CSE 190: Virtual Reality Technologies

LECTURE #7: VR DISPLAYS

Presentations

App:

- Justin: Gorilla Tag

Tech:

- Danny: Force Feedback Interactions

Reading

SLAM Algorithm

- Describe 3 scenarios which are particularly challenging for the SLAM algorithm

Display Characteristics

Definition of Display

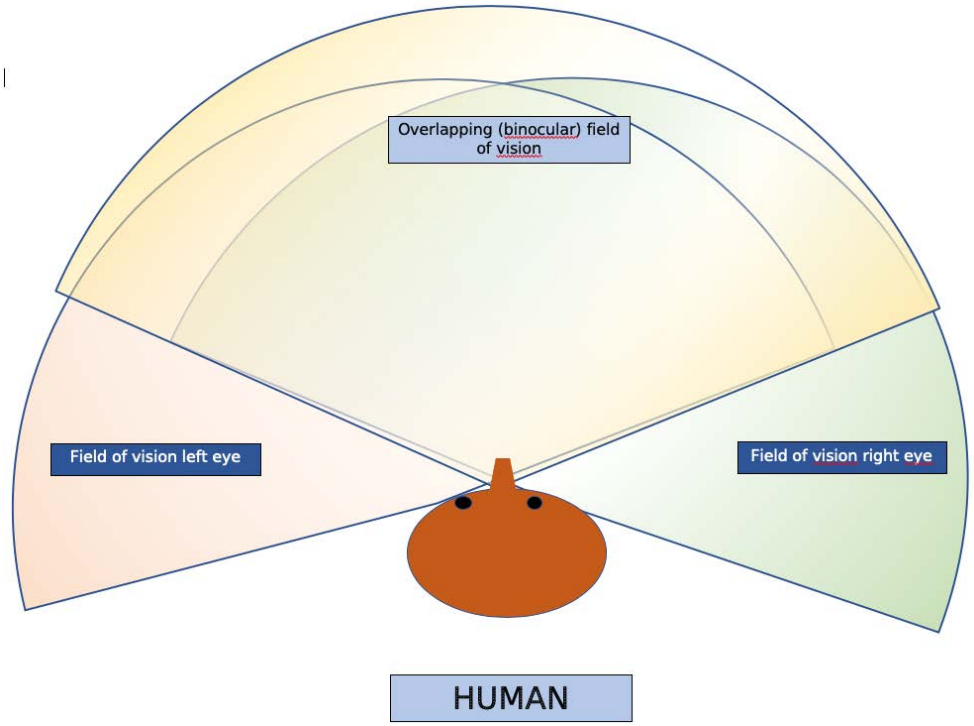
- *Display*: a device which presents **perceptual information**
- In most cases the term “display” is used for “**visual display**”
- Goal for VR: to use display devices which accurately represent **visual perception** in a **simulated world**

Visual Display Characteristics

- Field of View
- Field of Regard
- Spatial Resolution
- Screen Geometry
- Light Transfer Mechanism
- Refresh Rate
- Ergonomics

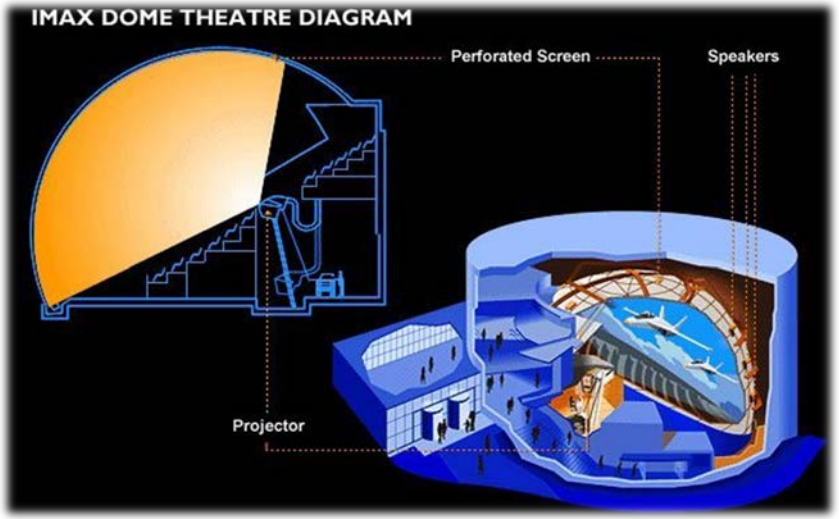
Field of View (FOV)

FOV = The total area in which VR images can be seen by a viewer **at a particular time instant**.



Field of Regard (FOR)

FOR = The total area in which VR images can be seen by a viewer **when allowed to move their head**.

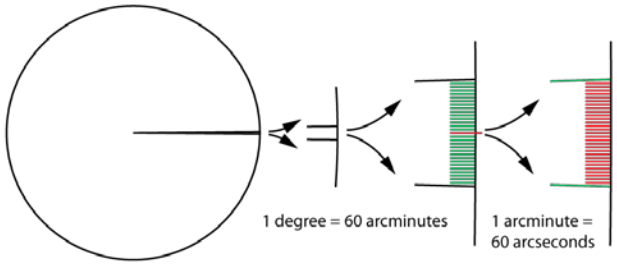


Example: IMAX Dome

The first permanent IMAX Dome installation, the Eugene Heikoff and Marilyn Jacobs Heikoff Dome Theatre at the **Reuben H. Fleet Science Center**, opened in San Diego's Balboa Park in 1973.

It was initially called “Omnimax” and wraps 180° horizontally, 100° above the horizon and 22° below the horizon for a viewer at the center of the dome for a total of 180° x 122° FOR.

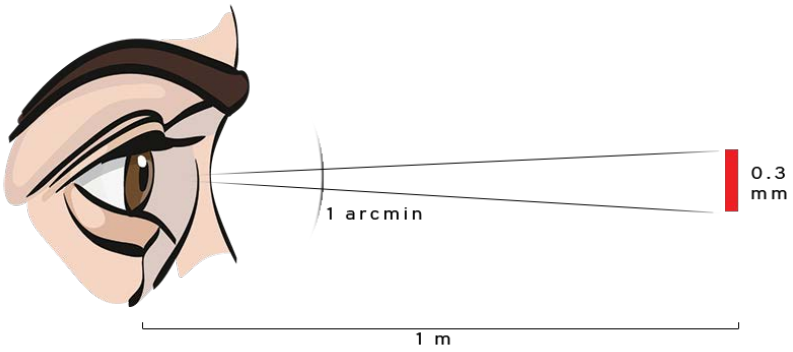
Spatial Resolution

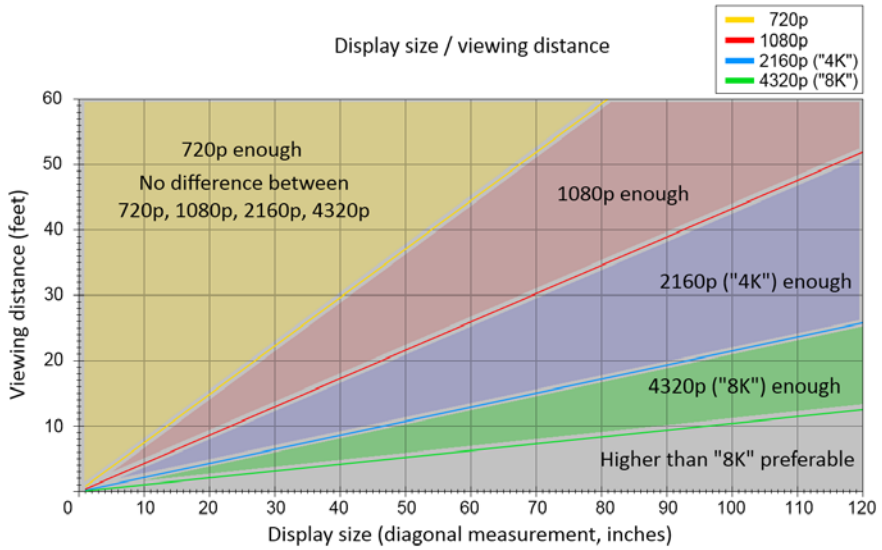


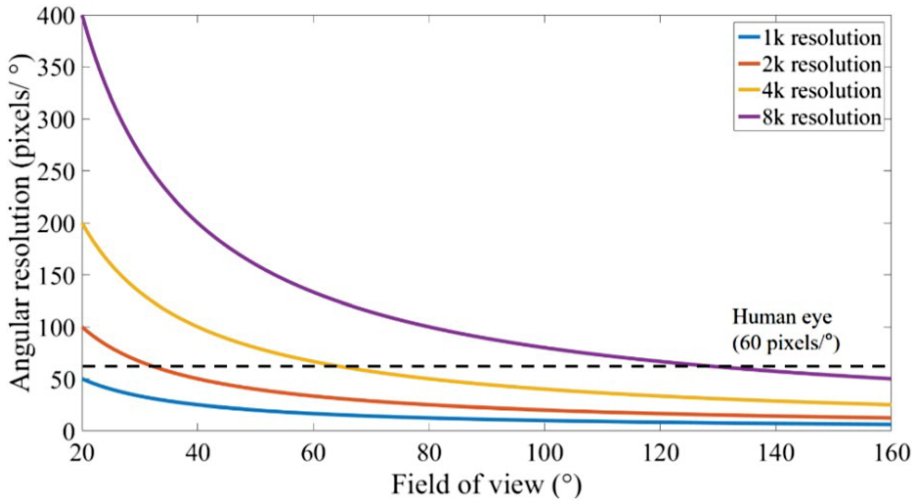
Ratio of pixels per screen area (=pixel density) or pixels per degree of the FOV (=angular resolution).

This is different than screen resolution, which is the absolute number of pixels a screen can display, for example 1920 x 1080 pixels.

Human eye: 150 pixels/degree in center of FOV, diminishes towards edge







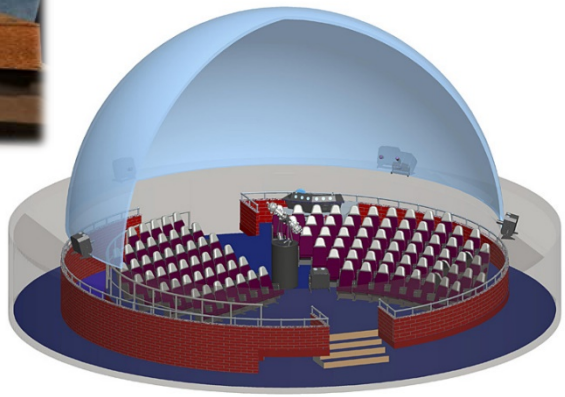
Screen Geometry

The geometric shape of the surface the image is displayed on.

Examples: rectangular, curved, hemispherical

Rectangular

Curved

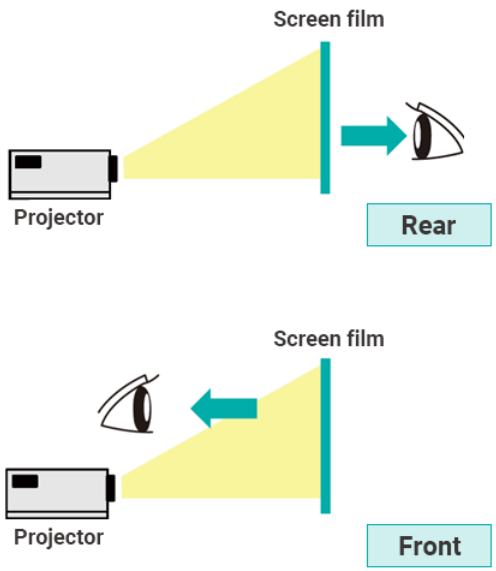


Hemispherical

Light Transfer Mechanism

How is the image generated?

Examples: LCD, front projection, rear projection, laser projection

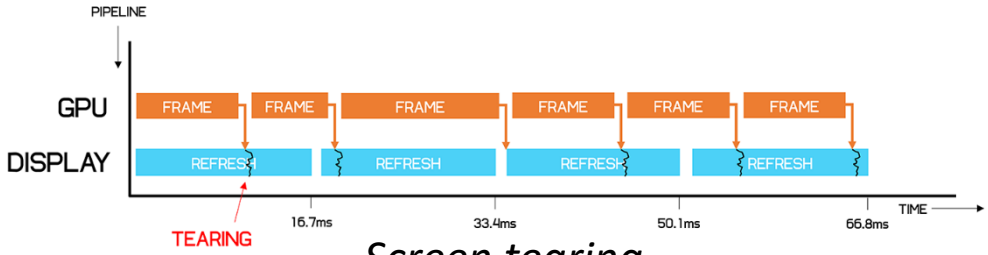


Rear vs. Front Projection

The planetarium at Griffith Observatory (Los Angeles) has one of the first **digital laser projection** systems

- Two laser projectors are used
- System features: high resolution, brightness, color contrast, saturation
- Reduced image distortion on curved planetarium dome surface
  - With lasers, depth of focus is unlimited
- Low maintenance costs

Refresh Rate



Screen tearing

Independent of frame rate

Higher refresh rate is better

Goal: frame rate = refresh rate (e.g., 90 Hz)

At minimum: frame rate = integer fraction of refresh rate (e.g., 45 Hz, 30 Hz)

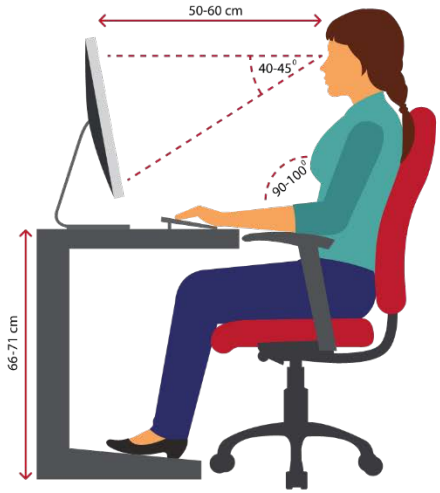
Otherwise: screen tearing

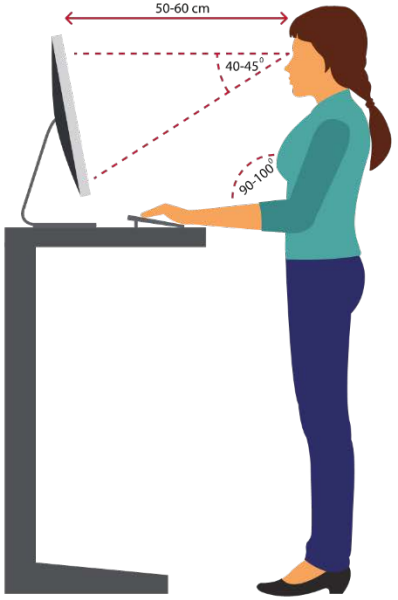
Screen tearing example

Ergonomics

How is the system used?

- Seated
- Standing
- Hands on a surface
- Hands in the air





Screen-Based VR

3D Monitor

PC with 3D capable monitor

Active or passive stereo

A.k.a. “Fishtank VR”

Requires separate tracking system

VR CAVE

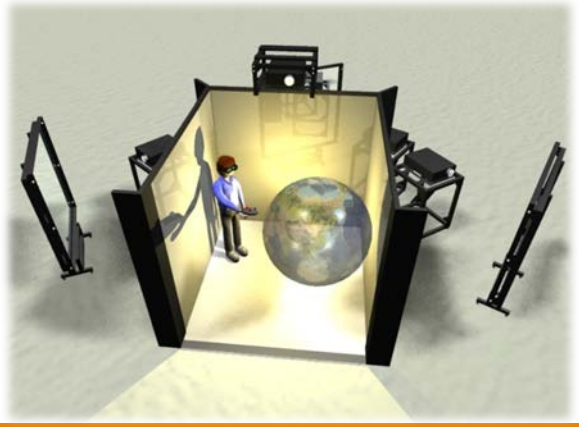
CAVE = CAVE Automated Virtual Environment

Puts user in a room for visual immersion

Usually driven by a cluster of powerful graphics computers

Multiple displays around the user

3D tracking for head and controllers



SunCAVE at UCSD

Since 2017

70 x 55” LCD 4k displays

Passive stereo

36 graphics PCs

71 Nvidia GTX 1080 GPUs

~500 Mpixels

40 Gbps network

Head-Mounted Displays (HMDs)

Head Mounted Displays

Head-worn displays with special optics in front of the eyes

Provide a stereoscopic view that is updated with the user's head motion

VR HMDs occlude the real world

AR HMDs can be translucent or video see-through

Oculus Quest 2

Microsoft Hololens 2

HMD Advantages

Provide an immersive experience by allowing a 360 degree FOR

Easy to transport and to set up

Do not restrict user from moving around in the real world

Inexpensive

High quality stereo without ghosting

Only one computer needed, some are stand-alone

HMDs – Disadvantages

Limited resolution and field of view (FOV)

Do not take advantage of peripheral vision

Can be heavy and uncomfortable, cumbersome to put on

Isolating, collaboration best done virtually (users in same room can't see each other)

Risks related to not seeing the real world (e.g., stumbling)

Emergence of Modern HMDs

Cell phone technology has matured

- High resolution screens (~3k since Galaxy S6)
- Integrated fast gyroscopes, accelerometers, magnetometers

Games use real 3D coordinate spaces

Graphics cards support 3D because of 3D monitors

Real-time rendering quality close to photo-realistic

Google Cardboard

Requires smart phone

Compatible with Android and iOS

Built-in magnet serves as button

Inexpensive: <$10

Standardized QR code system to customize rendering

Cardboard and plastic versions available

Sometimes used for promotions

Nintendo Labo VR Kit

Cardboard VR viewer and attachments for Switch console

- Resolution: 1280 x 720 pixels (640 x 720 for each eye) at 60fps

Also includes games for the attachments

Oculus Rift DK1

Funded through Kickstarter with $2.4M

Released March 2013

Single LCD display with 1280 x 800 pixels

110 degrees FOV

60 Hz refresh rate

Head orientation tracking only (3 DOF)

- Fast, custom IMU

No tracked controllers available

Oculus Rift DK2

Released July 2014

Single OLED display (same as Samsung Galaxy Note 3)

1920 x 1080 pixels

Field of view: 95 x 105 degrees

75 Hz refresh rate

Same IMU as DK1

6 DOF tracking with IMU and camera for head location tracking

No tracked controllers available

Sony Playstation VR

Released October 13, 2016

Sold for Play Station 4

Single OLED display

960 x 1080 pixels per eye

100 degrees field of view

90 or 120 Hz refresh rate

Fixed IPD

Headphone jack

Innovative head strap

External camera for tracking

6 DOF tracking with visible light in different colors

Uses Sony Move controllers

HTC Vive

Released April 5, 2016

2 OLED displays

1200 x 1080 pixels per eye

110 x 113 degrees field of view

90 Hz refresh rate

Adjustable eye distance (IPD)

Integrated camera

Headphone jack

Includes two controllers

6 DOF tracking with 2 Lighthouses

Oculus Rift CV1

Released March 28, 2016

2 OLED displays

1200 x 1080 pixels per eye

94 x 93 degrees field of view

90 Hz refresh rate

Adjustable eye distance (IPD)

Integrated headphones

Infrared LEDs on HMD and controllers

6 DOF tracking with infrared cameras (“sensors”)

Initial Oculus Rift kit

Oculus Touch Controllers

Microsoft Mixed Reality

First devices released October 17, 2017

Virtual Reality HMDs

- No augmented reality, despite the name

Specifications by Microsoft

Dual 6 DOF controllers with infrared LEDs

Inside-out 6 DOF HMD tracking with two cameras

HMDs built by:

- Samsung, Dell, HP, Lenovo, Acer, Asus

Oculus Quest 2

Release date: Oct 13, 2020

Standalone VR HMD
- Inside-out 6 DOF tracking

LCD display

1832 x 1920 pixels per eye

90 Hz refresh rate

90 degrees FOV

Adjustable IPD (3 settings)

Qualcomm Snapdragon XR2

Built-in headphones

Includes 2 controllers

DEVICE	FOV	REFRESH RATE	TRACKING TECHNOLOGY	PLATFORM SUPPORT	PRICE (USD)	WIRELESS CAPABLE	DISPLAY DETAILS	RESOLUTION PER EYE
Google Cardboard 	~90	(as low as) 60Hz (as high as) 144Hz	✗	G	HEADSET $15 FULL KIT ✗	✓	VARIES	(as low as) 540x480 (as high as) 2160x2160
Switch LABO 	~90	60Hz	✗	Nintendo	CONSOLE $299 LABO KIT $39	✓	LCD RGB	640x480
Playstation VR 	100	120Hz (REPROJECTION)	✓	PS	HEADSET ✗ FULL KIT $349	✗	OLED RGB	960x1080
Oculus Rift S 	90	80Hz	✓	Steam, Oculus	HEADSET ✗ FULL KIT $399	✗	LCD RGB	1280x1440
Asus HC102 	95	90Hz	✓	Steam, Oculus, Windows	HEADSET ✗ FULL KIT $400	✗	OLED PENTILE	1440x1440
Lenovo Explorer 	110	90Hz	✓	Steam, Oculus, Windows	HEADSET $349 FULL KIT $450	✗	LCD	1440x1440
Dell Visor 	110	90Hz	✓	Steam, Oculus, Windows	HEADSET $350 FULL KIT $450	✗	LED RGB	1440x1440
Oculus Quest 2 	89	120Hz (EXPERIMENTAL)	✓	Steam, Oculus	64GB $299 256GB $399	✓	LCD RGB	1832x1920
Oculus Quest 	94	72Hz	✓	Steam, Oculus	64GB $399 128GB $499	✓	OLED PENTILE	1600x1440
Odyssey+ 	110	90Hz	✓	Steam, Windows	HEADSET ✗ FULL KIT $499	✗	AMOLED PENTILE	1440x1600
HP Reverb G1 	114	90Hz	✓	Steam, Windows	HEADSET ✗ FULL KIT $599	✗	LCD RGB	2160x2160
HP Reverb G2 	115	90Hz	✓	Steam, Windows	HEADSET ✗ FULL KIT $599	✗	LCD RGB INDEX LENSES	2160x2160

DEVICE	FOV	REFRESH RATE	TRACKING TECHNOLOGY	PLATFORM SUPPORT	PRICE (USD)	WIRELESS CAPABLE	DISPLAY DETAILS	RESOLUTION PER EYE
Vive Cosmos 	110	90Hz	✓	Steam	HEADSET ✗ FULL KIT $699	✓	LCD RGB	1440x1700
HTC Vive Focus 	110	75Hz	✓	Vive	HEADSET ✗ FULL KIT $799	✓	AMOLED PENTILE	1440x1600
Cosmos Elite 	110	90Hz	✓	Steam	HEADSET $549 FULL KIT $899	✓	LCD RGB	1440x1700
PiMAX 8K 	170	80Hz	✓	Steam	HEADSET $499 FULL KIT $999	✗	LCD RGB	3840x2160
Valve Index 	130	144Hz	✓	Steam	HEADSET $499 FULL KIT $999	✗	LCD RGB	1440x1600
HTC Vive Pro 	110	90Hz	✓	Steam	HEADSET $799 FULL KIT $1199	✓	AMOLED PENTILE	1440x1600
PiMAX 8K 	170	80Hz	✓	Steam	HEADSET $1299 FULL KIT ✗	✗	LCD RGB	3840x2160
PiMAX 5K PLUS 	170	144Hz	✓	Steam	HEADSET $899 FULL KIT $1399	✗	OLED PENTILE	2560x1440
StarVR ONE 	210	90Hz	✓	Steam	HEADSET $3200 FULL KIT ✗	✗	AMOLED RGB TOBII EYE	1830x1464
HTC Vive 	110	90Hz	✓	Steam	HEADSET DISCONTINUED FULL KIT DISCONTINUED	✓	AMOLED PENTILE	1080x1200
Oculus CV1 	94	90Hz	✓	Steam, Oculus	HEADSET DISCONTINUED FULL KIT DISCONTINUED	✓	OLED PENTILE	1080x1200
Virtual Boy 	~30	50Hz	✗	Nintendo	HEADSET DISCONTINUED FULL KIT DISCONTINUED	✗	LED	384x224 (1×224 scanned)

Discalimers:
Field of view depends highly on the screen size and eye relief (eye to lens distance).
All FOVs listed are the **horizontal** specifications.
All specifications listed are from the "Comparison of virtual reality headsets" Wiki Article

V1.3

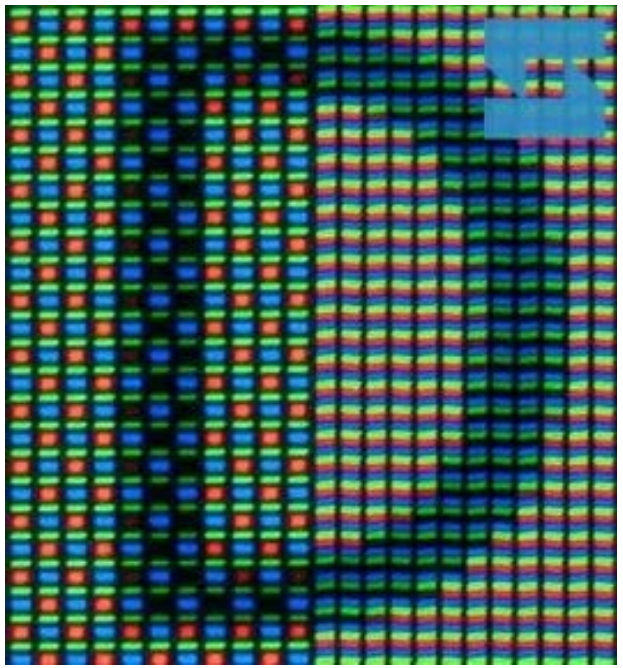
AMOLED vs. LCD

AMOLED = Active-Matrix Organic Light-Emitting Diode

AMOLED screens don't need a backlight, as each pixel is able to produce **its own light** when it needs to. This makes **blacks look amazing** when viewing a picture or video, because the pixels do not have a to provide light at all, rather than LCD displays where the backlight bleeds through and you get a dark grey color where there should be black.

AMOLED drawbacks:

- more expensive to produce
- not as sharp as LCD displays when looking up close
  - AMOLED uses a different subpixel arrangement than LCD displays, which makes individual pixels more noticeable (see picture)



AMOLED LCD