EE 267: Introduction and Overview

Gordon Wetzstein
Stanford University

EE 267 Virtual Reality

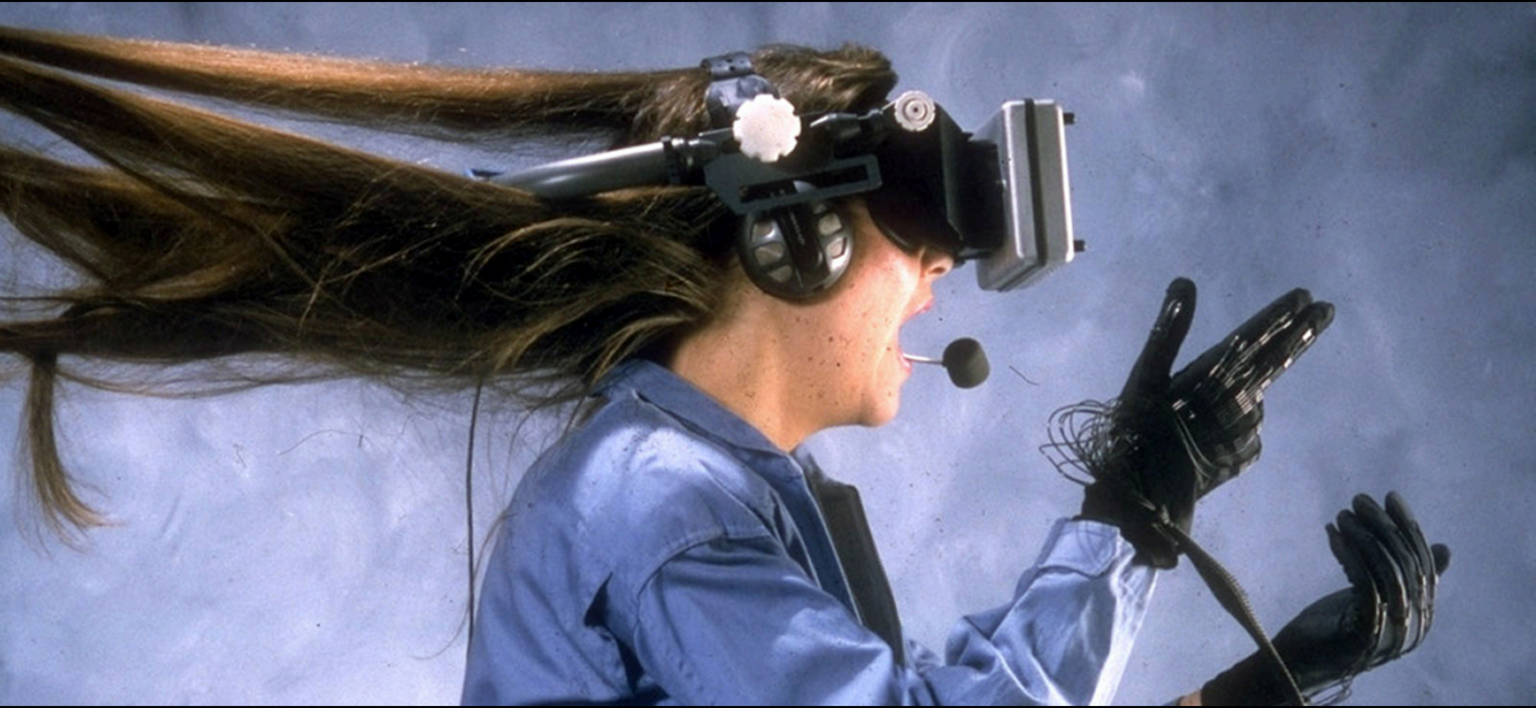
Lecture 1

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

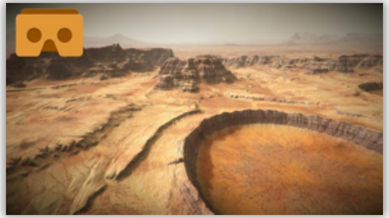
remote control of vehicles, e.g. drones

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

- VR cameras

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

- HCI
- applications

images by microsoft, facebook

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

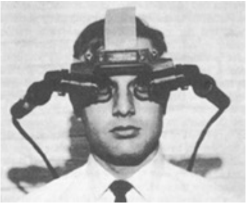
AR/VR
e.g. Microsoft Hololens

???

A Brief History of Virtual Reality

Stereoscopes
Wheatstone, Brewster, …

VR & AR
Ivan Sutherland



Nintendo
Virtual Boy

VR explosion
Oculus, Sony, HTC, MS, …

???

1838 1968 1995 2012-2020

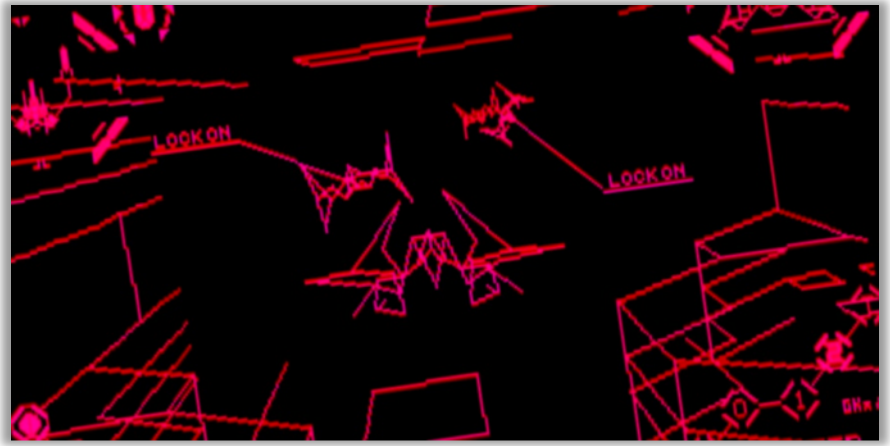
Ivan Sutherland's HMD

- 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

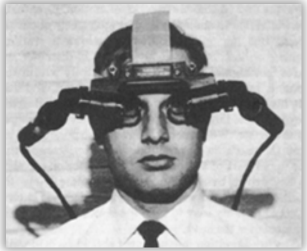
- computer graphics & GPUs were not ready yet!



Game: Red Alarm

Where we are now

IFIXIT teardown



electronic / digital

1968

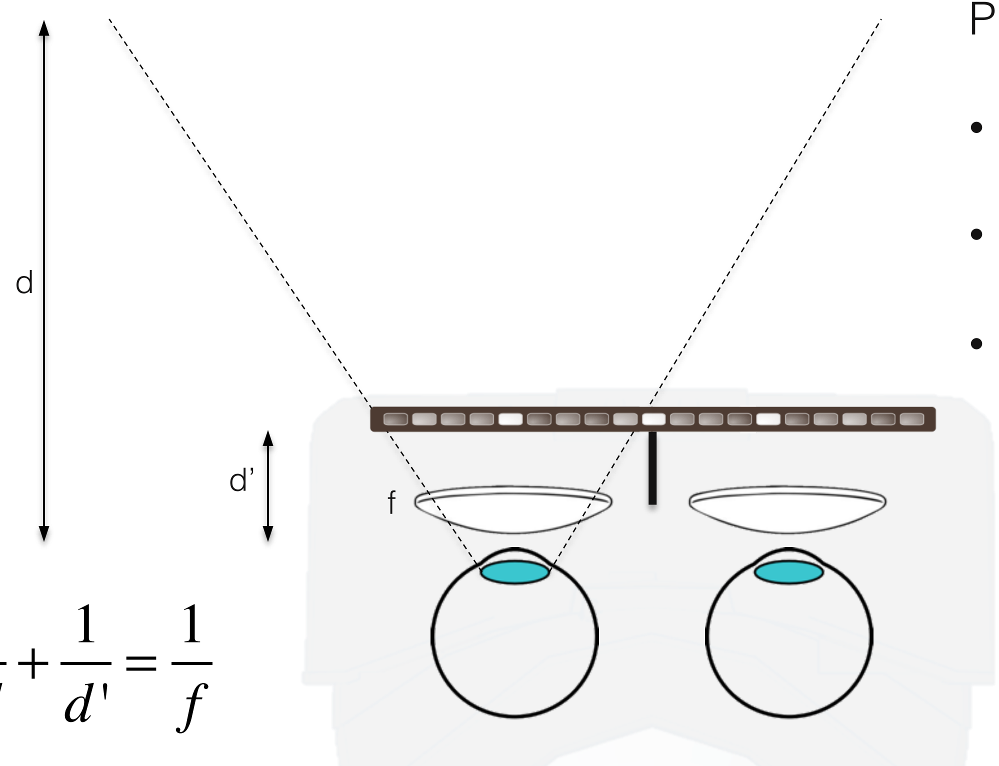
HCI / haptics

1980s

low cost, high-res, low-latency!

2000s

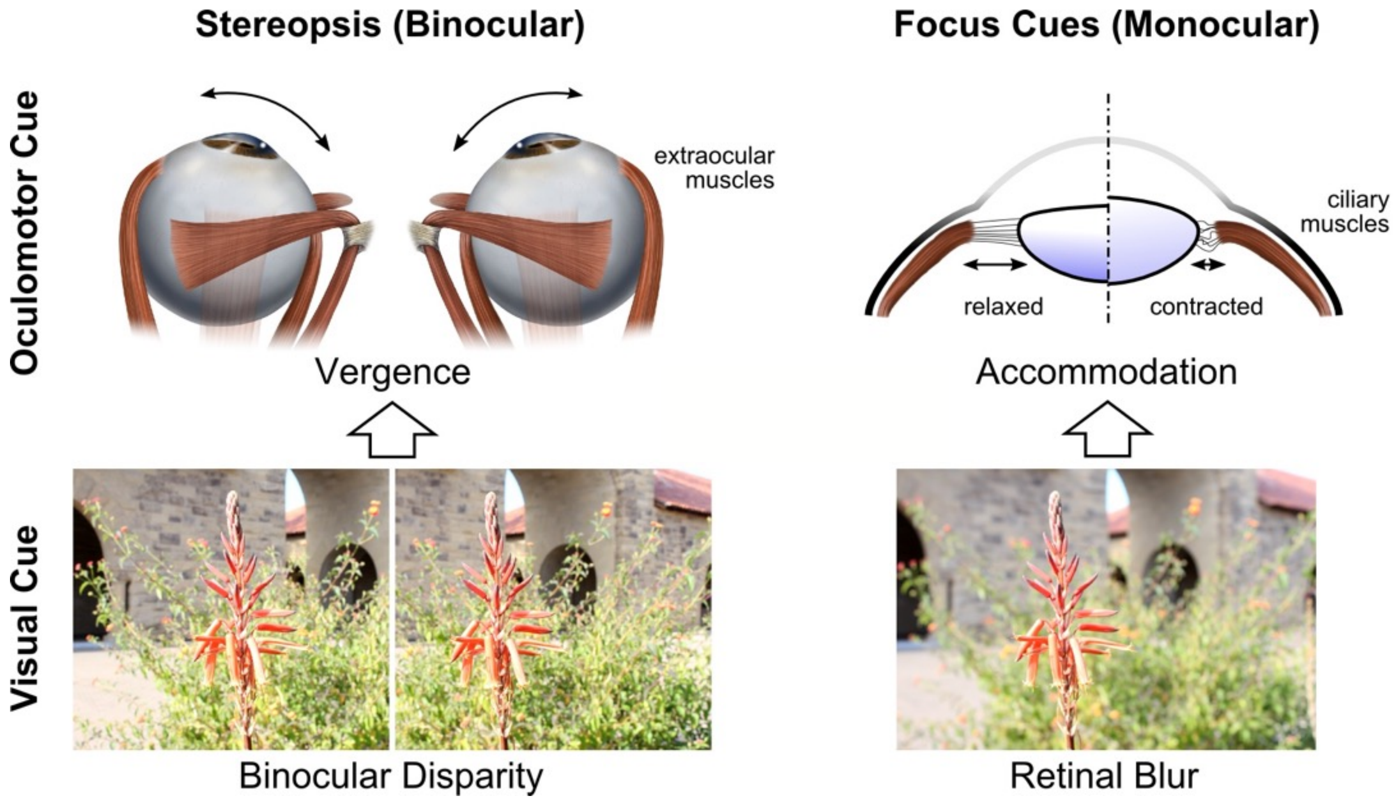
Virtual Image

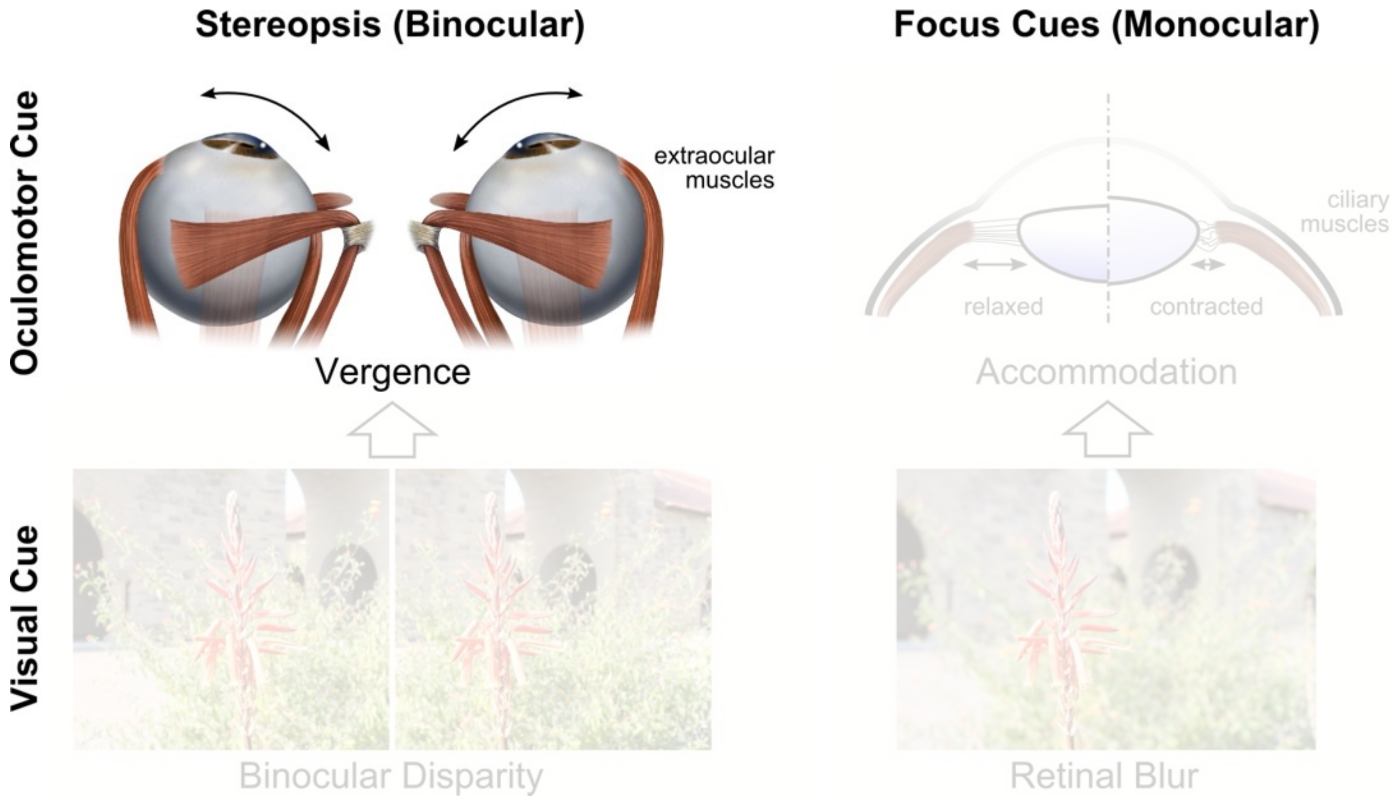


$$\frac{1}{d}+\frac{1}{d'}=\frac{1}{f}$$

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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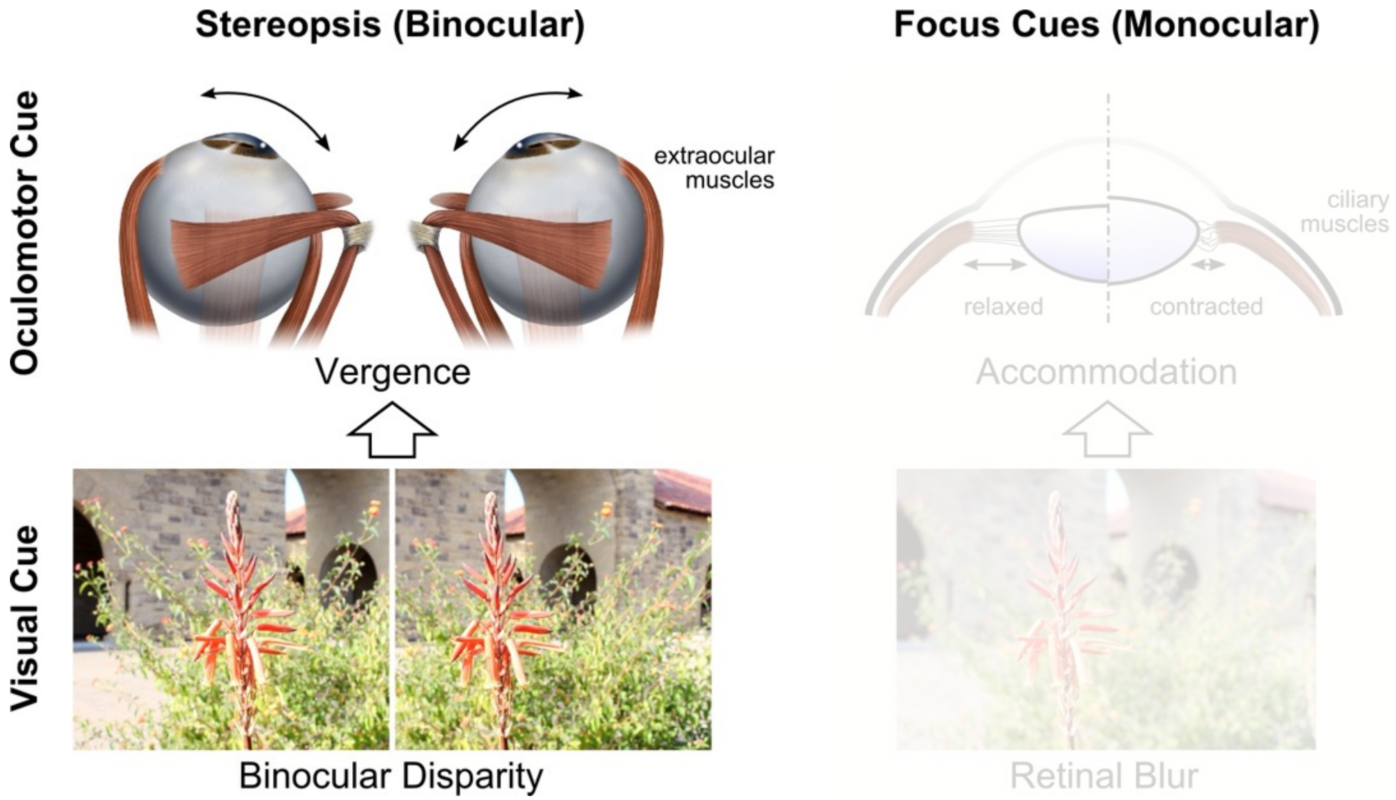
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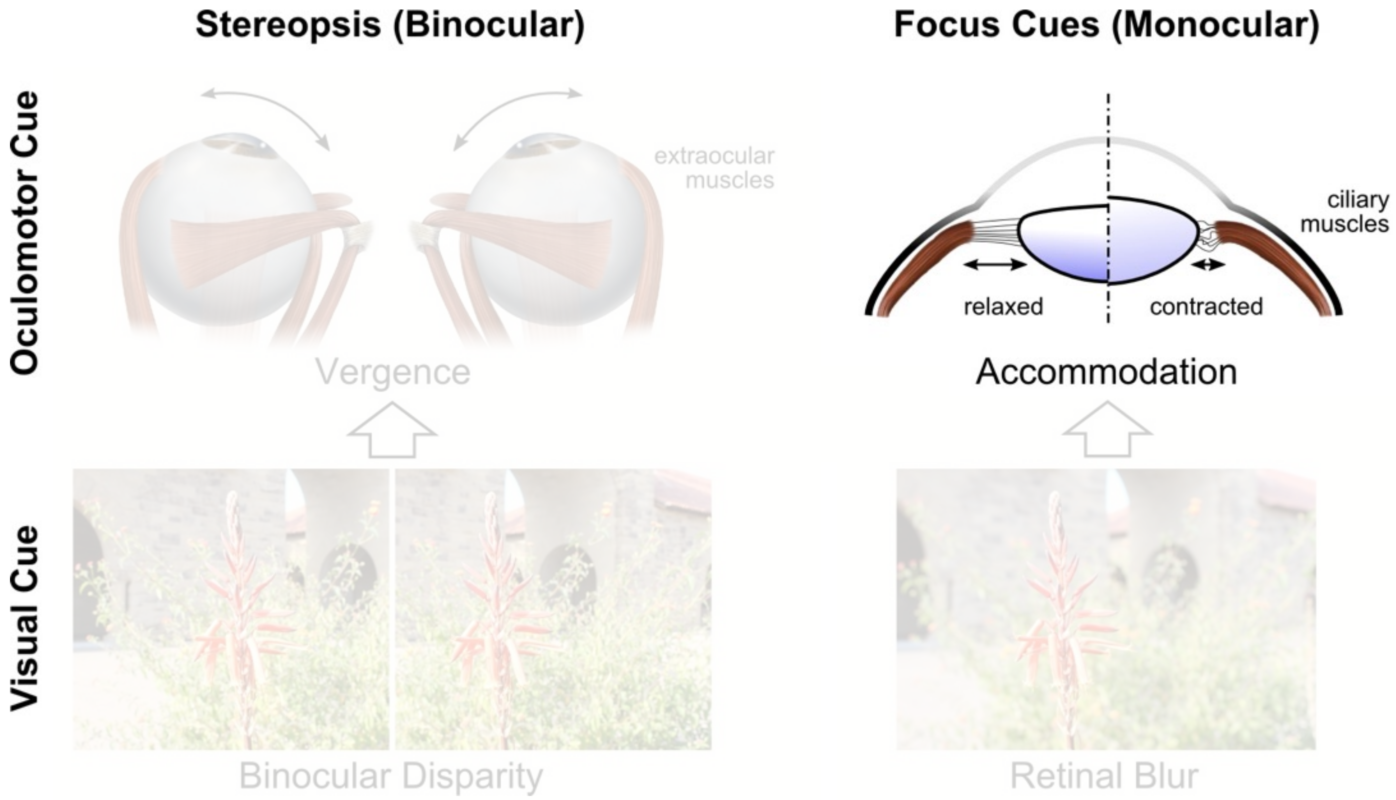
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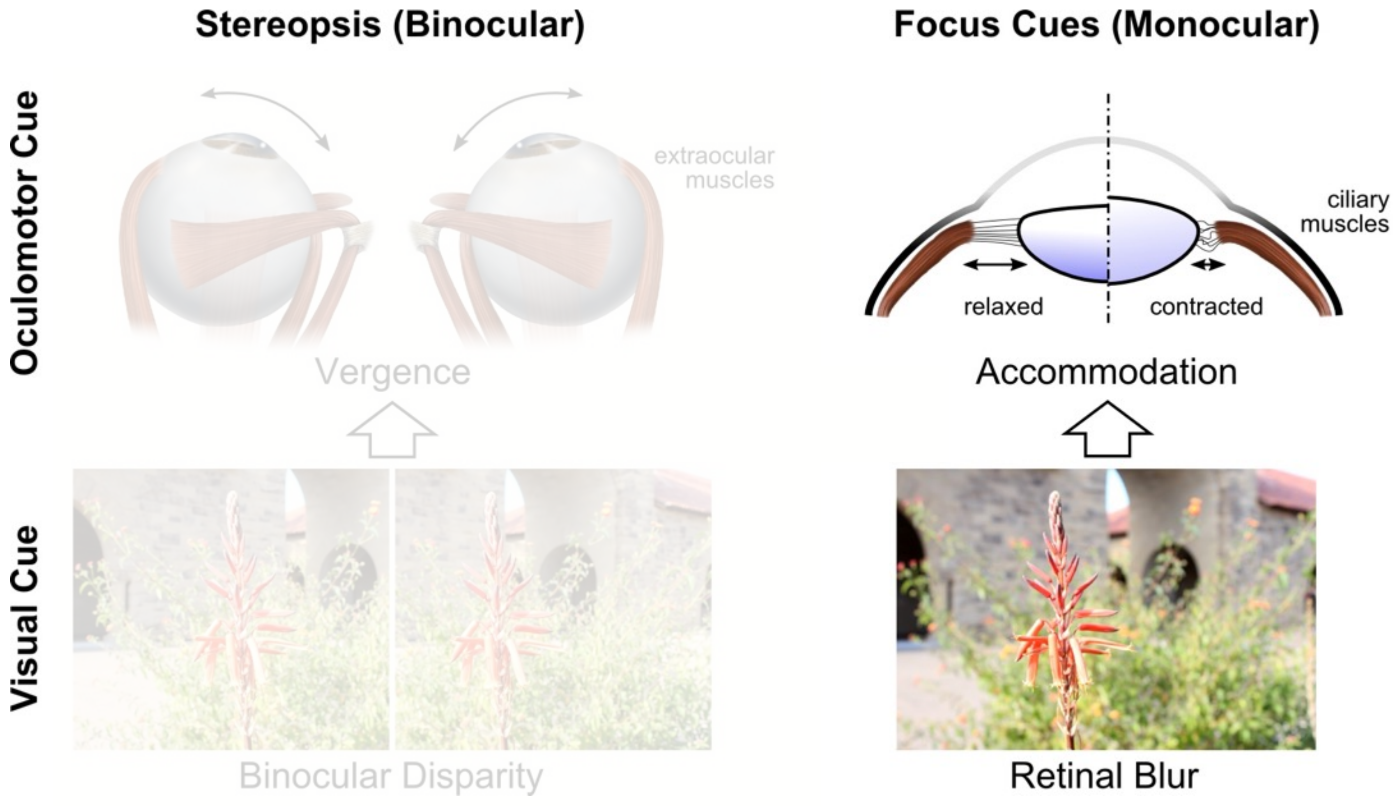
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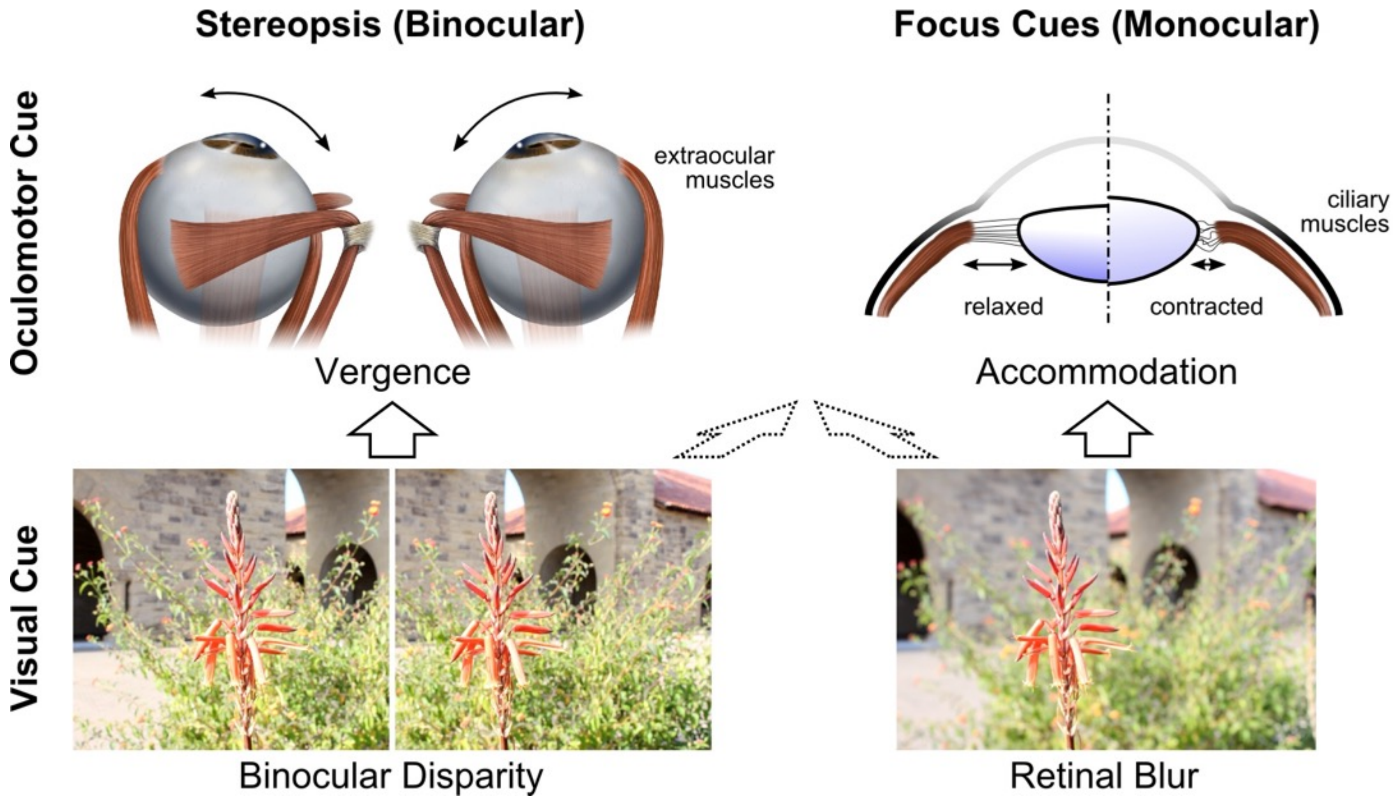
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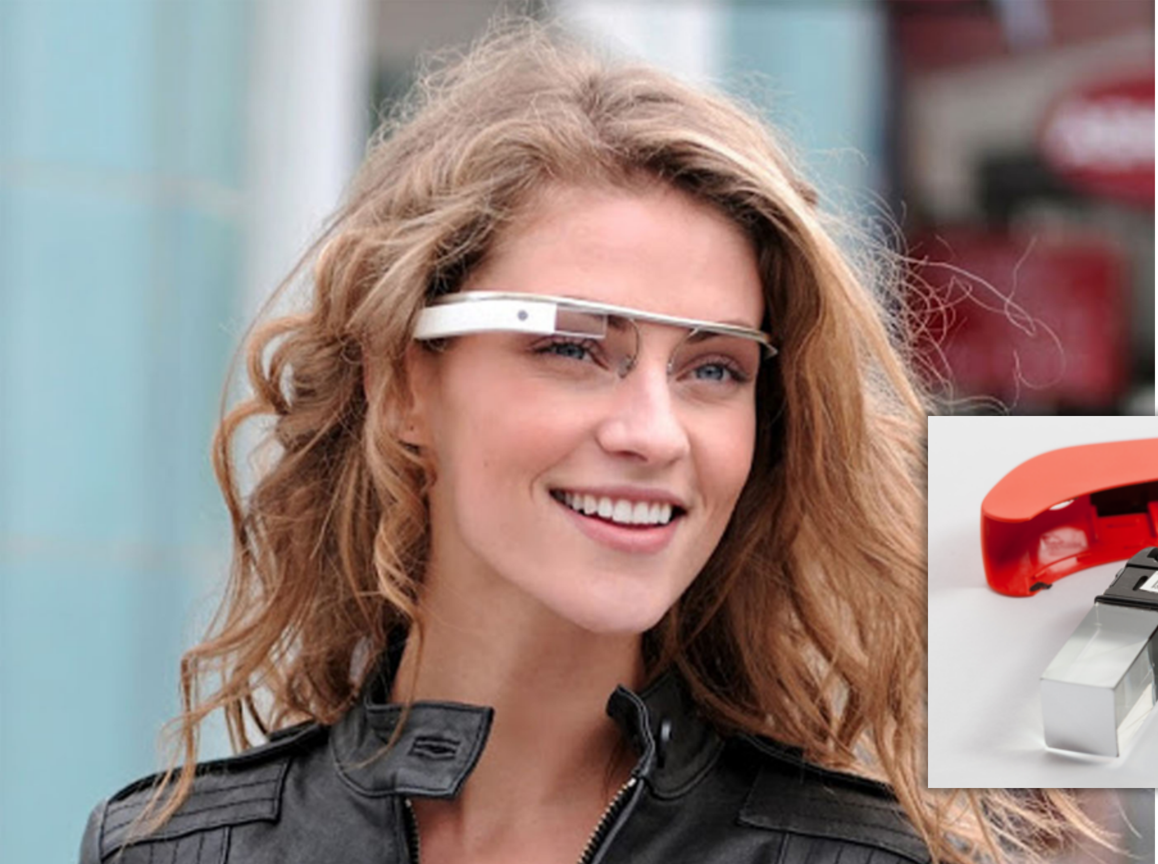
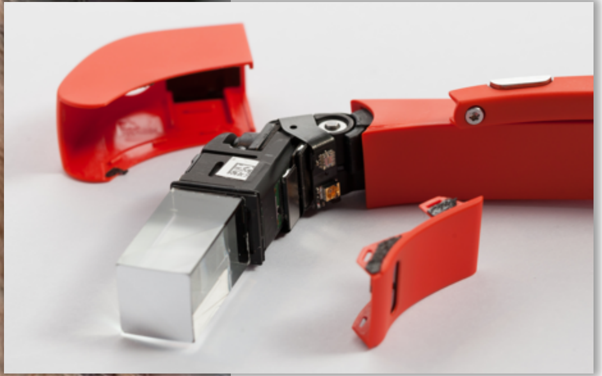
Augmented Reality

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

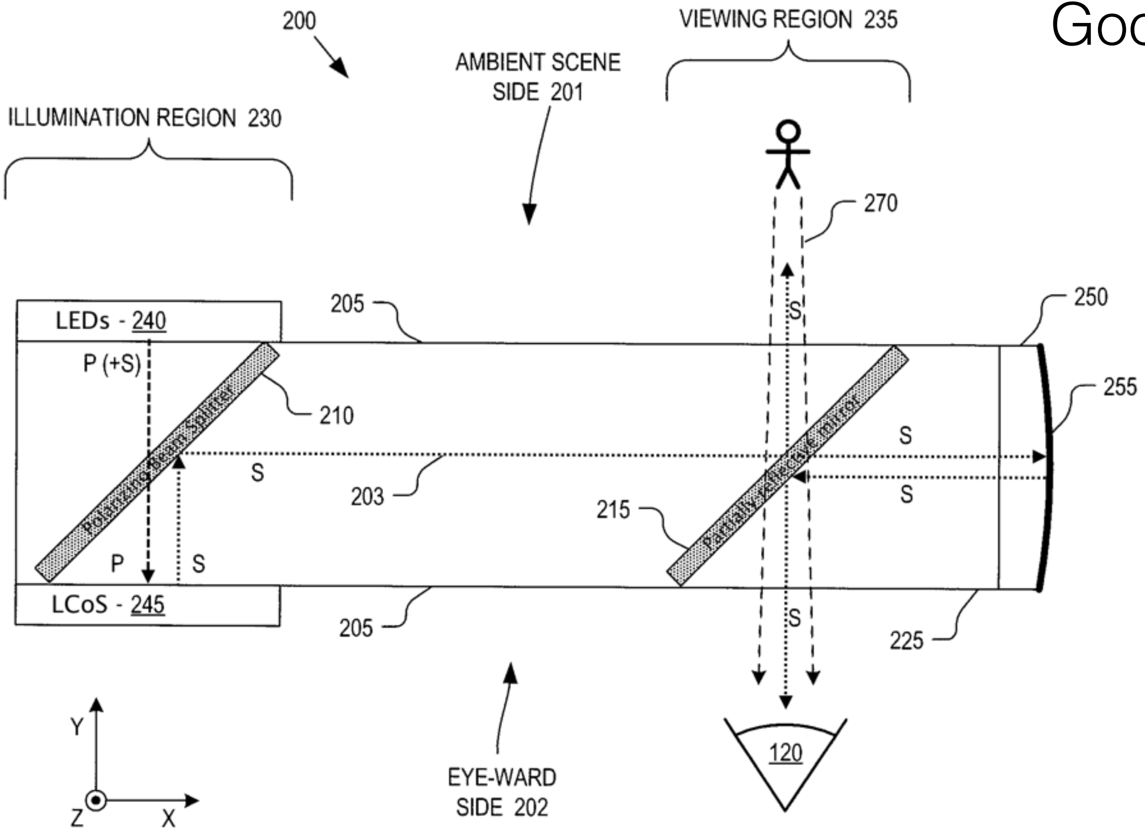
Pepper's Ghost 1862

Google Glass





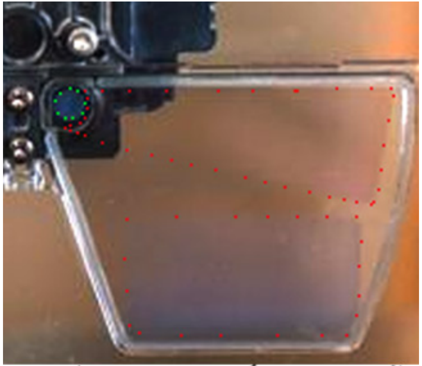
Google Glass

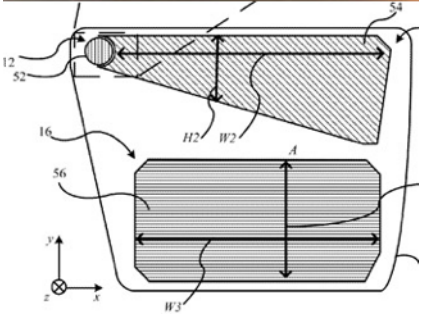


Microsoft HoloLens

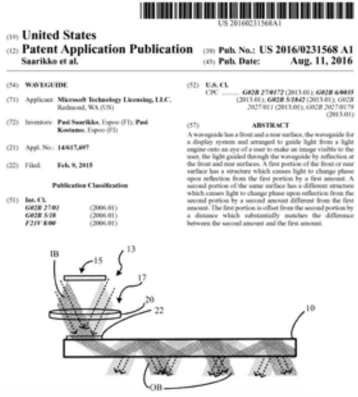
Microsoft HoloLens

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





US 2016/0231568 Fig. 3B


US 20160231568A1

(19) United States
(12) Patent Application Publication
Saarikko et al.
(10) Pub. No.: US 2016/0231568 A1
(43) Pub. Date: Aug. 11, 2016

(54) WAVEGUIDE

(71) Applicant: Microsoft Technology Licensing, LLC, Redmond, WA (US)

(72) Inventors: Pasi Saarikko, Espoo (FI); Pasi Kostamo, Espoo (FI)

(21) Appl. No.: 14/617,697

(22) Filed: Feb. 9, 2015

Publication Classification

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G02B 5/18 (2006.01)
F21V 8/00 (2006.01)

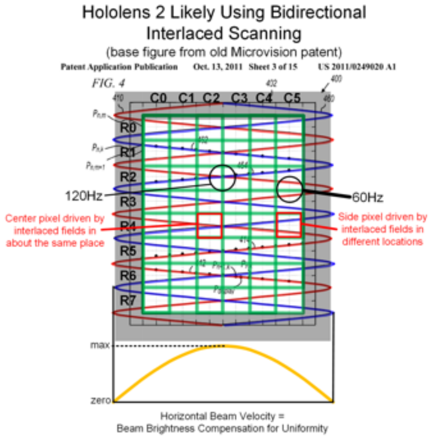
(52) U.S. Cl.
CPC G02B 27/0172 (2013.01); G02B 6/0035 (2013.01); G02B 5/1842 (2013.01); G02B 2027/011 (2013.01); G02B 2027/0178 (2013.01)

(57) ABSTRACT

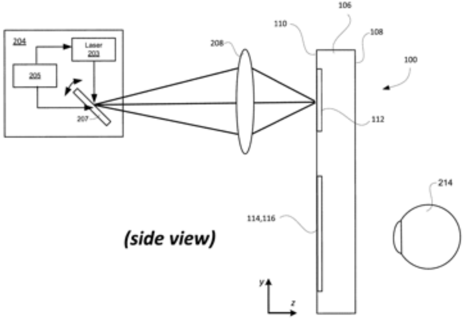
A waveguide has a front and a rear surface, the waveguide for a display system and arranged to guide light from a light engine onto an eye of a user to make an image visible to the user, the light guided through the waveguide by reflection at the front and rear surfaces. A first portion of the front or rear surface has a structure which causes light to change phase upon reflection from the first portion by a first amount. A second portion of the same surface has a different structure which causes light to change phase upon reflection from the second portion by a second amount different from the first amount. The first portion is offset from the second portion by a distance which substantially matches the difference between the second amount and the first amount.

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)

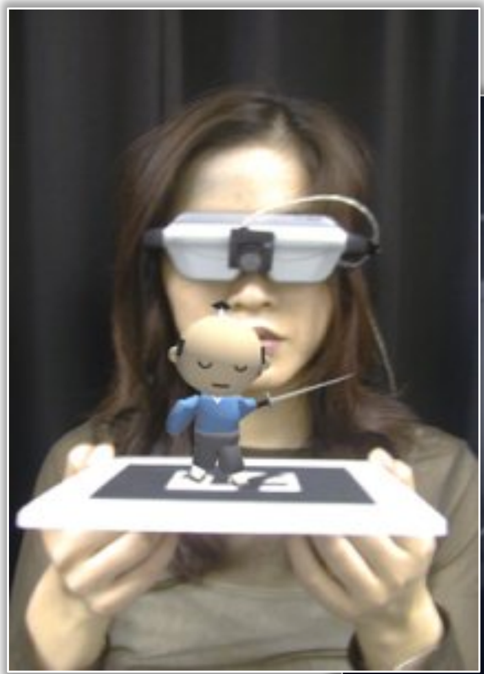


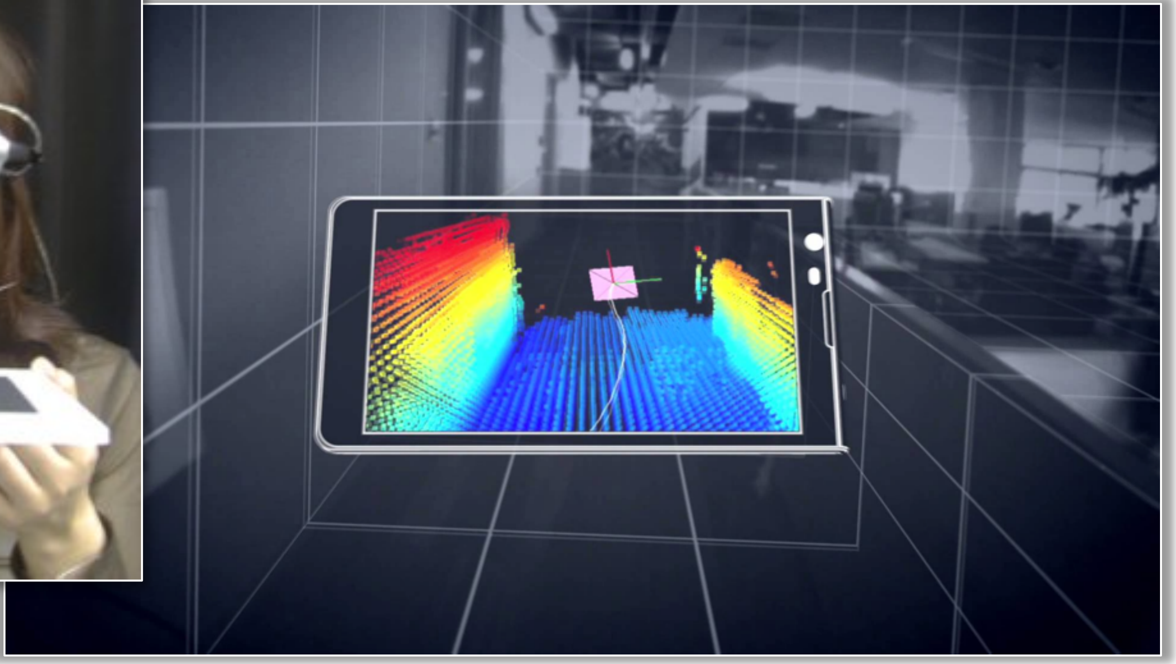
https://www.kguttag.com/2019/02/27/hololens-2-first-impressions-good-ergonomics-but-the-lbs-resolution-math-fails/



Wall et al. US 10,025,093 2018

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



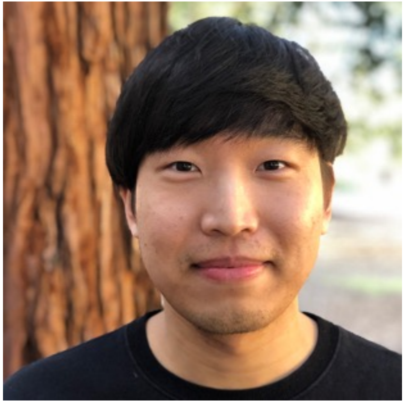


EE267 Instructors

Gordon Wetzstein

Assistant Professor of EE/CS

Hayato Ikoma



Suyeon Choi

Research Assistants and EE267 – VR experts!

STANFORD COMPUTATIONAL IMAGING LAB

About EE 267

- experimental class, only taught at Stanford and also only a few times so far (help us improve it!)
- COVID-19 situation is particularly challenging for us – please be patient
- lectures + assignments = one big project – <u>build your own VR HMD</u>
- all hardware provided (shipped), but must return at the end
- enrollment limited, because it's a lab-based class and we only have limited hardware kits
- a few guest lectures by industry 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

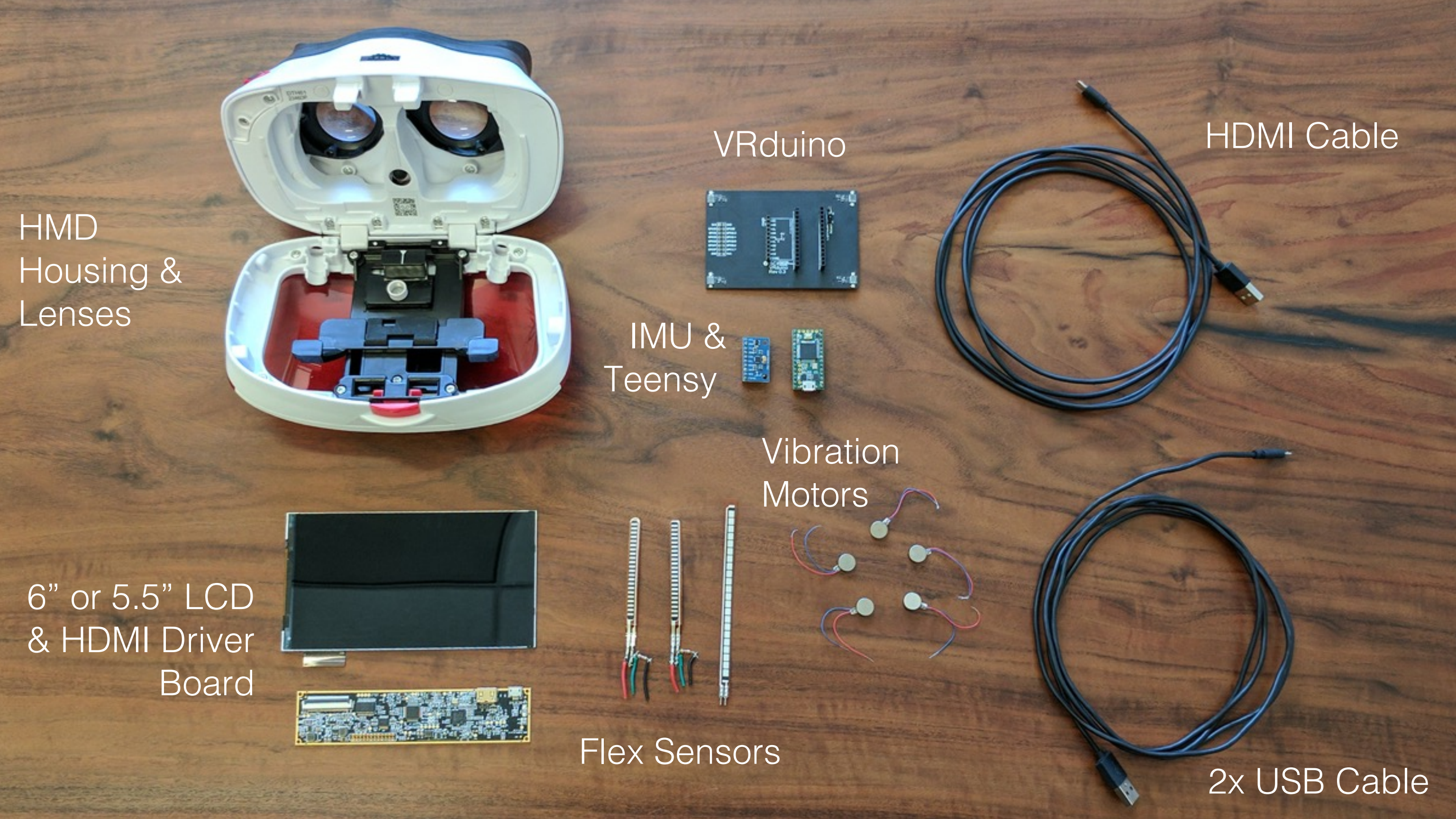
- very technical course! lots of math and programming!!

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!

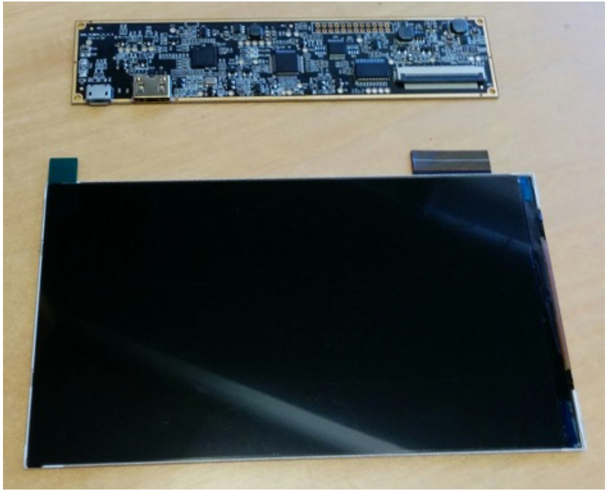
- *not a* “build VR application in Unity” course, although you can do that in your project
- *not a* “here is a high-level overview of VR” course – you need to implement everything discussed in the lectures in your weekly assignments
- *not a* super hard course, but requires consistent work effort and 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

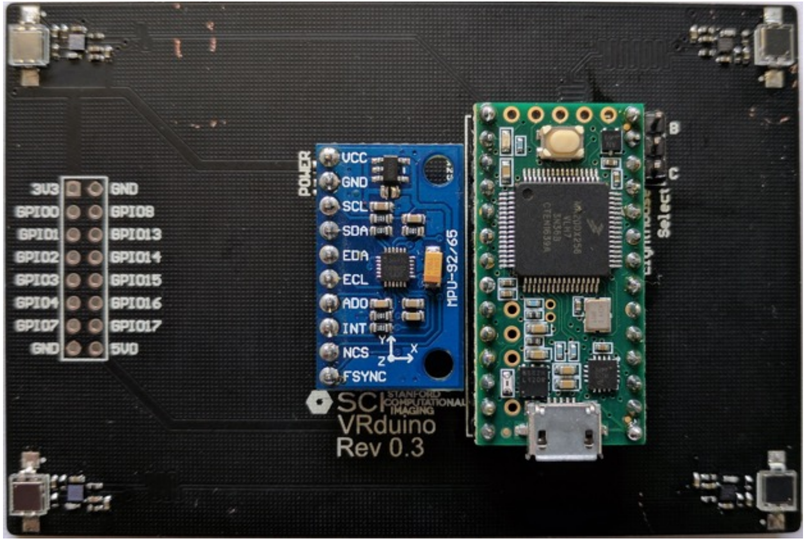
- View-Master VR Starter Kit ($15-20) or Deluxe VR Viewer ($23)
    - implements Google Cardboard 1.0/2.0
    - very durable – protect flimsy LCDs

Display



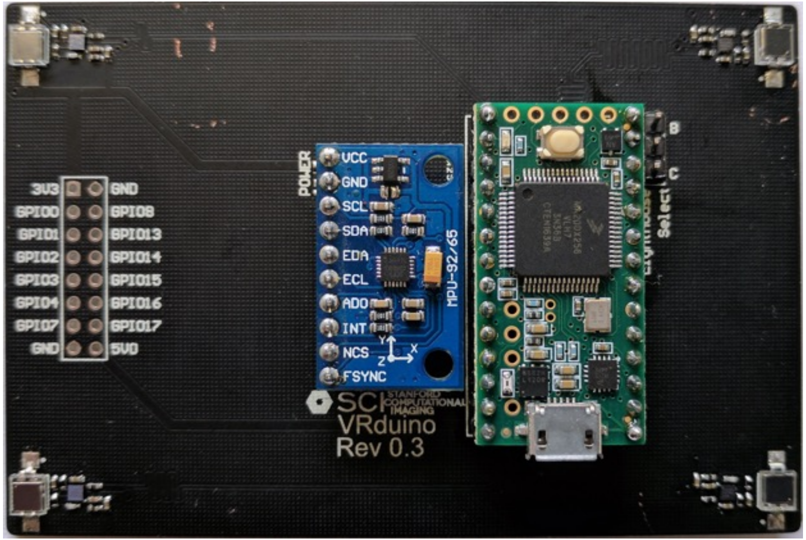
- Topfoison LCDs, either 6” or 5.5”
- HDMI driver boards included
- super easy to use as external monitor on desktop or laptop

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

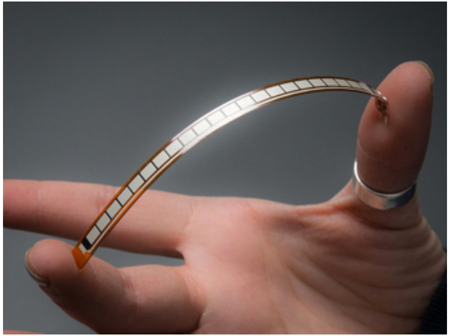
VRduino

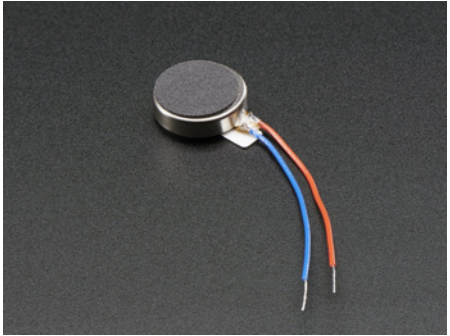


- Teensy 3.2 microcontroller (48 MHz, $20) for all processing & IO
- InvenSense 9250 IMU (9-DOF, $6) for orientation tracking
- Triad photodiodes & precondition circuit ($1) for position tracking with HTC Lighthouse

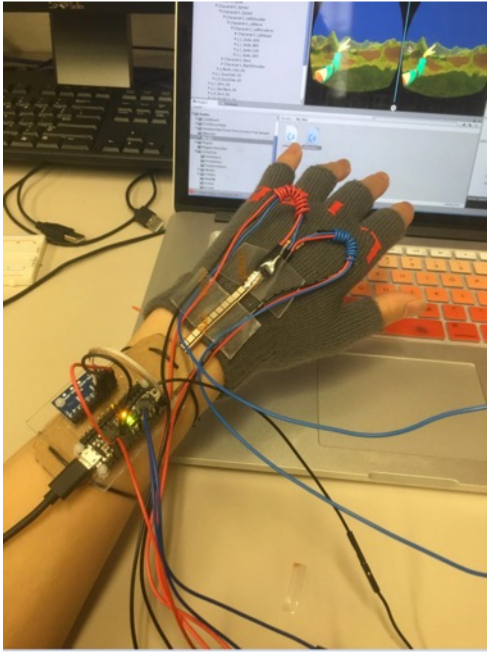
Some Student Projects - Input Devices

- 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 piazza for discussion: see website
- contact: ee267-spr2021-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: Mo/We 2:30-3:50 pm
  - First lecture on zoom, then videos available on canvas
  - All lectures released as videos on canvas

- 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 <u>*do the lab first and then start working on the homework*!</u>

About EE 267 – Labs & Assignments

- labs and homeworks released every Friday
- ~~24h teaching lab (Packard 001) access will be provided upon request, can do everything on your laptop~~ → no teaching lab, everything on zoom
- We will ship you all required hardware (details later)

About EE 267 – Office Hours

- Gordon (instructor): Mondays 4-5 pm, zoom
  come talk about projects, VR, course logistics, etc.

- Suyeon (TA): Wed,10:30 am – 12 pm, zoom
- Hayato (TA): Thu, 1-2 pm, zoom

  come talk about labs, assignments, …

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 remote midterm: 20%

- project (teams of ≤ 3): 20%
  - discuss project ideas with TA & instructor!
  - final presentation (video recordings) due 5/26/2021 at 11:59pm
  - reports & code due (gradescope): 5/28/2021, 11:59pm

Course Project Deliverables

- May 26 (11:59pm): submit your project presentation video
  - Record screenshots / videos of your demo or poster
  - see poster template on website (for non-demoable projects)
  - Sorry, no final demo session due to COVID-19 ☹

Course Project Deliverables

- May 29 (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/