virtual reality

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.
remote control of vehicles, e.g. drones

simulation & training

visualization & entertainment

robotic surgery

architecture walkthroughs

virtual travel

a trip down the rabbit hole
VR at Stanford’s Medical School

- 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
Exciting Engineering Aspects of VR/AR

- cloud computing
- shared experiences
- compression, streaming
- VR cameras
- sensors & imaging
- computer vision
- scene understanding
- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, …
- CPU, GPU
- IPU, DPU?
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Images by Microsoft, Facebook
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

- **1838**: Stereoscopes by Wheatstone and Brewster, ...
- **1968**: VR & AR by Ivan Sutherland
- **1995**: Nintendo Virtual Boy
- **2012-2022**: VR explosion by Oculus, Sony, HTC, MS, ...

???
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

Problems:
- fixed focal plane
- no focus cues 😞
- cannot drive accommodation with rendering!

\[ \frac{1}{d} + \frac{1}{d'} = \frac{1}{f} \]
Stereopsis (Binocular)

Vergence

Focus Cues (Monocular)

Accommodation

Binocular Disparity

Retinal Blur

Extraocular muscles

Relaxed

Contracted

ciliary muscles
Stereopsis (Binocular)

Oculomotor Cue

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**Stereopsis (Binocular)**

- Oculomotor Cue
  - Vergence
- Visual Cue
  - Binocular Disparity

**Focus Cues (Monocular)**

- Ciliary muscles
  - Relaxed
  - Contracted
- Visual Cue
  - Retinal Blur
Augmented Reality

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

- diffraction grating
- small FOV (30x17), but very good image quality
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)
Video-based AR: ARCore, ARKit, ARToolKit, …
EE267 Instructors

Gordon Wetzstein
Associate Professor of EE/CS

Suyeon Choi
Research Assistants and EE267 – VR experts!

Manu Gopakumar
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 – build your own VR HMD

- 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

- 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
6” or 5.5” LCD & HDMI Driver Board
VRduino
IMU & Teensy
Vibration Motors
Flex Sensors
HDMI Cable
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
About EE 267

• all important info here: http://stanford.edu/class/ee267/

• plenty of (zoom) office hours and Ed Discussion: see website

• contact: ee267-spr2122-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 9:45-11:15 am
  • Not sure yet how to support video recordings (please vote):
    1. No videos (default options)
    2. Recorded zoom sessions from last year
    3. Flipped classroom

• 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 12:30-1:30 pm, zoom talk about projects, VR, course logistics, etc.

- Manu (TA): Tue, 2-3pm, zoom

- Suyeon (TA): Thu, 4-5pm, zoom talk about labs, assignments, ...

All zoom links are on canvas!
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 \( \leq 2 \)): 60%
- **80 minute (in-person or remote) midterm**: 20%
- **project** (teams of \( \leq 3 \)): 20%
  - discuss project ideas with TA & instructor!
  - final presentation (video recordings) due 5/25/2022 at 11:59pm
  - reports & code due (gradescope): 5/27/2022, 11:59pm
Course Project Deliverables

- **May 25 (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 27 (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?