



Computational Imaging

Lecture 07: Display Tech, for VR/AR - Introductory



Qilin Sun (孙启霖)

School of Data Science

The Chinese University of Hong Kong, Shenzhen



Today's Topic

- What's Display
- Projectors Are Alternative
- Would Metaverse Really Come
- Virtual Reality
- Augmented Reality
- What's Next



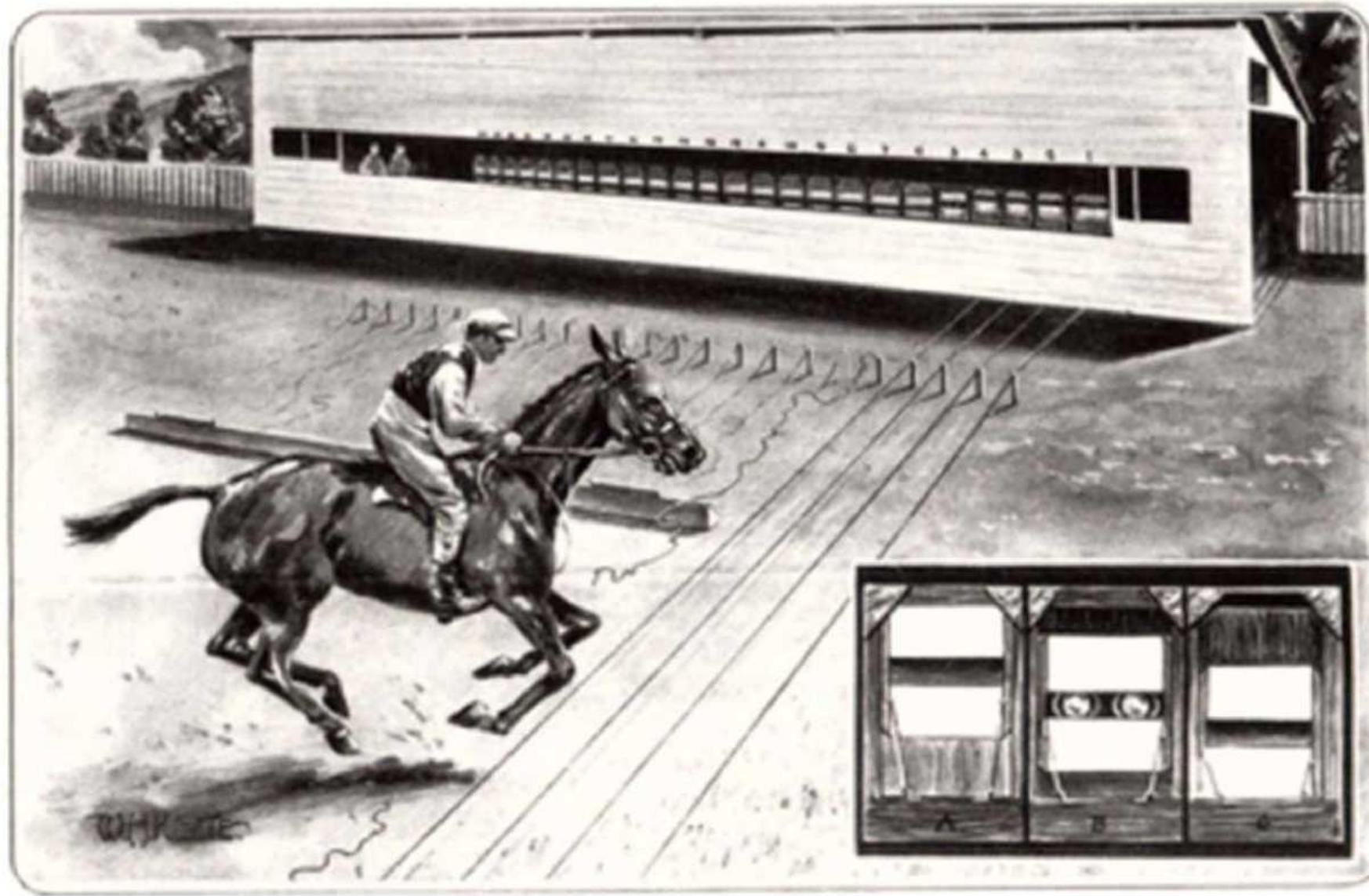
香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

What's Display



香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Historical Multi-Camera Array at Stanford



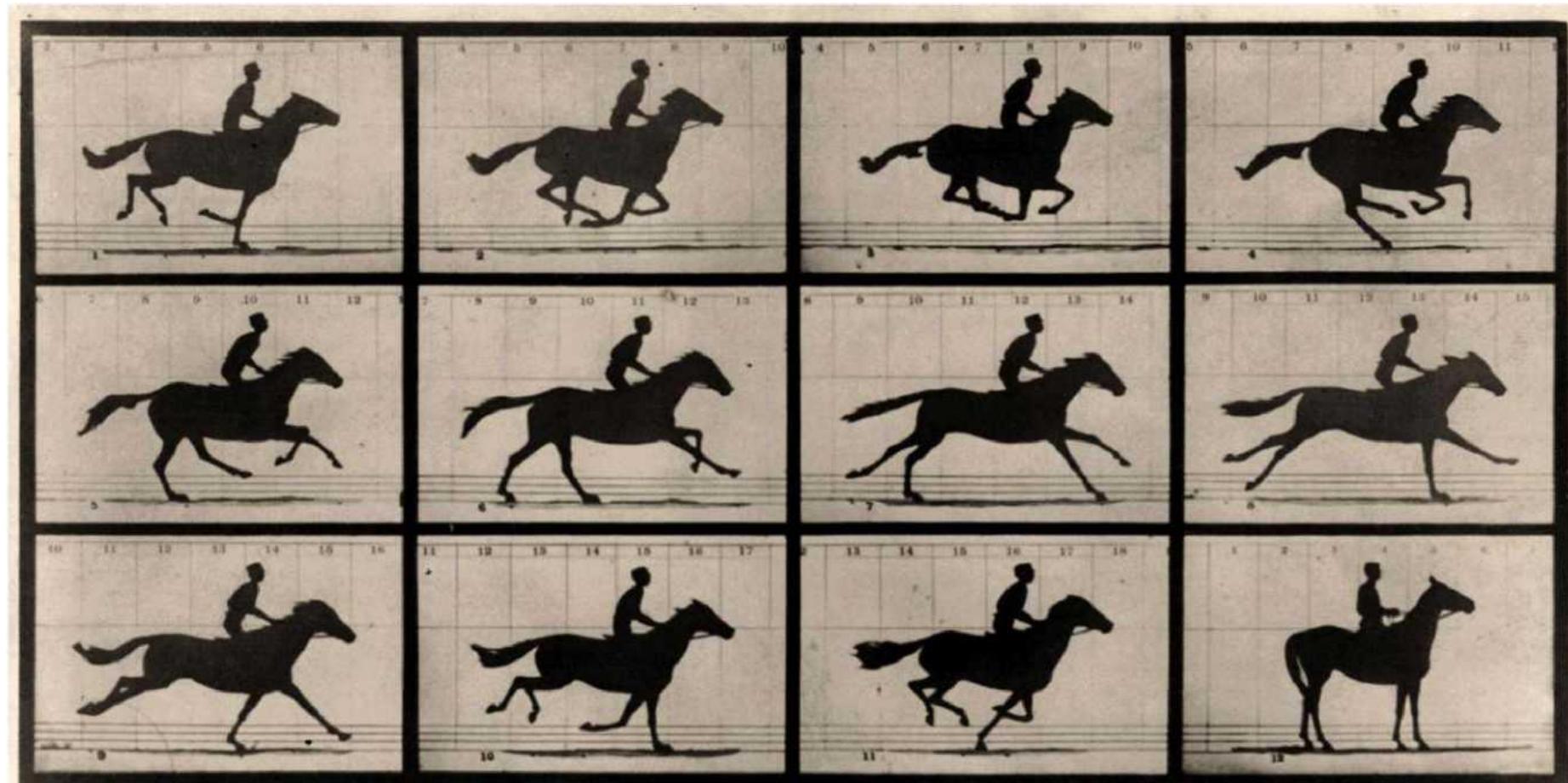
Images borrowed from public domain



香港中文大學(深圳)

The Chinese University of Hong Kong, Shenzhen

Historical Multi-Camera Array at Stanford



Copyright, 1878, by MUYBRIDGE.

MORSE'S Gallery, 417 Montgomery St., San Francisco.

THE HORSE IN MOTION.

Illustrated by
MUYBRIDGE.

AUTOMATIC ELECTRO-PHOTOGRAPH.

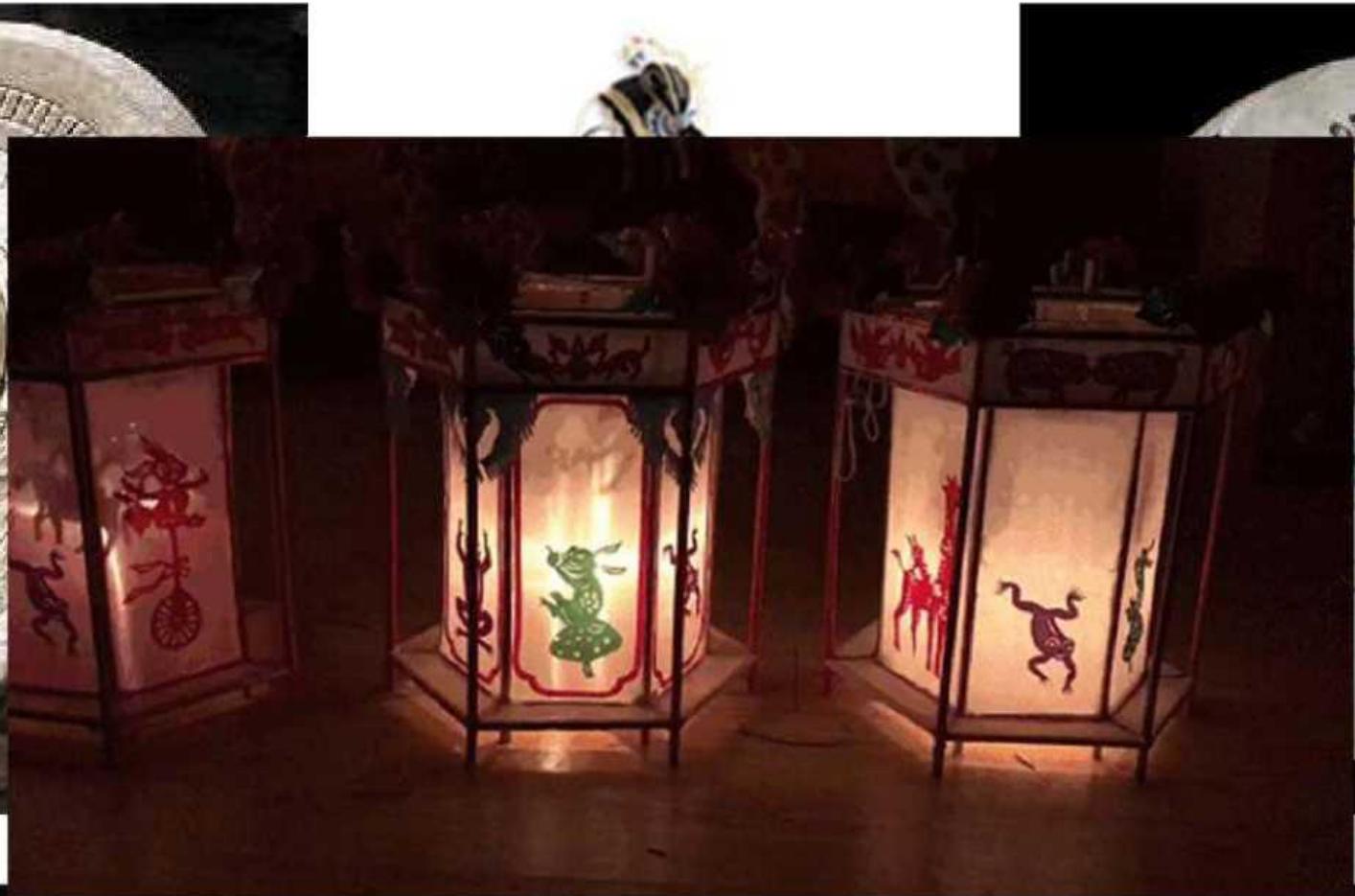
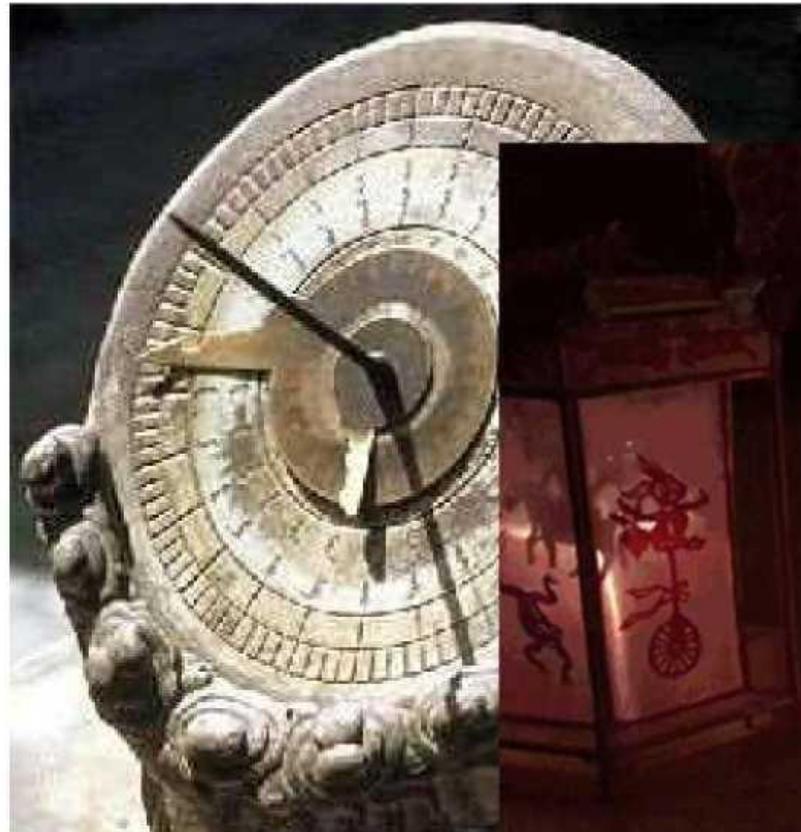
"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed in each twenty-seven inches of progress during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each. The exposure of each negative was less than the two-thousandth part of a second.

Images borrowed from public domain



Historical Chinese “Displays”



Images borrowed from public domain



Defination

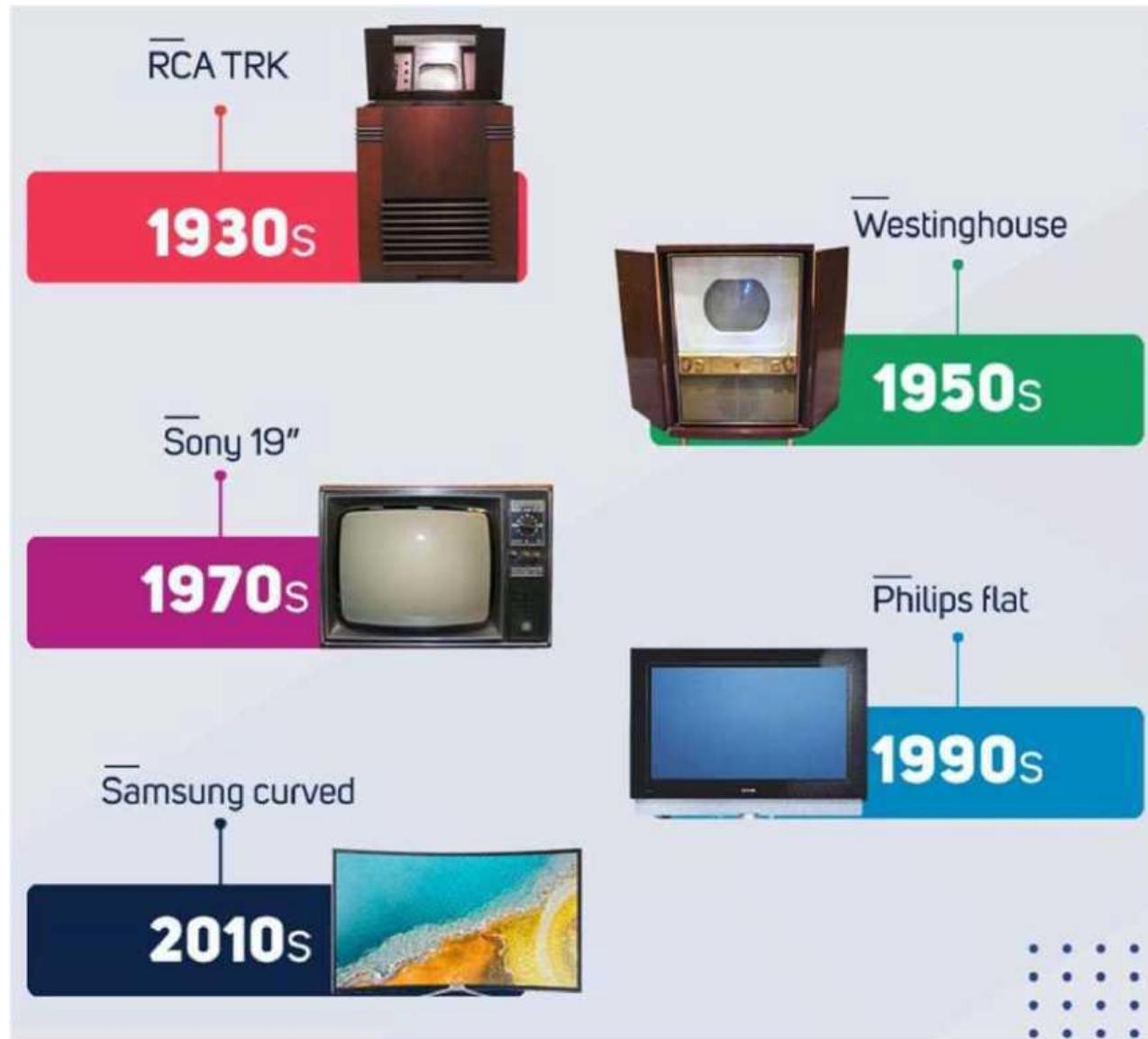
dis·pl·ay Display

An output device for presentation of information in visual or tactile form
(the latter used for example in tactile electronic displays for blind people).

When the input information that is supplied has an electrical signal
the display is called an electronic display.



Everyone Watches TVs



Images borrowed from public domain



SAMSUNG

PHILIPS

SONY
make.believe

benQ

ASUS

TCL

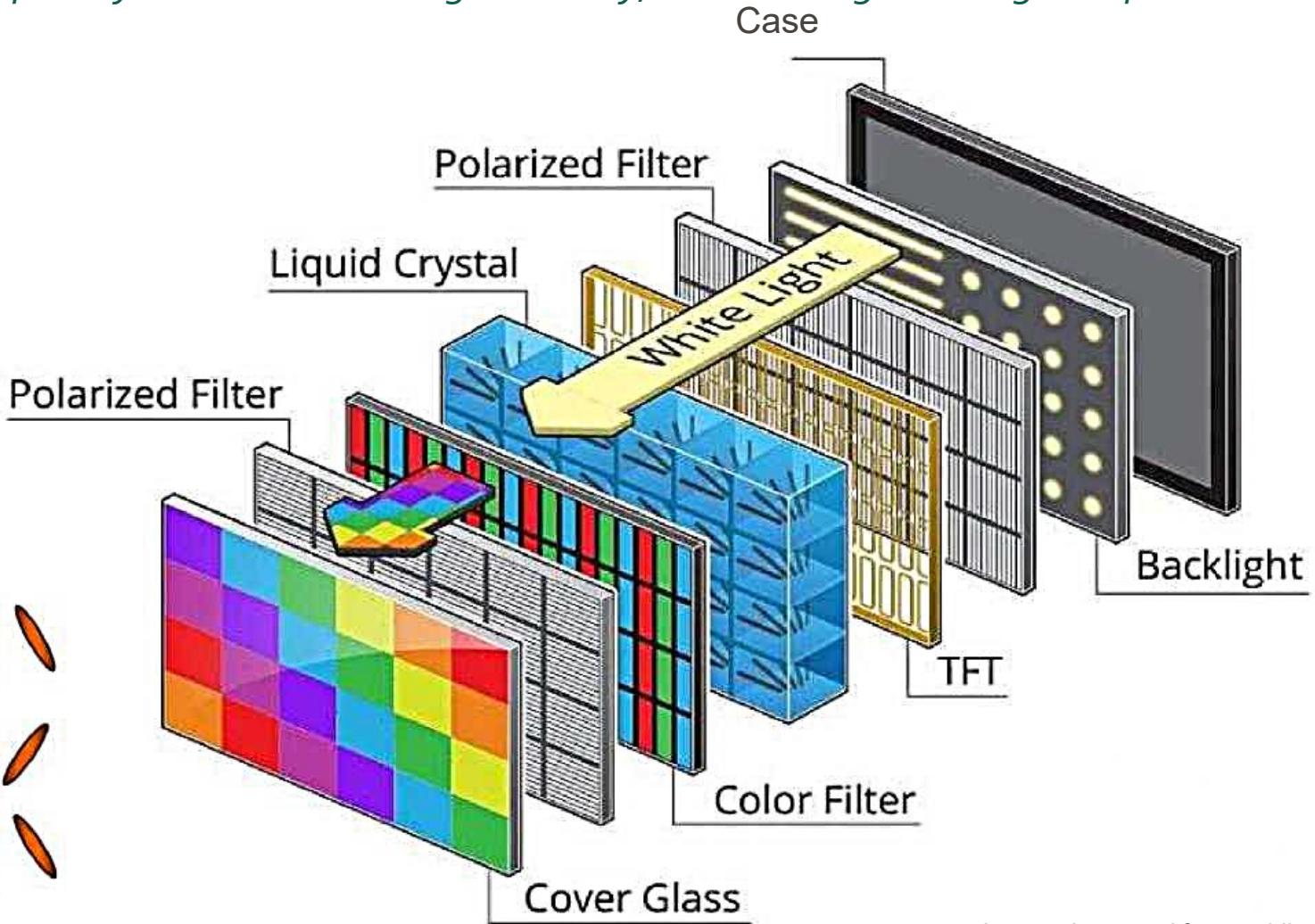
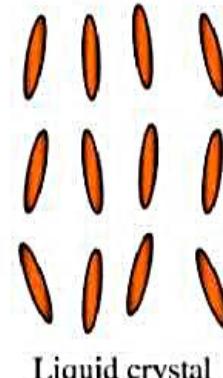
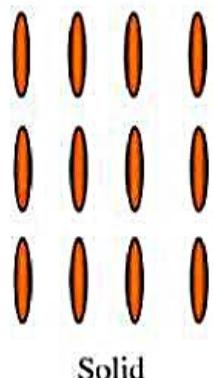
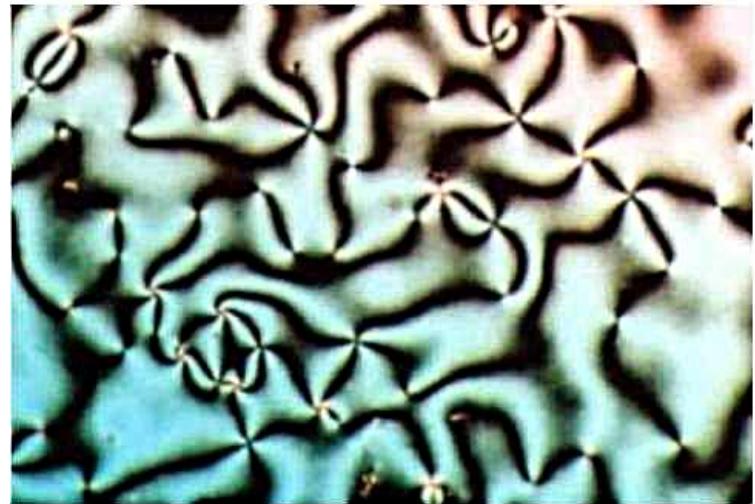
BOE SHARP
TOSHIBA

- CRT(cathode-ray tube)
- Flat Panel Displays
- EL(ElectroLuminescent)
- PDP(plasma display panel)
- LCD(liquid-crystal display)
- OLED (organic light-emitting diode)
- Projection



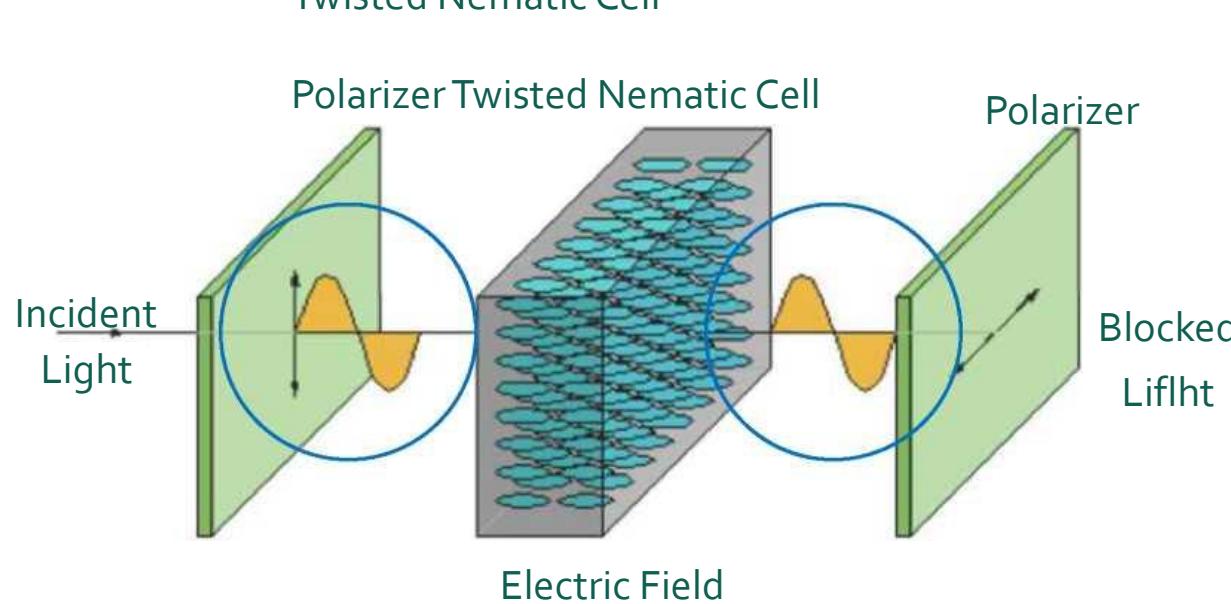
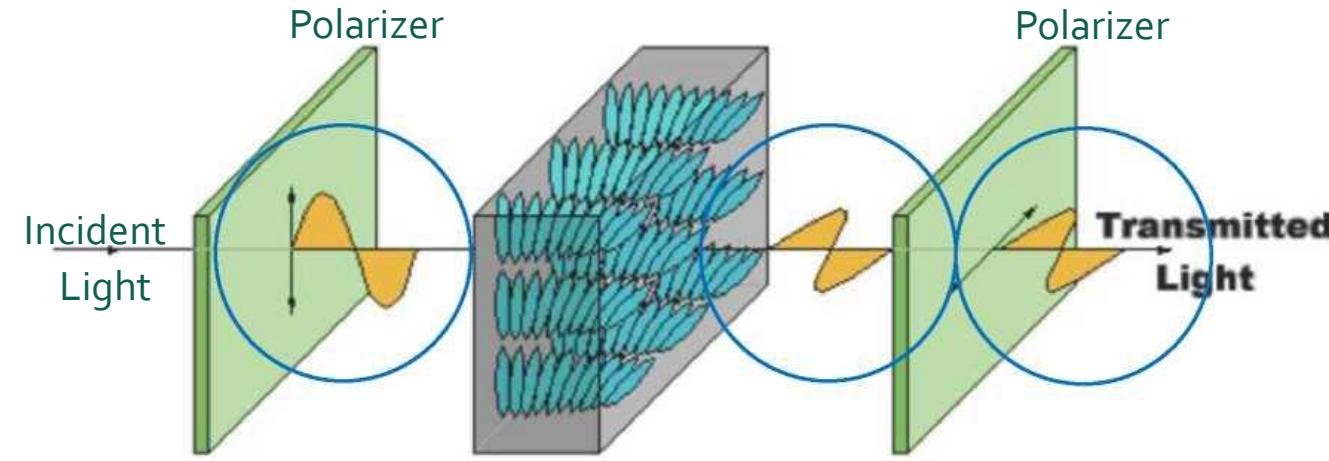
LCD Everywhere

a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals combined with polarizers. Liquid crystals do not emit light directly, instead using a backlight to produce images in color or monochrome.

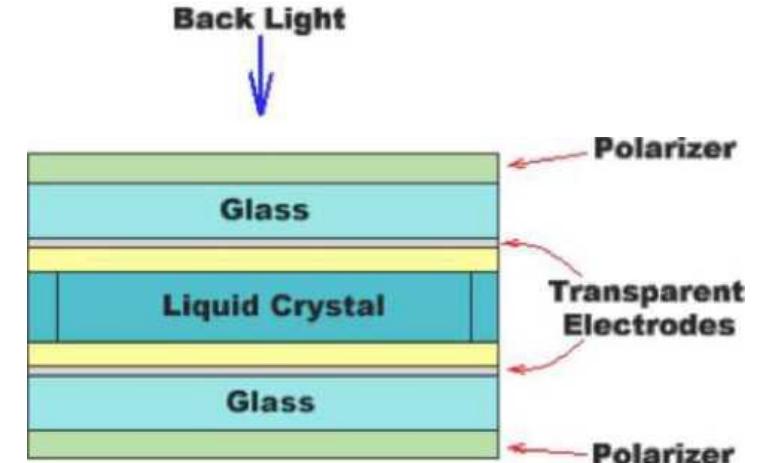




Working Example: TN LCD Panel



I Molecular
Orientation Layers





When Buying a Monitor

Panel Type



TN



VA



IPS



| Response Time | <1ms | 4-5ms | 1-2ms |
|---------------|----------------|----------------|----------------|
| Color | Poor | Good | Best |
| Contrast | Good 1000:1 | Best 3000:1 | Good 1000:1 |
| Viewing Angle | 170/160 | 178/178 | 178/178 |



香港中文大學(深圳)

The Chinese University of Hong Kong, Shenzhen

QLED: Quantum Dot Backlight

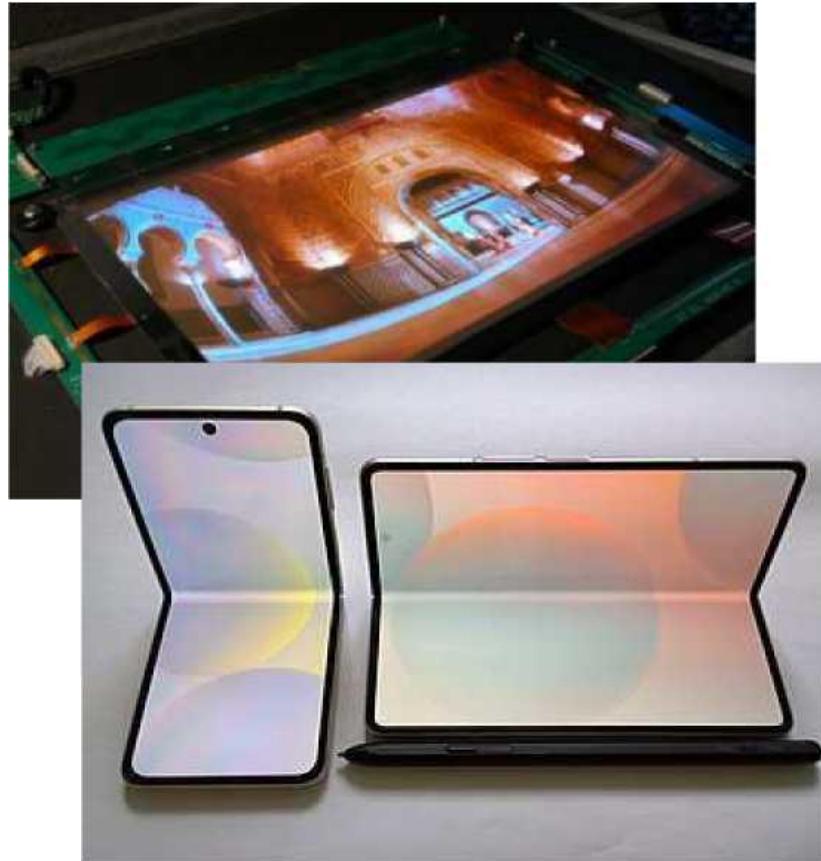
Still LCD, but with
better color fidelity





OLED: A Selling Point

a light-emitting diode (LED) in which the emissive electroluminescent layer is a film of organic compound that emits light in response to an electric current. This organic layer is situated between two electrodes; typically, at least one of these electrodes is transparent.

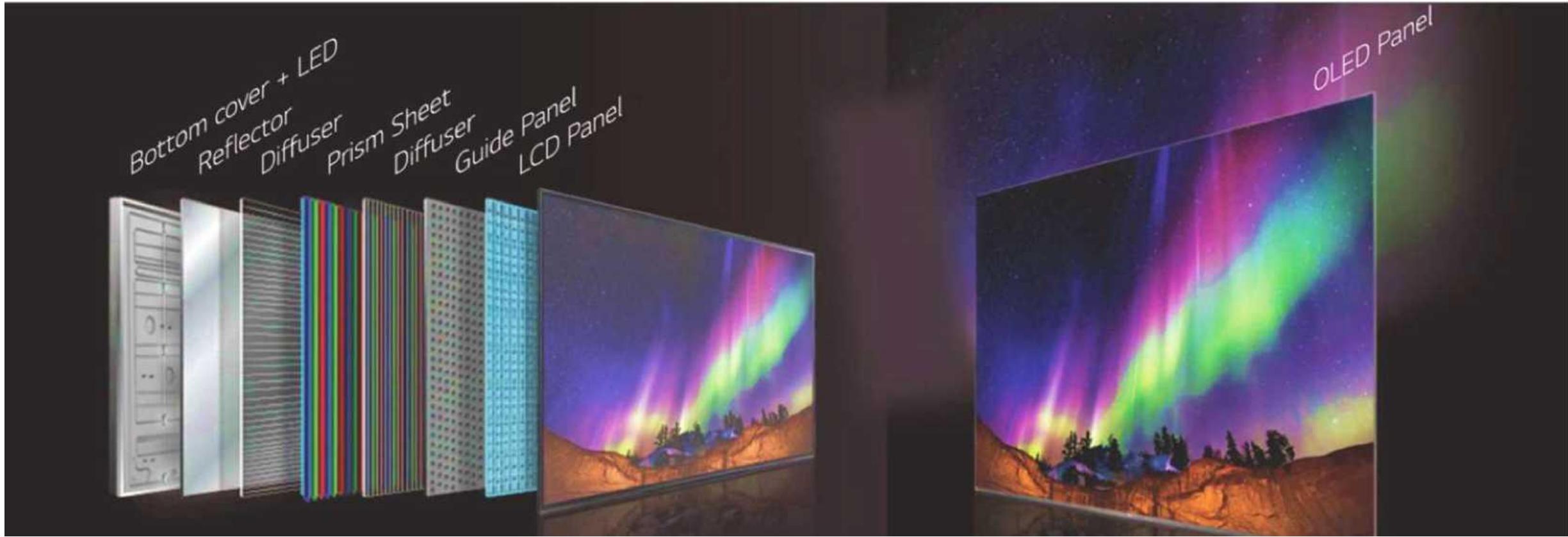




香港中文大學(深圳)

The Chinese University of Hong Kong, Shenzhen

LCD v.s. OLED



Structure | LCD(LED) OLED | Structure

Passive (BLU needed)

Limited contrast but lower cost

Self-emissive

Great light efficiency and contrast but higher cost

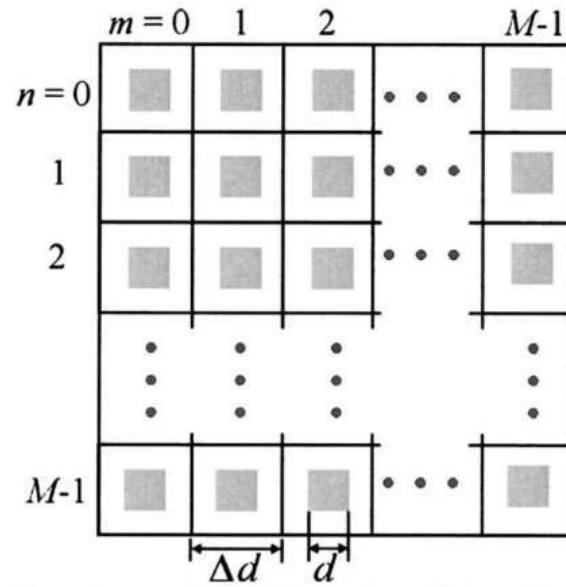


香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Projectors Are Alternative

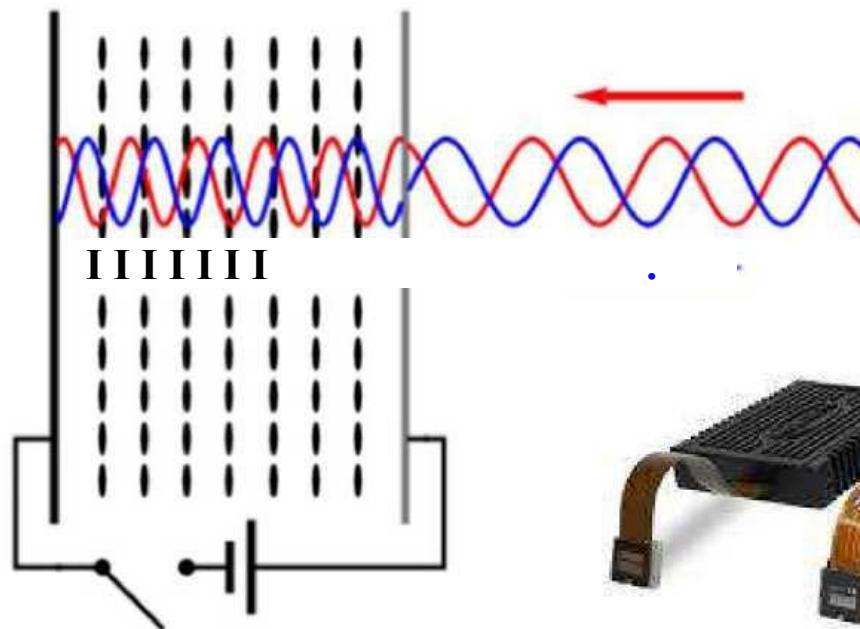


SLMs for Shaping Light



Geometry of the $M \times M$ phase-only spatial light modulator with a square pixel length d while M is the period length. The active phase-encoding area of a pixel is shaded gray.

[Palima et al. 2006]



*Pixel pitch
Resolution
Grayscale
Modulation range
Refresh rate*

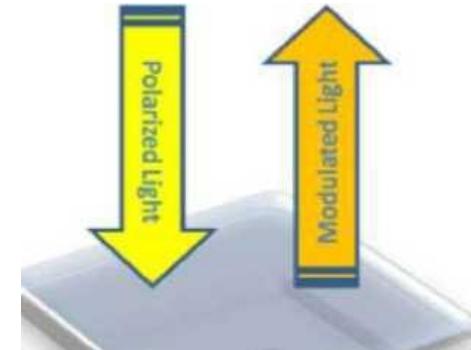
HAMAMATSU
PHOTON IS OUR BUSINESS

 **TEXAS
INSTRUMENTS**



SLM: Liquid Crystal on Silicon (LCoS)

a miniaturized reflective active-matrix liquid-crystal display or "microdisplay" using a liquid crystal layer on top of a silicon backplane.



Glass Layer



Transparent Layer

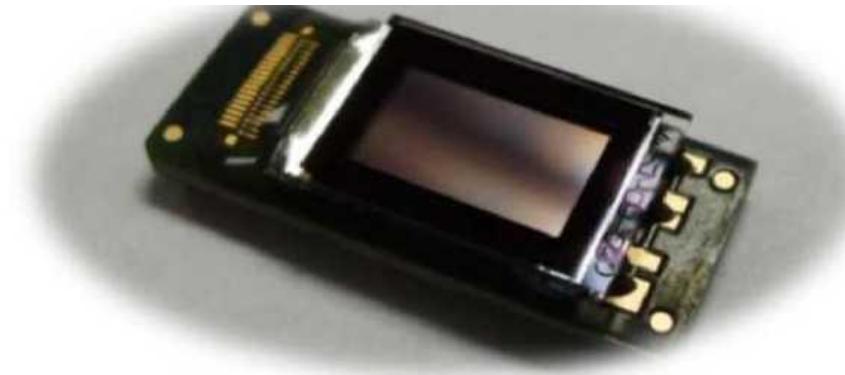
Alignment Layer

Liquid Crystal Layer

Reflective Layer

CMOS

Control Layer



Basically, a reflective LCD

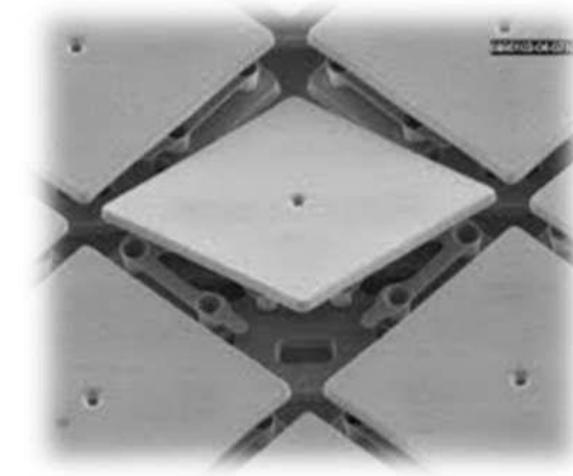
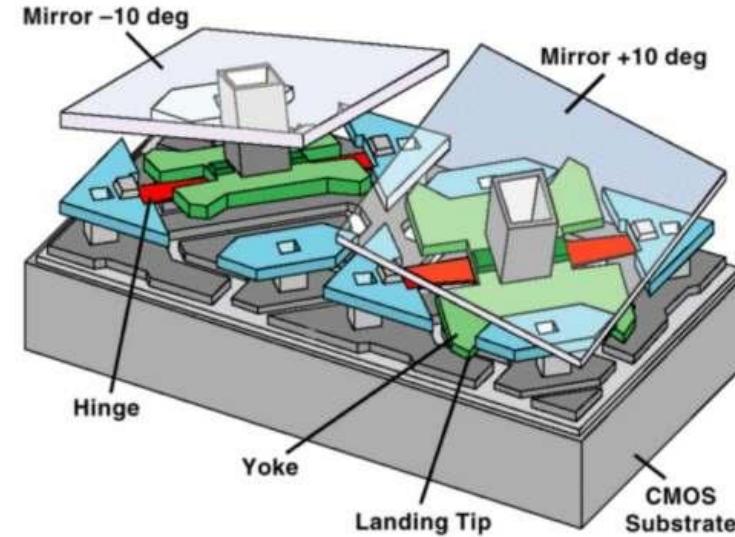
Standard component in projectors and head-mounted displays, e.g., google glass

Without the 2nd polarizer: phase modulation device



SLM: Digital Micromirror Device (DMD)

a micro-optoelectro-mechanical system (MOEMS) that is the core of the trademarked digital light processing (DLP) projection technology, basically micro-mirrors array.



MEMS device

- Binary states (+/- 10 deg.)
- Grayscale via pulse width modulation (PWM)

DLP®
TEXAS INSTRUMENTS

Images borrowed from public domain

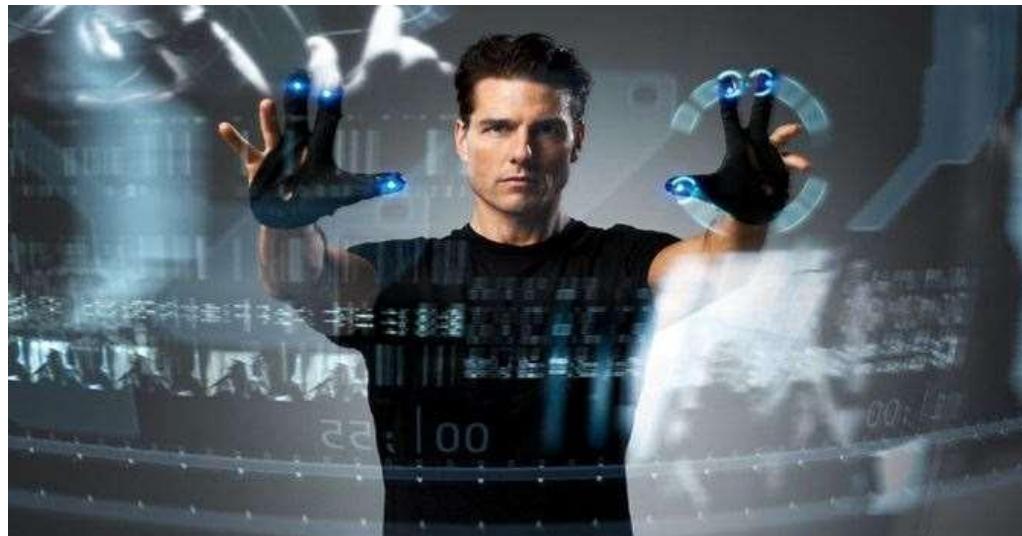
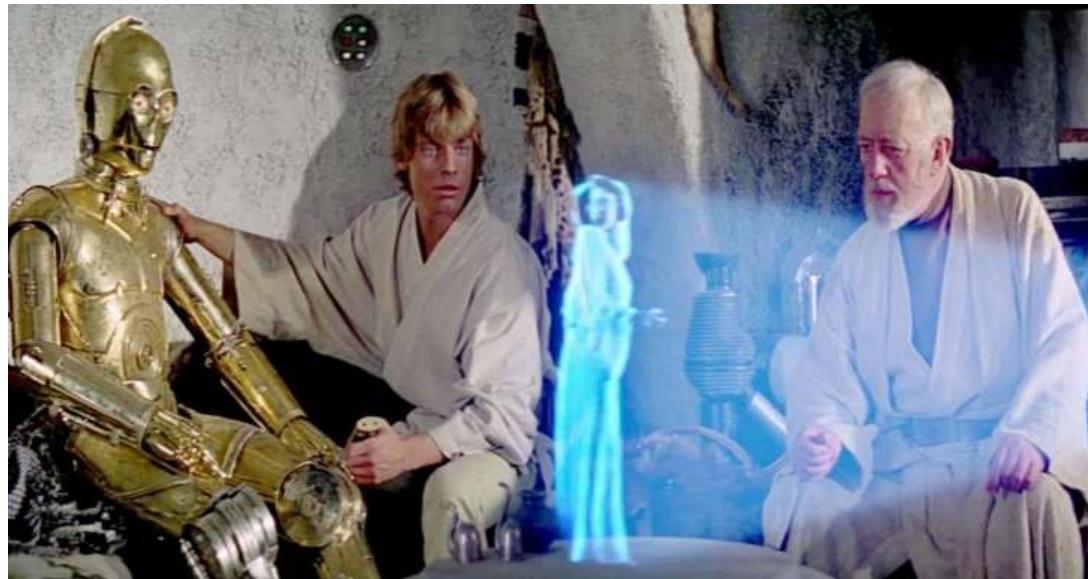


香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Would Metaverse Really Come



Metaverse





香港中文大學(深圳)

The Chinese University of Hong Kong, Shenzhen

Future Display and Visualization Scenarios



Images borrowed from public domain, credits @ Sony, ETH/UNC, Nvidia, Microsoft



vir·tu·al re·al·i·ty VR

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.



Message from National Academy of Engineering

“Enhance Virtual Reality⁵⁵ is 1 of 14 grand challenges for engineering in the 21st century





香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Raster File Formats



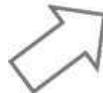
Scott Song for USC Roski Eye Institute



Fun” Engineering Aspects of VR/AR

- HCI
- applications

cloud computing
shared experiences



- VR cameras
- Compression, streaming



- sensors & imaging
- computer vision
- scene understanding

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



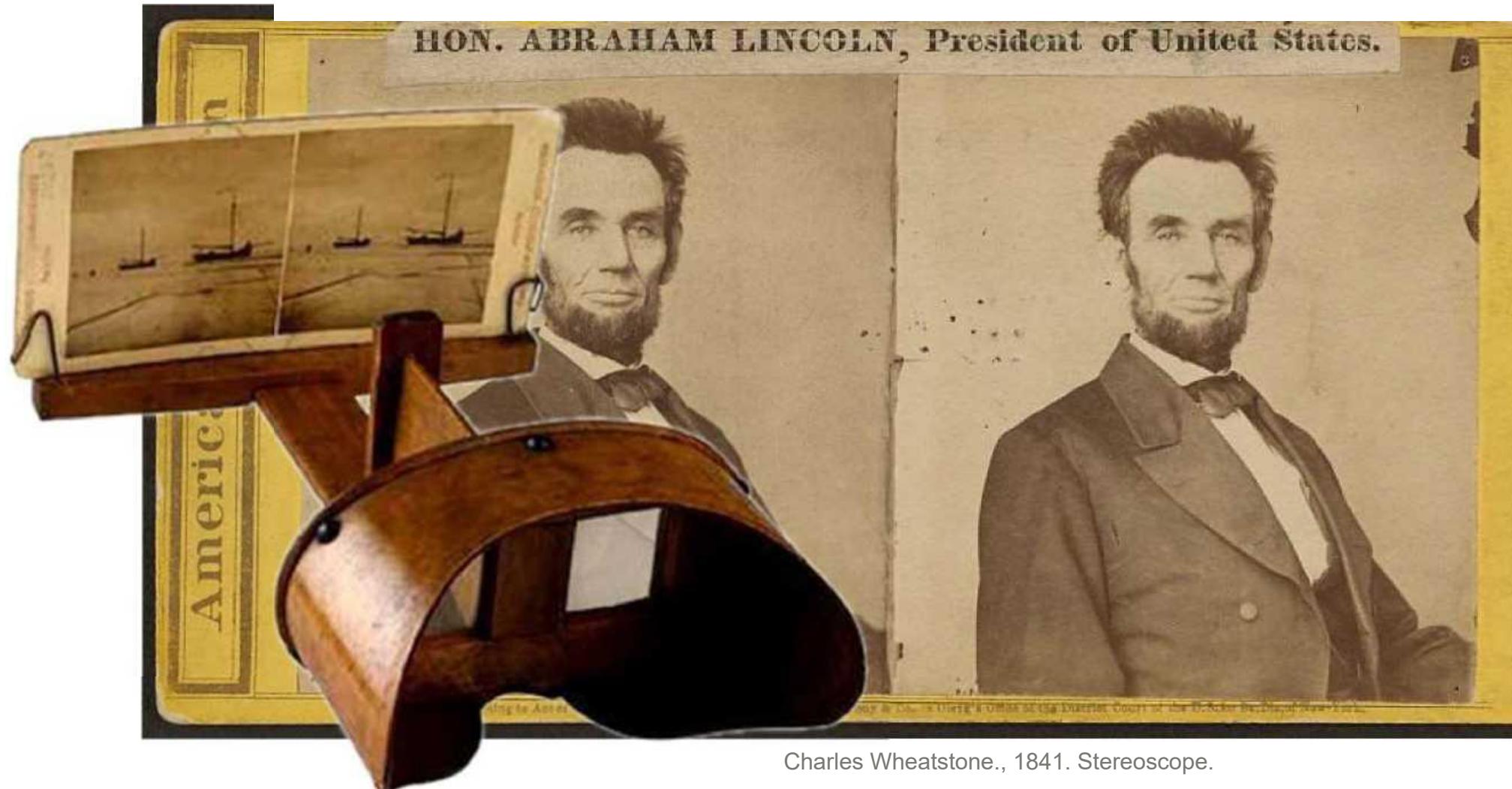
香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

Where We Want It To Be





Stereoscopic Displays

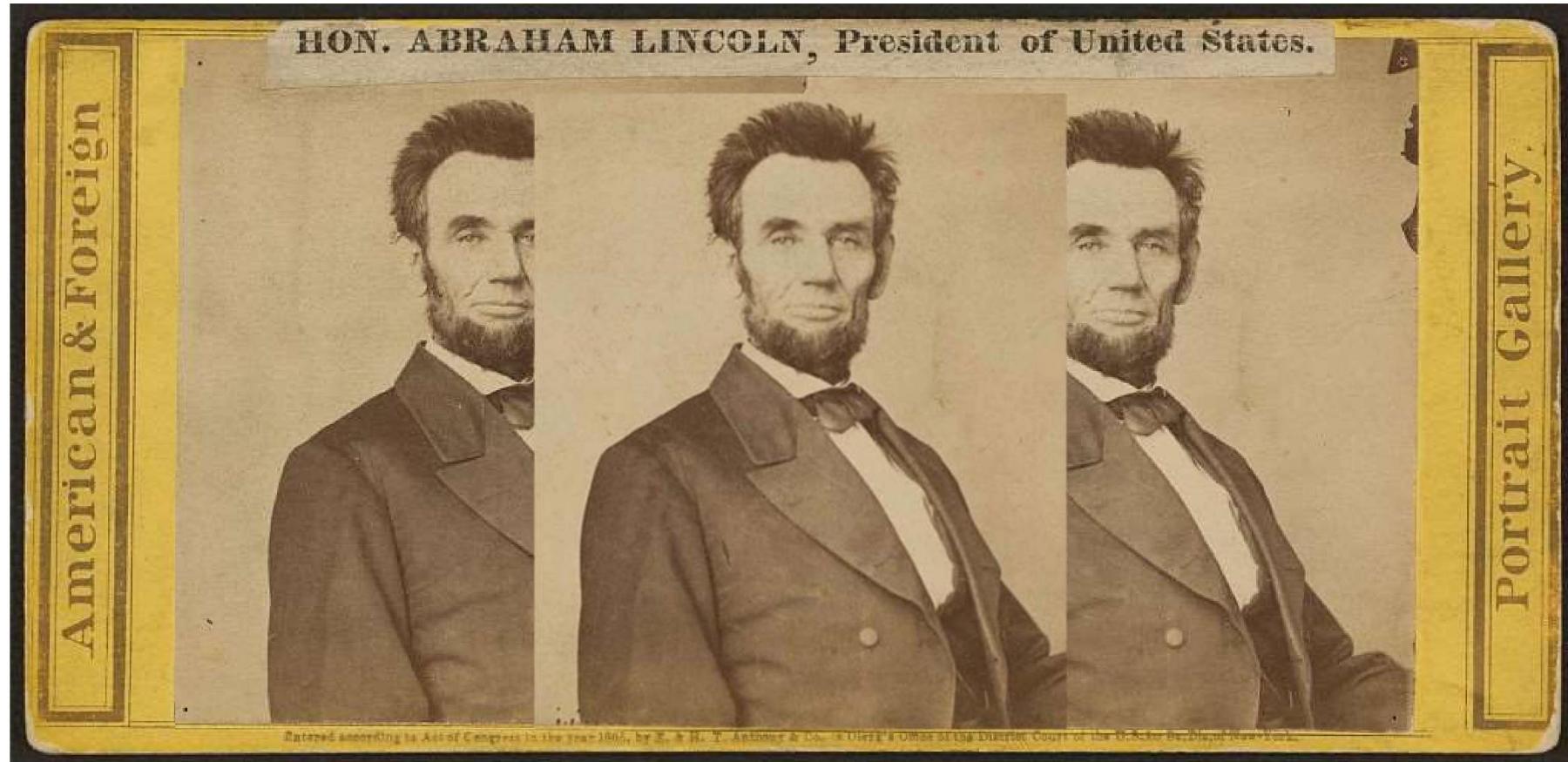


Charles Wheatstone., 1841. Stereoscope.

Walker, Lewis E., 1865. Hon. Abraham Lincoln, President of the United States. Library of Congi



Stereoscopic Displays



Charles Wheatstone., 1841. Stereoscope.

Walker, Lewis E., 1865. Hon. Abraham Lincoln, President of the United States. Library of Congi



A Brief History of Virtual Reality

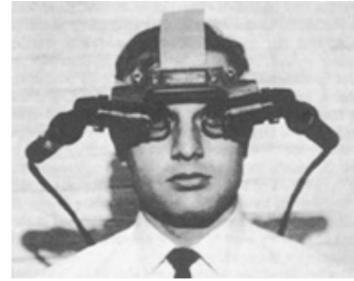
Stereoscopes

Wheatstone, Brewster, ...



VR & AR

Ivan Sutherland



Nintendo Virtual Boy



VR explosion

Oculus, Sony, HTC, MS, ...



???

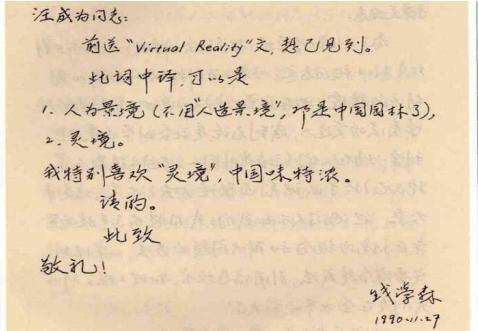
1838

1968

1995

2012-2022

People's scientist **Qian Xuesen** once served
in 1990 named
"virtual reality technology"
as "**Ling Jing**" ("spiritual realm") .

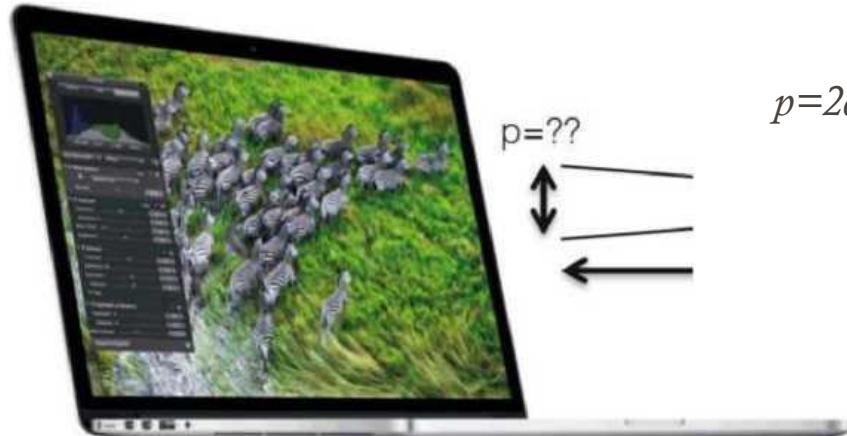




Recall Human Visual System (HVS)



- visual acuity: 20/20 is ~1 arc min
- field of view: -190° monocular, -120° binocular, -135° vertical
- temporal resolution: ~60 Hz (depends on contrast, luminance)
- dynamic range: instantaneous 6.5 f-stops, adapt to 46.5 f-stops
- color: everything in the CIE xy diagram; distances are linear in CIE Lab
- depth cues in 3D displays: vergence, focus, conflicts, (dis)comfort
- accommodation range: ~8cm to 8, degrades with age



$$p=2d \tan(\theta/2)$$

Steven Jobs said 300dpi
(286dpi in math)

tablet, 12" away, resolvable pixel:

$$p=2*12''*\tan(1 \text{ arc min } /2)=0.0035''$$



Where We Are Now





Naive Magnifier-type VR Displays

Oculus Rift



Sony Morpheus



DuroVis Dive



VrAse



3D Matters



Zeiss Cinemizer



Avegant Glyph



Hasbro My3D

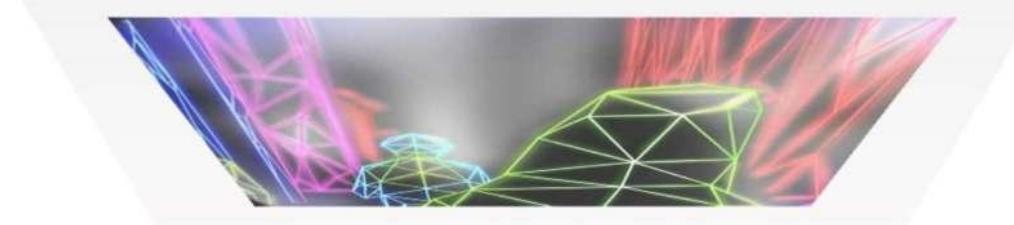


Altergaze

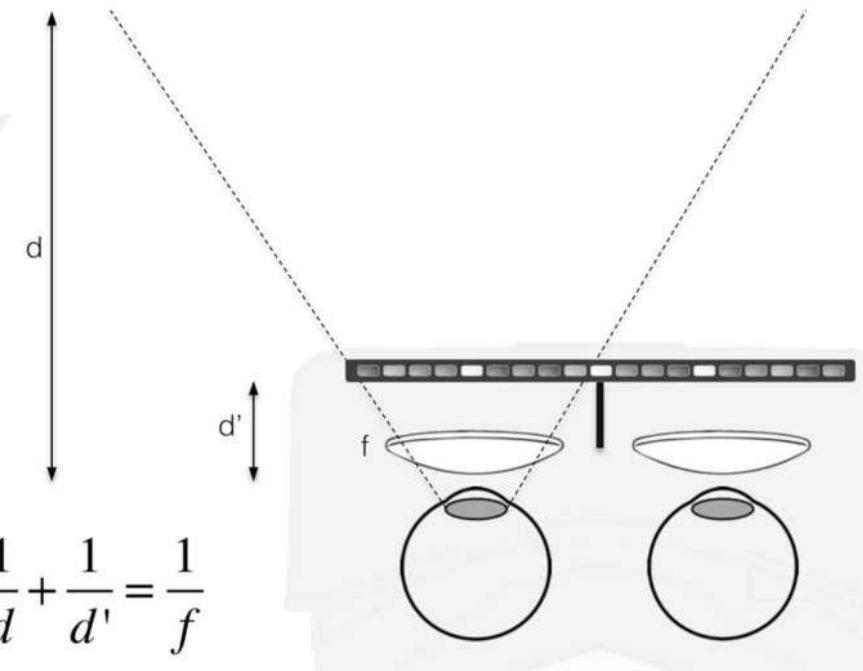


Naive Magnifier-type VR Displays

Virtual Image



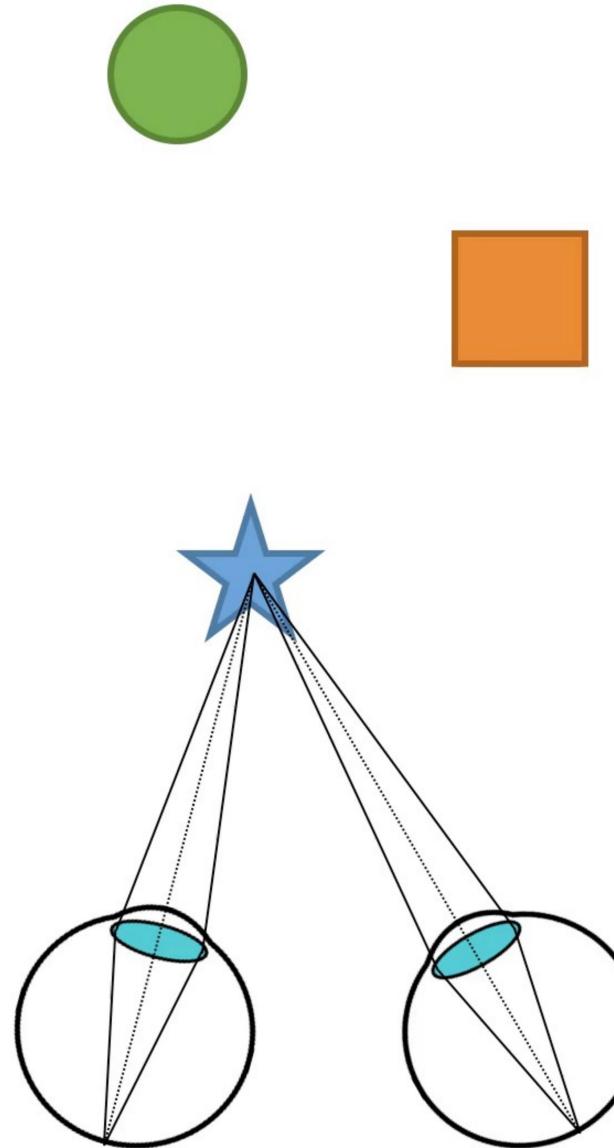
- Fixed focal plane
- No focus cues
- Cannot drive accommodation with rendering!





Accommodation – Vergence Conflict

Real World: **Vergence** &
Accommodation Match!





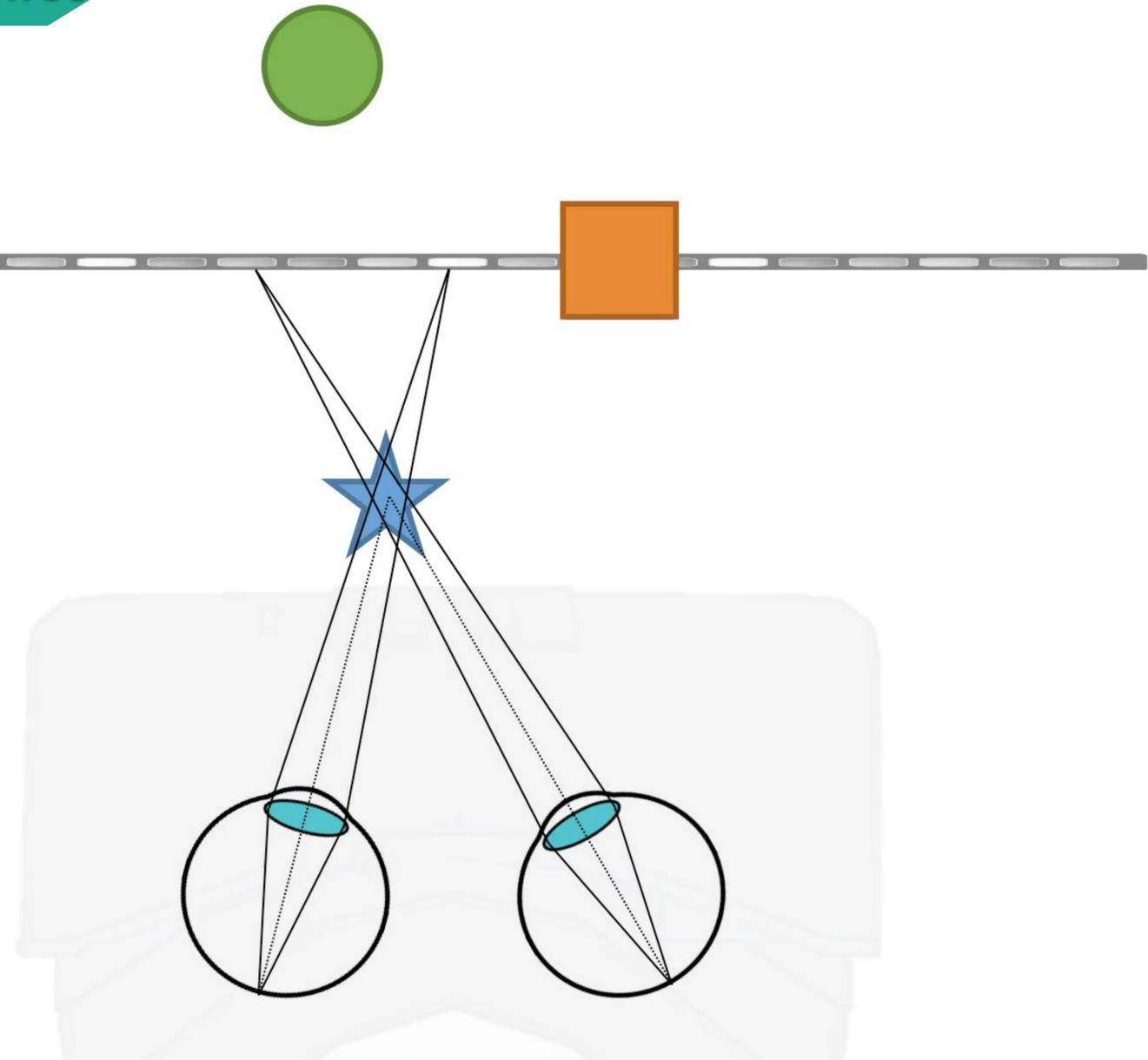
Accommodation – Vergence Conflict

Current VR Displays: Vergence &

Accommodation **Mismatch**

Visual discomfort

- visual fatigue
- nausea
- diplopic vision
- eyestrain
- compromised quality
- pathologies in
- developing visual system





aug·men·ted re·al·i·ty AR

an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, and olfactory.



Images borrowed from public domain



Microsoft Hololens



Meta 2



Magic Leap One

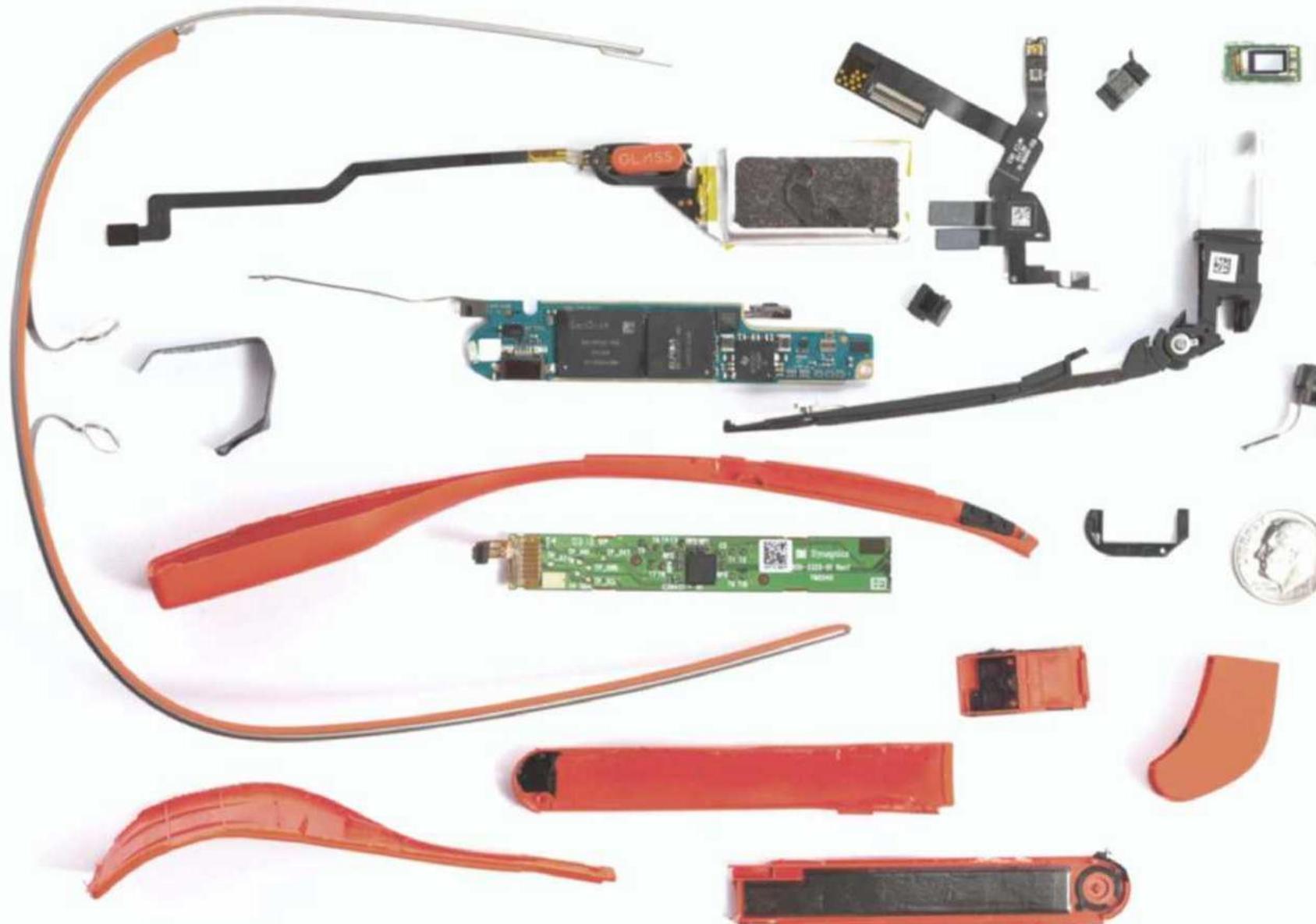
See-through AR Displays



Images borrowed from public domain

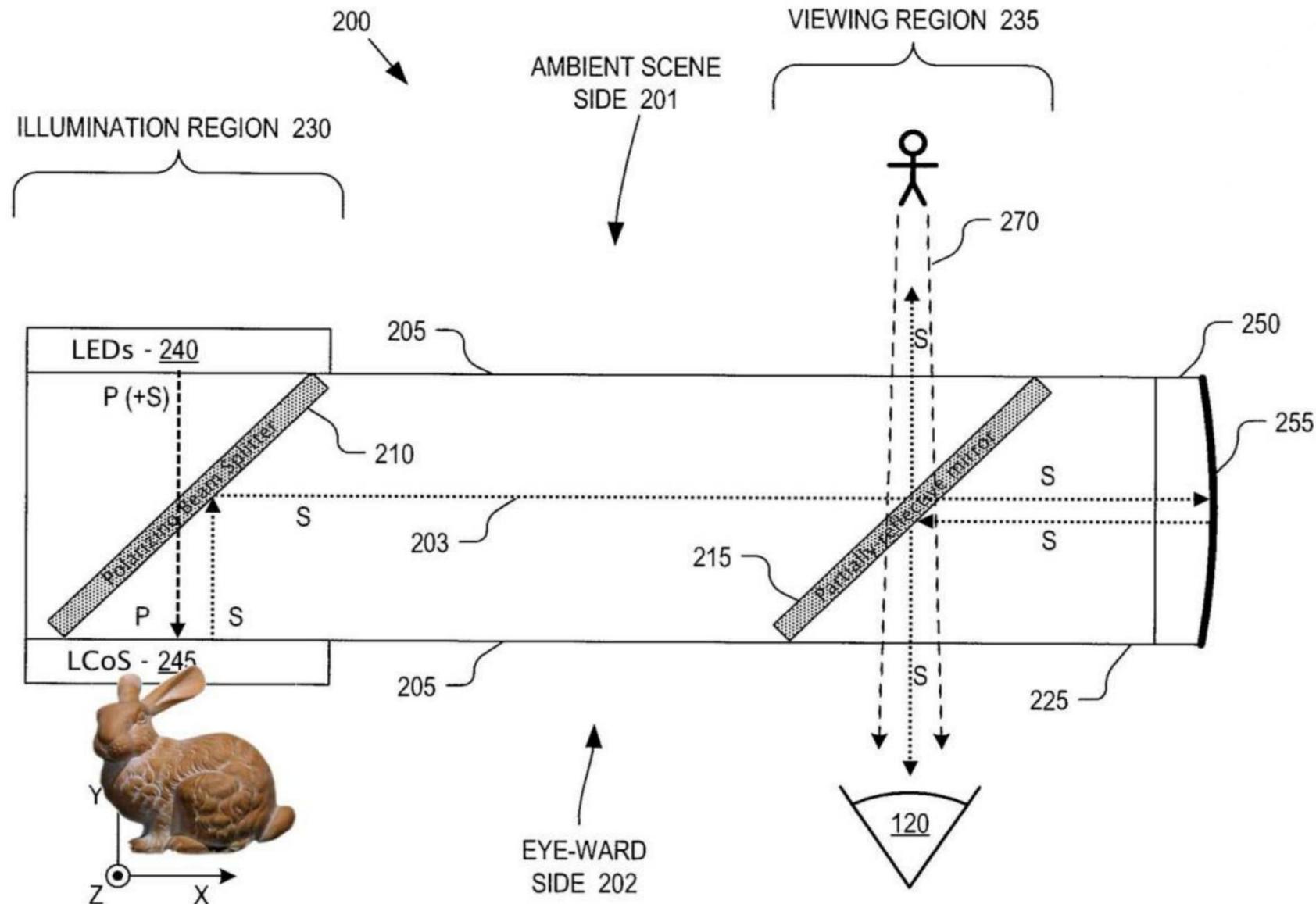


Where We Are Now

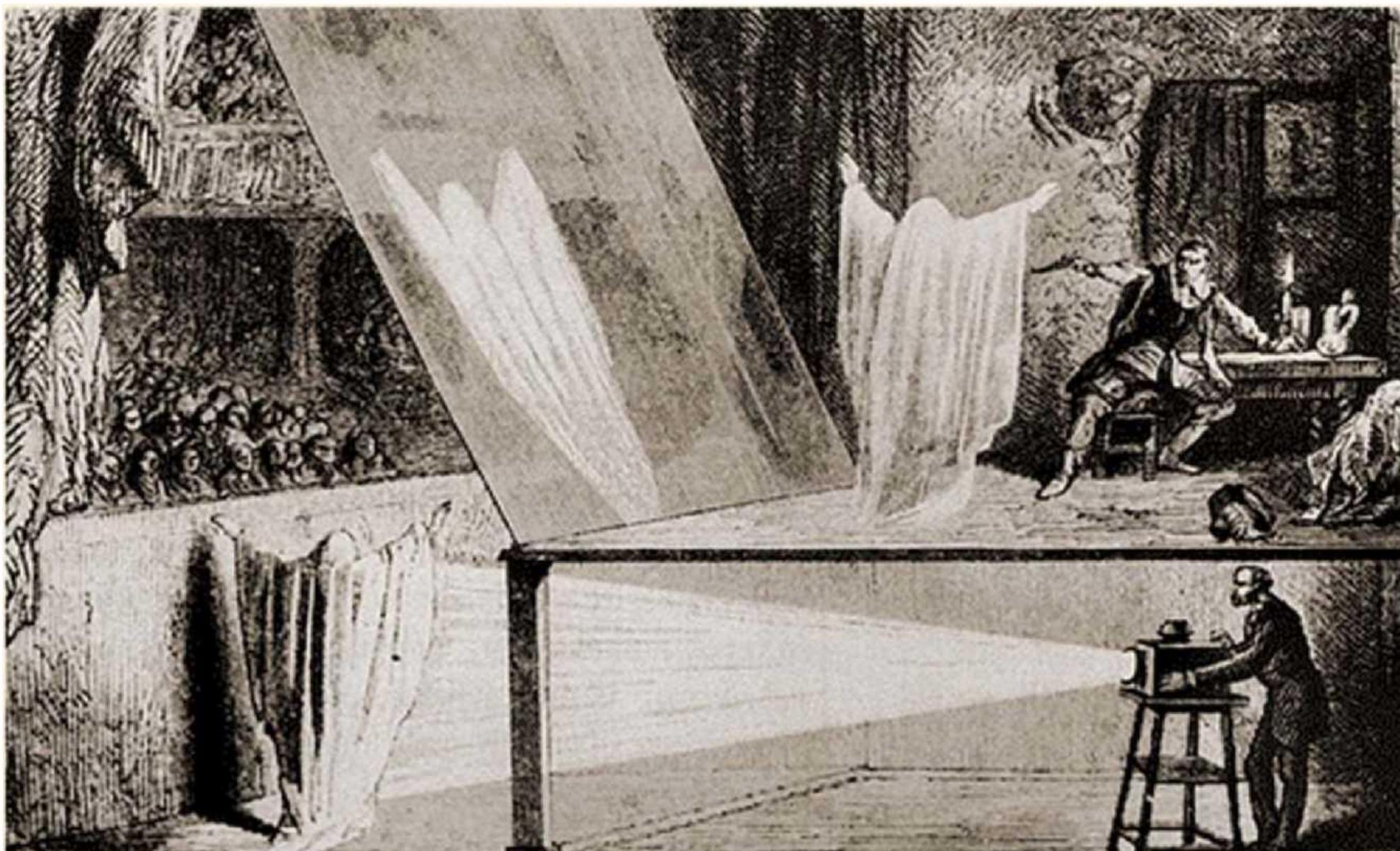




Google Glass



See-through AR Displays - Pepper's Ghost 1862





香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

See-through AR Displays—Waveguide



Microsoft HoloLens



- diffraction grating (SRG)
- small FOV ($30^\circ \times 17^\circ$), but good image quality

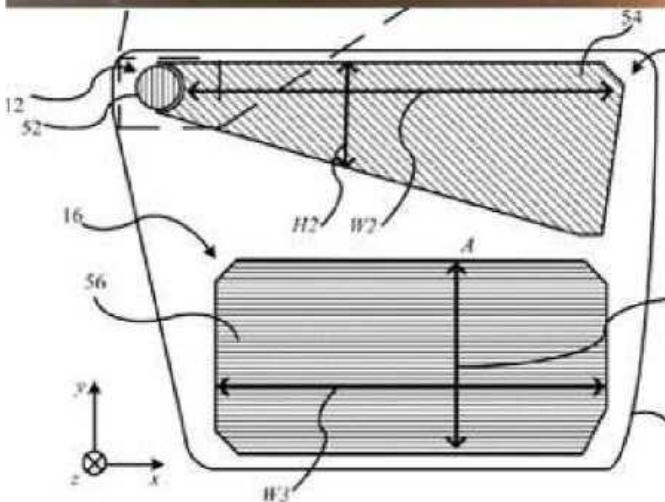
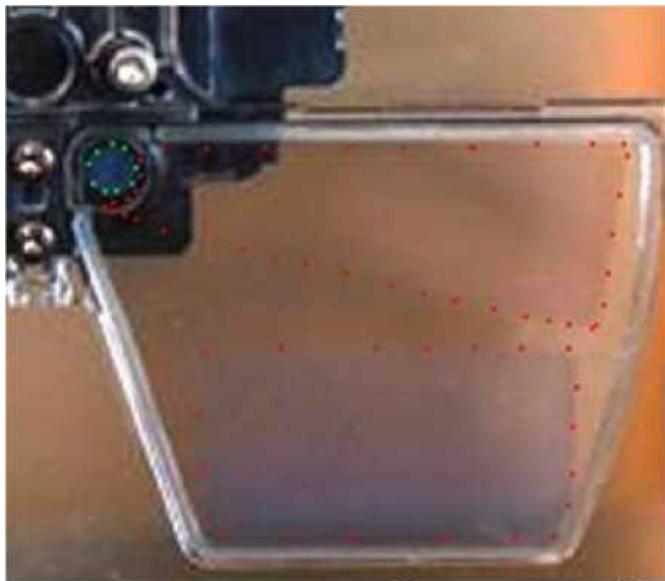


Fig. 3B



(19) A1
 (20) Pub. No.: US 20160221568A1
 (40) Pub. Date: Aug. 11, 2016

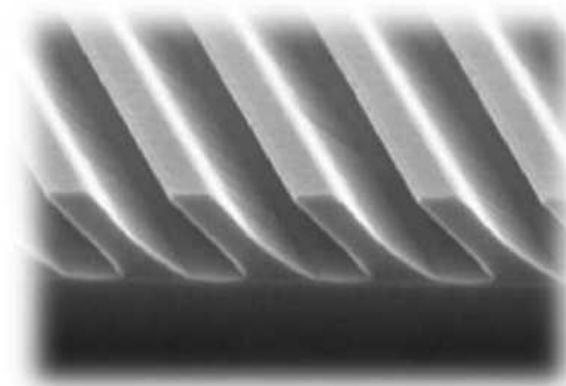
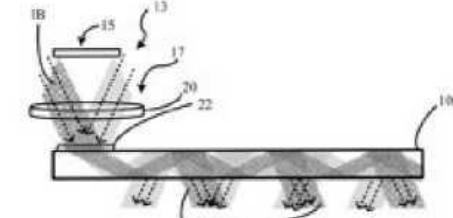
(54) **WAVEGUIDE**
 (73) Applicant: Microsoft Technology Licensing, LLC,
 Redmond, WA (US)
 (75) Inventor: Paul Savitski, (Europe (EU); Paul
 Kostom, (Europe (EU))
 (21) Appl. No.: 14/617,697
 (22) Filing Date: Feb. 9, 2015

Publication Classification

(31) Int. Cl.
 G02B 27/36 (2006.01)
 G02B 5/18 (2006.01)
 F21F 8/00 (2006.01)

(57) **U.S. CL.** CPC: G02B 27/37 (2013.01); G02B 6/00 (2013.01); G02B 5/18 (2013.01); G02B 205/17 (2013.01); G02B 205/17 (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 there by the waveguide by reflection at the front and rear surfaces. A second 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 segment. 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 segment different from the first segment. The second portion is offset from the second portion by a distance which is greater than the difference between the second segment and the first segment.



Images borrowed from public domain



- diffraction grating (SRG)
- small FOV ($30^\circ \times 17^\circ$), but good image quality

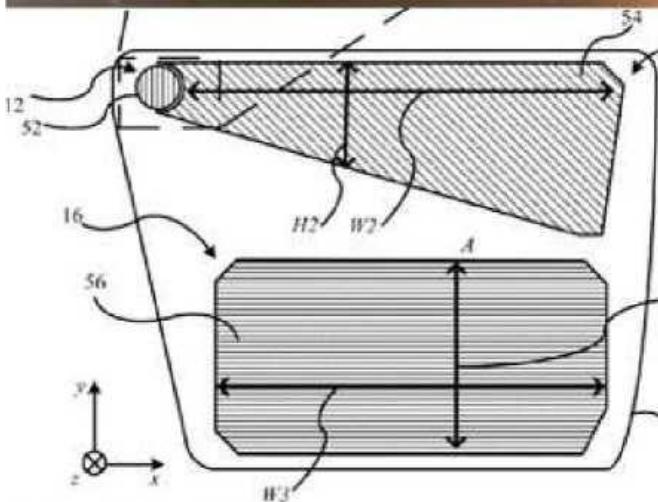
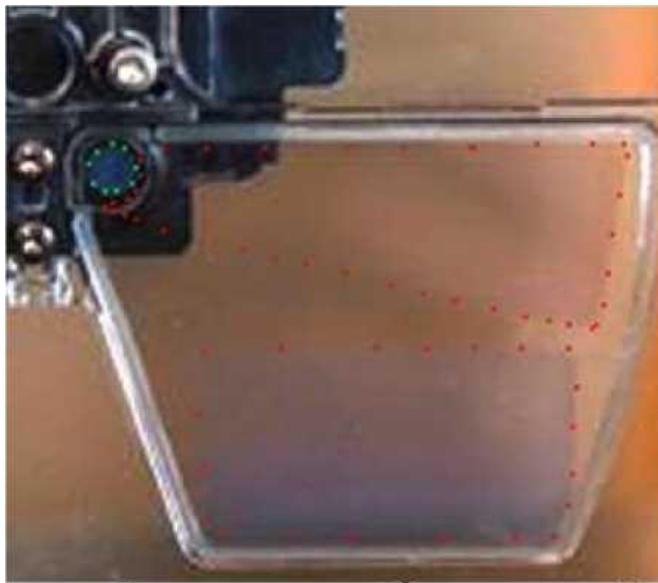


Fig. 3B



(19) A1
 (20) Pub. No.: US 20160221568A1
 (40) Pub. Date: Aug. 11, 2016

(54) **WAVEGUIDE**

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

(75) Inventor: Paul Savitski, Espoo (FI); Paul Kosminen, Espoo (FI)

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

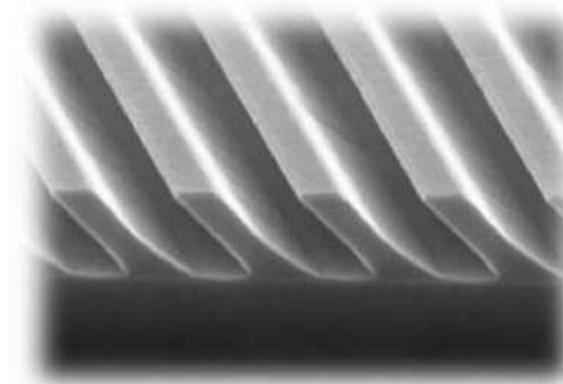
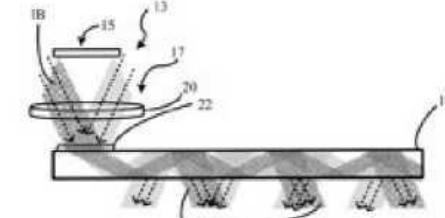
(22) Filing Date: Feb. 9, 2015

Publication Classification

(31) Int. Cl.: G02B 27/36 (2006.01); G02B 5/18 (2006.01); F21F 8/00 (2006.01)

(57) **U.S. CL.** CPC: G02B 27/027 (2013.01); G02B 6/0007 (2013.01); G02B 5/3642 (2006.01); G02B 2627/017 (2013.01); G02B 2627/079 (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 there by the waveguide by reflection at the front and rear surfaces. A second 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 segment. 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 segment different from the first segment. The wavelength difference between the second portion and the first portion may be used to provide a distance which is directly related to the difference between the second segment and the first segment.

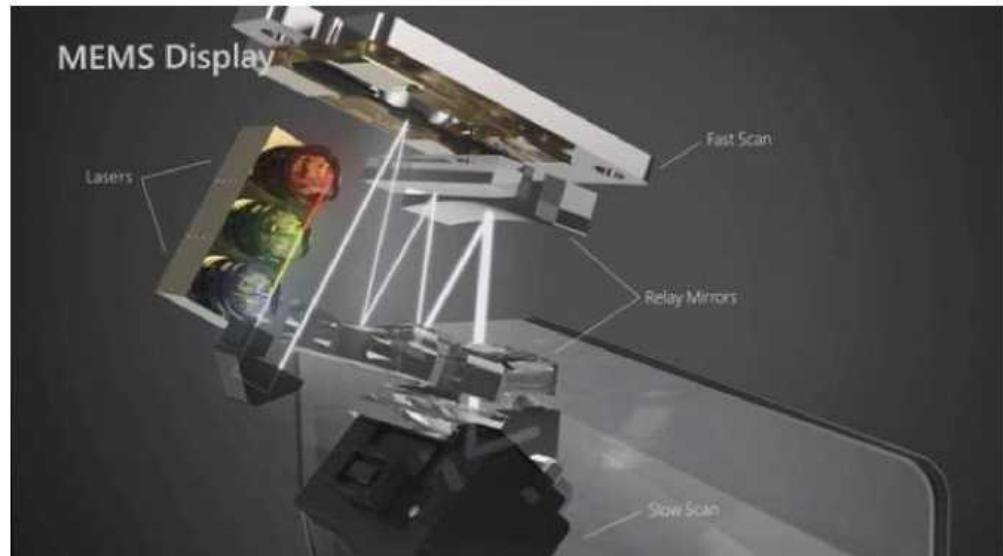


Images borrowed from public domain



See-through AR Displays—Waveguide

- laser-scanning waveguide display
- claimed 2K resolution per eye ($2,560 \times 1,440$), probably via “interlaced” scanning
- field of view: 52° diagonally (3:2 aspect, 47 pixels per visual degree)
- far from sufficient...



Images borrowed from public domain



香港中文大學(深圳)
The Chinese University of Hong Kong, Shenzhen

What's Next



Holographic Displays (Holograms)

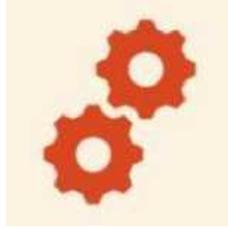




香港中文大學(深圳)

The Chinese University of Hong Kong, Shenzhen

Computational Displays:Bridging the Disciplines



COMPUTER
SCIENCE /
OPTIMIZATION



ELECTRONICS /
DEVICES /
SENSORS



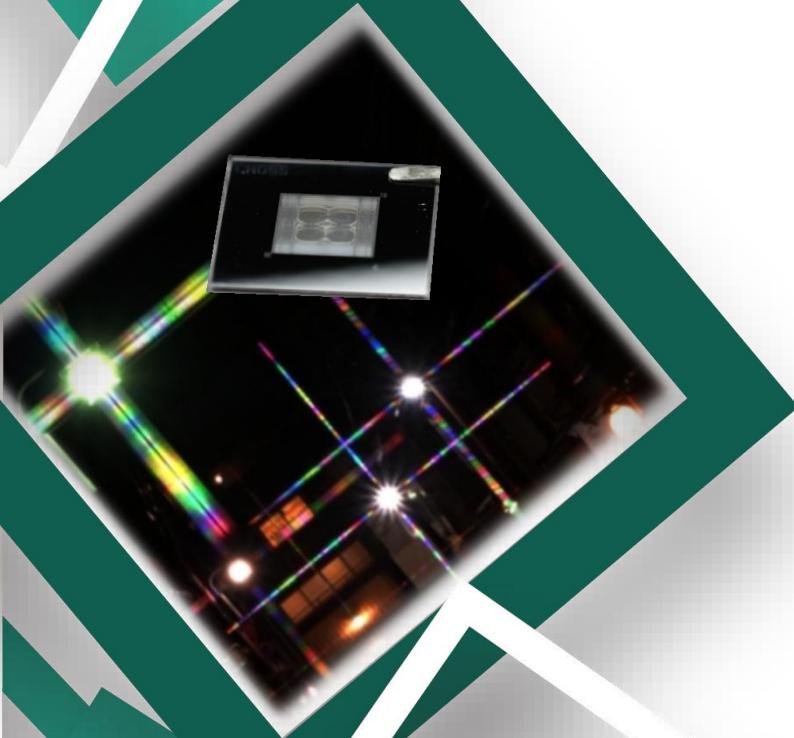
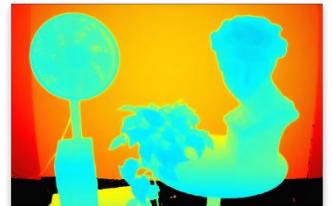
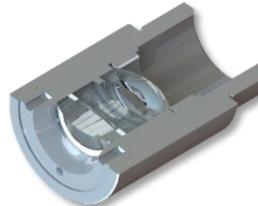
OPTICS /
PHOTONICS /
HUMAN VISION





Today's Topic

- What's Display
- Projectors Are Alternative
- Would Metaverse Really Come
- Virtual Reality
- Augmented Reality
- What's Next



Thank You!



Qilin Sun (孙启霖)

香港中文大学（深圳）
点昀技术（Point Spread Technology）

