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

gaming

education

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, …

photo from Stanford Medicine News
“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
- sensors & imaging
- computer vision
- scene understanding
- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, …
- VR cameras
- CPU, GPU
- IPU, DPU?
- shared experiences
- cloud computing
- compression, streaming
- sensors & imaging
- computer vision
- scene understanding
- photonics / waveguides
- human perception
- displays: visual, auditory, vestibular, haptic, …
- VR cameras
- CPU, GPU
- IPU, DPU?

Images by microsoft, facebook
Where We Want It To Be
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
  - Wheatstone, Brewster, ...

1968
- VR & AR
  - Ivan Sutherland

1995
- Nintendo
  - Virtual Boy

2012-2018
- VR explosion
  - 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
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)

Oculomotor Cue

Vergence

Visual Cue

Binocular Disparity

Focus Cues (Monocular)

Extraocular muscles

Accommodation

Ciliary muscles

Relaxed

Contracted

Retinal Blur
**Stereopsis (Binocular)**

- **Oculomotor Cue**
  - **Vergence**
- **Visual Cue**
  - **Binocular Disparity**

**Focus Cues (Monocular)**

- **Accommodation**
  - **Relaxed**
  - **Contracted**
- **Retinal Blur**
Stereopsis (Binocular)

Oculomotor Cue

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Visual Cue

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Extraocular muscles

ciliary muscles

relaxed

contracted
Stereopsis (Binocular)

Oculomotor Cue

Vergence

Focus Cues (Monocular)

Visual Cue

Binocular Disparity

Ciliary muscles

relaxed

contracted

Retinal Blur
Augmented Reality

(not really covered in this class, but closely related)
Pepper’s Ghost 1862
Meta 2

- larger field of view (90 deg) than Glass
- also larger device form factor
Microsoft HoloLens
Microsoft HoloLens

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

• great device form factor
• polycarbonate light guide – easy to manufacture and robust
• smaller field of view (17 deg)
Sony IMX-001

- also great form factor
- small FOV (9x6 deg)
- monochrome
Video AR: ARCore, ARKit, ARToolKit, …
EE267 Instructors

Gordon Wetzstein
Assistant Professor of EE/CS

Robert Konrad
Research Assistants and EE267 – VR experts!

Hayato Ikoma

Marcus Pan
About EE 267

- experimental class, taught for the 3rd time (help us improve it!)

- lectures + assignments = one big project – build your own VR HMD

- 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

- will be offered again, but come to class, hand in hw if you are on waitlist!
About EE 267 - Goals

• understand fundamental concepts of VR and Computer Graphics

• implement software + hardware of a head mounted display

• learn basic WebGL/JavaScript and Arduino programming

• build your own HMD
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
  - may need to drill additional holes
Display

• Topfoison LCDs:
  • 1080p - $90
  • 1440p (2K) - $100

• 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/

- piazza: https://piazza.com/class/jekn2ktpfag2g3 (see website)

- contact: ee267-spr1718-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 in 4x4 matrices

- introduction to computer graphics or vision helpful
About EE 267 – Lectures & Labs

• 2 lectures per week: Mo/Wed 3-4:20 pm, 200-034

• 1 lab per week starting in week 1 (do at home, will release writeups 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

• TA will help you get started in Friday office hours, finish weekly assignment/project on your own

• 24h teaching lab access will be provided after first lab ➔ Packard 001
About EE 267 – Lab Access

• review this website for lab policy: https://stanford.app.box.com/v/Basic-Lab-Safety

• to get ID access, email Steven Clark (EE teaching lab manager) your name & Sunet ID number (as well as an acknowledgement that you read the lab policy): steveclark@ee.stanford.edu
About EE 267 – Office Hours

- Gordon (instructor): Mondays 2-3pm, Packard 236 come talk about projects, VR, course logistics, etc.

- Hayato (TA): Tuesdays 9-10:30 am, Packard 001

- Marcus (TA): Wednesdays 1:30-3 pm, Packard 001

- Robert (TA): Thursdays 4:30-6 pm, Packard 001 come talk about labs, assignments, ...

- TAs: Fridays 10-11:30 am, Packard 001 lab & get started on homework
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

3 Unit version:

• long 7\textsuperscript{th} assignment / short project (2 weeks)
• 1-2 page project report

4 Unit version:

• major final project – hardware, software, or perceptual experiments
• 8 page project report required (more details later)
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-class midterm: 10%

- project (teams of ≤ 2): 30%
  - discuss project ideas with TA & instructor!
  - final presentation / demos: 6/6/2018 in teaching lab
  - reports & code due: Thu in finals week, midnight
Course Projects

- **June 6:** project demo + poster session
  - emphasis is on demo, but some projects are better presented as posters
  - see poster template on website
  - celebrate your work and connect with students, faculty, and industry!
  - may invite many people from industry: Oculus, Google, Magic Leap, Intel, Nvidia, Olympus, Canon, …
Course Projects – ONLY for 4 unit version

- **June 8**: report + source code due (at midnight)

- report = conference paper format 6-8 pages with
  - abstract
  - introduction
  - related work
  - your thing
  - results, qualitative and quantitative evaluation
  - discussion, future work, and conclusion
  - references
  - see latex template on website (will be there)
Possible Course Projects

• be experimental!

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

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