Review of

Immersive Display Technology

30 September 2020

MissionRock DIGITAL

Pete Ludé

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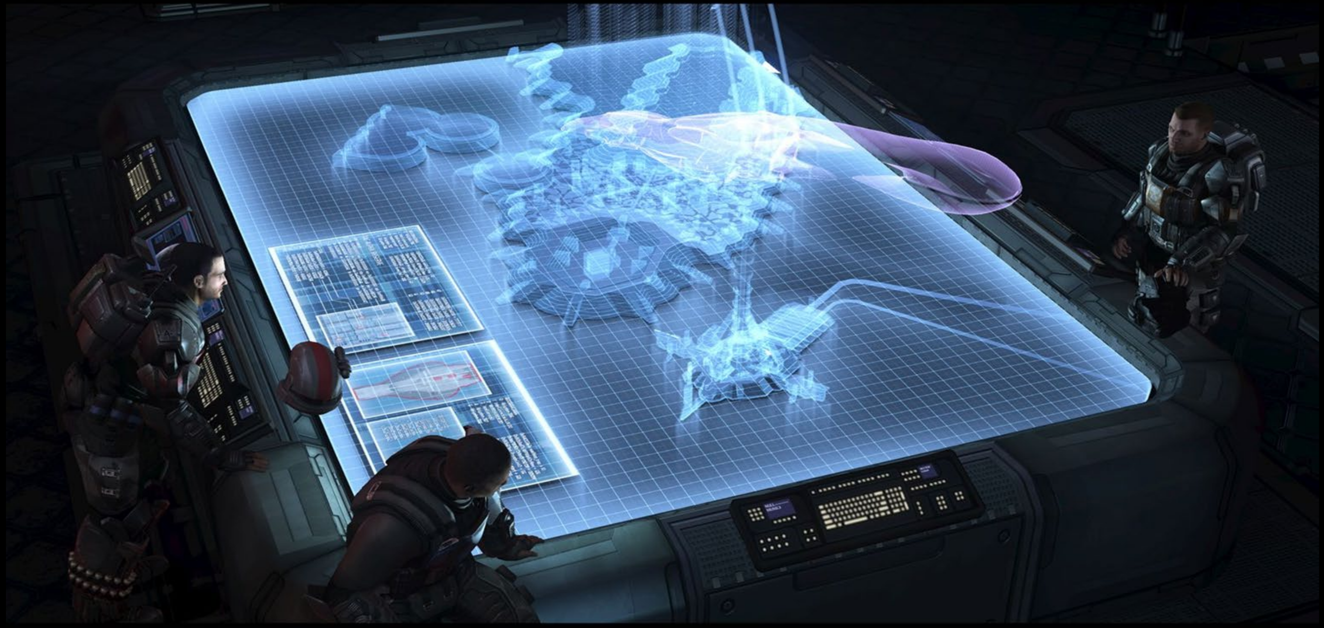
Topics

- A Taxonomy of Display types
- Review of current products
- Consideration of ***Ray Density*** as differentiation between Lenticular and Light Field
- Conclusions

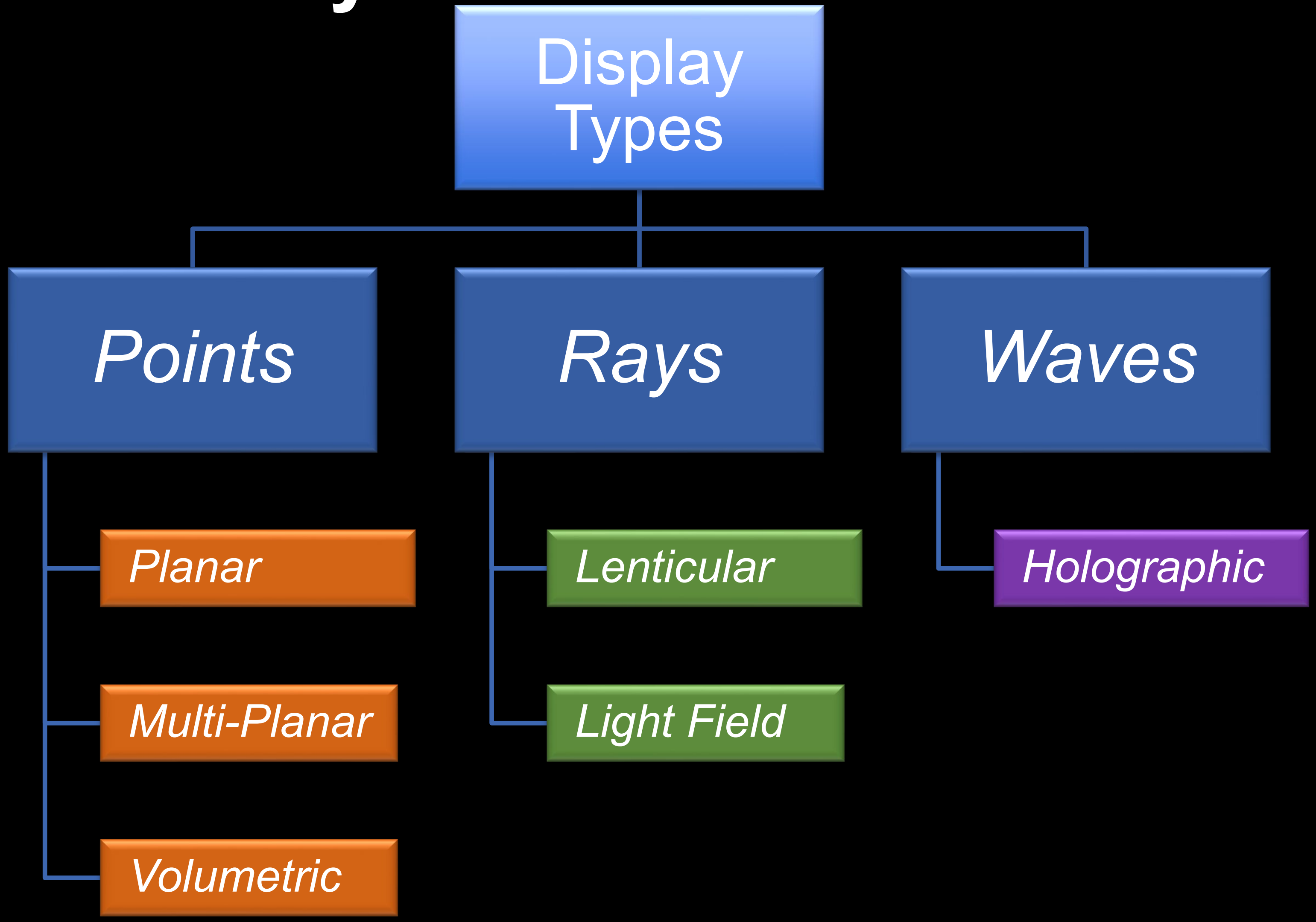


A Taxonomy of Display types

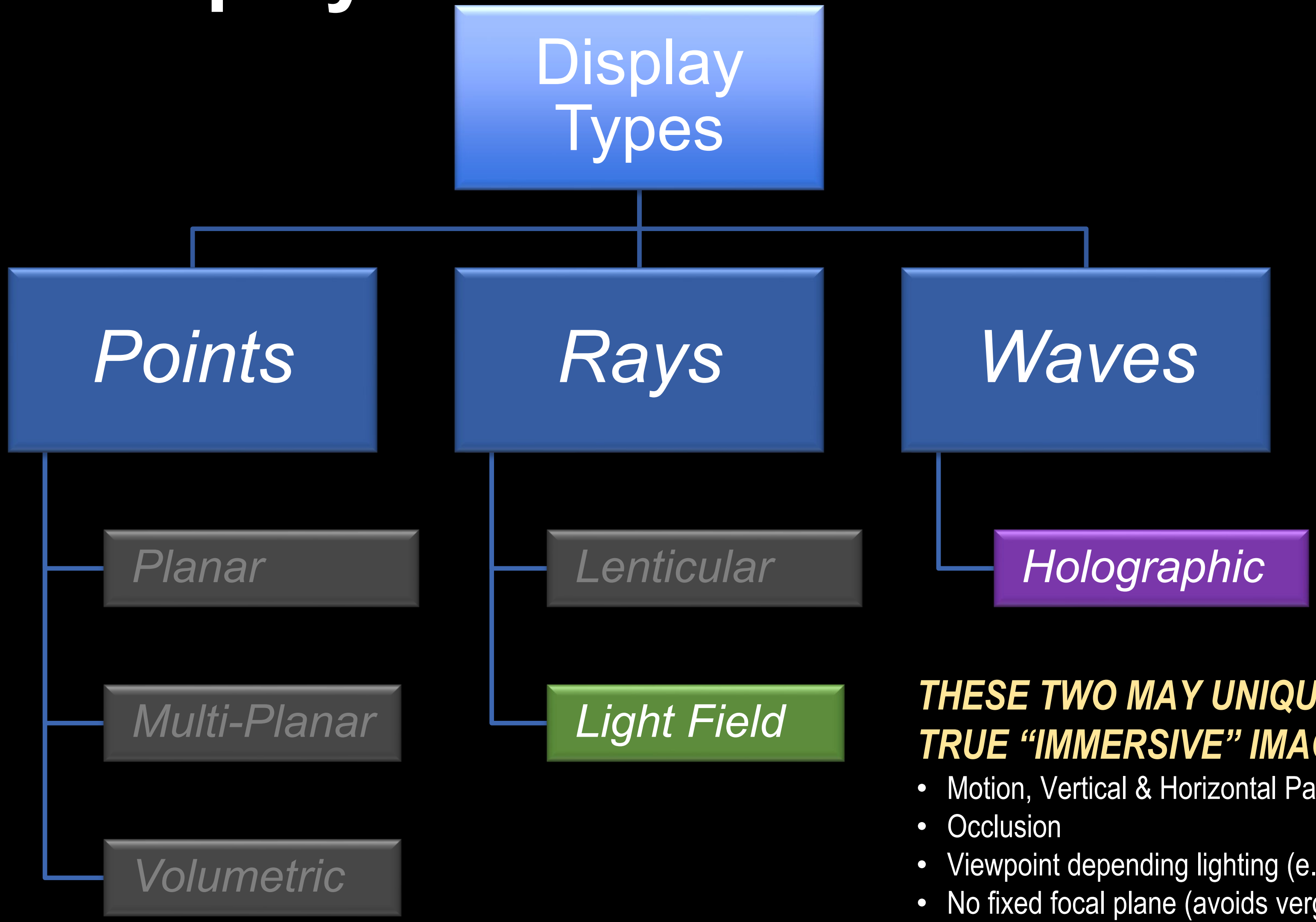
All imaging display might be considering to be in one of these three categories…

Points	Diverge light from a point, rather than converge light from a surface Familiar as raster displays, and multi-planar displays But also applicable for light sources in 3D volumetric space
Rays	Includes lenticular, parallax barrier and coded aperture displays. The display forms real points from intersecting rays in space.
Waves	Include holographic and nanophonic phased arrays Utilizes wavefront interference patterns, often from coherent light sources

Display Taxonomy



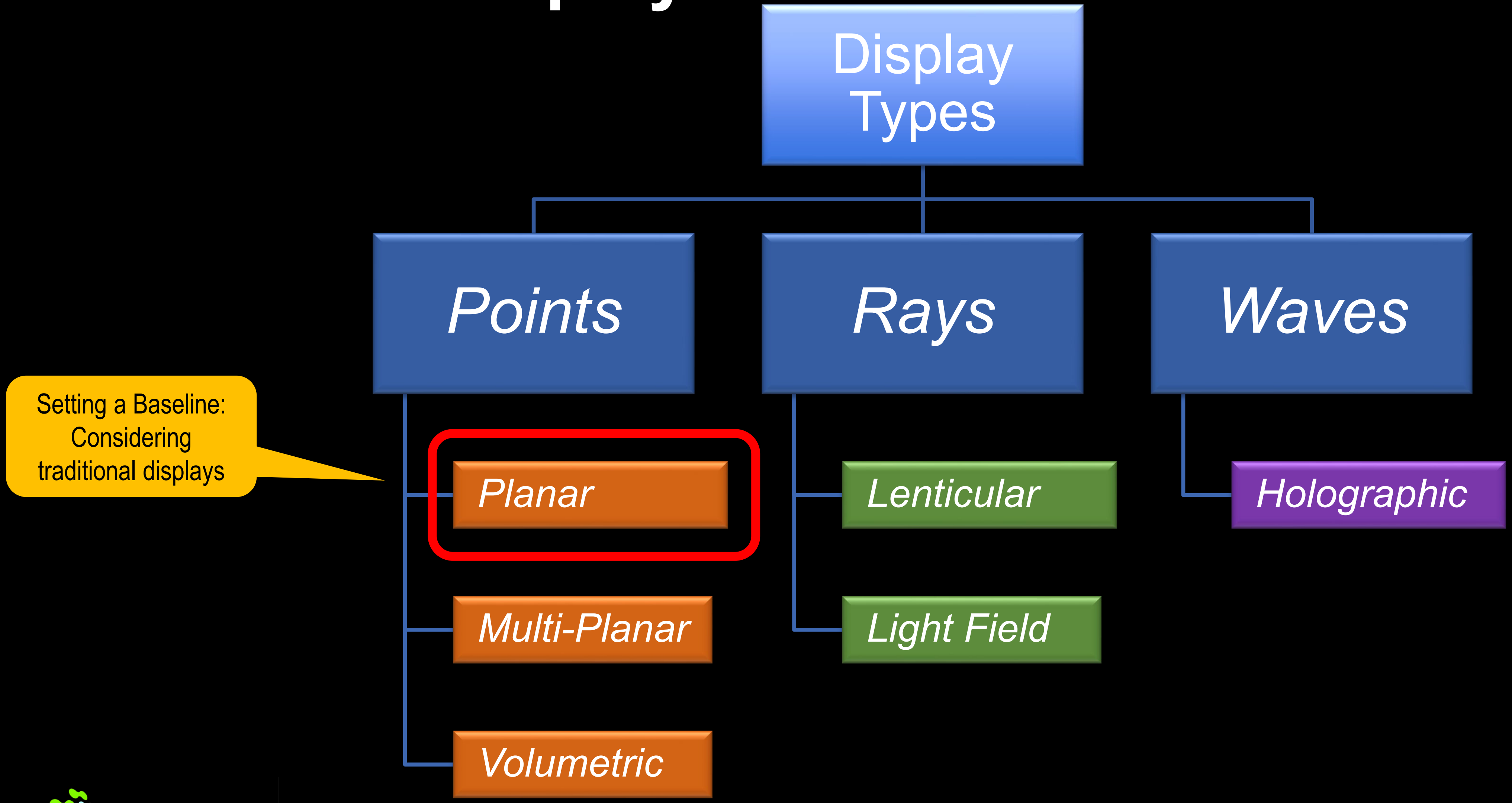
Immersive Displays



THESE TWO MAY UNIQULY PROVIDE TRUE “IMMERSIVE” IMAGES

- Motion, Vertical & Horizontal Parallax
- Occlusion
- Viewpoint depending lighting (e.g. specular reflections)
- No fixed focal plane (avoids vergance-accomodation error)

Immersive Displays



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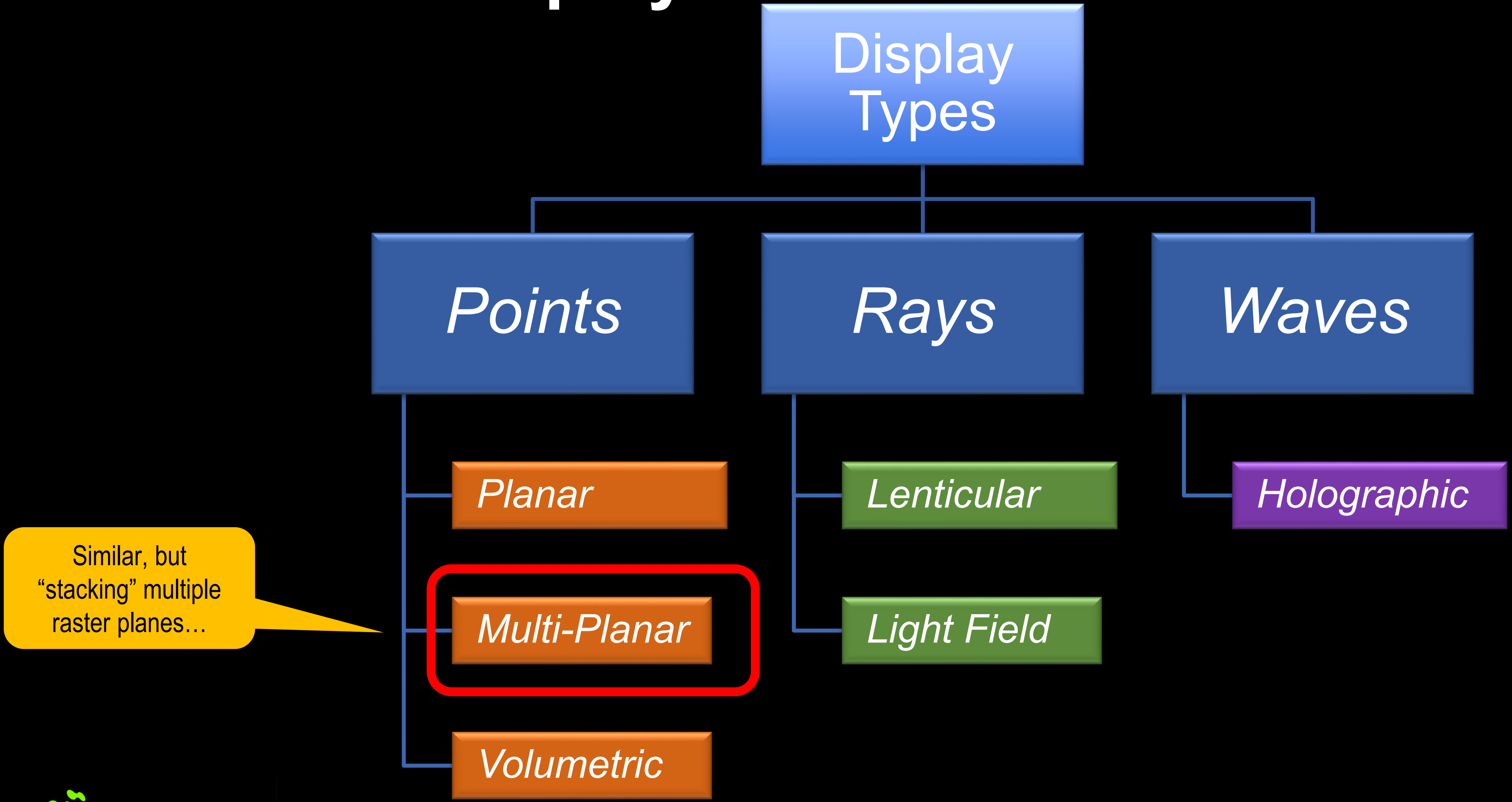
Typical 2D Displays

Planar

Points (pixels) in 2D Plane

Immersive Displays



Magic Leap

Multi-Planar

- Multiplanar AR HMD
- Dual plane per eye
- LCOS SLM
- Waveguide optics

Approaches to variable focal point HMD's

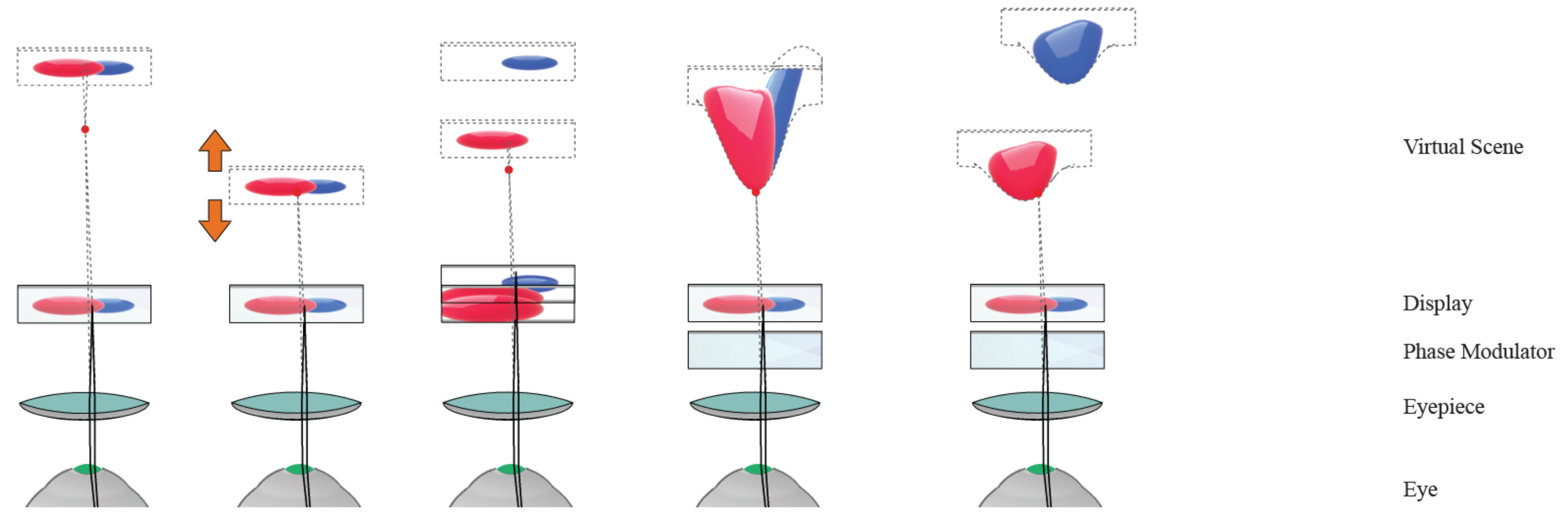


Fig. 2. Focal surface displays generalize the concept of manipulating the optical focus of each pixel on an HMD. Configurations (d,e) augment a fixed-focus HMD (a) with a programmable phase modulator placed between the eyepiece and display. (b) Varifocal HMDs use a globally addressed tunable lens. (c) Multifocal displays may use a high-speed tunable lens and display to create multiple focal planes. (f) In contrast, certain light field HMD concepts fall at the other end of this spectrum, using a finely structured phase modulator (a microlens array) placed near the display. (d) In this paper, we consider designs existing between these extremes in which a phase modulator locally adjusts the focus to follow the virtual geometry, generalizing varifocal and multifocal concepts. (e) Similar to multifocal displays, multiple focal surfaces can be synthesized with high-speed phase modulators and displays.

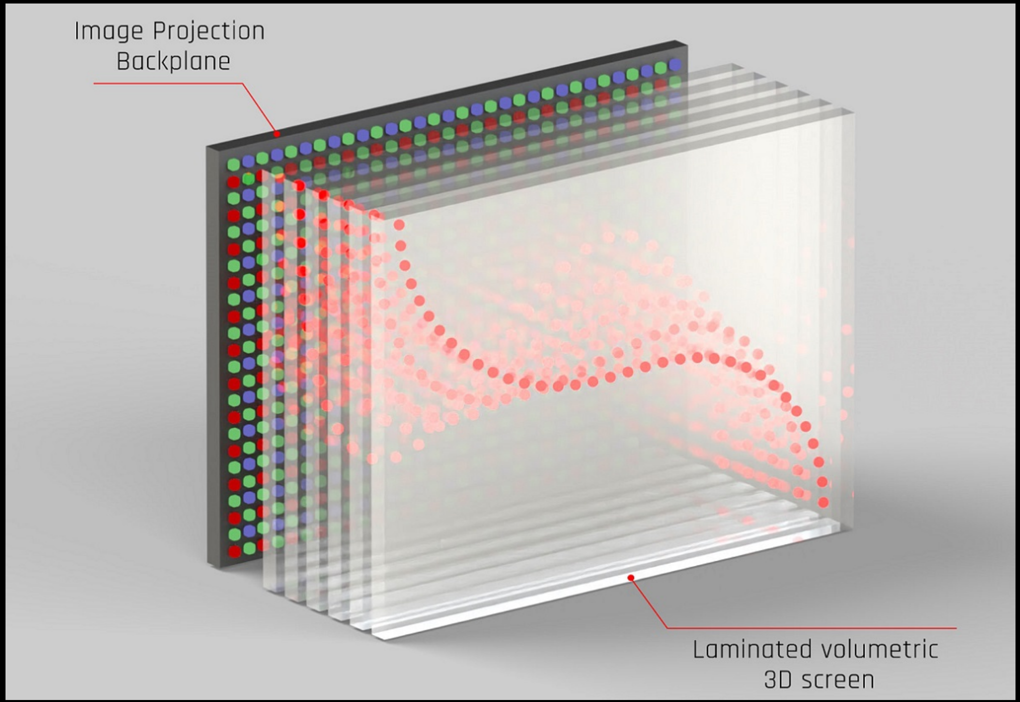
Focal Surface Displays, N Matsuda, A Fix, D Lanman, Oculus Research; ACM Transaction on Graphics, Vol. 36, No. 4, Article 86, July 2017

LightSpace Technology

Multi-Planar

LightSpace Technologies

- 3rd Gen Multi-planar 3D display
- Multiplane laminated volumetric switching screen
- Several approaches including
  - Optical diffuser elements (LCD)
  - Refractive index-matched polymer fill-in
  - MicroLED back plane
  - Collimating lens arrays



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Immersive Displays

- Display Types
  - *Points*
    - *Planar*
    - *Multi-Planar*
    - *Volumetric*
  - *Rays*
    - *Lenticular*
    - *Light Field*
  - *Waves*
    - *Holographic*

Moving pixels from a fixed plane to a 3D volume…

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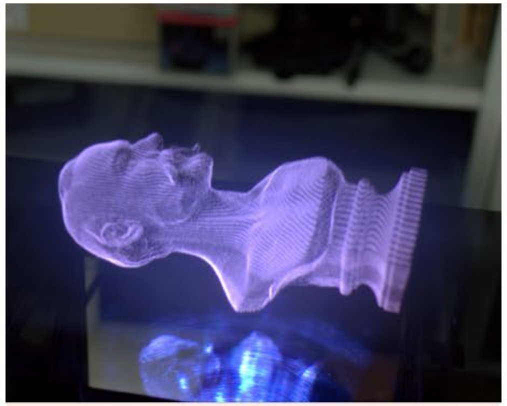
Types of Volumetric Displays

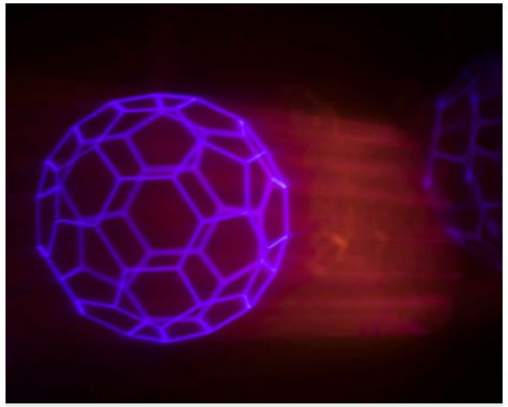


Voxon VX1 / Courtesy of Voxon Photonics

SWEPT-VOLUME DISPLAYS

Rotating emissive or reflective screens, including illuminated spinning paddles, spinning LEDs or translating projection surfaces

1948 Parker and Wallis
1958 Peritron
2002 Perspecta
2009 Spinning LED
2014 Voxon VX1



Excited Gas / Courtesy of Adam Fenster

STATIC-VOLUME DISPLAYS

Form images by upconversion in non-linear gases or solids or by projecting onto a number of diffusing planes.

1914 Luzy and Dupuis
1961 Fajan
1963 Zito
1996 Doped Glass
2003 Depthcube
2003 Texas DMD
2017 Excited Gas

OTD* / Courtesy of Daniel Smalley

FREE-SPACE DISPLAYS

Operate in air, with no barrier between user and image; can include free-particle, trapped-particle and plasma emission displays

2004 Holodust
2005 Fog Display
2006 Plasma Emission
2016 Holovect
2018 Optical Trap Display (OTD)

**OTD image was created with a long exposure.*

Volumetric Displays, D Smalley, T-C Poon, H Gao, S Kvavle, K Qaderi, OSA Optics & Photonics News, June 2018

Voxon Photonics

Volumetric

- VX-1 Volumetric display
  - 200 mil voxels (1000 x 1000 x 200)
  - High-speed reciprocating screen
    - 500 Mvox/sec – 30 “volumes per sec)
  - Geometry rasterizer
  - 650 lumens

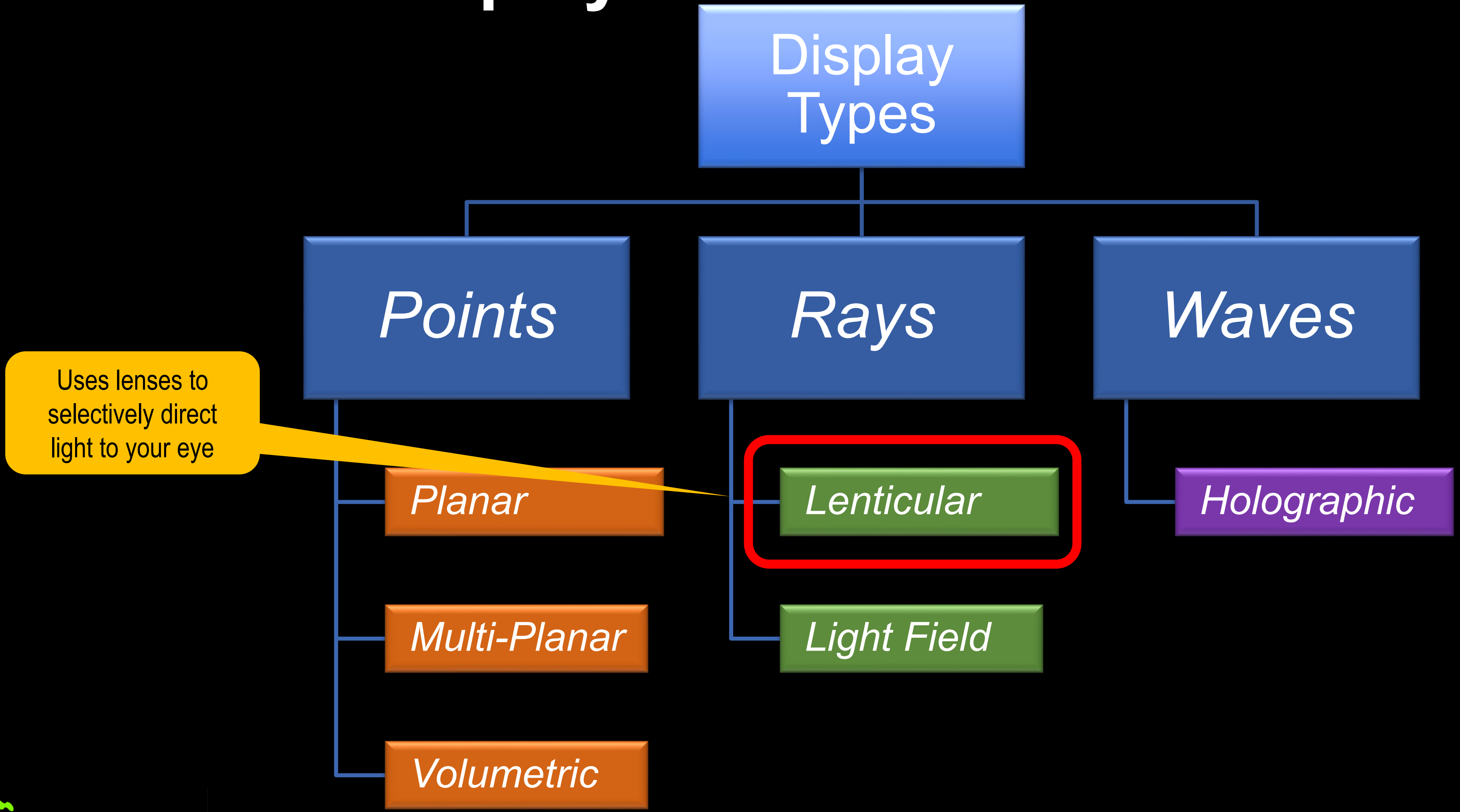
Voxon Photonics

Volumetric

- VX-1 Volumetric display
  - 200 mil voxels (1000 x 1000 x 200)
  - High-speed reciprocating screen
    - 500 Mvox/sec – 30 “volumes per sec)
  - Geometry rasterizer
  - 650 lumens
  - Available now – about $10,000

Actual product

Immersive Displays



Leia

Lenticular

Leia Inc.

- LCD display with
- “Diffractive Lightfield Backlight”
- 4 x 4-views
- Latest implementation in 10.8-inch tablet

Looking Glass Factory

Lenticular

- 32-inch 8K lenticular display
- 45-zone horizontal parallax
- 50° FoV
- Includes RTX-2080Ti GPU
- Now shipping

Dimenco

Lenticular

- 32-inch 8K lenticular panel
- Includes eye-tracking (single-viewer)
- UltraLeap hand-tracking
- Includes RTX-2080Ti GPU
- Devkit now shipping
- Consumer product “early 2021”

Immersive Displays

- Display Types
  - *Points*
    - *Planar*
    - *Multi-Planar*
    - *Volumetric*
  - *Rays*
    - *Lenticular*
    - *Light Field*
  - *Waves*
    - *Holographic*

Very high density of light rays, able to recreate the "Plenoptic" function

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What is a Light Field Display?

- **Before we talk about various products – a fundamental question:**
  - If Light Field images are created by a bundle of light rays…
  - And simple lenticular display – like auto-stereoscopic -- also use rays…
  - *At what point does a "sparse set of rays" become a "light field"?*

- In other words:
  - *What does the Human Vision System require in order to make a scene indistinguishable from Reality?*

- Maybe we don't yet have a good answer.
  - *But the solution may involve ray density* (per *subtended angle* or per *area*)

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Comparing Ray Density

Increasing Light Field fidelity

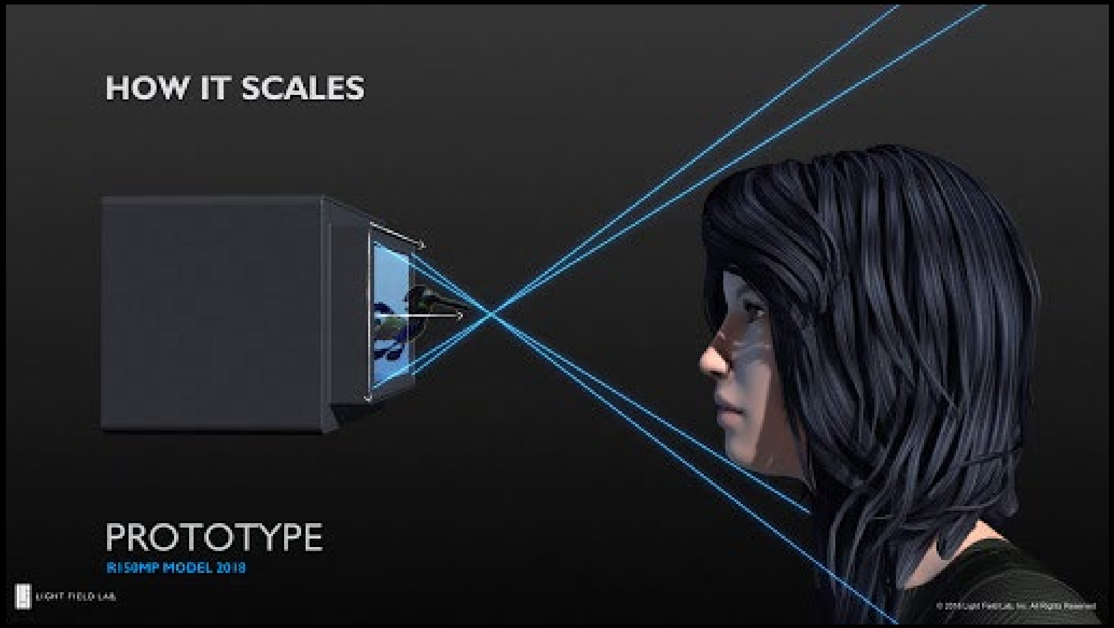
	Alioscopy 3DUHD 31.5” 8-zone AutoStereo	Looking Glass Factory 32” - 8K Display – 45 zone	Avalon Holographics 29” Light Field Display	Fovi3D DK2 Light Field Display
Display Size	70 x 40cm	69 x 38cm	63 x 36cm	9 x 9cm
Source pixels (rays)	8,294,000	33,177,600	230,000,000	81,000,000
Source pixel size (estimated)	182 µm	90 µm	31.5 µm	10 µm
Ray density (rays/ cm^2)	**3,036**	**12,521**	**100,932**	**1,000,173**

Light Field Display Examples

Light Field Labs

Light Field

- Developing wall-scale LF display
- $28m funding as of Aug 2019
- Planning large (cinema size) panels
- Beta systems within 2 years ?



Avalon Holographics

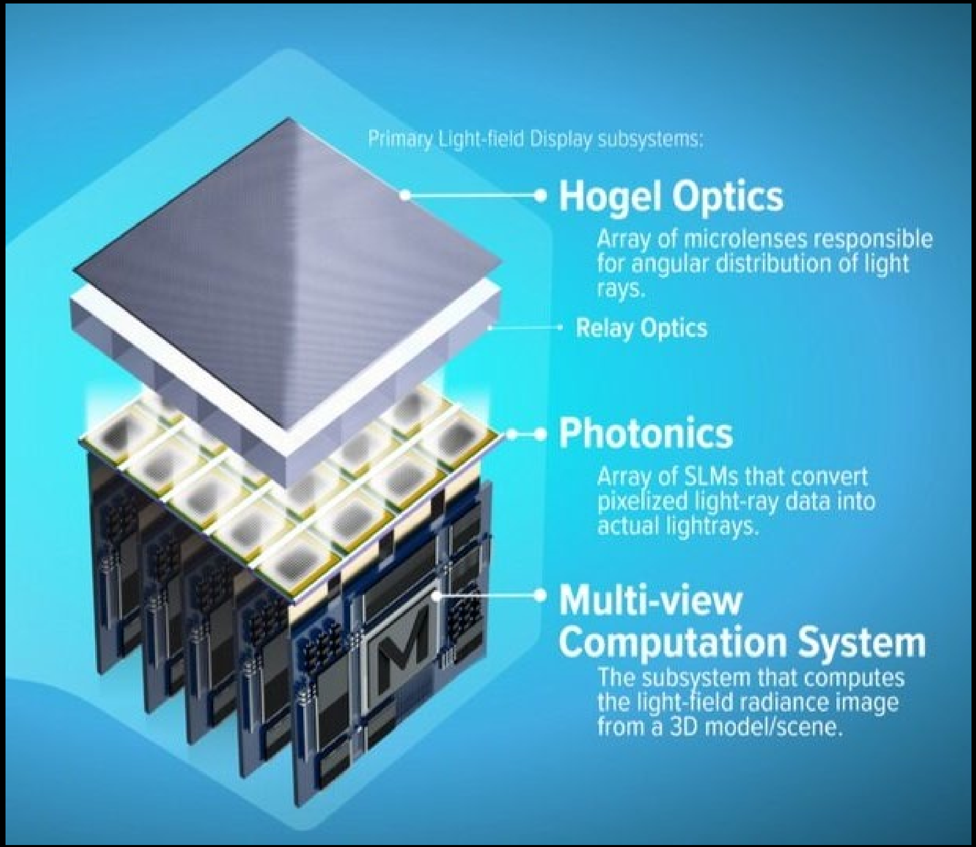
Light Field

- First Gen Product Released
  - 29-inch development system
  - Announced Aug 25
  - 230M+ viewable rays
  - Vertical & Horizontal Parallax
- Aimed at
  - Medical Imaging
  - Defense Industry
  - Industrial Design

Fovi3D

Light Field

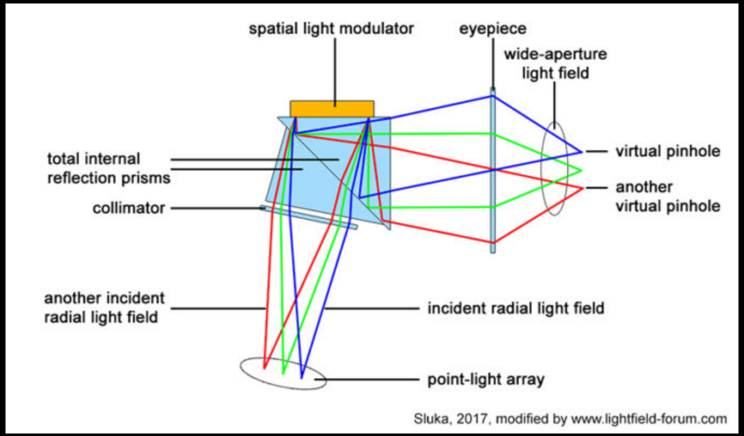
- DK2 Prototype full color LF display
- 9cm x 9cm (180 x 180 hogels)
- 60° viewing angle
- 8cm image depth



cReal

Light Field

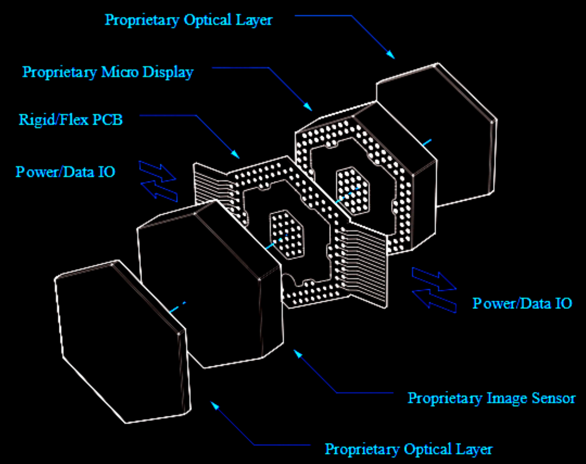
- Swiss startup - $7.4 million funding
- Spinoff from CERN
- Multiple pinhole mask
- Planning AR Headset LF in 2021

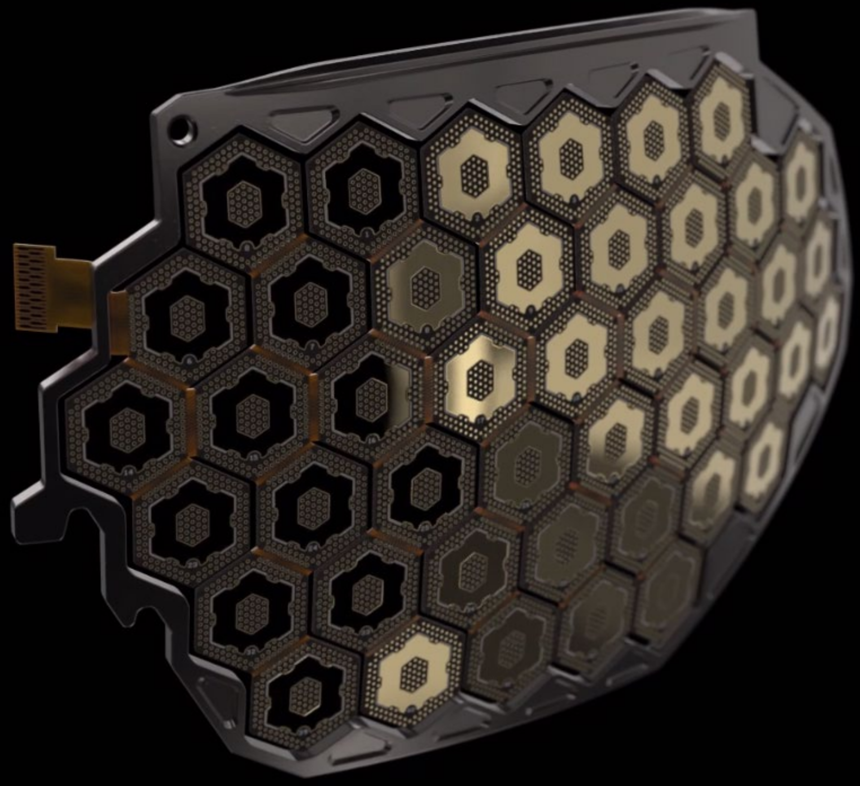


FYR

Light Field

- Early stage start-up
- Spun out of Lockheed Martin
- Working on Light field HMD
  - "Emulated Reality"
  - Small, tiled, dual-sided electro-optics

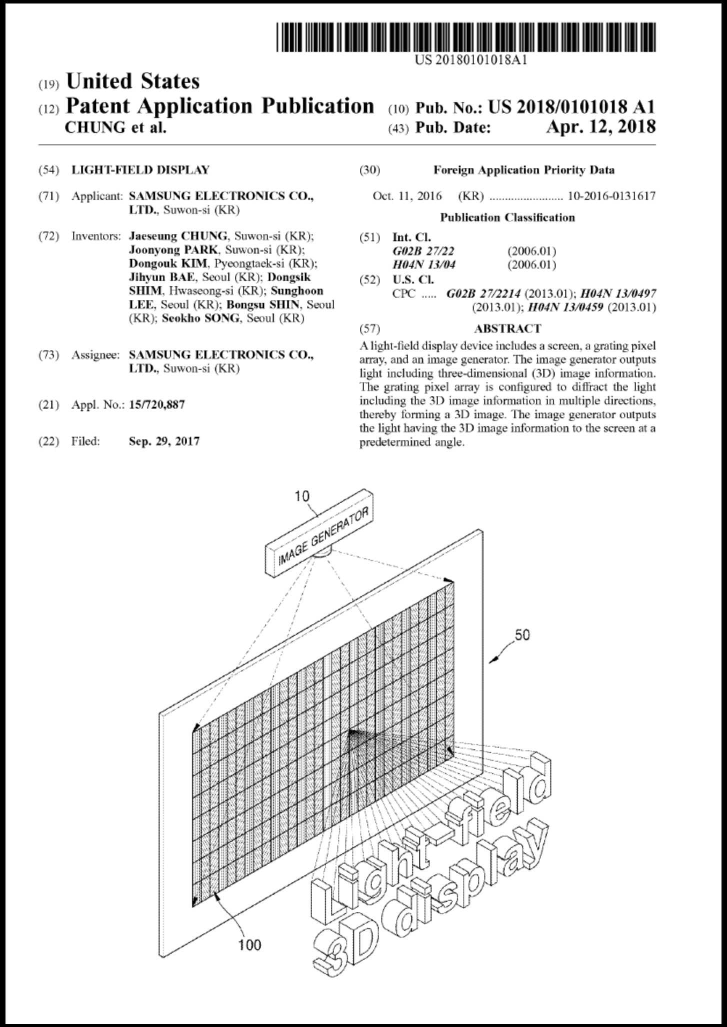




Samsung

Light Field

- Light field display patent
- Grating pixel array & Image Generator
- Cites automotive, mobile and wearable display applications



US 20180101018A1

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(12) **Patent Application Publication** (10) **Pub. No.: US 2018/0101018 A1**
CHUNG et al. (43) **Pub. Date: Apr. 12, 2018**

(54) **LIGHT-FIELD DISPLAY**

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(72) Inventors: **Jaeseung CHUNG**, Suwon-si (KR); **Joonyong PARK**, Suwon-si (KR); **Dongouk KIM**, Pyeongtaek-si (KR); **Jihyun BAE**, Seoul (KR); **Dongsik SHIM**, Hwaseong-si (KR); **Sunghoon LEE**, Seoul (KR); **Bongsu SHIN**, Seoul (KR); **Seokho SONG**, Seoul (KR)

(73) Assignee: **SAMSUNG ELECTRONICS CO., LTD.**, Suwon-si (KR)

(21) Appl. No.: **15/720,887**

(22) Filed: **Sep. 29, 2017**

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Publication Classification

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G02B 27/22 (2006.01)
H04N 13/04 (2006.01)

(52) **U.S. Cl.**
CPC *G02B 27/2214* (2013.01); *H04N 13/0497* (2013.01); *H04N 13/0459* (2013.01)

(57) **ABSTRACT**

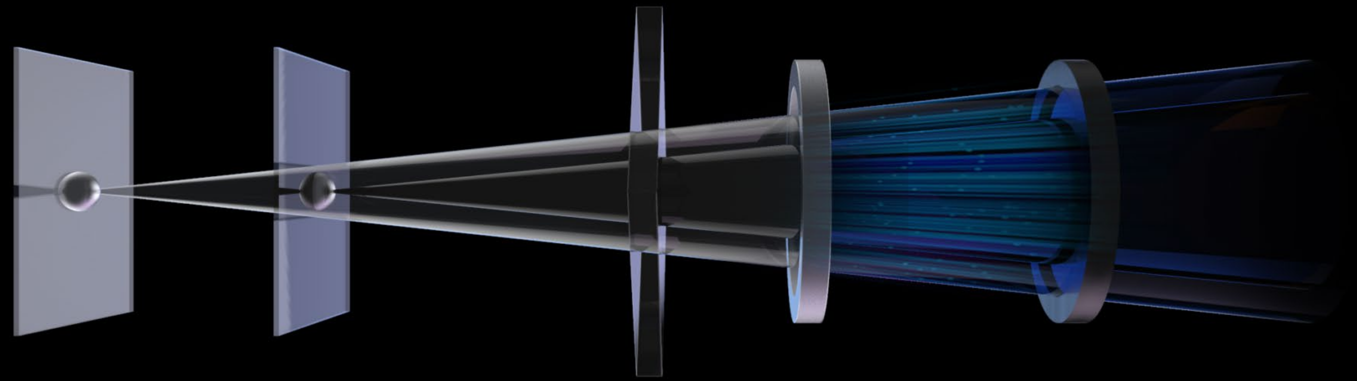
A light-field display device includes a screen, a grating pixel array, and an image generator. The image generator outputs light including three-dimensional (3D) image information. The grating pixel array is configured to diffract the light including the 3D image information in multiple directions, thereby forming a 3D image. The image generator outputs the light having the 3D image information to the screen at a predetermined angle.

Brelyon

Light Field

BRELYON™

- SF-Area startup - $1.6m seed funding (July 2020)
- Promoting “Superconic light-field expansion tech” (SLET)
- “Panoramic visually immersive experience”
- 101° FoV at 4K or 8K
- Up to ten 24-inch tiled monitors



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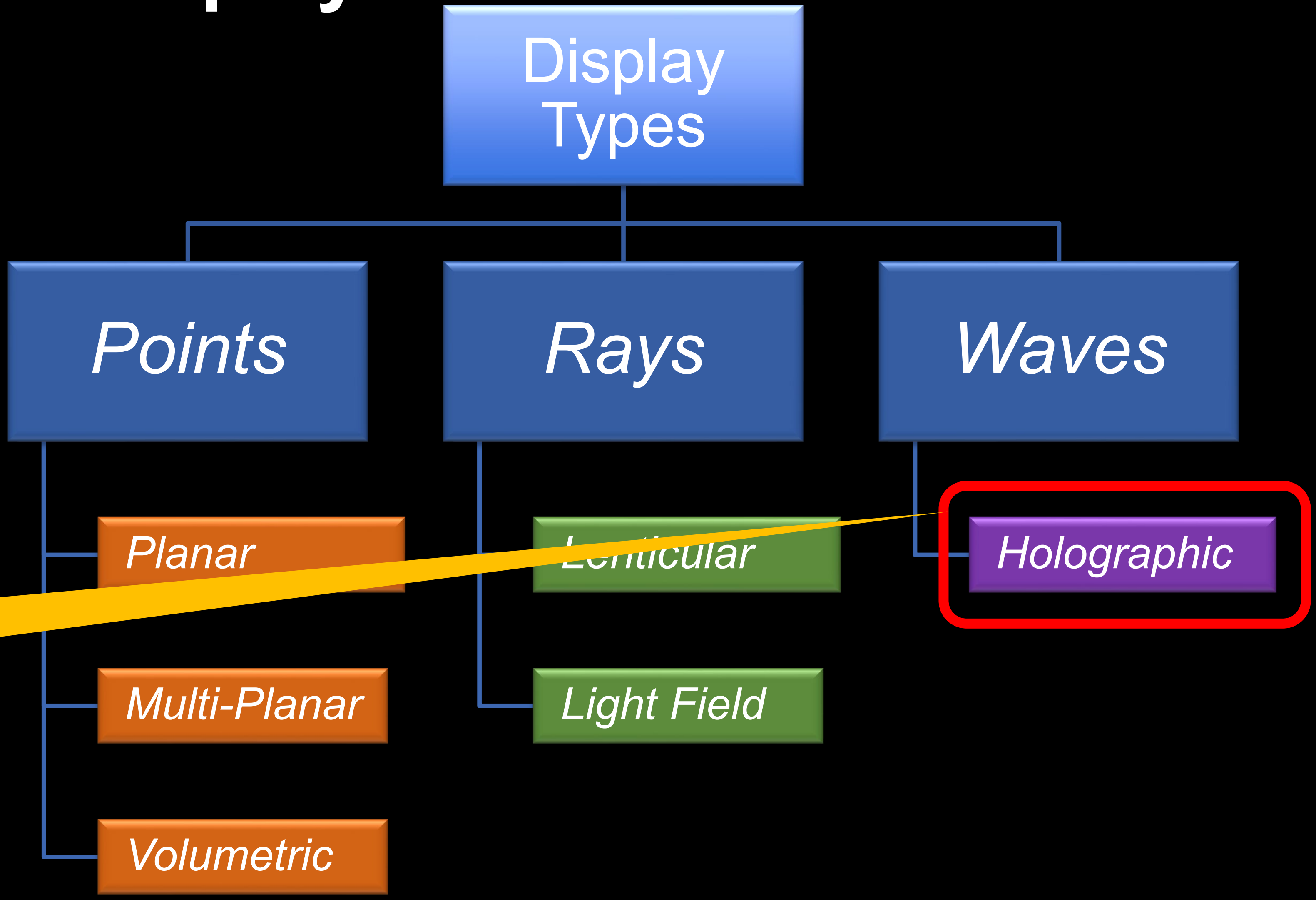
Immersive Displays



Our last category substitutes discreet light rays for wavefront interference patterns..

Vivid Q

Holographic

VIVIDQ

- Diffractive Holography
- RGB Lasers
- LCoS Spatial Light Modulator
- Software processing
  - 64 depth layers on single GPU
- “Natural Focus” w/o Eye tracking

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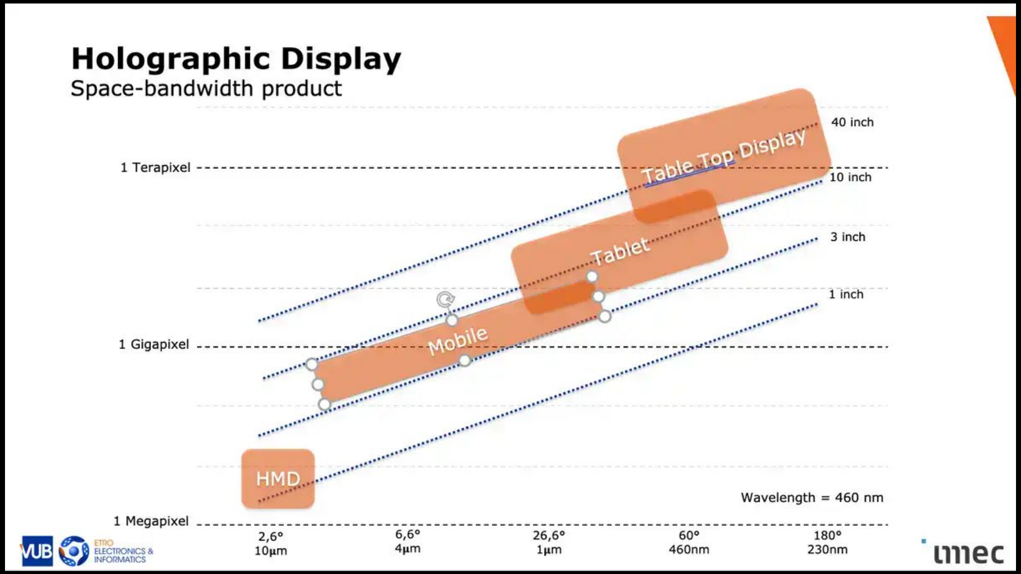
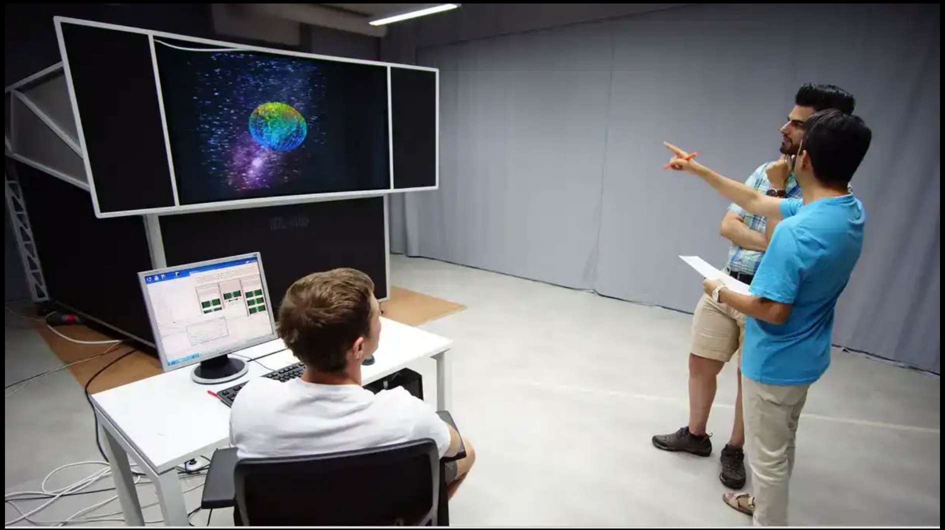
IMEC

Holographic

- SLM with 0.5 micron pixels
- Holograph Compression techniques
- Using JPEG Pleno encoding

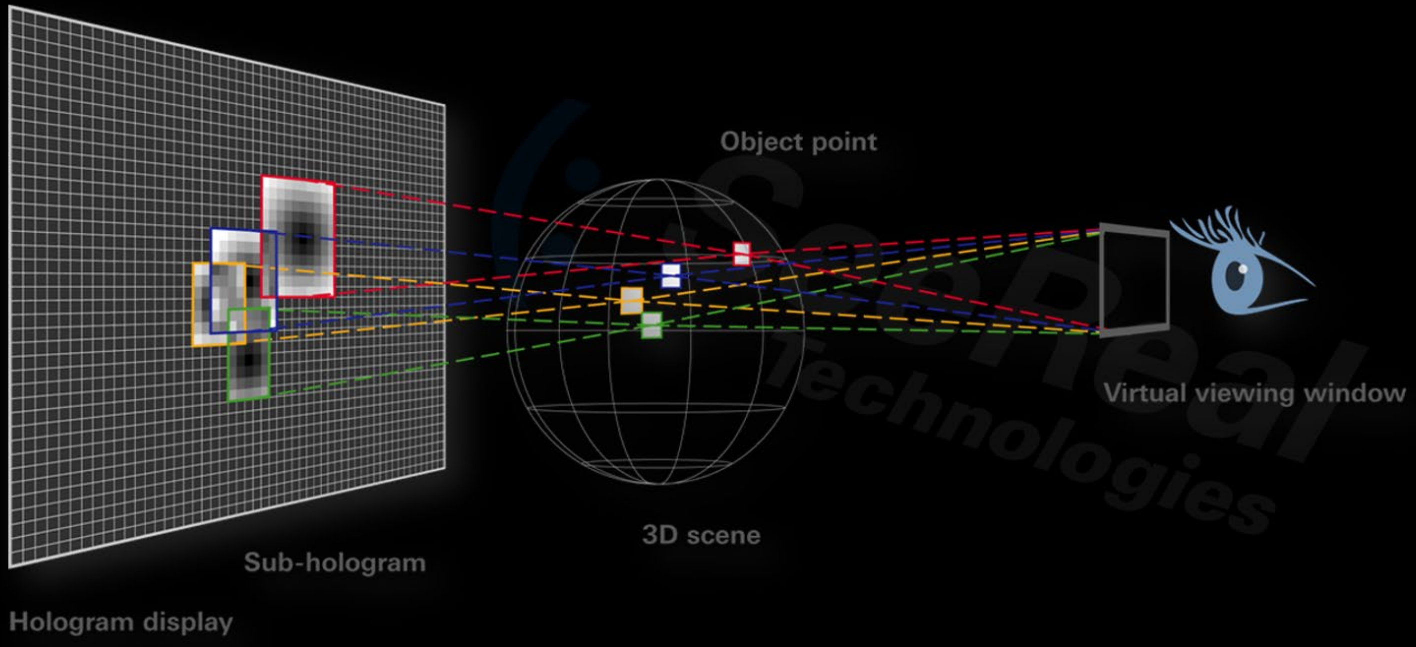




SeeReal

Holographic

- Luxenbuourg-based startup
- Interference-based Holograph Display
  - Uses eye tracking for confined Viewing Window
  - RGB laser
  - Diffractive Optical Elements (DOE)

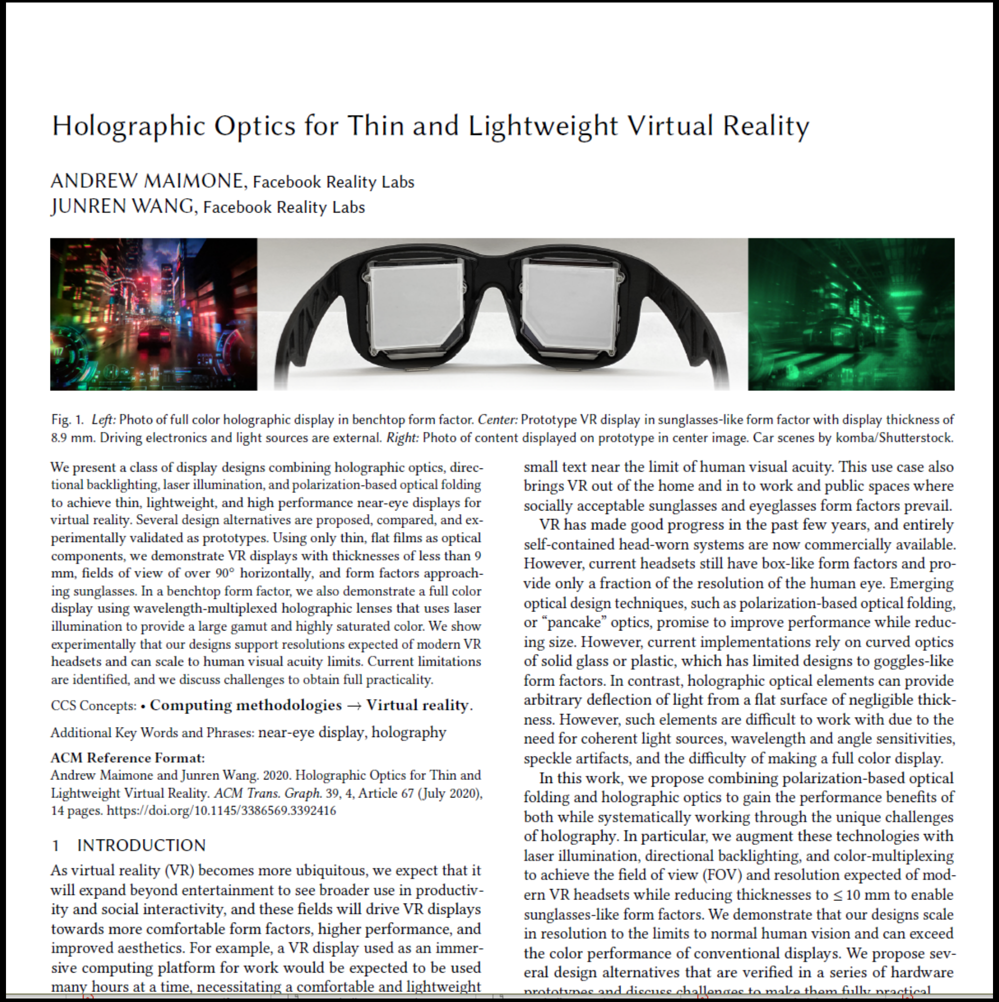


Facebook

Holographic

facebook Reality Labs

- Prototype development
  - RGB Laser
  - Diffractive wavefront optics
  - 90° FOV



Holographic Optics for Thin and Lightweight Virtual Reality

ANDREW MAIMONE, Facebook Reality Labs
JUNREN WANG, Facebook Reality Labs

Fig. 1. *Left:* Photo of full color holographic display in benchtop form factor. *Center:* Prototype VR display in sunglasses-like form factor with display thickness of 8.9 mm. Driving electronics and light sources are external. *Right:* Photo of content displayed on prototype in center image. Car scenes by komba/Shutterstock.

We present a class of display designs combining holographic optics, directional backlighting, laser illumination, and polarization-based optical folding to achieve thin, lightweight, and high performance near-eye displays for virtual reality. Several design alternatives are proposed, compared, and experimentally validated as prototypes. Using only thin, flat films as optical components, we demonstrate VR displays with thicknesses of less than 9 mm, fields of view of over 90° horizontally, and form factors approaching sunglasses. In a benchtop form factor, we also demonstrate a full color display using wavelength-multiplexed holographic lenses that uses laser illumination to provide a large gamut and highly saturated color. We show experimentally that our designs support resolutions expected of modern VR headsets and can scale to human visual acuity limits. Current limitations are identified, and we discuss challenges to obtain full practicality.

CCS Concepts: • **Computing methodologies → Virtual reality.**

Additional Key Words and Phrases: near-eye display, holography

ACM Reference Format:
Andrew Maimone and Junren Wang. 2020. Holographic Optics for Thin and Lightweight Virtual Reality. *ACM Trans. Graph.* 39, 4, Article 67 (July 2020), 14 pages. https://doi.org/10.1145/3386569.3392416

1 INTRODUCTION

As virtual reality (VR) becomes more ubiquitous, we expect that it will expand beyond entertainment to see broader use in productivity and social interactivity, and these fields will drive VR displays towards more comfortable form factors, higher performance, and improved aesthetics. For example, a VR display used as an immersive computing platform for work would be expected to be used many hours at a time, necessitating a comfortable and lightweight small text near the limit of human visual acuity. This use case also brings VR out of the home and in to work and public spaces where socially acceptable sunglasses and eyeglasses form factors prevail.

VR has made good progress in the past few years, and entirely self-contained head-worn systems are now commercially available. However, current headsets still have box-like form factors and provide only a fraction of the resolution of the human eye. Emerging optical design techniques, such as polarization-based optical folding, or "pancake" optics, promise to improve performance while reducing size. However, current implementations rely on curved optics of solid glass or plastic, which has limited designs to goggles-like form factors. In contrast, holographic optical elements can provide arbitrary deflection of light from a flat surface of negligible thickness. However, such elements are difficult to work with due to the need for coherent light sources, wavelength and angle sensitivities, speckle artifacts, and the difficulty of making a full color display.

In this work, we propose combining polarization-based optical folding and holographic optics to gain the performance benefits of both while systematically working through the unique challenges of holography. In particular, we augment these technologies with laser illumination, directional backlighting, and color-multiplexing to achieve the field of view (FOV) and resolution expected of modern VR headsets while reducing thicknesses to ≤ 10 mm to enable sunglasses-like form factors. We demonstrate that our designs scale in resolution to the limits to normal human vision and can exceed the color performance of conventional displays. We propose several design alternatives that are verified in a series of hardware prototypes and discuss challenges to make them fully practical.

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Tokyo University
of Agriculture & Technology

Holographic

- Metasurface Holographic Cinema
    - Frame sequential approach
    - Meta-surface optics
    - Wavefront modulation
    - 2,048 x 2,048 monochrome

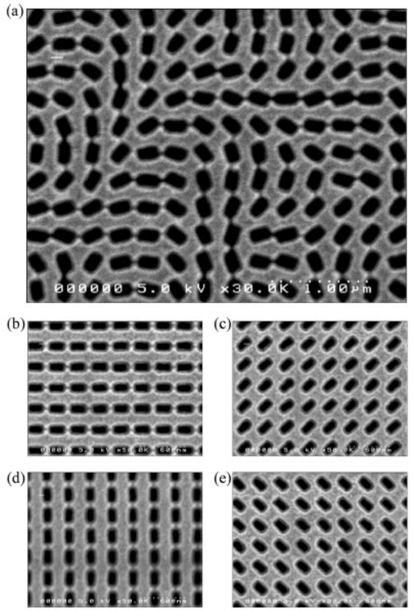

Fig. 3. Scanning electron microscopy (SEM) images of fabricated sample. (a) A hologram frame and aperture array patterns for retardation measurement with the fast axis angles θ of (b) 0°, (c) 45°, (d) 90°, and (e) 135°.

https://www.osapublishing.org/oe/abstract.cfm?doi=10.1364/OE.399369

Conclusion

- Displays may be categorized as emitting points, rays, or waves of light

- In considering Immersive displays:
  - Points in a volume are useful, but very limited
  - Wavefront imaging is promising, but much development remains
  - Rays of light may scale to full Plenoptic function – but what ray density is needed?

- In regard to representation format for motion imaging:
  - Goal should be “highest common denominator” to cover most sophisticated display
  - However, an ideal format would be display-type agnostic – can be used for any
  - Therefore provision to “downscale” or “transcode” should be faciliated

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