Visual Display

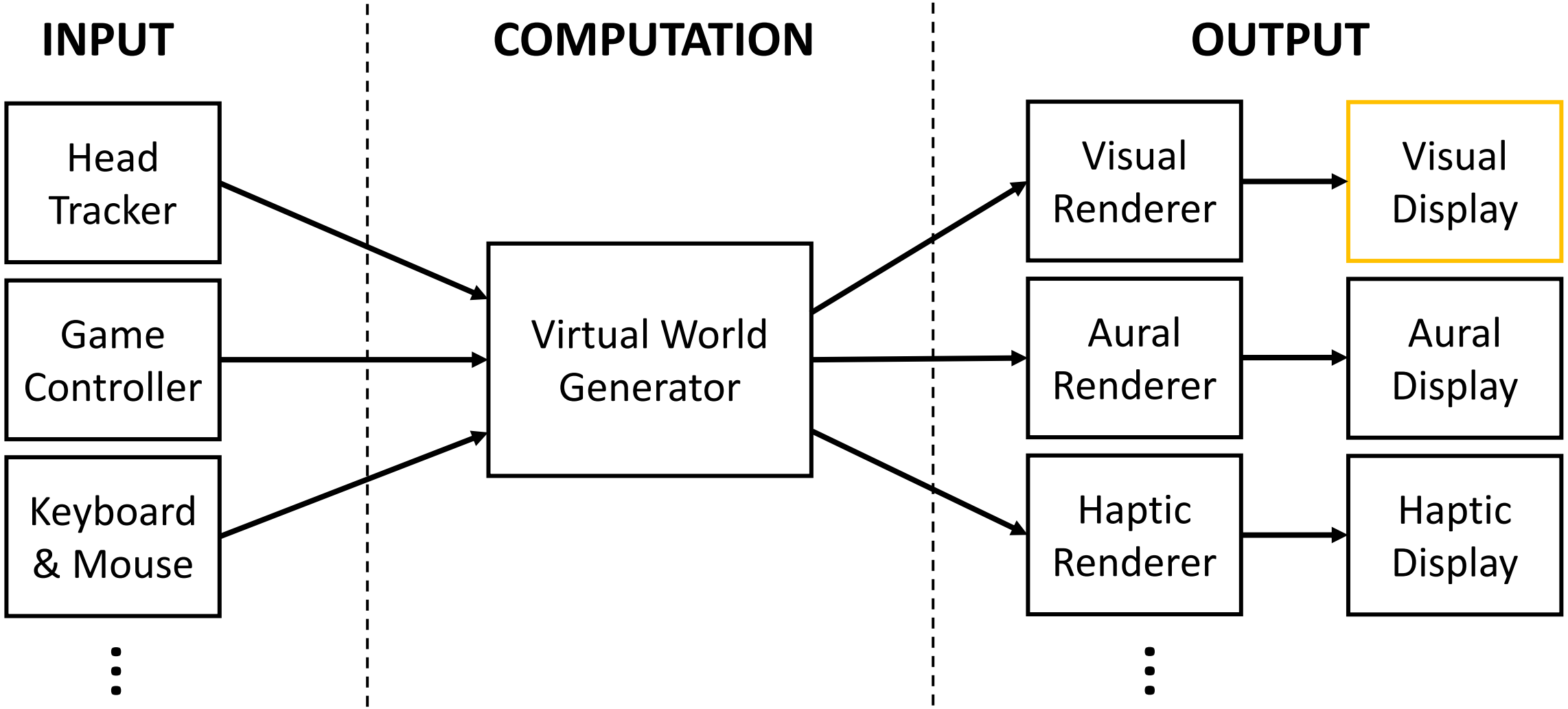
CS 6334 Virtual Reality

Professor Yu Xiang

The University of Texas at Dallas

Some slides of this lecture are based on the Virtual Reality textbook by Steven LaValle

Review of VR Systems



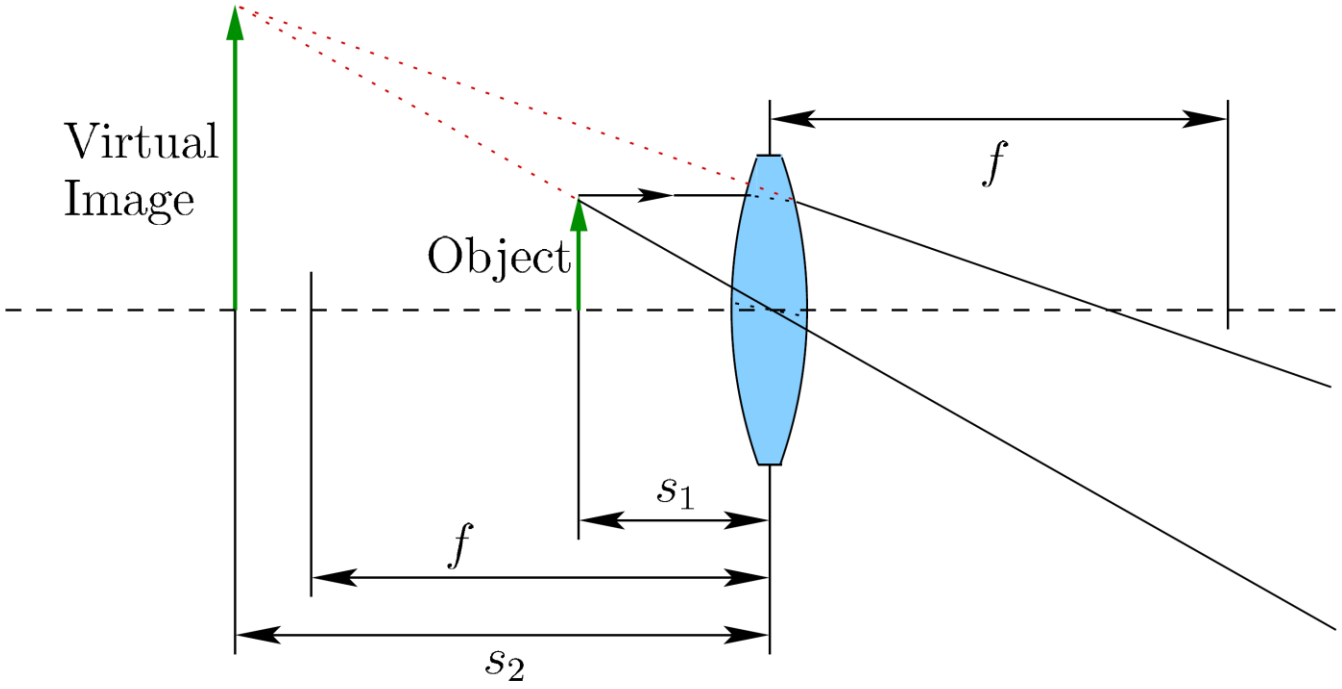
Head Mounted Display in VR

Oculus Rift

HTC Vive

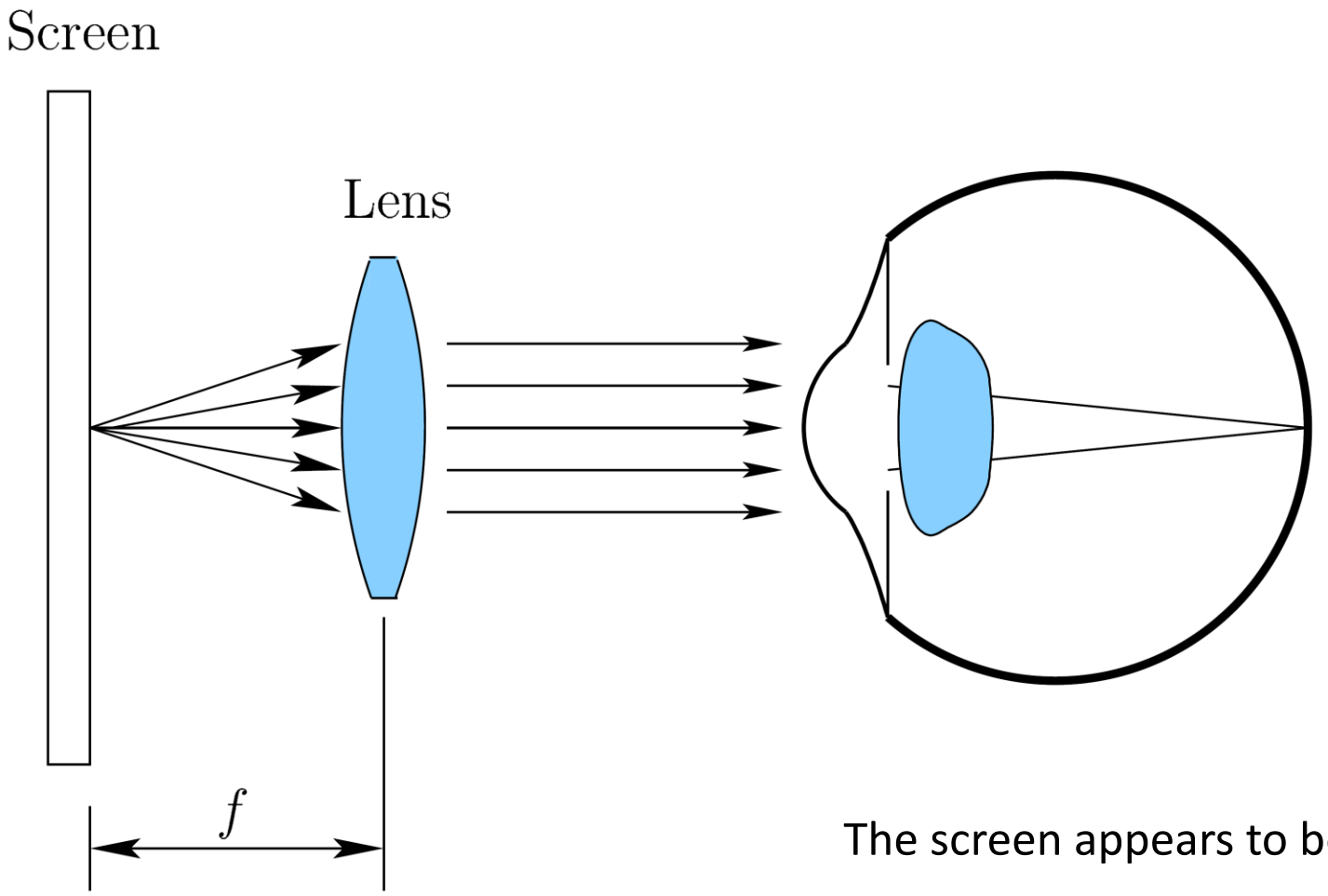
Playstation VR

Recall Lenses in VR Headsets



$$\frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f}$$

Recall Lenses in VR Headsets



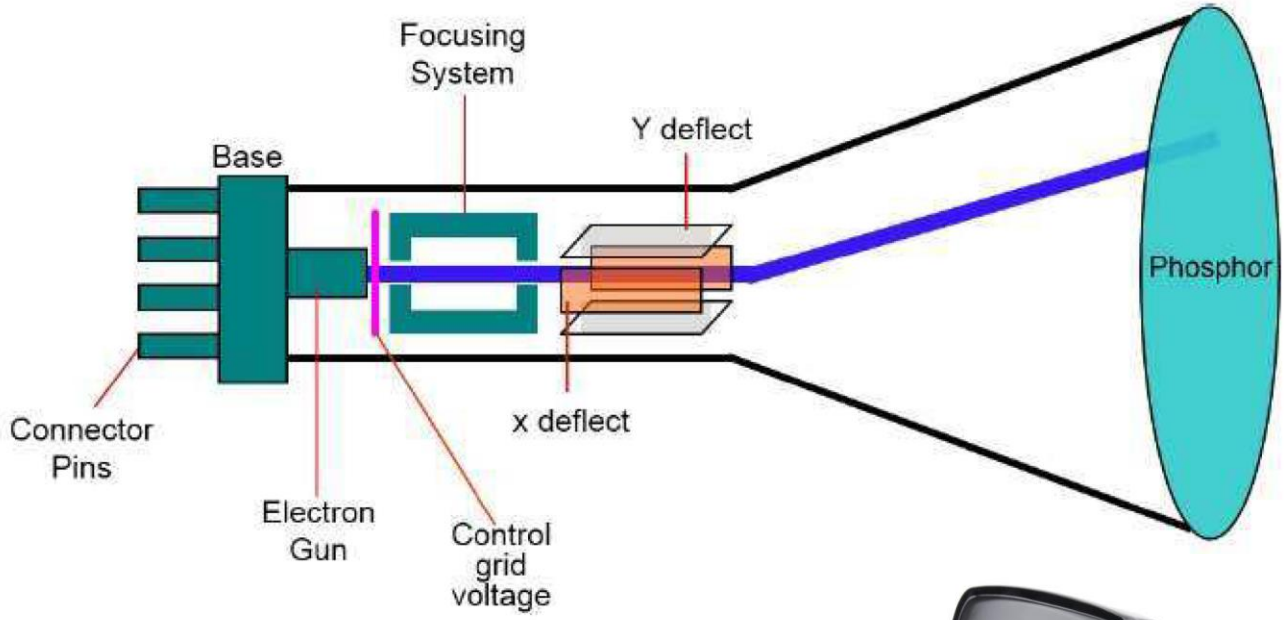
$$\frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f}$$

$$s_2 = f$$

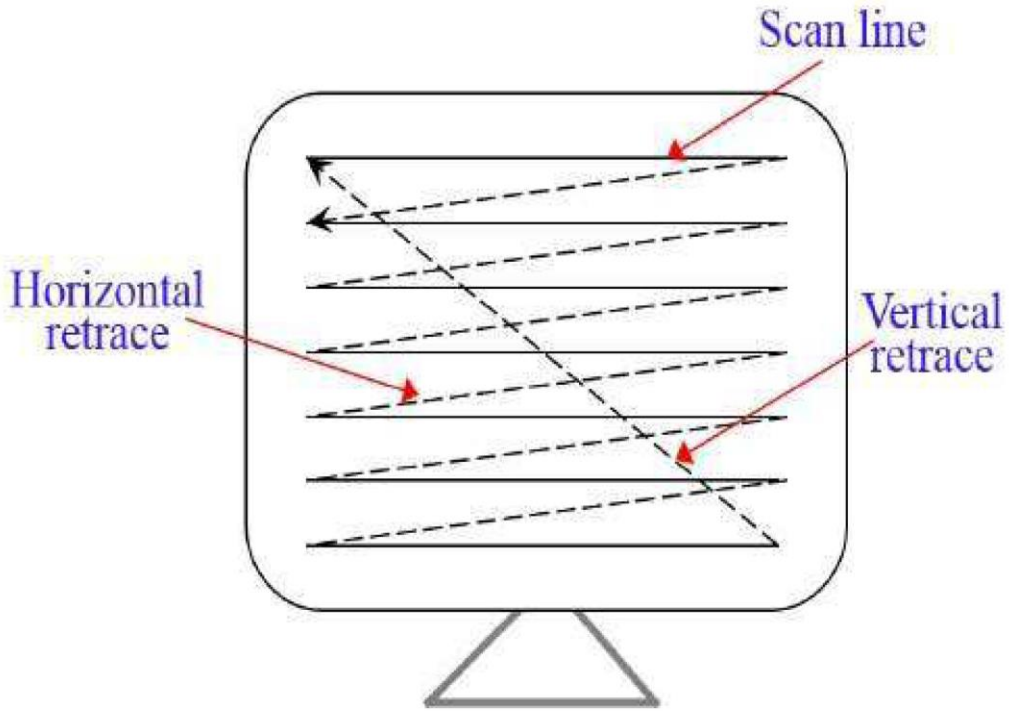
$$s_1 = \infty$$

The screen appears to be infinity far away.

Cathode Ray Tubes (CRTs)

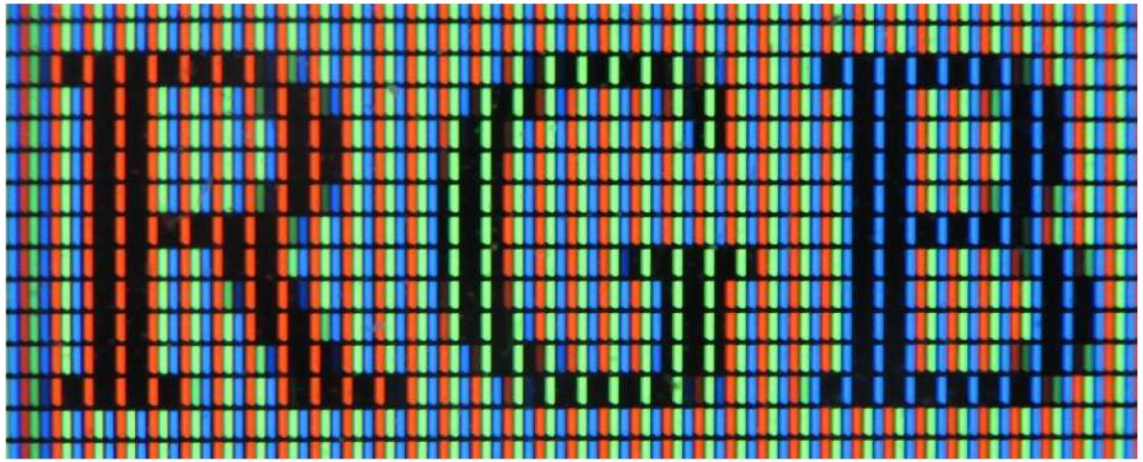


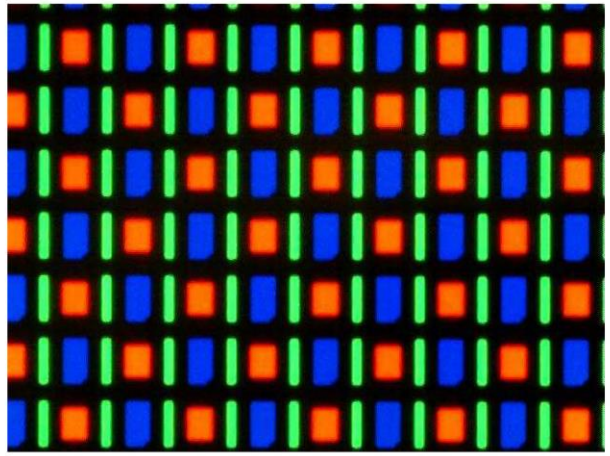
(a)



(b)

Liquid Crystal Displays (LCDs)



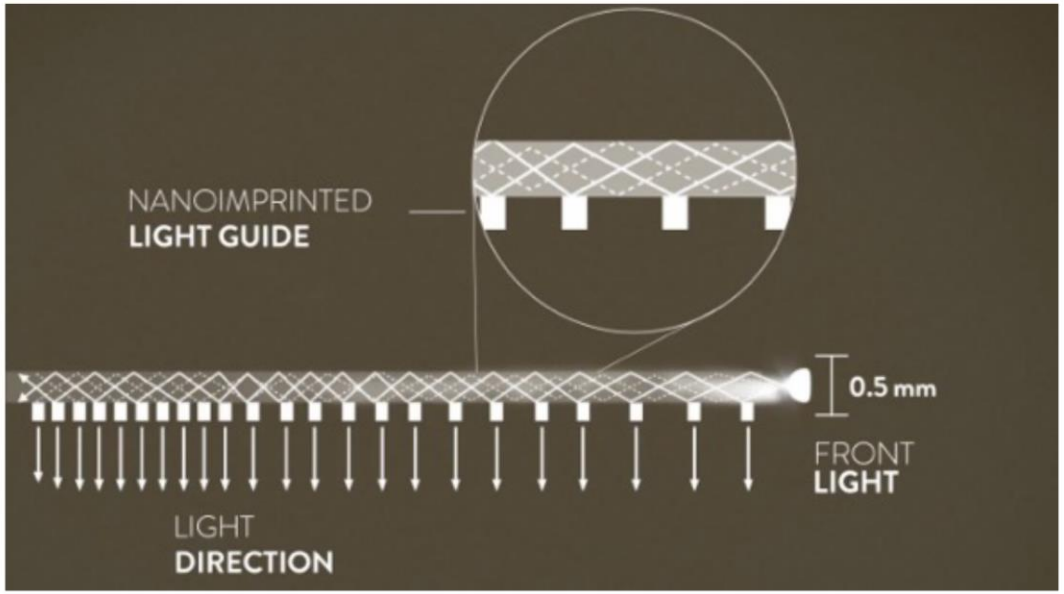


- The liquid crystals do not emit light
- A backlight shines the screen

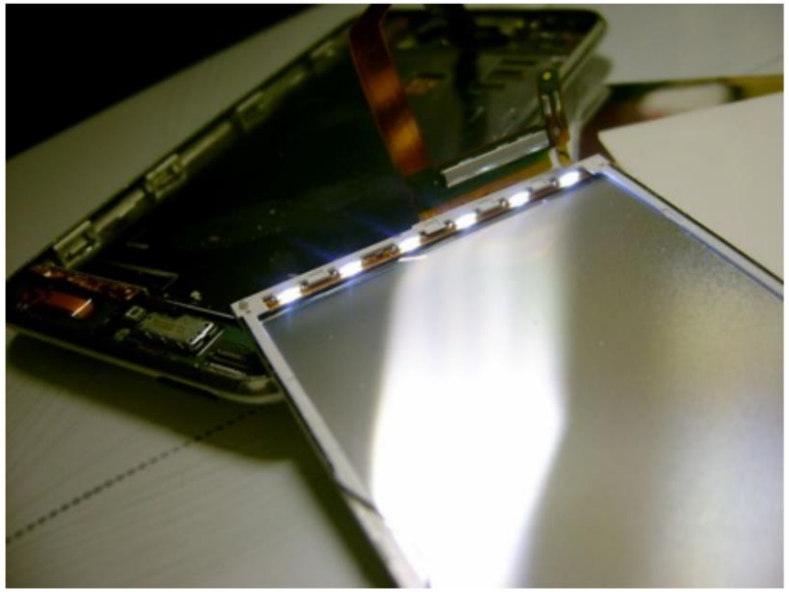
Pixels are break into subpixels (red, green, blue)

LCD Backlight

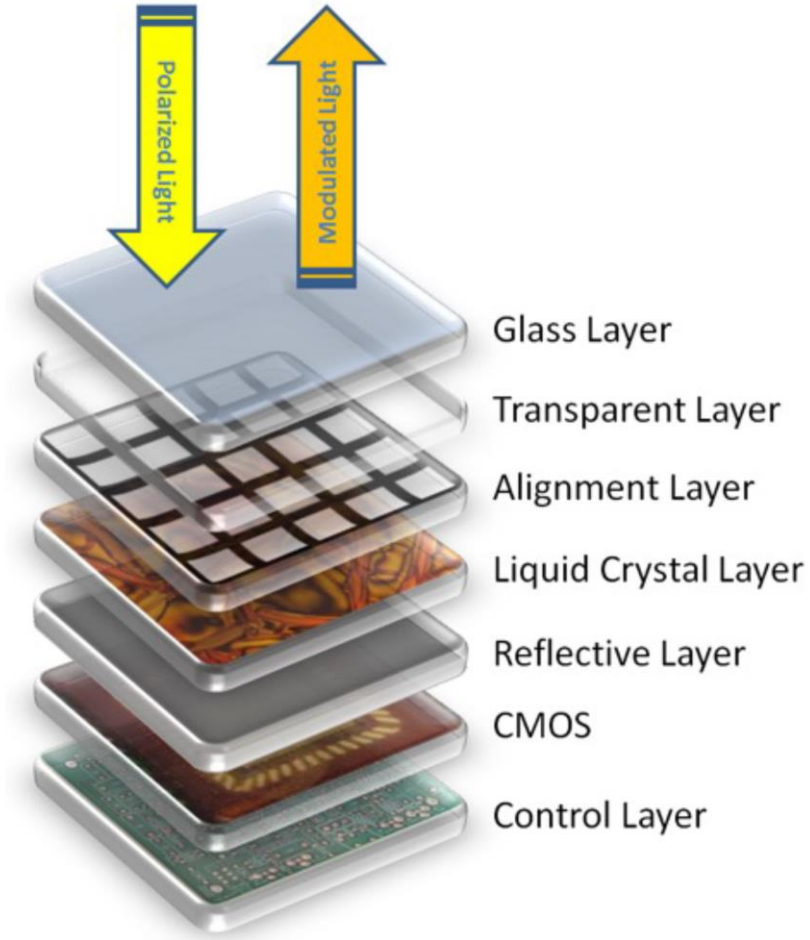
extremetech.com



wikipedia



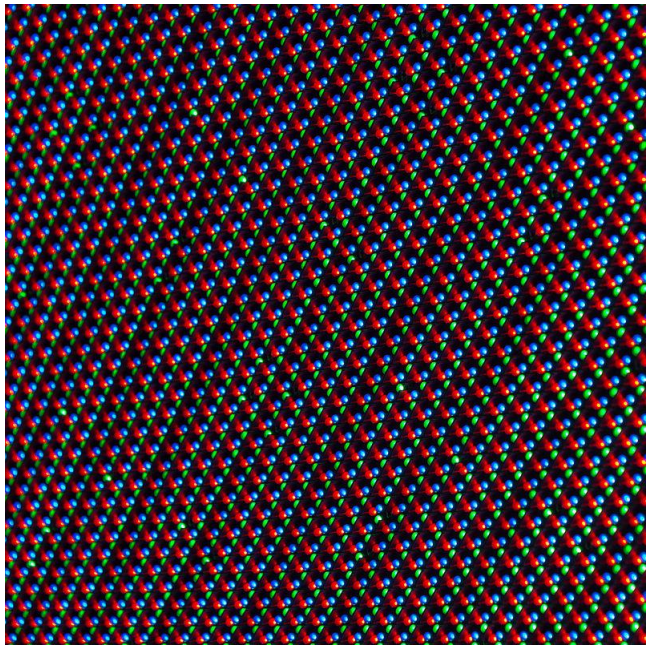
Liquid Crystal on Silicon (LCoS)



- Basically a reflective LCD
- Standard component in projectors and head mounted displays
- E.g., google classes

Light Emitting Diodes (LEDs)

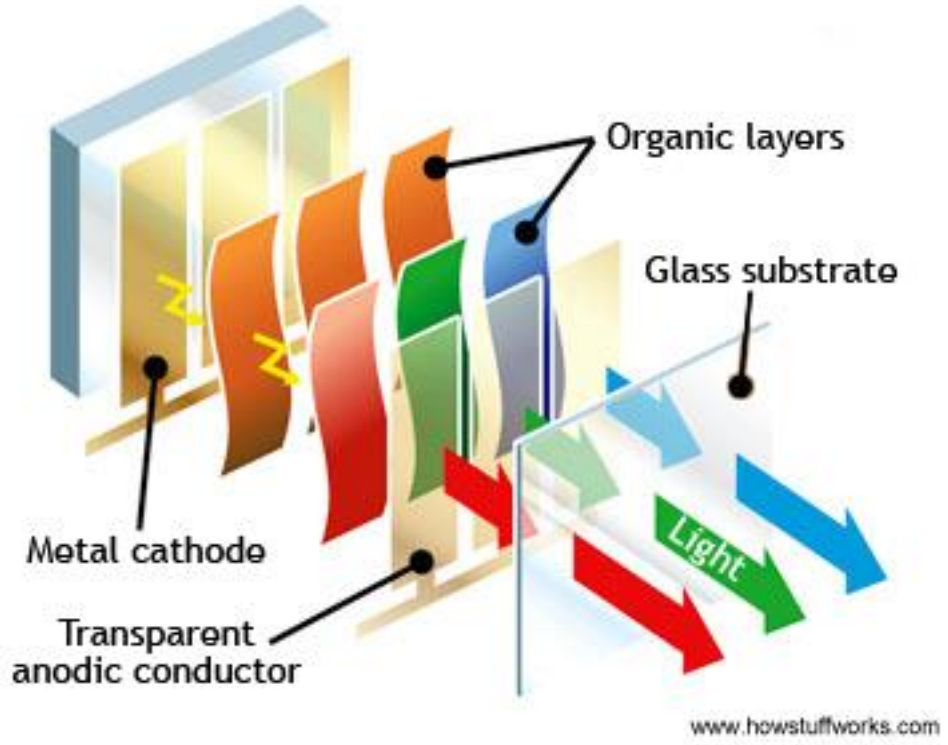
RGB LEDs: emit lights when current flows through



LED display

The 1,500-foot (460 m) long LED display on the Fremont Street Experience in Downtown Las Vegas, Nevada is currently the largest in the world.

Organic Light Emitting Diodes (OLEDs)



- Self emissive
- Lower persistence (can turn on and off faster than LCD/LCoS)
- E.g., VR compatible phones, Google's Pixel

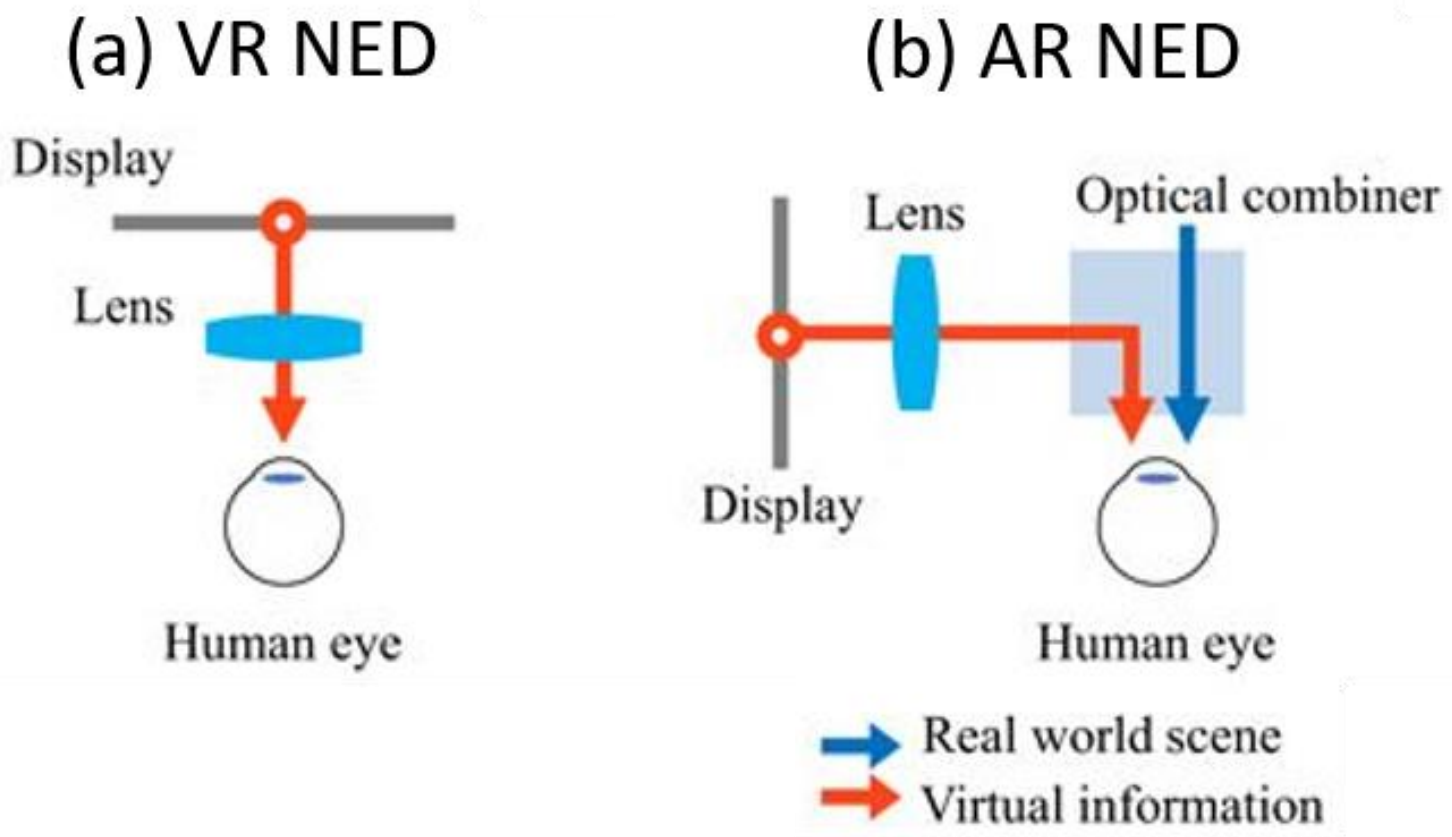
http://met.usc.edu/projects/oled.php

VR Displays

- Naked-eye display
  - CAVE

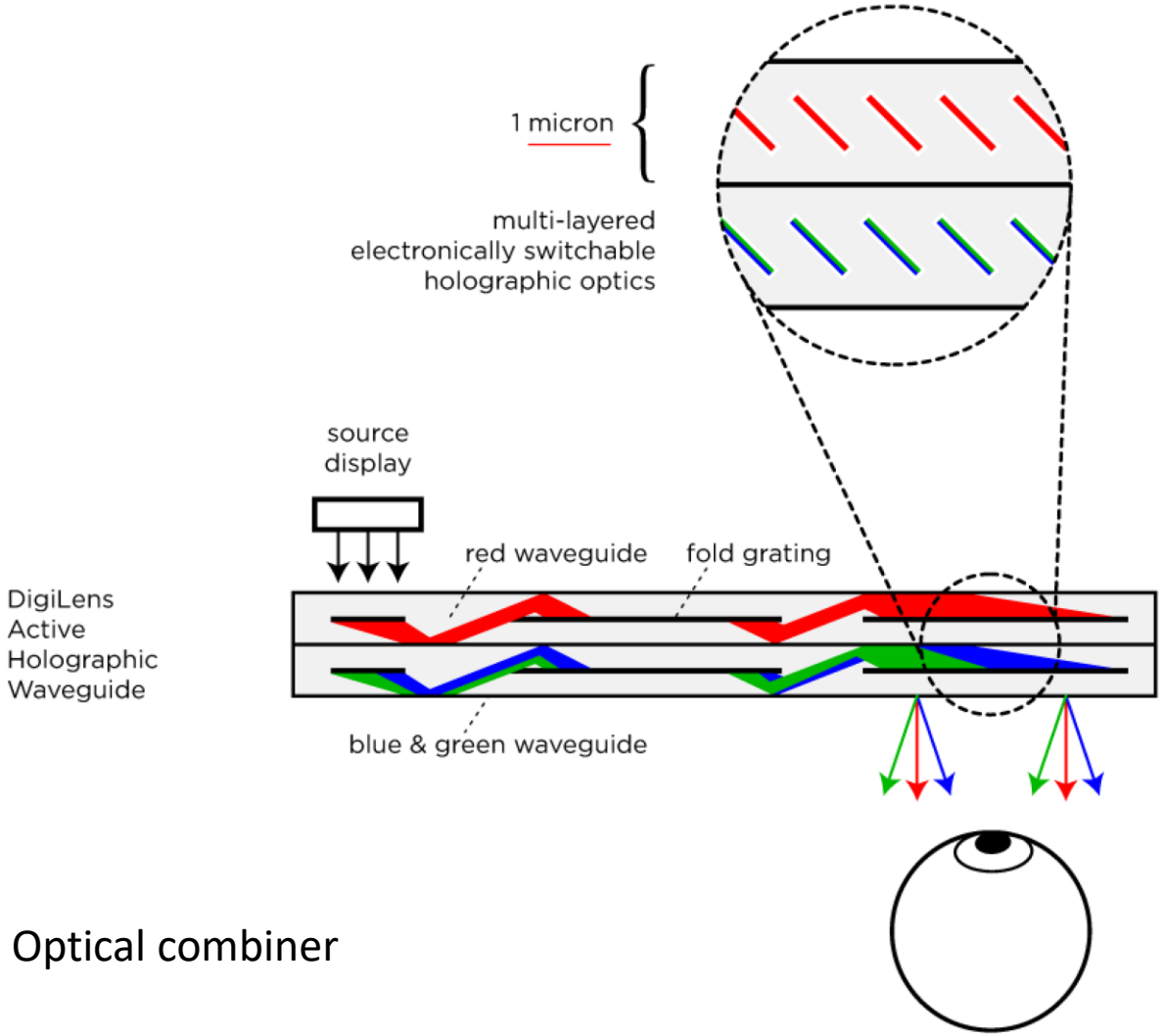
- Near-eye display
  - VR headsets

Near-Eye Display (NED)



https://virtualrealitypop.com/understanding-waveguide-the-key-technology-for-augmented-reality-near-eye-display-part-i-2b16b61f4bae

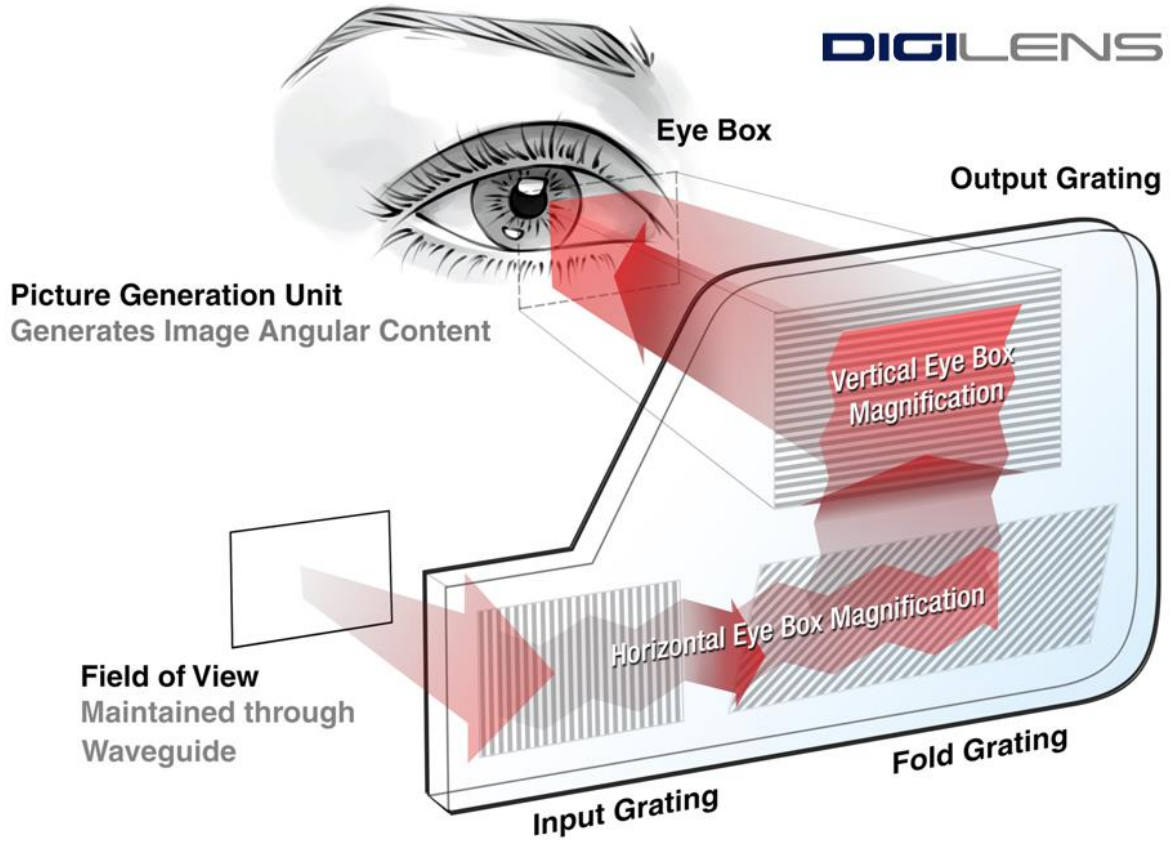
Waveguide



Optical combiner

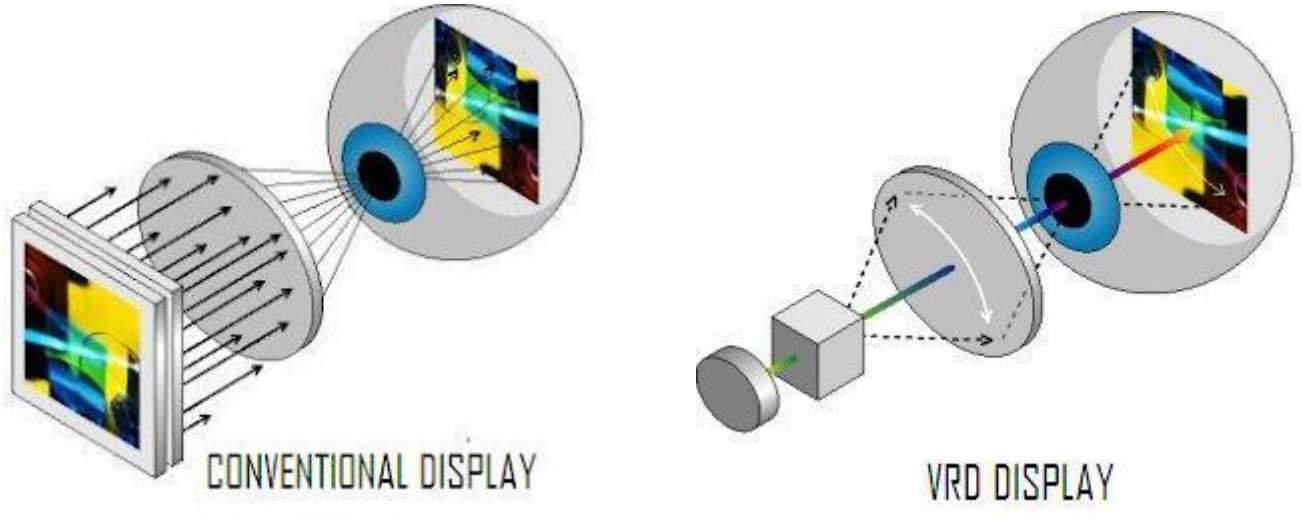
- Microdisplay
  - Liquid crystal on silicon (LCoS)
  - Organic LEDs (OLEDs)
- Examples
  - Microsoft HoloLens
  - Google Glass
  - Magic Leap One

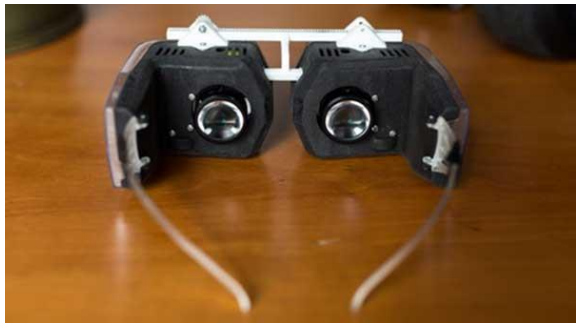
Waveguide


DIGILENS
Eye Box
Output Grating
Picture Generation Unit
Generates Image Angular Content
Vertical Eye Box Magnification
Horizontal Eye Box Magnification
Field of View
Maintained through
Waveguide
Input Grating
Fold Grating

Virtual Retinal Display

- Draw images directly onto the human retina
  - Challenges: eye safety, mirror rotation frequency, eye movement



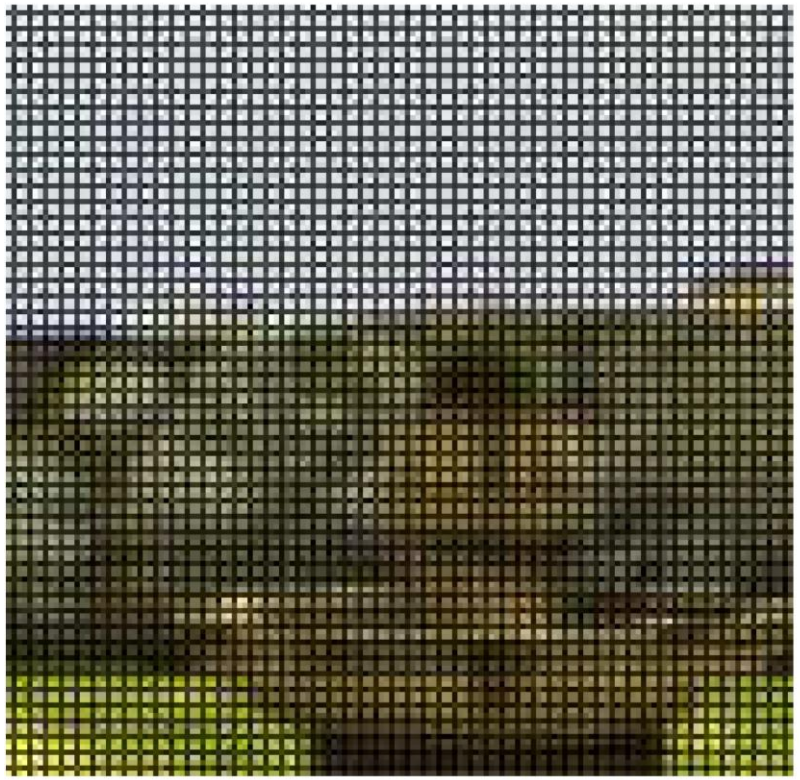


http://danielmunk.blogspot.com/2008/11/defining-virtual-retinal-display.html

Spatial Resolution of VR Display

- How much pixel density is enough?

Jaggies (aliasing)



Screen-door effect (LCD projectors)

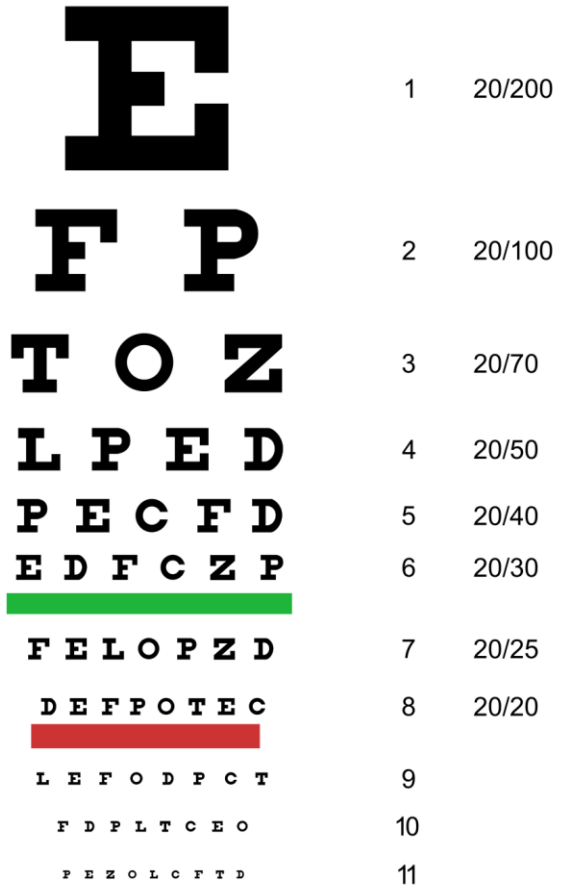
Not enough pixels

Retina Display

- Steven Jobs: 326 pixels per inch (PPI)

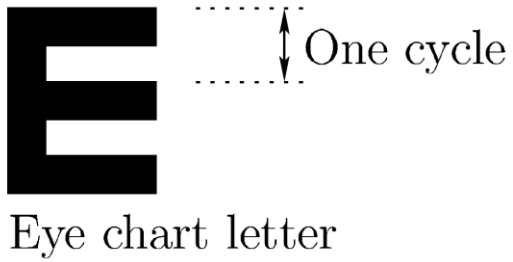
2010

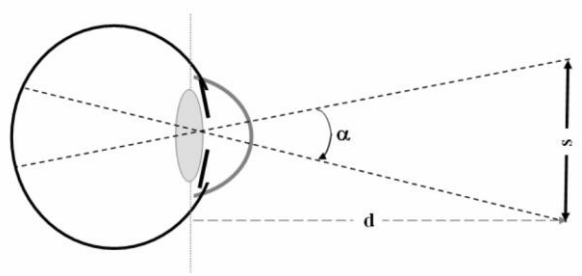
Visual Acuity



Snellen Chart

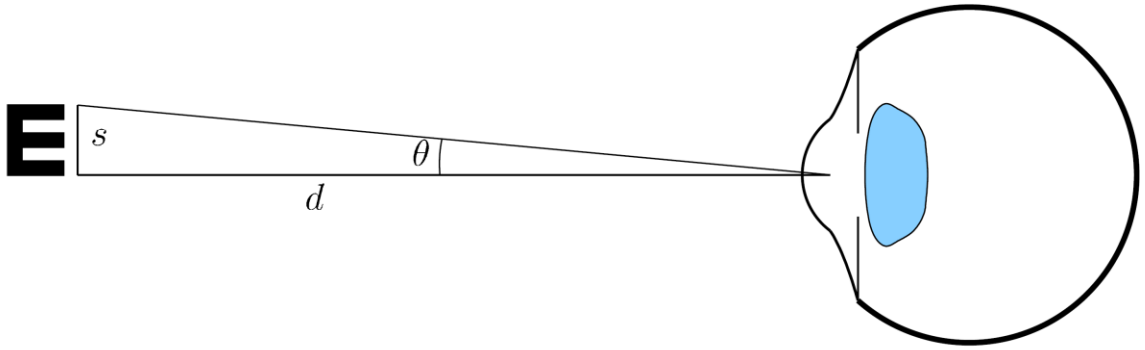
- Can a subject detect or recognize a particular target from certain distance?
- Cycles per degree: number of stripes that can be seen as separate along a view arc of 1 degree





- 20/20 line on the eye chart, letter size is 30 cycles per degree viewed from 20 feet
- The height of E: 2.5 cycles / 30 = 1/12 degree

Visual Acuity



$$s = d \tan \theta$$

- A person with 20/20 vision, 20 feet away, 30 cycles per degree needs 60 pixels per degree (black stripe and white stripe)

$$s = 20 * \tan 1^\circ = 0.349\text{ft}$$

$$60/4.189 = 14.32 \text{ PPI}$$

- Smart phone d = 12 inches

$$s = 12 * \tan 1^\circ = 0.209\text{in}$$

$$60/0.209 = 286.4 \text{ PPI}$$

- VR headset with a lens d = 1 inch

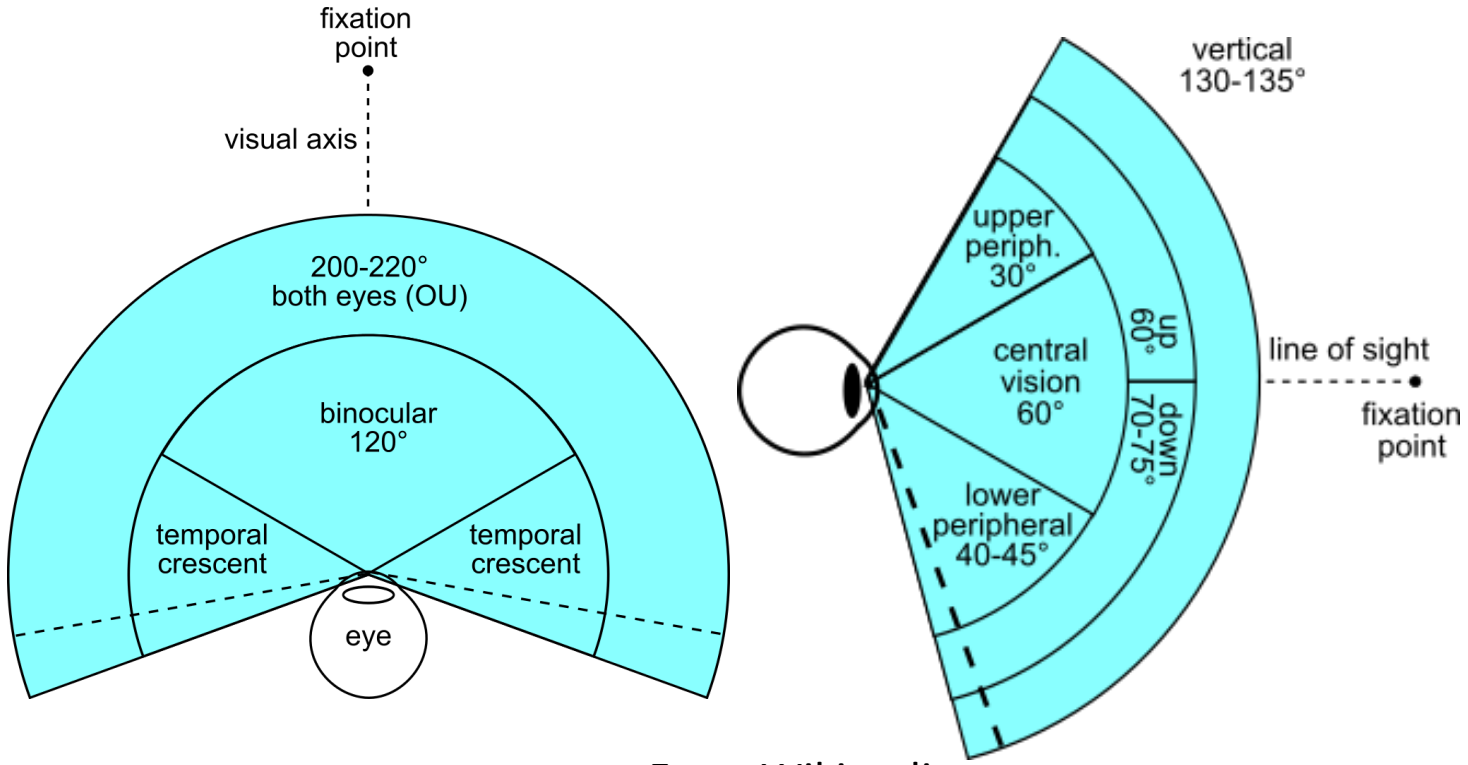
$$s = 1 * \tan 1^\circ = 0.0261\text{in}$$

The resolutions that exist today in consumer VR headsets are Inadequate.

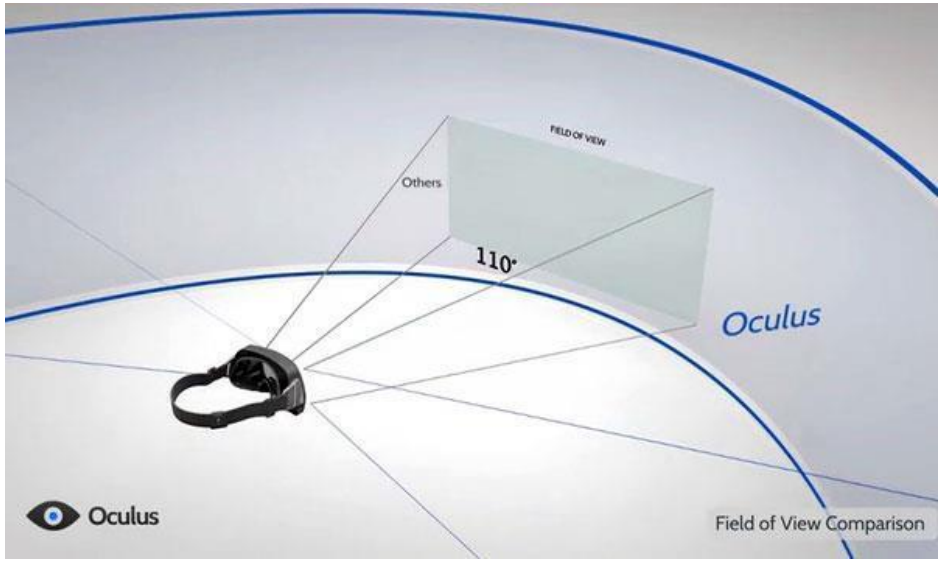
2291.6 PPI !!

Visual Field

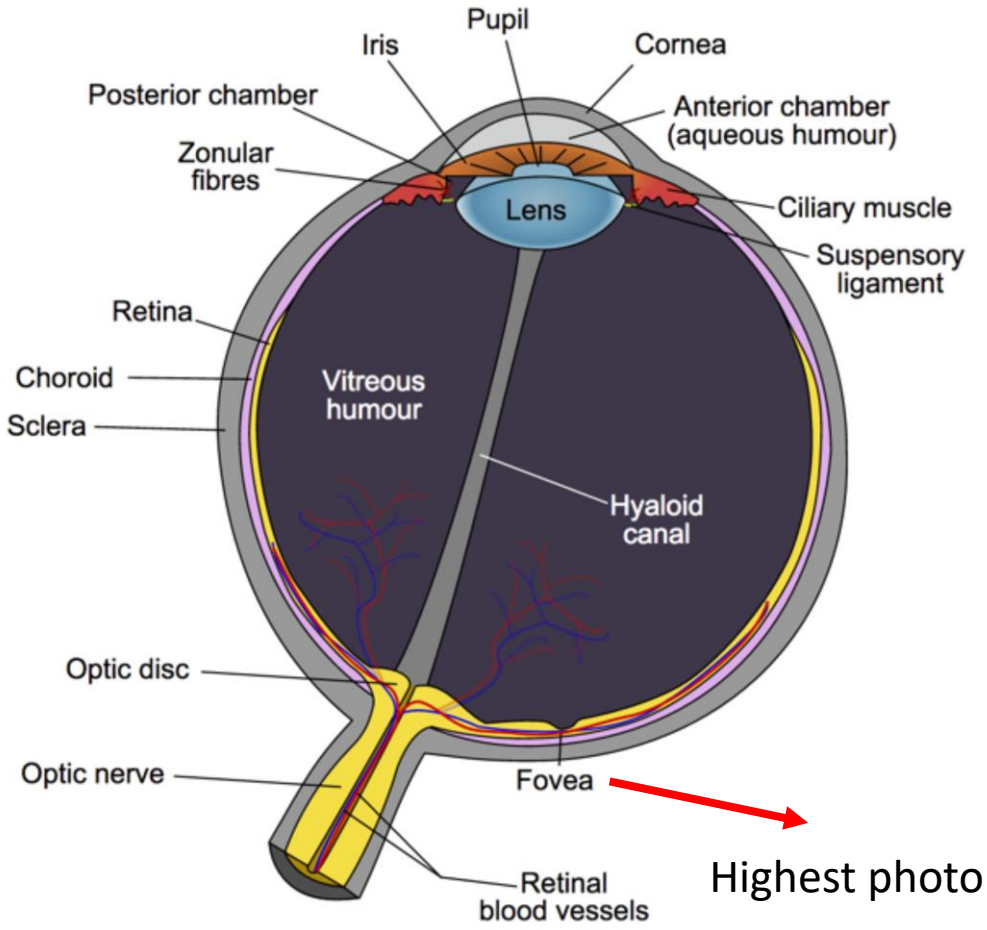
- How much field of view is enough?



From Wikipedia

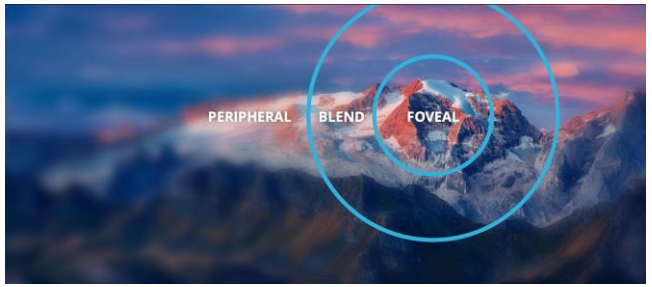


Foveated Rendering



Highest photoreceptor density

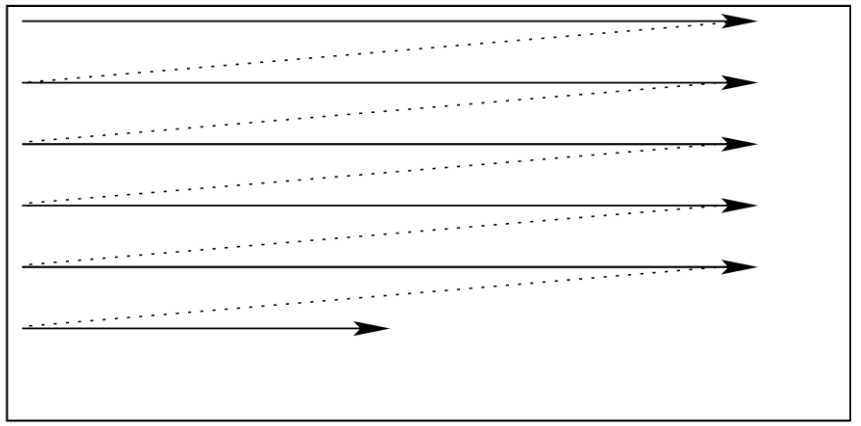
- Track where the eye is looking at
- Focus on the graphical rendering only in the spot where the eye is looking at
- Reduce computation burdens on rendering

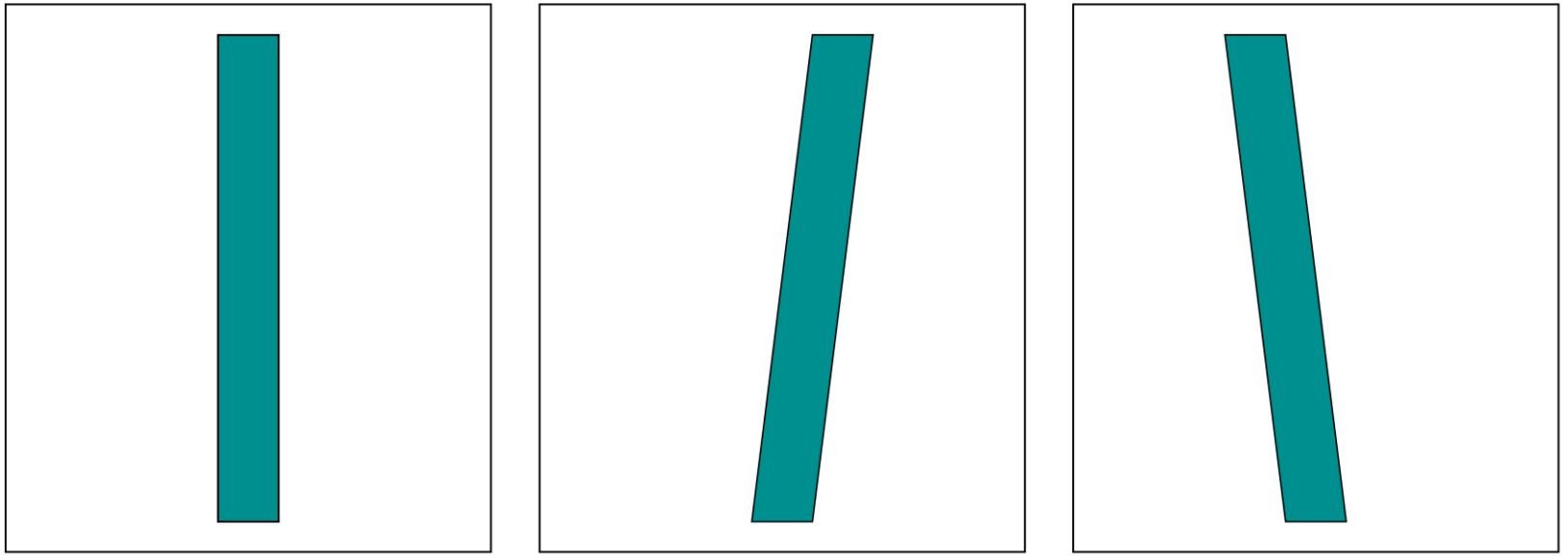


Issues: currently too costly, too much delay between eye tracking and display updates

Display Scanout

- Rolling scanout (raster scan)



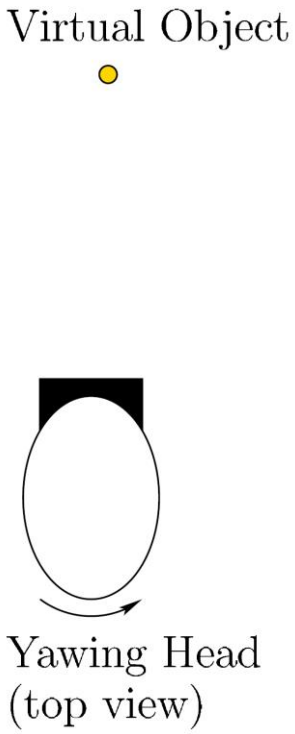


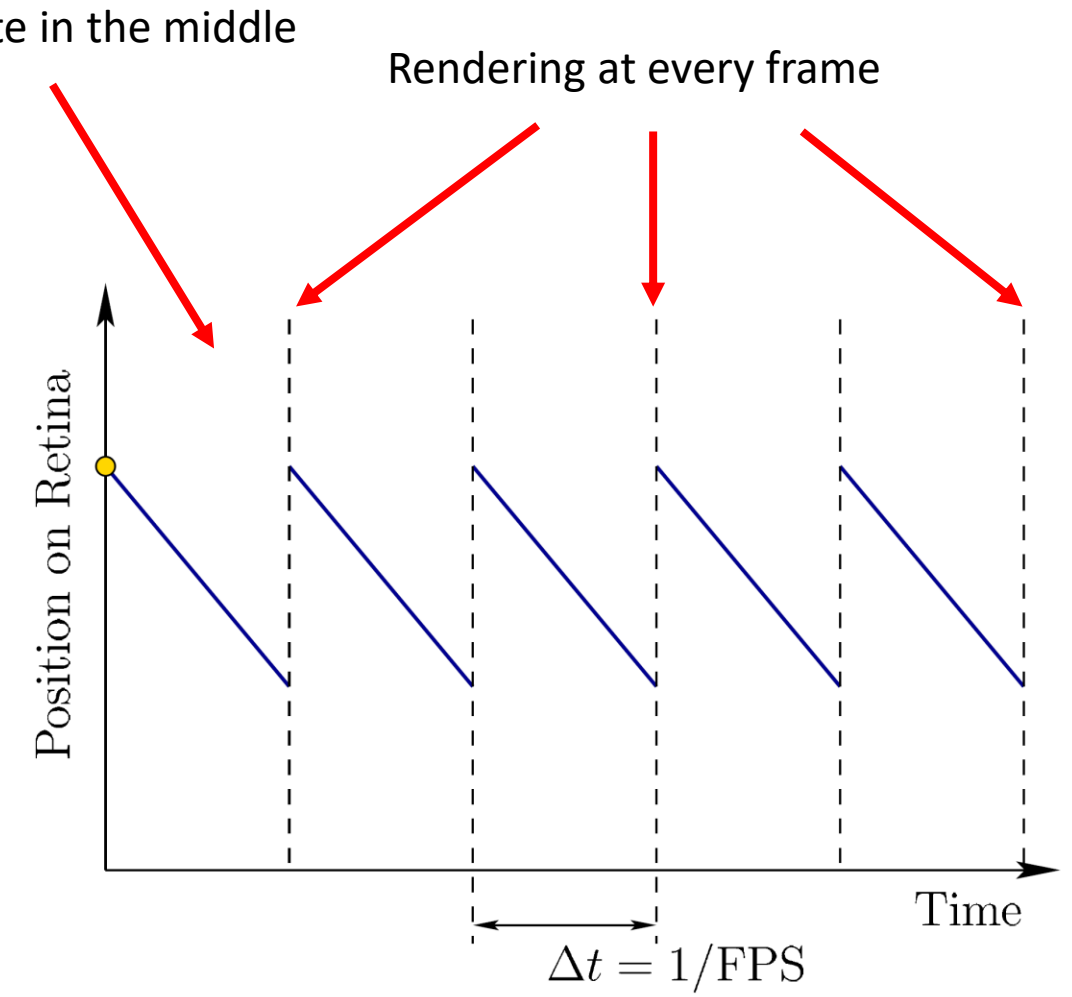
A stationary rectangle Moving rectangle to the right Rotating head to the right

- Rectify rendering
- Speed up rolling scanout

Frame Rate

- Perception of stationary



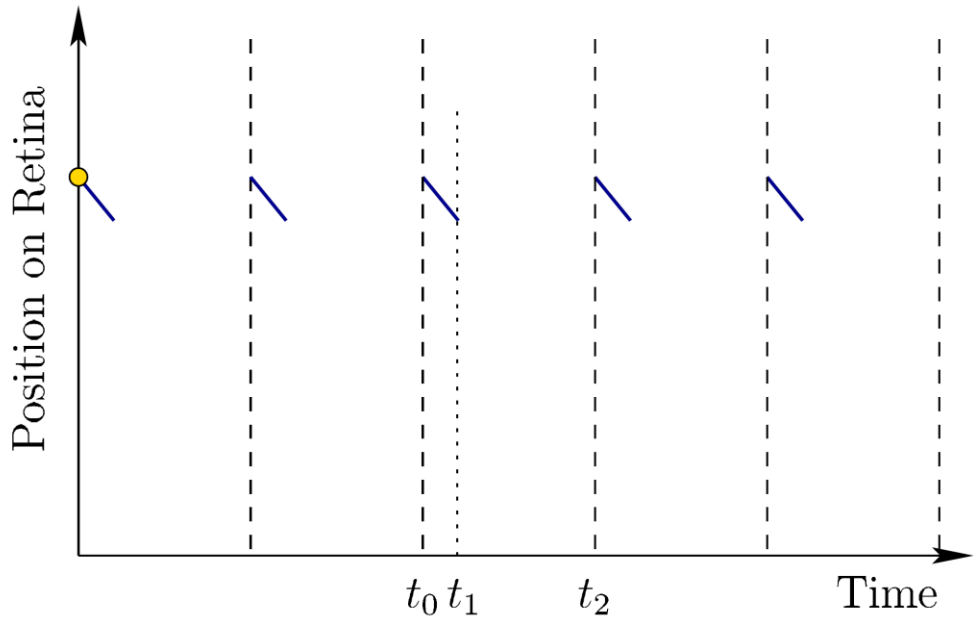


60 FPS
- 16.67ms per frame

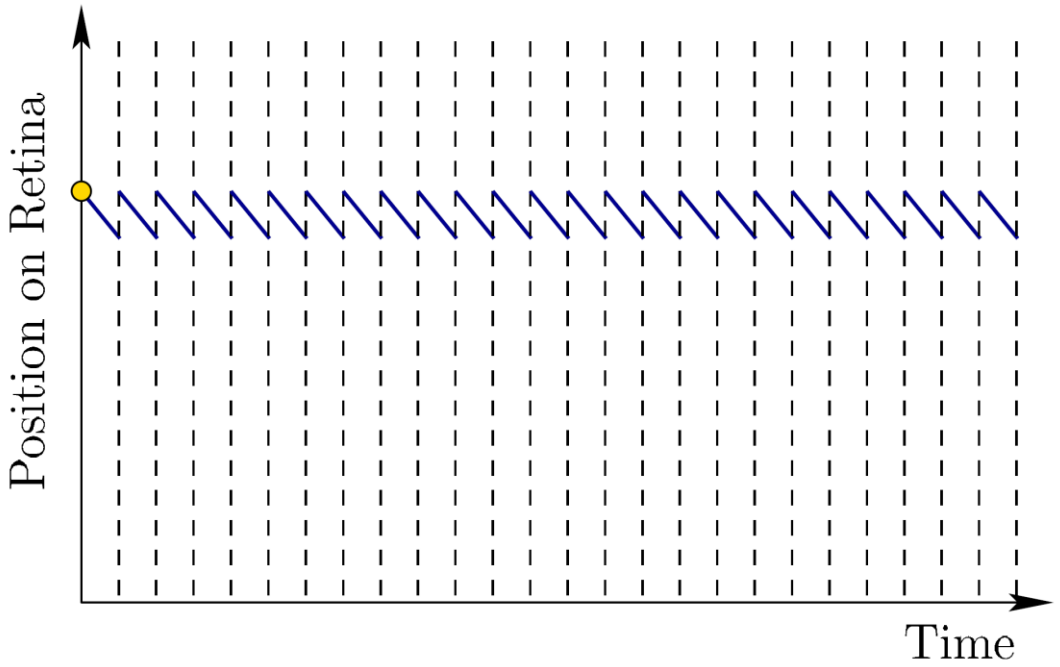
The virtual object needs to be on the same location of the retina to maintain the perception of stationary.

Frame Rate

- Perception of stationary



- OLED can reach intensity values less then 0.1ms
- LCD 20ms



Low persistence mode: turn on the screen for 1 or 2 ms
Problem: flicker

500 FPS

- 2ms per frame

Summary

- Displays
  - Cathode Ray Tubes (CRTs)
  - Liquid Crystal Displays (LCDs)
  - Liquid Crystal on Silicon (LCoS)
  - Light Emitting Diodes (LEDs)
  - Organic Light Emitting Diodes (OLEDs)
- Design
  - Spatial resolution
  - Visual Field
  - Frame rate

Further Reading

- Section 4.6, 5.4, Virtual Reality, Steven LaValle