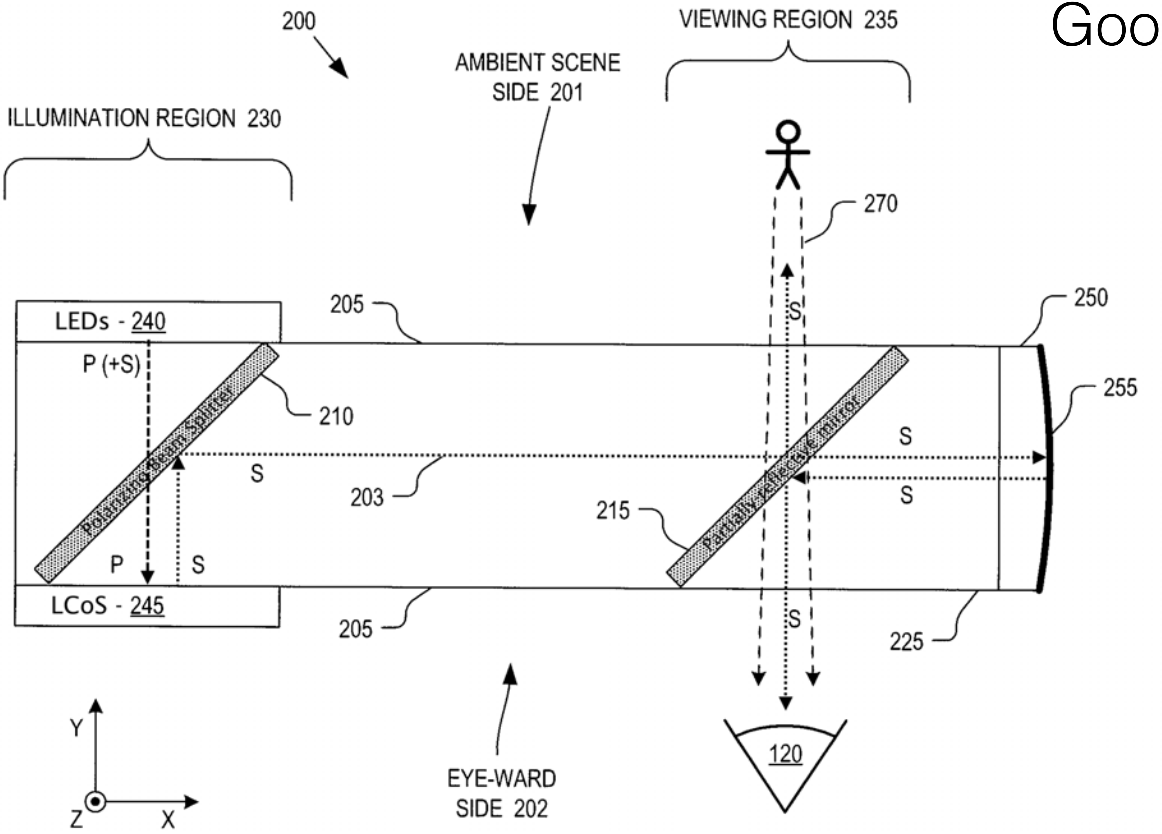
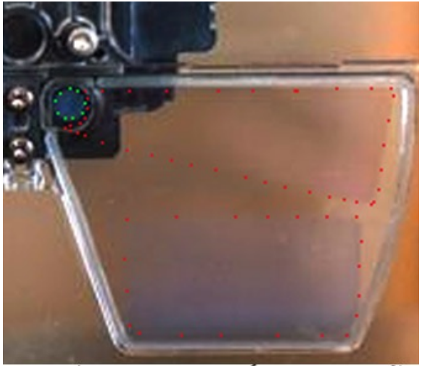
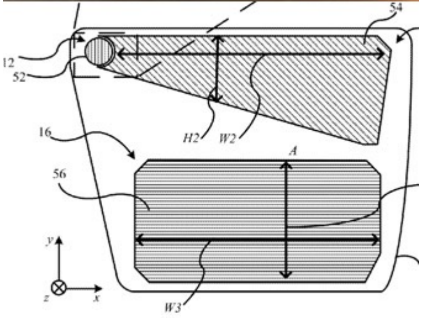


# Microsoft HoloLens

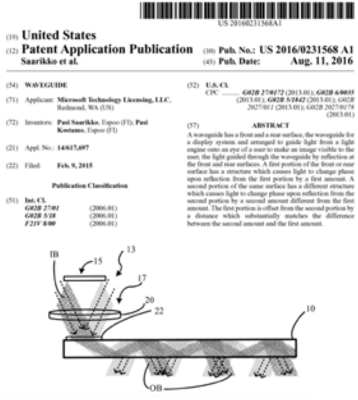
# Microsoft HoloLens

- diffraction grating
- small FOV (30x17), but very good image quality



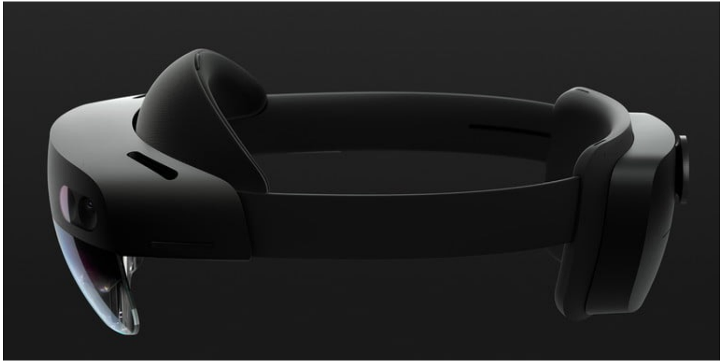


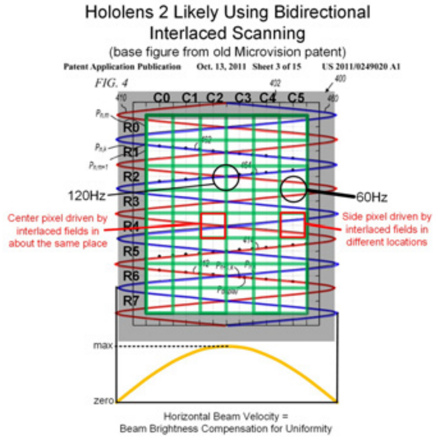

US 2016/0231568 Fig. 3B


United States
Patent Application Publication
Saarikko et al.
Pub. No.: US 2016/0231568 A1
Pub. Date: Aug. 11, 2016
(54) WAVEGUIDE

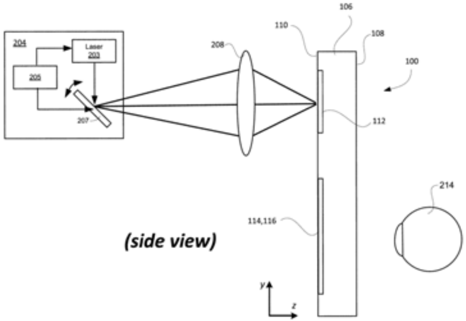
# Microsoft HoloLens 2

- laser-scanned waveguide display
- claimed 2K resolution per eye (2560x1440), probably via “interlaced” scanning
- field of view: 52°  diagonally (3:2 aspect, 47 pixels per visual degree)



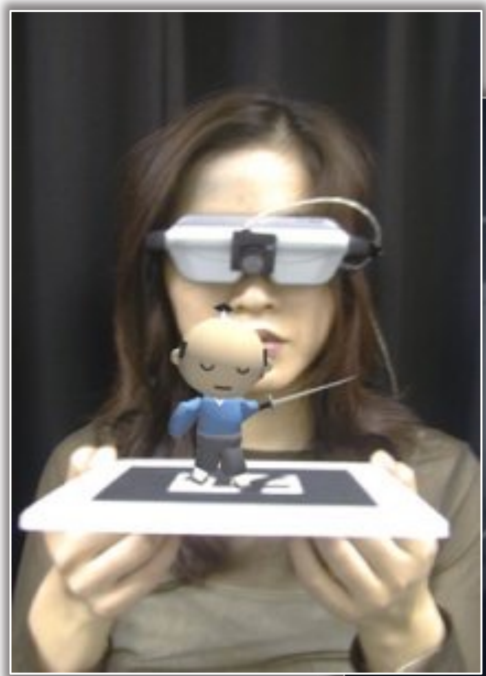


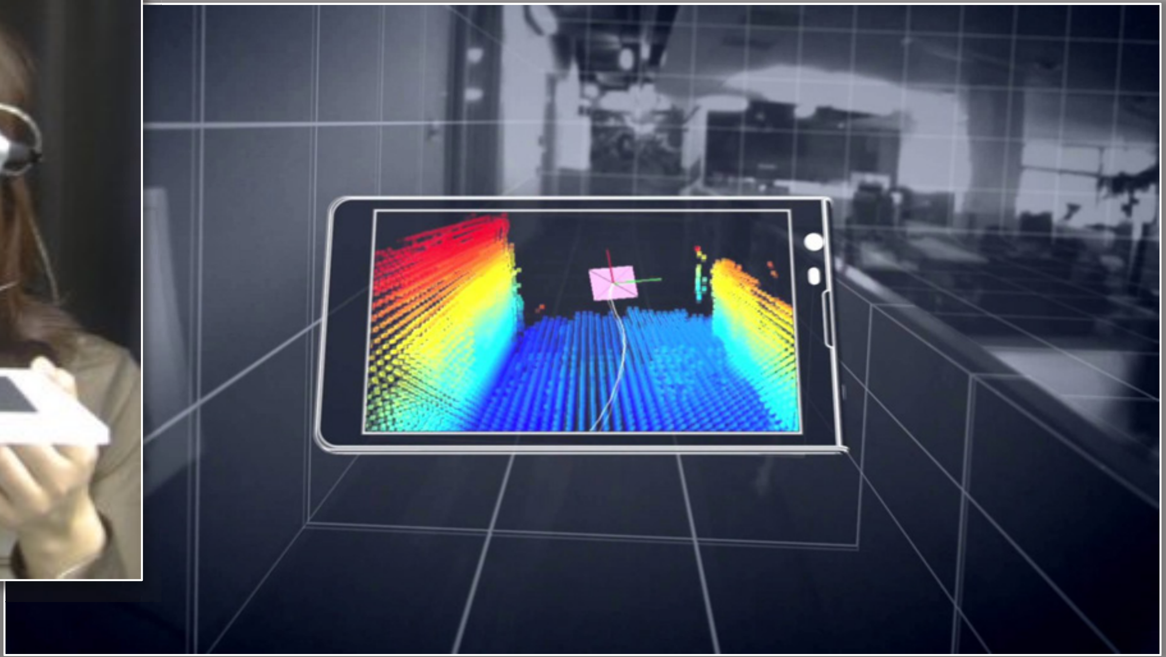

https://www.kguttag.com/2019/02/27/hololens-2-first-impressions-good-ergonomics-but-the-lbs-resolution-math-fails/




Wall et al. US 10,025,093 2018

# Video-based AR: ARCore, ARKit, ARToolKit, …





Your first (unofficial = we won’t check) homework:

Book a demo session with the Apple Vision Pro at the Apple Store (e.g., in the Stanford Mall)

# EE267 Instructors

Gordon Wetzstein

Associate Professor of EE/CS

Suyeon Choi

Manu Gopakumar

Research Assistants and EE267 – VR experts!

SCI STANFORD COMPUTATIONAL IMAGING LAB

# About EE 267

- experimental class, only taught at Stanford
- lectures + assignments = one big project – <u>build your own VR HMD</u>
- all hardware provided, but must return at the end
- enrollment limited, because it's a lab-based class and we only have limited hardware kits – <u>share kits to let more students take the class!</u>
- 1 or a few guest lectures by leaders toward the end of the quarter

# About EE 267 - Goals

- *again, primary goal: build your own HMD!*

- learn what is necessary to get there along the way:
    - computer graphics / real-time rendering
    - human visual system
    - magnifying optics
    - orientation (i.e. “3 DoF”) and pose (i.e. “6 DoF”) tracking

- very technical course! lots of math and programming!!

# About EE 267 – Learning Goals

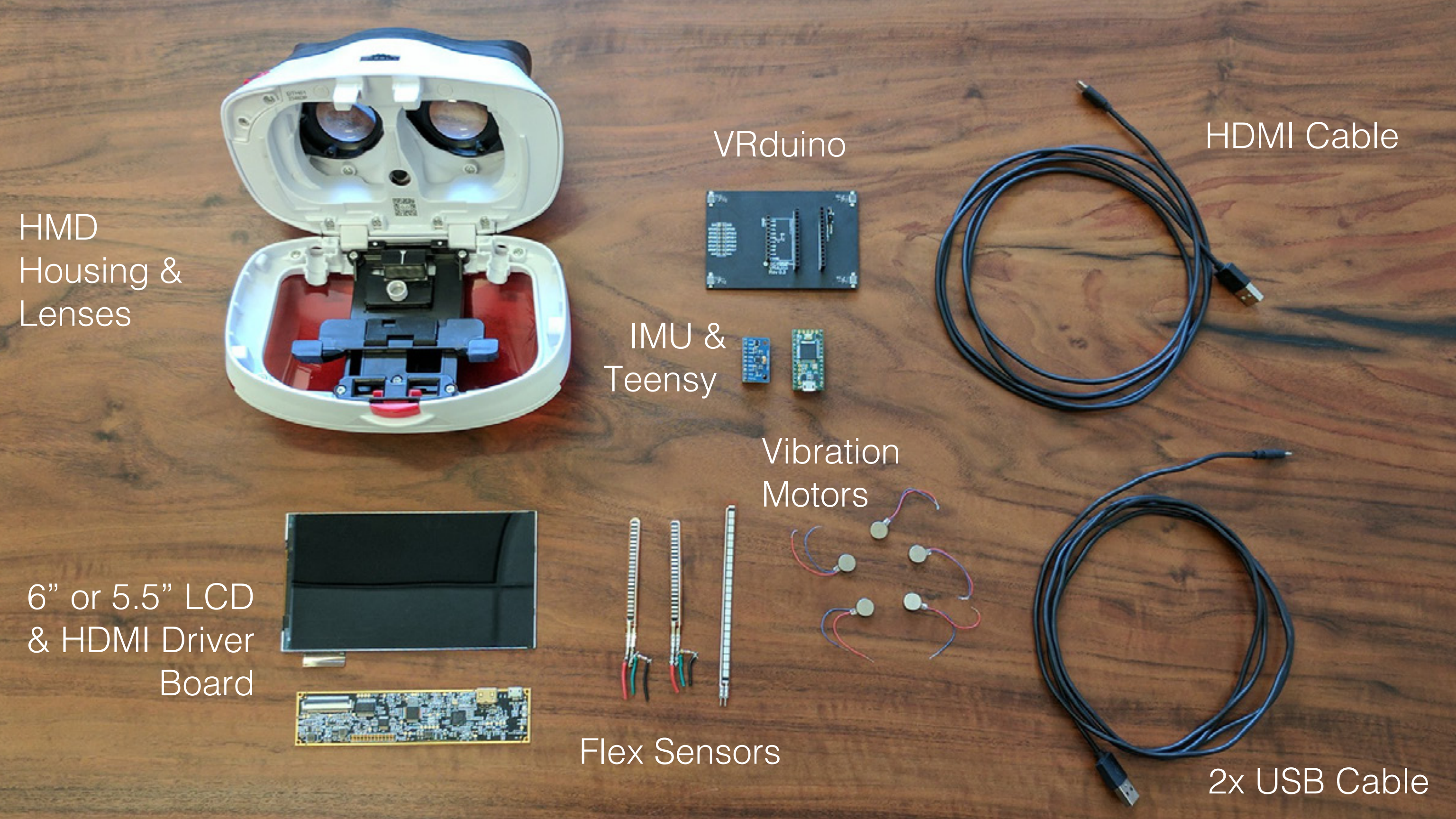
- understand fundamental concepts of VR and Computer Graphics
- implement software + hardware of a head mounted display
- learn basic WebGL/JavaScript and Arduino programming

# What EE 267 is not!

- *not a* “build VR application in Unity” course, although you can do that in your project

- *not a* “here is a high-level overview of VR” course – you need to implement everything discussed in the lectures in your weekly assignments

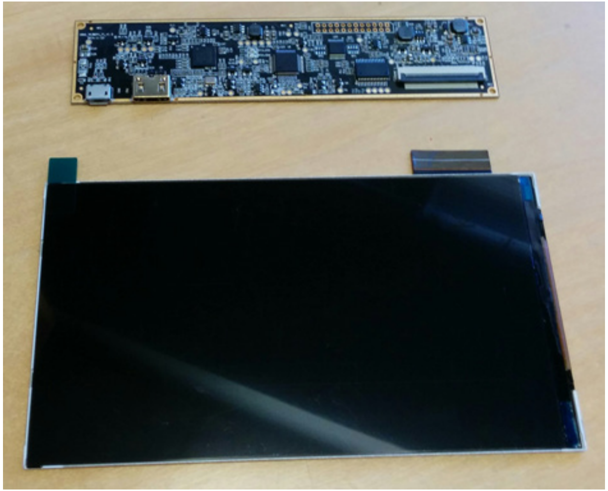
- *not a* super hard course, but requires consistent work effort and time commitment throughout the quarter


HMD Housing & Lenses
VRduino
HDMI Cable
IMU & Teensy
Vibration Motors
6” or 5.5” LCD & HDMI Driver Board
Flex Sensors
2x USB Cable

# HMD Housing and Lenses

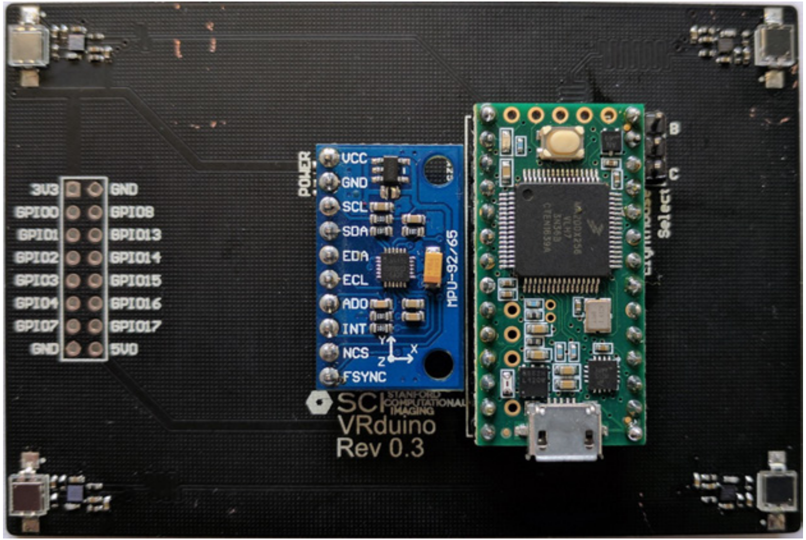
- View-Master VR Starter Kit ($15-20) or Deluxe VR Viewer ($23)
  - implements Google Cardboard 1.0/2.0
  - very durable – protect flimsy LCDs

# Display



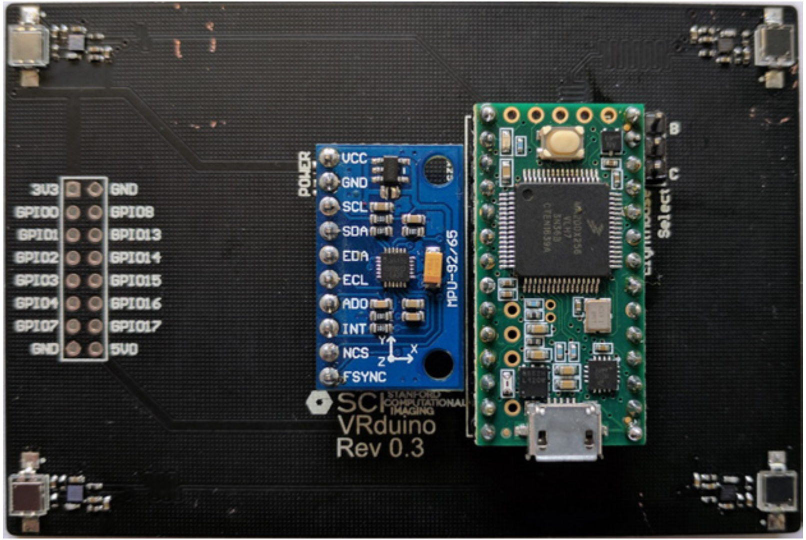
- Small LCDs, either 6” or 5.5”
- HDMI driver boards included
- super easy to use as external monitor on desktop or laptop

# VRduino




- Arduino-based open source platform for:
  - orientation tracking
  - positional tracking
  - interfacing with other IO devices
- custom-design for EE 267 by Keenan Molner
- all HW-related files on course website

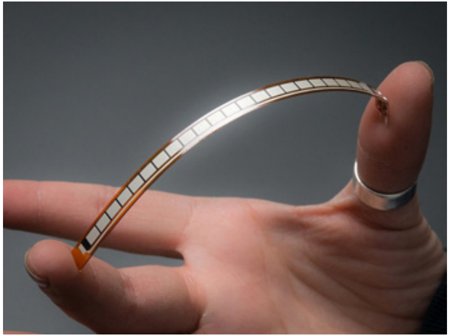
# VRduino

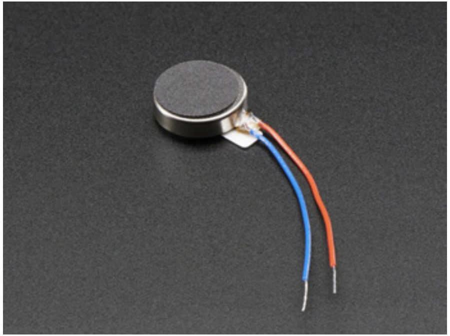



- Teensy 3.2 microcontroller (48 MHz, $20) for all processing & IO
- InvenSense 9250 IMU (9-DOF, $6) for orientation tracking
- Triad photodiodes & precondition circuit ($1) for position tracking with HTC Lighthouse

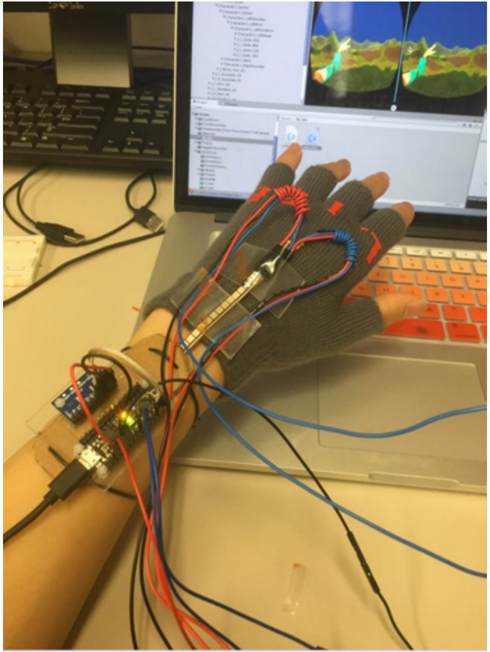
# Some Student Projects - Input Devices

- data gloves with flex sensors
- different types of controllers with tactile feedback via vibration motors
- all connected to VRduino GPIO pins





images from Adafruit.com



# About EE 267

- all important info here: http://stanford.edu/class/ee267/
- plenty of (zoom) office hours and Ed Discussion: see website
- contact: ee267-spr2324-staff@lists.stanford.edu

# About EE 267 - Prerequisites

- strong programming skills required (ideally JavaScript)
  do NOT take this course if you have not programmed!

- basic linear algebra required – we will start dreaming about 4x4 matrices (must know what a matrix, matrix-vector product, etc. is)

- introduction to computer graphics or vision helpful

# About EE 267 – Lectures & Labs

- 2 lectures per week: Tue/Thu 12-1:50 pm
    - Video recordings:
        1. No videos (default options)
        2. May record lectures on zoom and upload on canvas (don’t rely on it!)

- 1 lab per week starting in week 1 (do at home, will release writeups and videos with links to online tutorials and other important things)

- you will need the skills of the lab to complete the homework, so ***do the lab first and then start working on the homework***!

# About EE 267 – Labs & Assignments

- labs and homeworks released every Friday
- do all of these at home by yourself or in small teams
- we will hand out all required hardware (details later)

# About EE 267 – Office Hours

- Gordon (instructor): Mondays 1-2 pm, Packard 236
  talk about projects, VR, course logistics, etc.

- Suyeon (TA): Tue, 11am-12pm, Packard 104
- Manu (TA): Thu, 1:30-2:30pm, Packard 104

  talk about labs, assignments, …

No zoom by default!

# EE 267 – 3/4 unit version

Both versions:

- 6 assignments covering all aspects of VR tech: 2x basic computer graphics, 2x perception+graphics+optics, 2x tracking
- Final project (hardware, software, or perceptual experiments) worth ~ 2x regular homework

3 Unit version:

- 1-2 page project report

4 Unit version:

- 6–8 page project report required (more details on website)

# EE 267W – 5 unit WIM version

- satisfies writing in the major requirement
- only available for undergraduates already enrolled in the 4 unit version
- will get extra weekly writing and peer-reviewing assignments + 2 writing / presentation workshops
- *talk to instructors if you want to do this in first week of class!*

# Requirements and Grading

- 6 assignments (teams of ≤ 2): 60%
- 80 minute in-person midterm: 20%
- project (teams of ≤ 3): 20%
    - discuss project ideas with TA & instructor!
    - final presentation (poster/demo session) on 5/30/2024
    - reports & code due (gradescope): 5/31/2024, 11:59pm

# Course Project Deliverables

- May 30, 11am – 1:30pm: In-person poster/demo session
  - By default: show demo on your own HMD or some commercial HMD
    - Generally, we do not provide commercial HMDs for your project
    - A few items can be lent out for the project – limited quantity!
  - Show a poster for non-demoable projects (see template on website)

# Course Project Deliverables

- May 31 (11:59pm): report + source code
- report (3 unit course version) = 1-2 page summary with the same topics listed below, just shorter (think “extended conference abstract”)
- report (4/5 unit course version) = conference paper format 6-8 pages with
    - abstract
    - introduction and motivation
    - related work
    - your thing
    - results, qualitative and quantitative evaluation
    - discussion, future work, and conclusion
    - references (scientific papers, not websites)
    - see latex template on website (will be there)

# Possible Course Projects

- be experimental!
- for example:
  - Default: build an elaborate virtual environment, e.g. with unity
  - psycho-physical experiments (e.g. test stereo rendering with color/gray, low-res/high-res, …)
  - hardware projects: IMU, positional tracking, eye tracking, haptics, …

# Relevant Scientific Venues

- ACM SIGGRAPH / SIGGRAPH Asia conferences (general computer graphics)
- IEEE VR, ISMAR, VRST conferences (focused on VR/AR)
- HCI conferences: ACM SIGCHI, UIST, …
- Optics journals: OSA Optics Express, Optics Letters, Applied Optics, …

# Tentative Schedule

http://stanford.edu/class/ee267/

Questions?