LIGHT FIELD AND HOLOGRAPHIC 3D DISPLAY TECHNOLOGIES

Guest Lecture
University of Edinburgh

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ABOUT DR JAVID KHAN

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- Project Officer, European Commission
- Engineer at Philips Electronics, Philips Telecom
- Fellow Institute of Engineering Technology
- Awards

MOTIVATION: WHY 3D?

- Because we see in 3D!
- Grand Challenge
- Generate revenue
- Why not?

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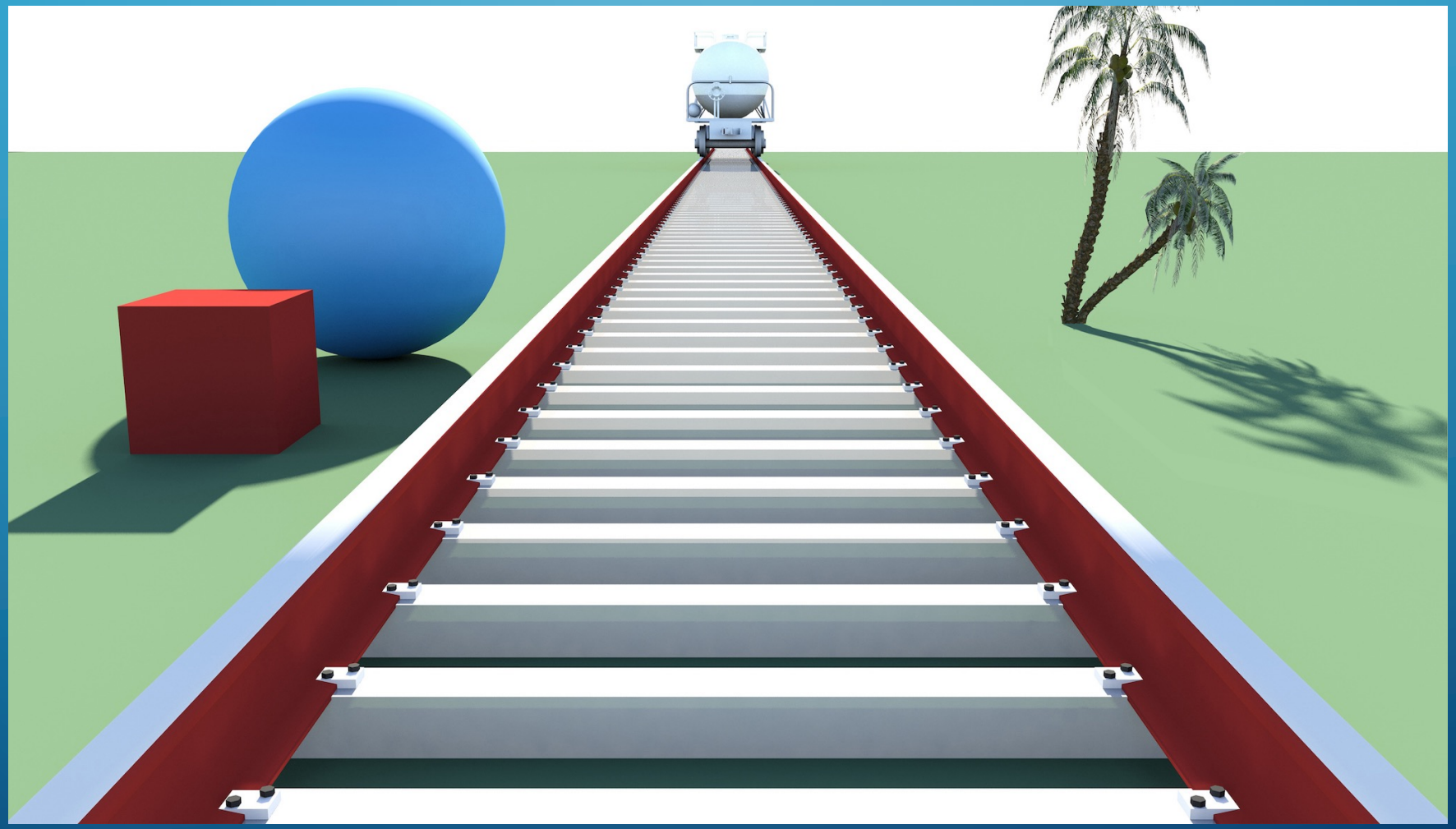
3D DEPTH PERCEPTION



TERMINOLOGY & PROPERTIES

ALL DISPLAYS

- Visual perception limits
- Colour response
  - ✓Red, Green & Blue
- Persistence of vision
- Field of view
- Multi-viewer

3D DISPLAYS

- Multiviewer?
- Binocular vision
  - ✓Stereopsis
  - ✓Vergence
- Monocular depth cues
  - ✓Accommodation
- Voxel/Hogel = 3D pixel

CLASSIFICATION OF 3D DISPLAYS

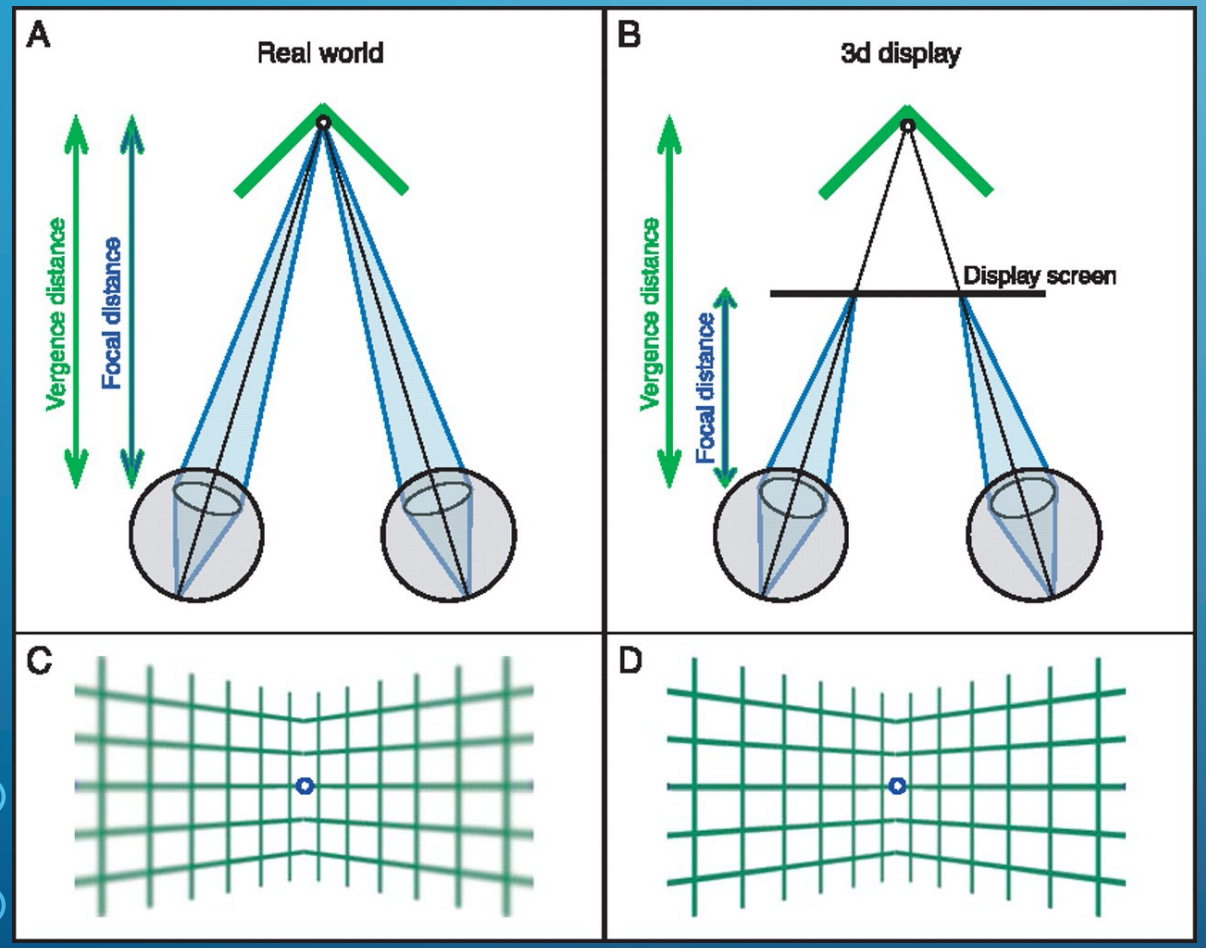
- Stereoscopic
- Auto-stereoscopic
- Volumetric
- Holography
- Light-field
- "Others"

© Keio University, JP

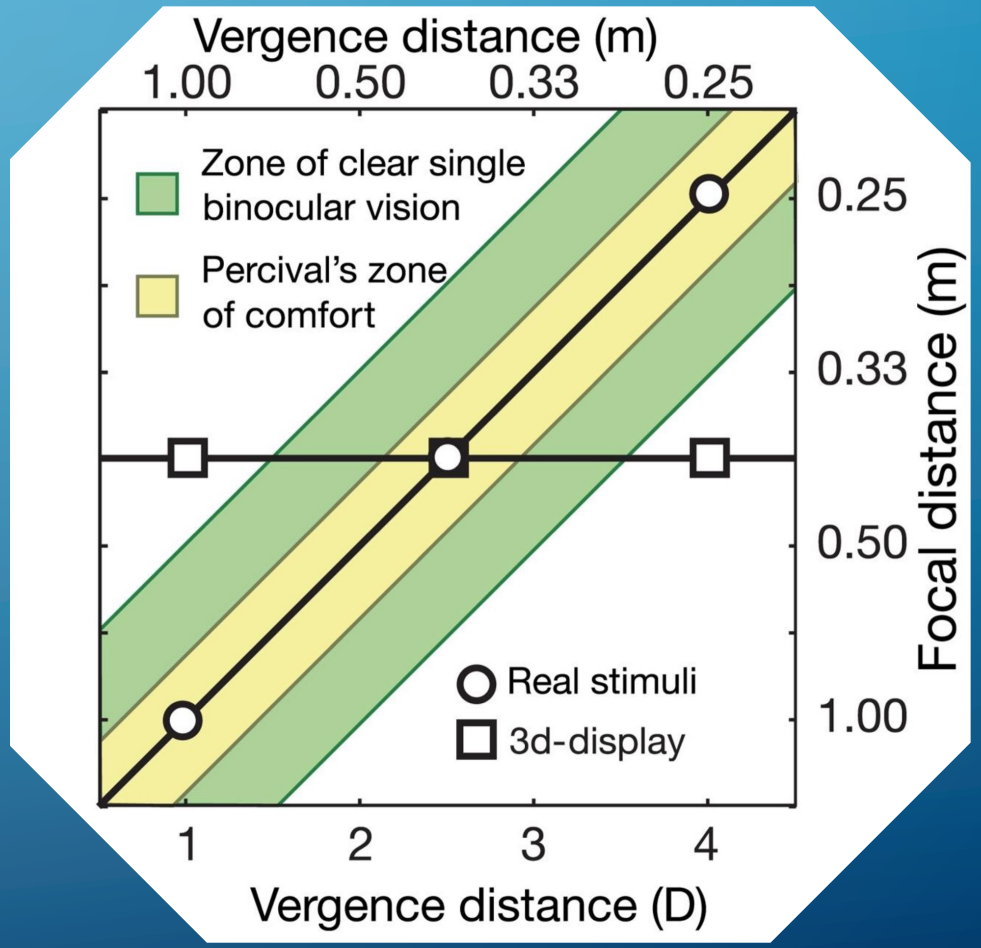
CONVENTIONAL 3D

- Stereoscopic
  - ✓ Cinema, 3D TV
  - ✓ AR & VR
- Issues [1-2]
  - ✓ V-A conflict
  - ✓ Discomfort

VERGENCE-ACCOMMODATION CONFLICT

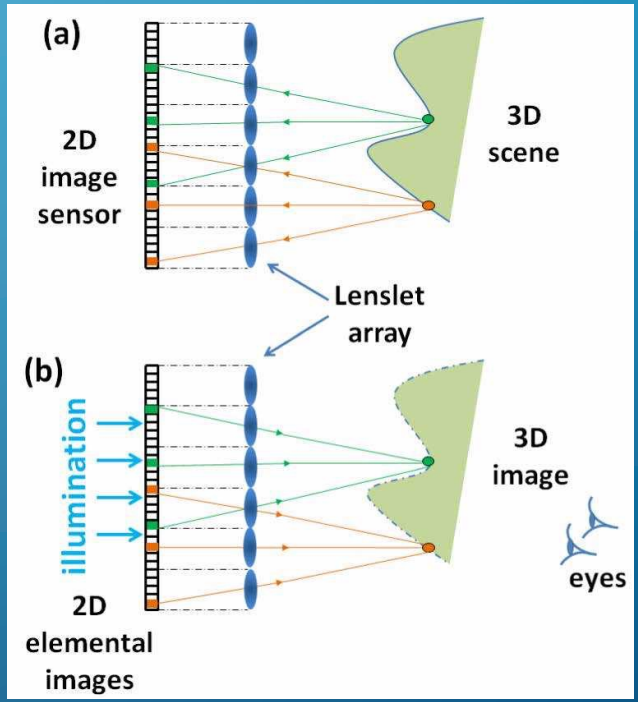


Source: D. M. Hoffman [1]



INTEGRAL IMAGING

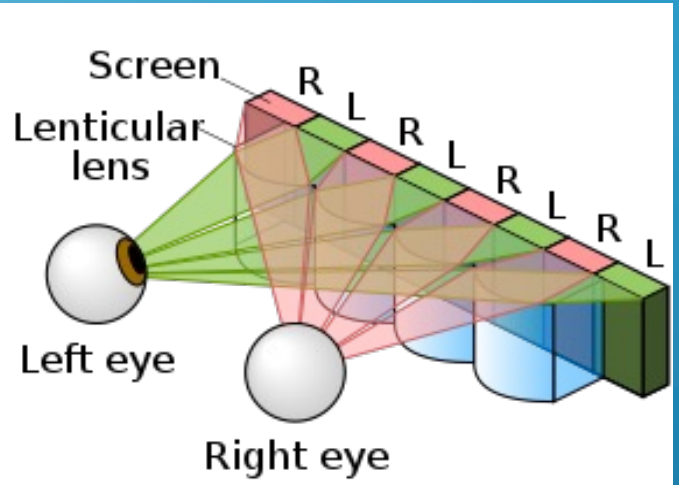
- 3D Imaging technique
  - ✓ Uses lenslet arrays
  - ✓ Capture/reproduce Light Field
- Light Field
  - ✓ Describes light flowing through space
  - ✓ Vector plenoptic function $L = f(I\{r, g, b\}, \theta, \varphi, t)$
- Idea by Gabrielle Lippmann 1908 [3]
  - ✓ Inspired by insectoid eyes
  - ✓ 2D lenslet arrays, pinholes
  - ✓ 1D lenticular/cylindrical arrays

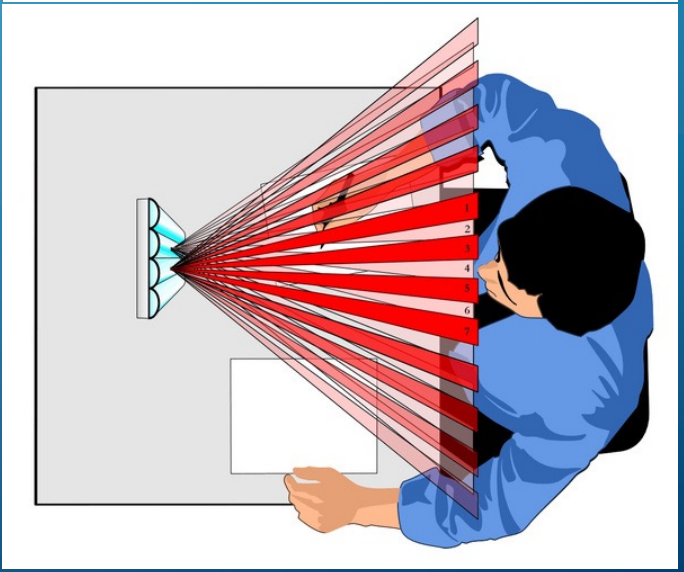


Xin Chen, Computational Imaging

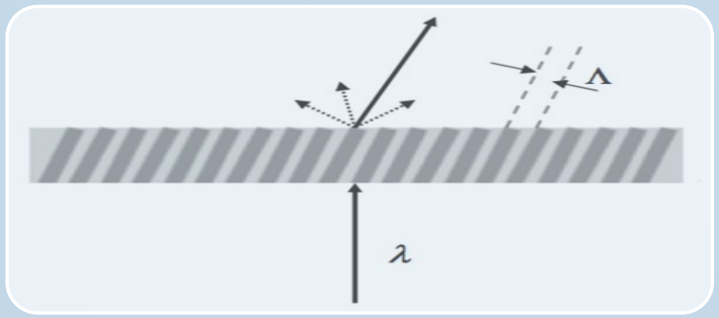
AUTOSTEREO 3D DISPLAYS

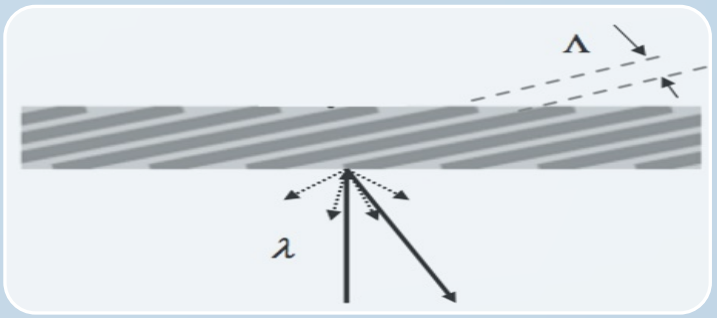
- LCD with lenticular lens
- Stereo binocular views
  - ✓Headset/glasses-free
  - ✓Large area
  - ✓V-A conflict
- Eye tracking displays
- Multi-view displays, Philips
  - ✓Slanted lens array: 4, 8, 16 view points
- Multiscopic displays
  - ✓Super muti-view displays ≈ Light Field





HOLOGRAPHY & DIFFRACTION





Fresnel-Huygens

- Transmissive
- Coherent
- Wavelength dependent

$$m\lambda = \Lambda \sin\theta$$

Bragg

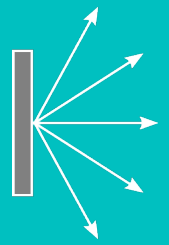
- Reflective
- Incoherent
- Wavelength selective

$$m\lambda = 2\Lambda \sin\theta$$

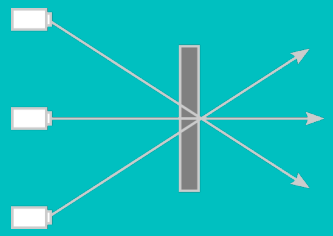
PIXELS & HOGELS & HOXELS

2D pixel
Amplitude

Light field
Direction &
Amplitude

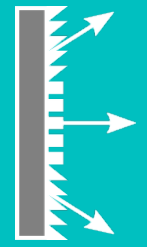


Multi-projector arrays

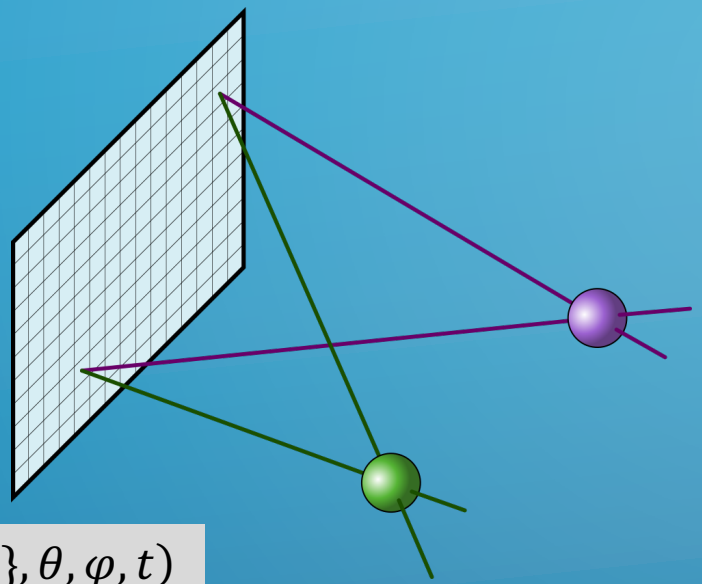


Refractive optics

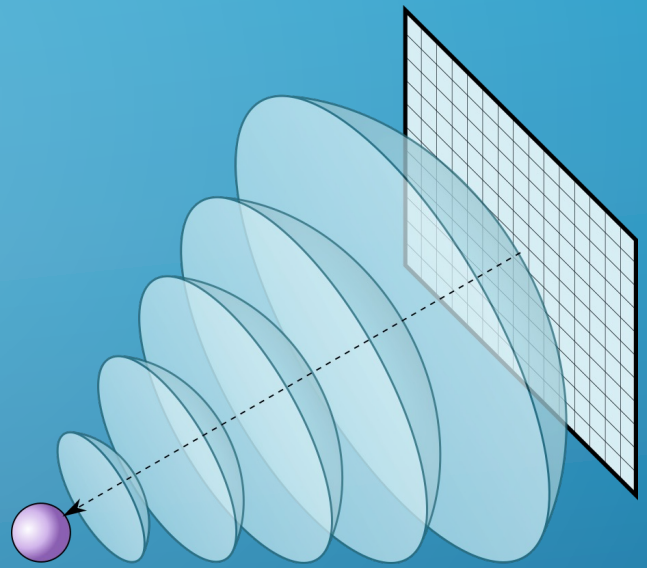
Diffractive optics



LIGHT FIELD VS HOLOGRAPHIC



$$L = f(I\{r, g, b\}, \theta, \varphi, t)$$



$$Electromagnetic - waves$$

$$\vec{\nabla} \cdot \vec{E} = 0 \qquad \vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla} \cdot \vec{B} = 0 \qquad \vec{\nabla} \times \vec{B} = \mu\varepsilon \frac{\partial \vec{E}}{\partial t}$$

$$m\lambda = \Lambda \sin\theta$$

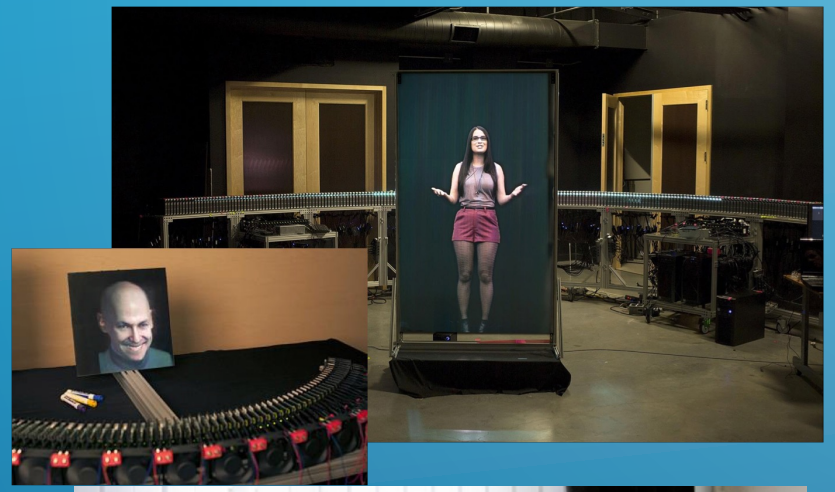
Light Field Display

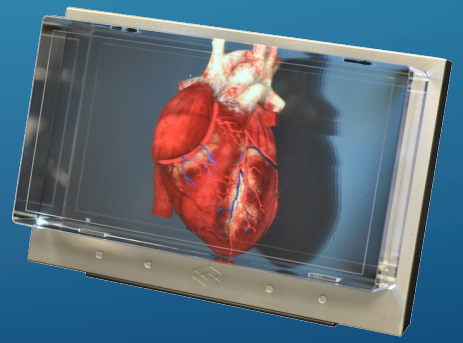
- Directed light *rays*
- Geometric optics
- Piecewise approximation
- Compatible with existing GPUs

Holographic Display

- Interference of light *waves*
- Physical optics
- Full recreation of light field
- Requires coherent light
- Difficult to compute

HOLOGRAPHIC DISPLAYS

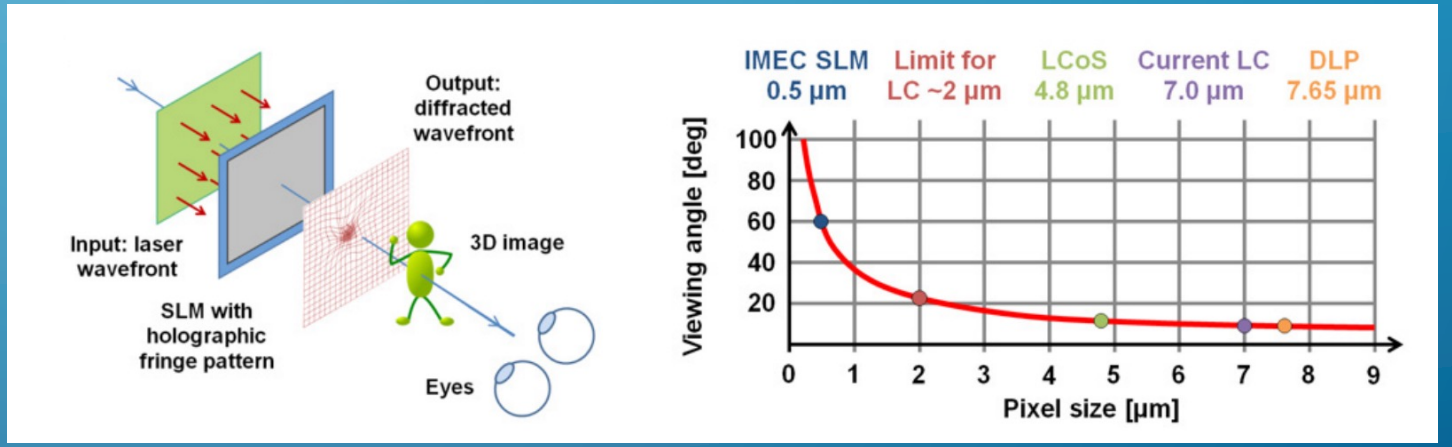




Source: HoloVizio 80WLT - Holografika

SPATIAL LIGHT MODULATORS

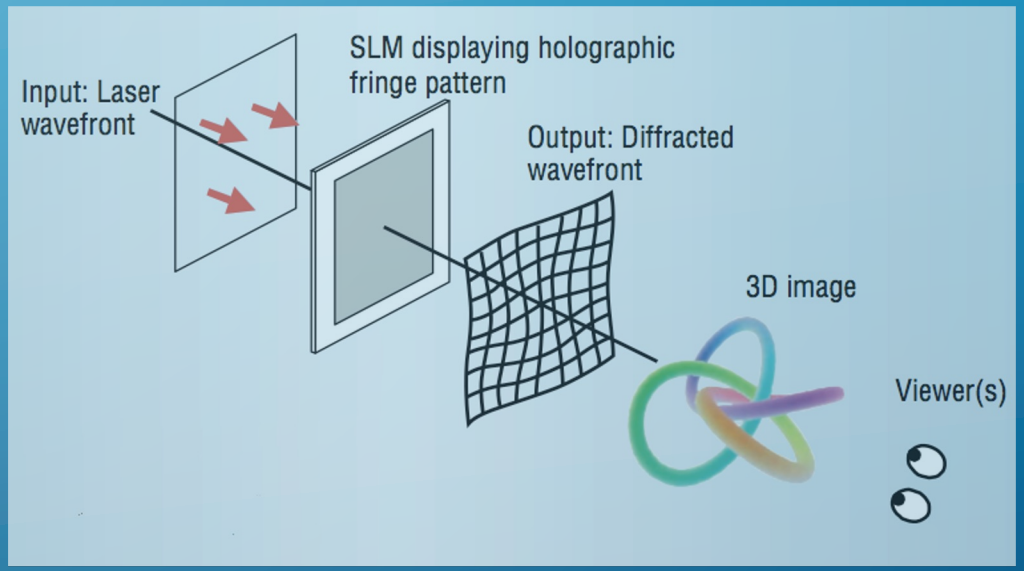
- Phase Modulation
- Pitch/Angle
- Technologies
  - ✓ Acousto-Optic Modulator
  - ✓ Liquid Crystal on Silicon



Source: J. Geng

HOLOGRAPHIC DISPLAY DESIGN

- SLM-type display
  - ✓0.5 µm pixels
  - ✓FoV: ~60 deg
  - ✓50x50mm = 10 Gpx
- Bandwidth ~280 GBytes/s
- Computation ~7.5 Peta Flops/s



Chris Slinger et al [4]

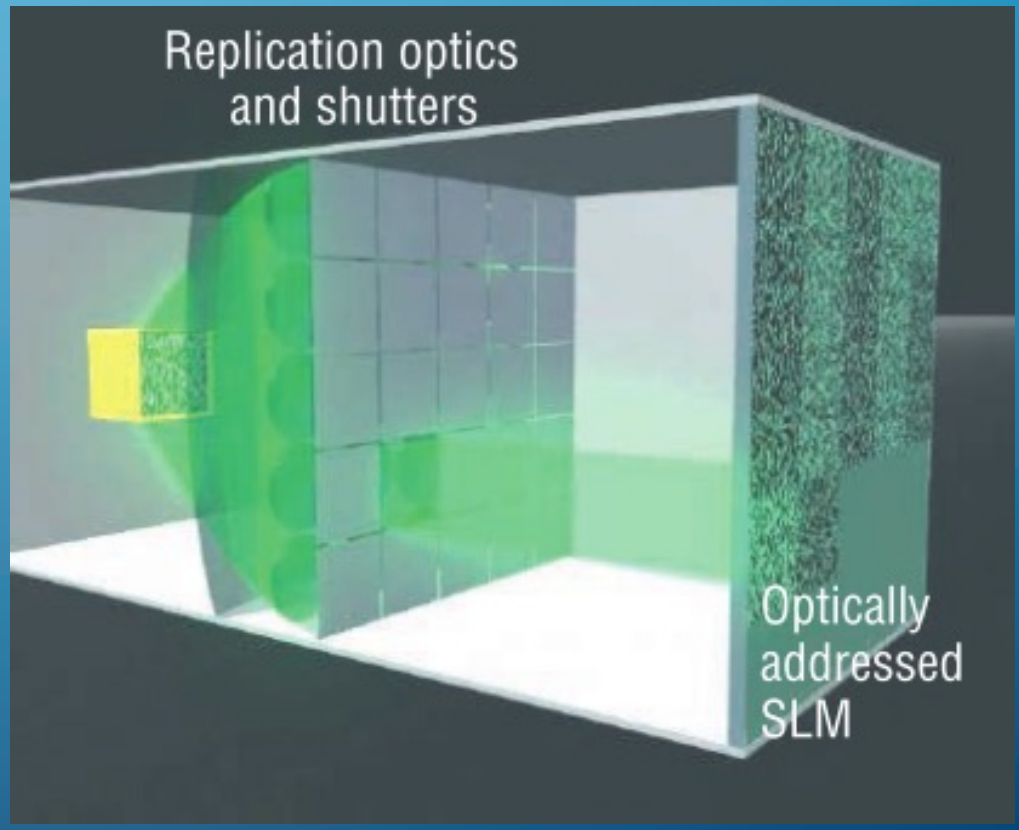
PRACTICAL CONSIDERATIONS

Parameter	8K Display	Design
Diagonal	13.3”	2.8”
Resolution px	33.1M RGB 99.3M Mono	10G
Pixel density ppi	~1373 (H)	50k (H/V)
Pixel size	18.5µm	0.5µm
Bandwidth GB/s	~8	280
Computation PFlops	-	7.5

- Very challenging!
  - ✓ Simplifications
  - ✓ Optimisation
  - ✓ Single parallax
  - ✓ Compression
- Use arrays of SLMs

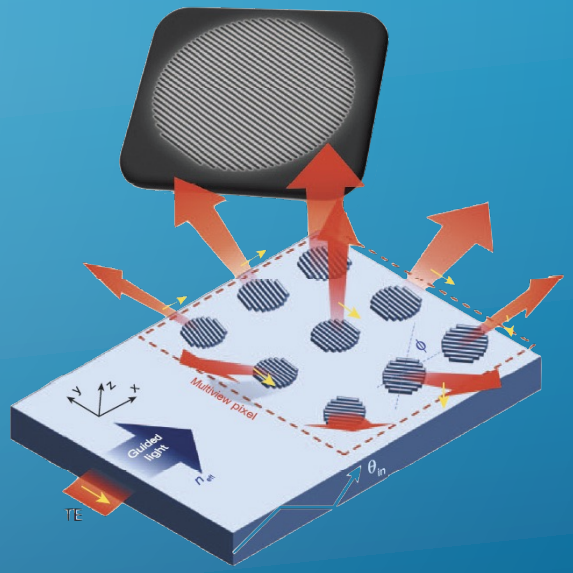
QINETIQ DISPLAY

- Tiled OASLMs 2005 [4]
  - ✓Full colour/parallax
  - ✓4.4 deg angle
  - ✓20:1 contrast
  - ✓30Hz refresh



LEIA DISPLAY

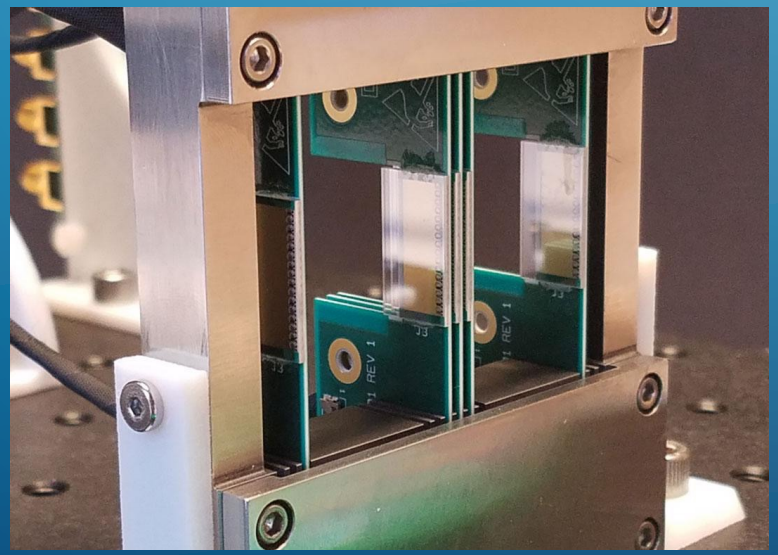
- Diffractive nanostructures [5]
- Directed illumination
- Integrate in LCD panels
- Limited views

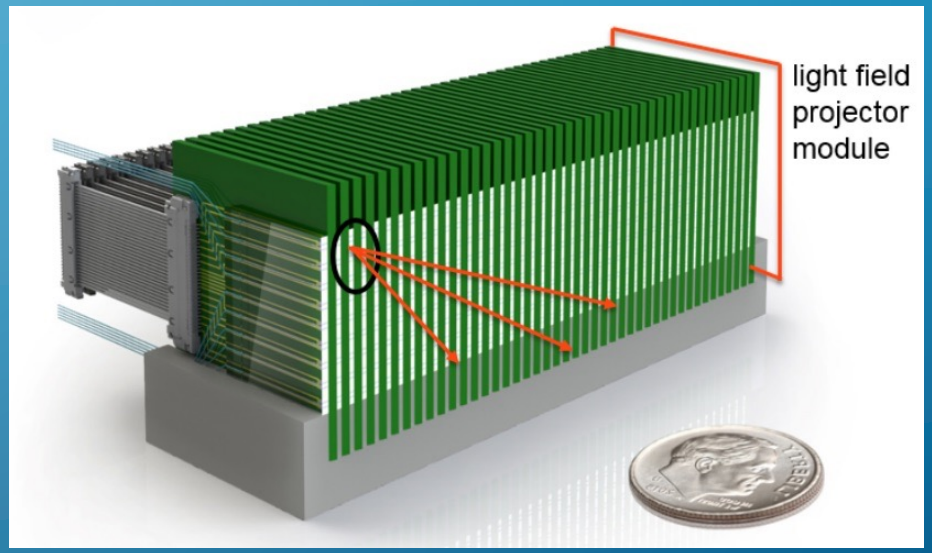


Source: F. Aieta [10]

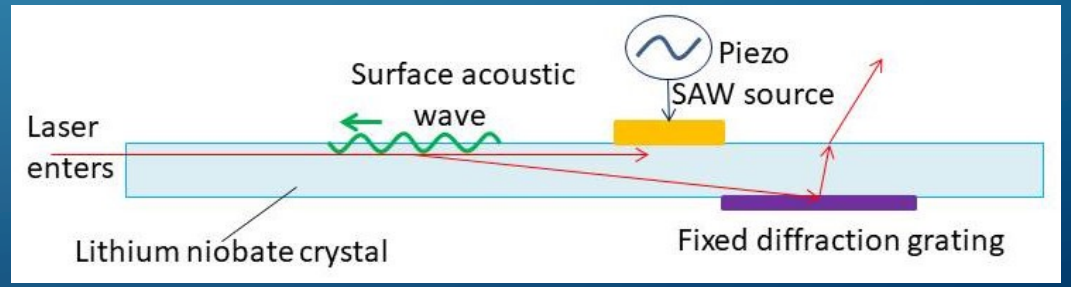
DRAPER HOLOGRAPHIC DISPLAY

- Electro-holographic display [6]
  - ✓SAW Optical Modulator
  - ✓Light Field Projector Module



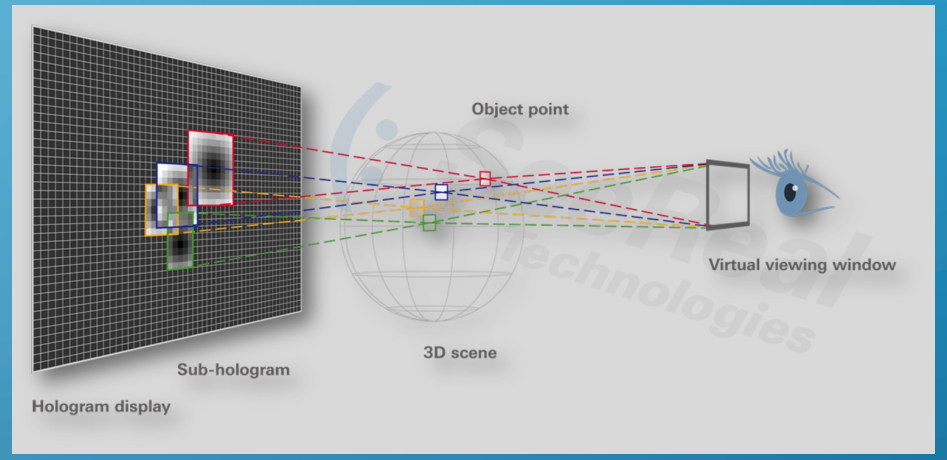


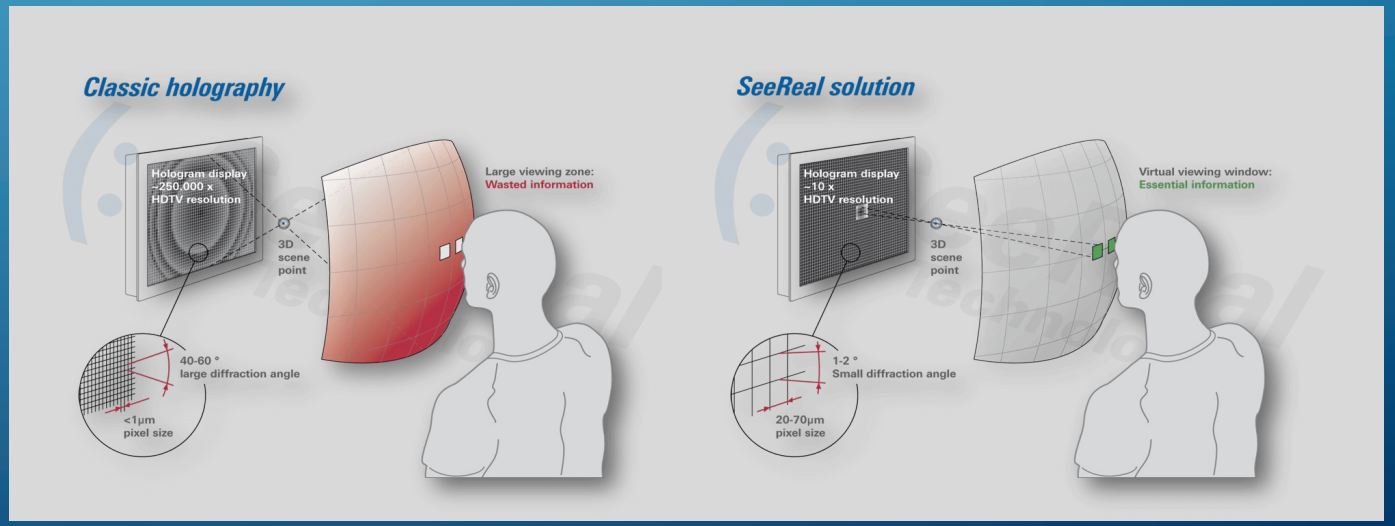
Source: Draper



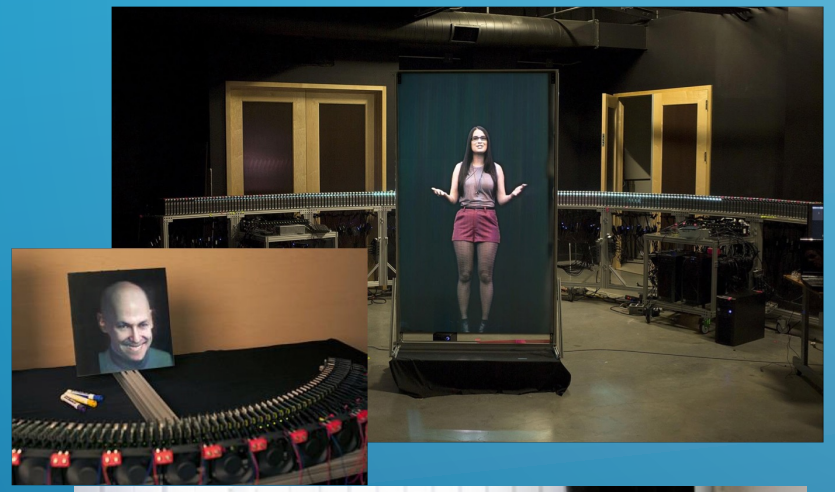
SEEREAL TECHNOLOGIES

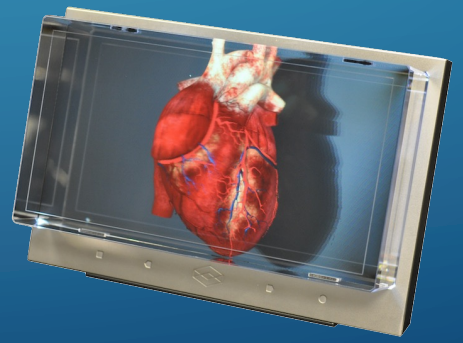
- Constrained display [7]
  - ✓ Eye tracking
  - ✓ Sub-holograms
  - ✓ Single viewer





SEMI-HOLOGRAPHIC DISPLAYS

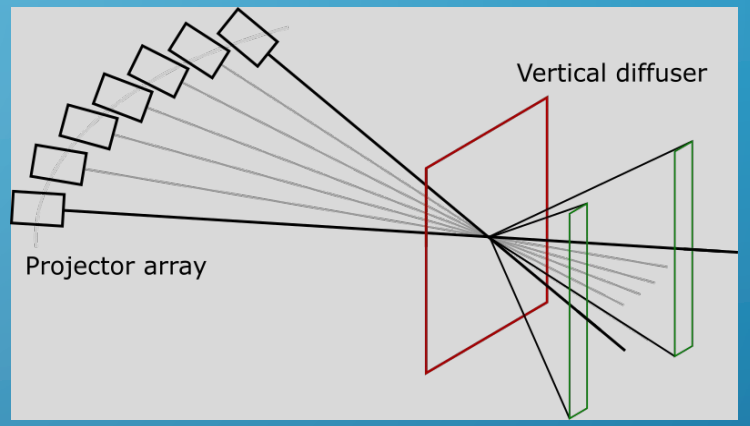




Source: HoloVizio 80WLT - Holografika

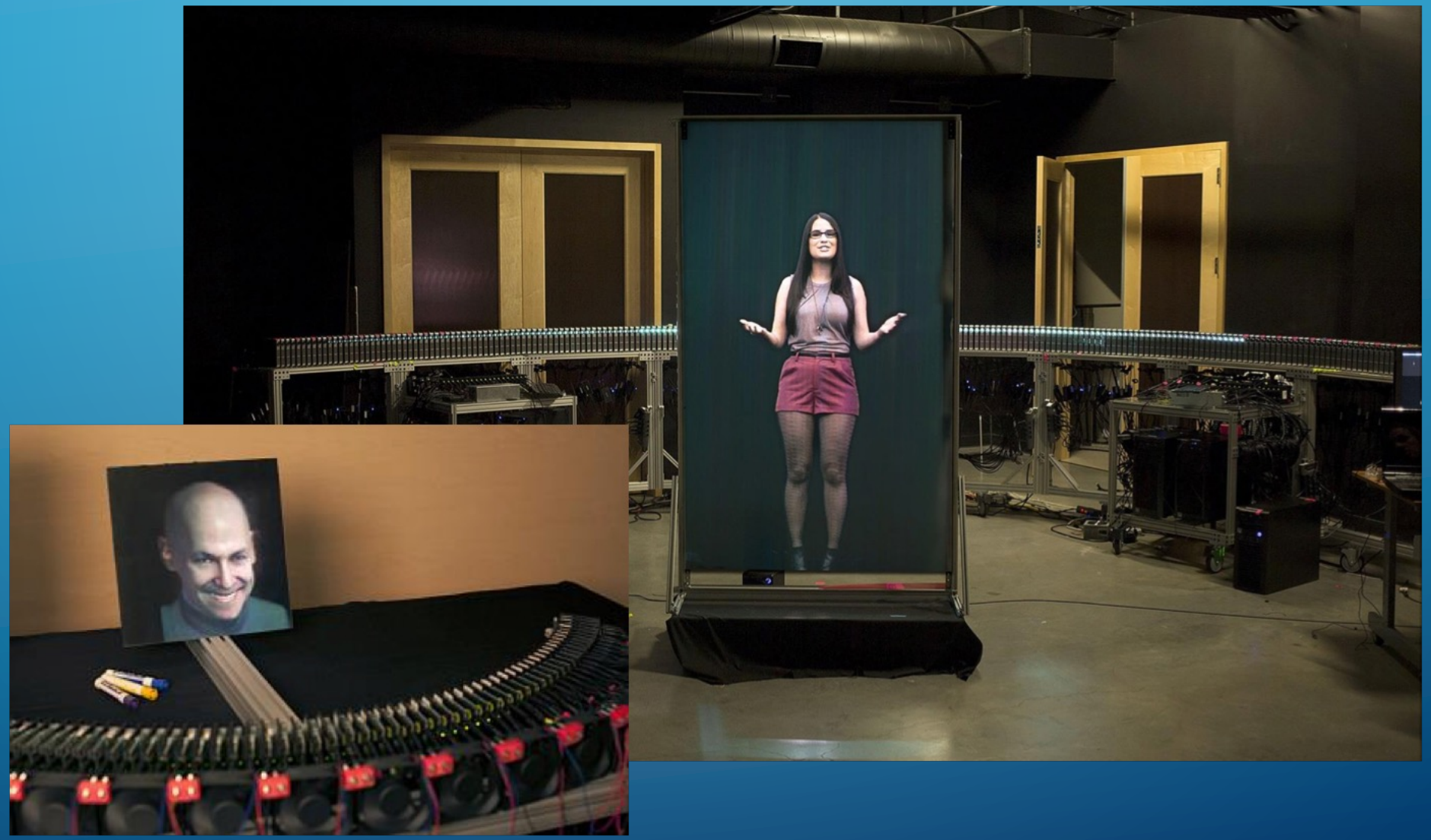
MULTI-PROJECTOR ARRAYS

- 1D array of projectors
  - ✓ Vertically diffusing screen
- Large, bulky, expensive
- Holografika 80WLT
  - ✓ 162 rays/mm^2
  - ✓ ~1 deg. per view



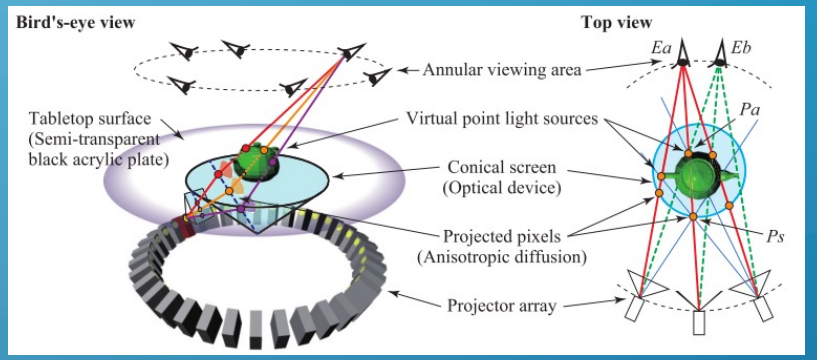
Source: HoloVizio 80WLT - Holografika

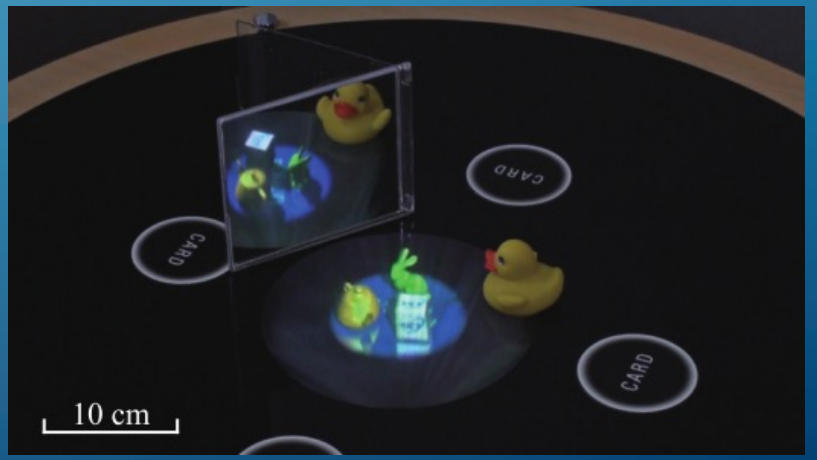
USC DAVIS SYSTEMS



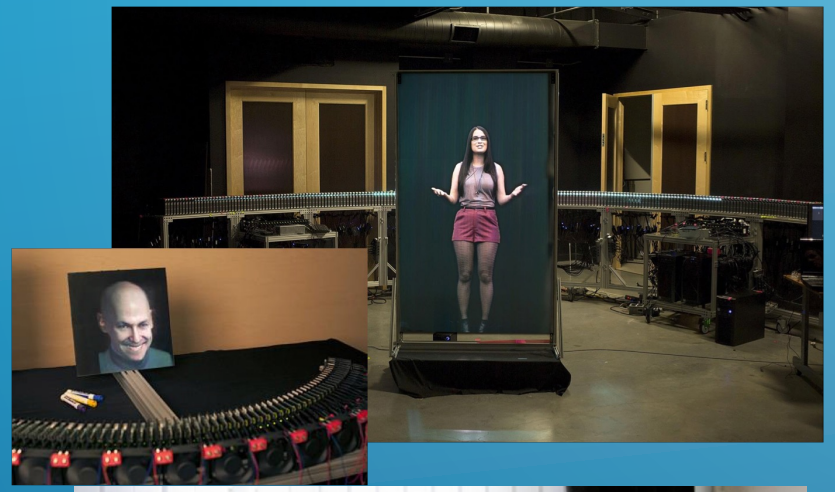
TABLETOP NICT

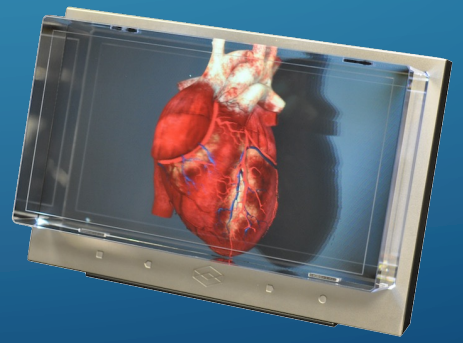
- fVisiOn [8] Display
  - ✓Conical projector array
  - ✓Diffusive screen
  - ✓360 degree horizontal view





LIGHT FIELD DISPLAYS

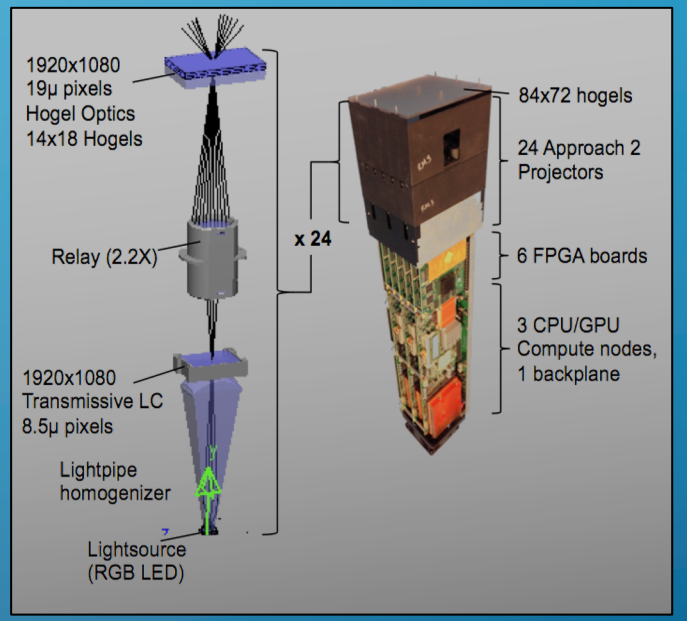


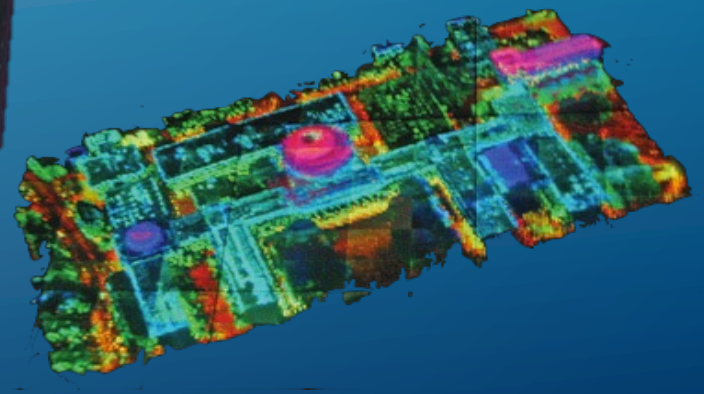


Source: HoloVizio 80WLT - Holografika

ZEBRA IMAGING

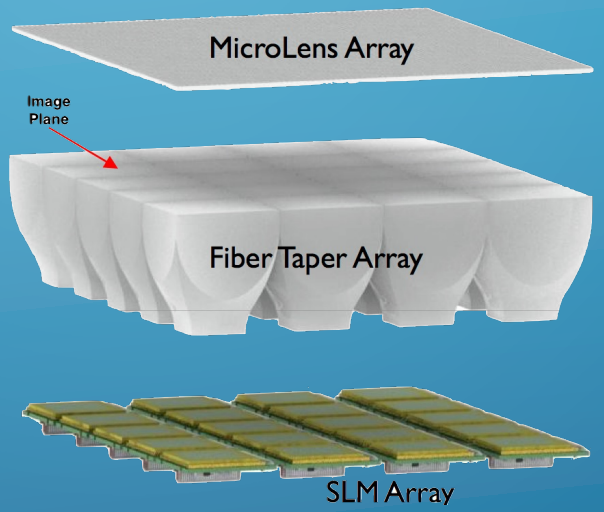
- Tabletop display [9]
  - ✓ 21” diagonal
  - ✓ FoV 90 deg.
  - ✓ ~2,100 rays/mm^2
  - ✓ Refresh rate ~3Hz
  - ✓ 4000 colours



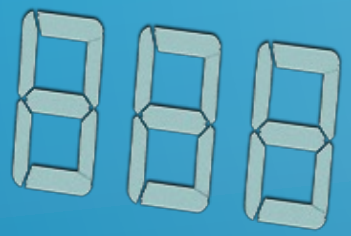
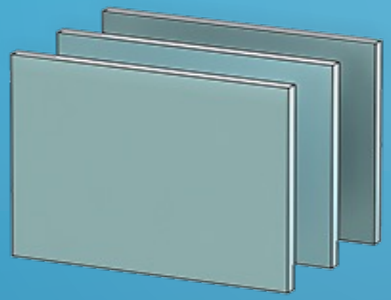
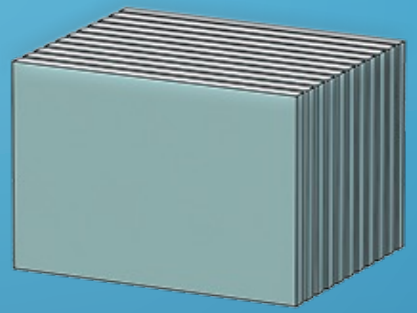
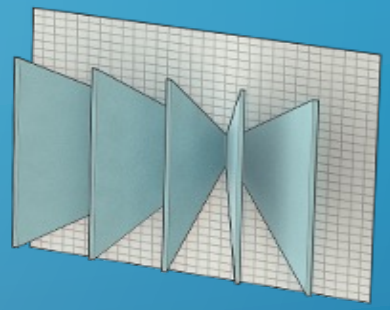
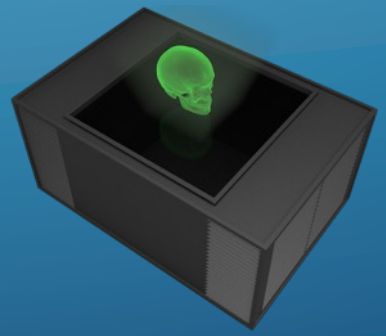
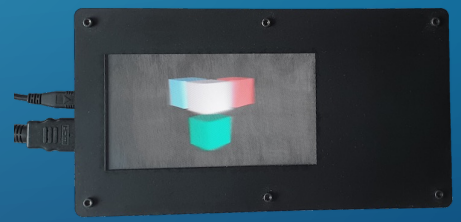


FOVI-3D

- 0.5mm Hogels
- ~10k rays/mm^2
- FoV 90 deg
- Matrix of microdisplays
- Colour (now)



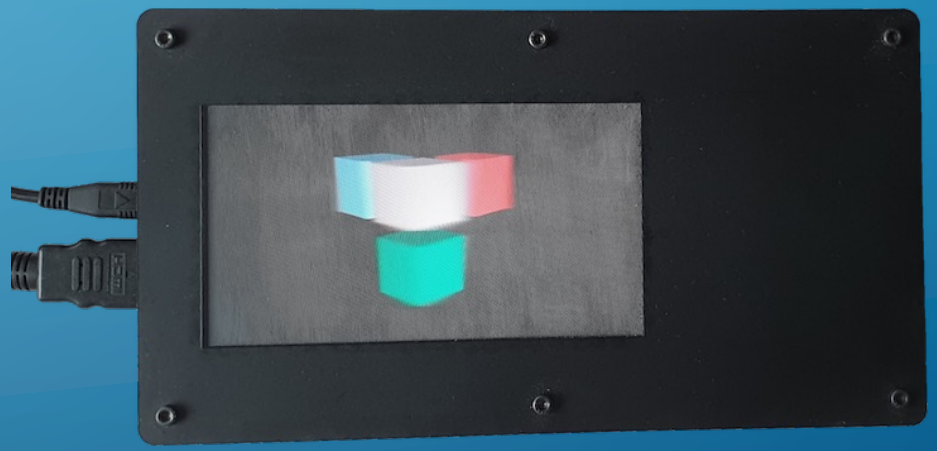
HOLOXICA DISPLAYS

Gen: 1st	2nd	3rd	4th
			
Segmented	Planar	Volumetric	Light Field
10~100 px [10]	100~500k px	1~10M vox [11]	10M+ rays [12]
			

Time: 2010 — 2013 — 2016 — 2018 — 2020

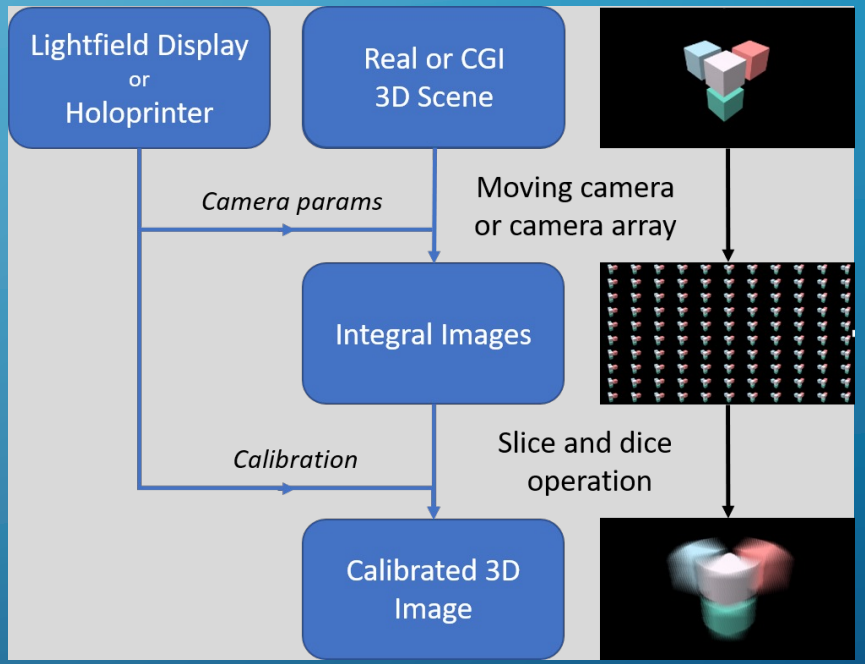
LIGHT FIELD MULTIVIEW DISPLAY DESIGN

- OLED/LCD & lenticular display
  - ✓ High resolution panel
  - ✓ Slanted lenticular design
  - ✓ Horizontal parallax
  - ✓ FoV: ~50 deg
  - ✓ Angular pitch: <1 deg
- Matlab design & sim tool
- EngD project, C. Blackwell [12]



LF DISPLAY IMPLEMENTATION

Parameter	Value	
Panel size	5.5”	Sony phone
Resolution px	8.3M RGB	3820x2160
Panel resolution	806 PPI	
Lenticular	75 LPI	49 deg
Lenticular slant angle	5.71 deg	
Px per hogel	10x11 px	
Hogel resolution	349x216 hgls	
Angular pitch	0.45 deg	
Computation GPU	3300 renders/s	



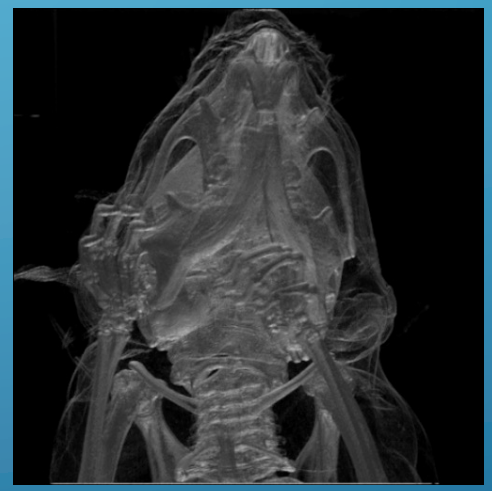
LOOKING GLASS 3D DISPLAYS

- 32” & 65” Displays (new)
- 15.6” Display (also 7.9”)
  - ✓ ~50 deg FoV
  - ✓ 45 Views
  - ✓ Colour, 60 fps
- Multiple Viewers
  - ✓ No headset/glasses
  - ✓ Replace AR/VR

COMPUTER GENERATED IMAGES

- Rendering: Ray Tracing
  - ✓ Algorithms: Ray Casting
  - ✓ PoVray. Cycles, Octane
- Volume Rendering
  - ✓ Special case of ray tracing
  - ✓ Medical imaging
- Rasterisation
  - ✓ Transformation of matrices

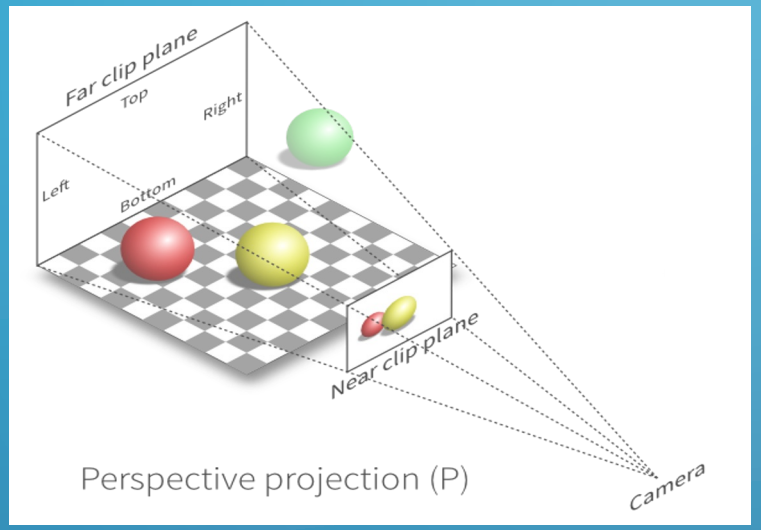
$$L_o(\mathbf{x}, \mathbf{w}) = L_e(\mathbf{x}, \mathbf{w}) + \int_\Omega f_r(\mathbf{x}, \mathbf{w}', \mathbf{w}) L_i(\mathbf{x}, \mathbf{w}')(-\mathbf{w}' \cdot \mathbf{n}) d\mathbf{w}'$$

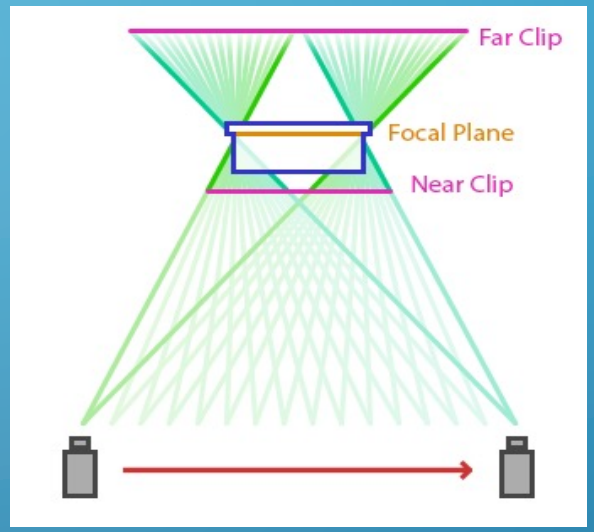


$$V_i = V_{i-1}(1 - \alpha_i) + \gamma\alpha_i$$

GRAPHICS PROCESSING PIPELINE

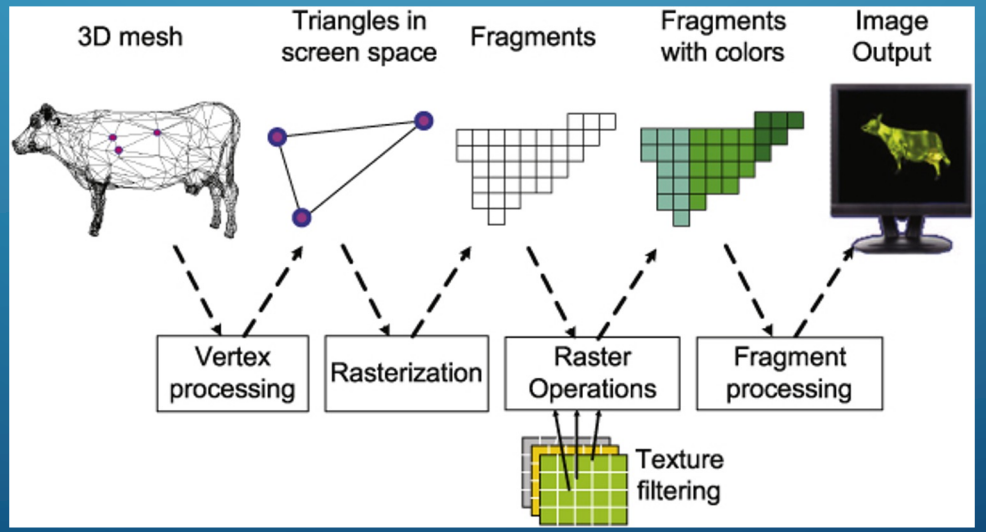
Camera settings





Camera array for Multi-view renders

GPU Processing Pipeline



COMPUTER GRAPHICS ENGINES

- 3D Graphics frameworks
  - ✓OpenGL,WebGL, Vulkan
  - ✓Vulcan, DirectX, Metal
- Unity
  - ✓Proprietary, royalty based
- Unreal Engine, EPIC Games
  - ✓Proprietary, royalty for commercial use
- ThreeJS
  - ✓Open Source (MIT)

THREE.JS FEATURES

- Objects, geometry & materials
- Scene setup
  - ✓ Meshes, textures, geometries
  - ✓ Lights
  - ✓ Camera arrays for multi-view
- Shaders (GLSL)
  - ✓ Effects
  - ✓ Slice & dice for LF rendering
- Loaders, import/export
  - ✓ GLB/GLTF, point clouds, OBJ

CODE EXAMPLE

- Spinning cube
  - ✓ Camera
  - ✓ Mesh(Geometry/Material
  - ✓ Scene (Mesh)
  - ✓ Render (camera, scene)
- Main animation loop
  - ✓ https://jsfiddle.net/theo/VsWb9/

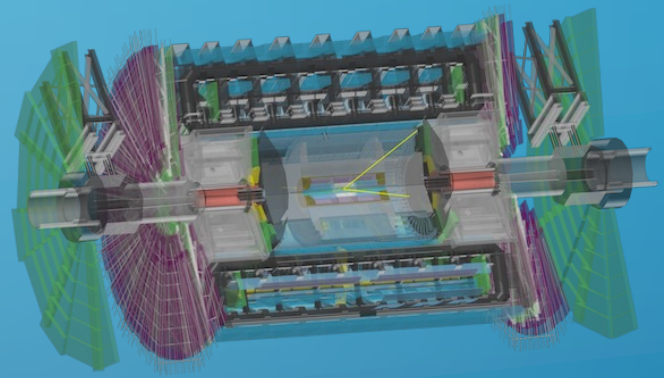
```
var camera, scene, renderer, geometry, material, mesh;

init();
animate();

function init() {

    scene = new THREE.Scene();

    camera = new THREE.PerspectiveCamera(50, window.innerWidth / window.innerHeight, 1, 10000);
    camera.position.z = 500;
    scene.add(camera);

    geometry = new THREE.CubeGeometry(200, 200, 200);
    material = new THREE.MeshNormalMaterial();

    mesh = new THREE.Mesh(geometry, material);
    scene.add(mesh);

    renderer = new THREE.CanvasRenderer();
    renderer.setSize(window.innerWidth, window.innerHeight);

    document.body.appendChild(renderer.domElement);

}

function animate() {

    requestAnimationFrame(animate);
    render();

}

function render() {

    mesh.rotation.x += 0.01;
    mesh.rotation.y += 0.02;

    renderer.render(scene, camera);

}
```

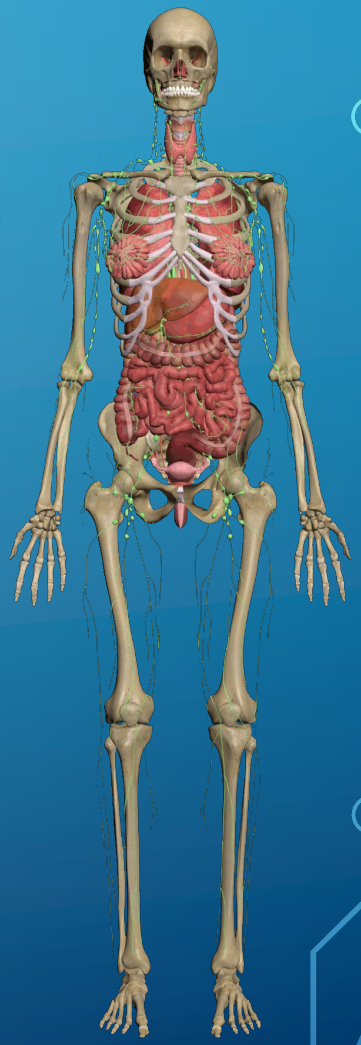
RENDERING FRAMEWORK

- Multiview Rendering
  - ✓48 camera views
    - Quilt, 8x6
- 60 fps => 2880 renders/s
- GPU Nvidia RTX 30 series
- Frameworks
  - ✓Unity, UE, ThreeJS

APPLICATION DOMAINS

- Medical Imaging
- Engineering Design
- Scientific Data Visualisation
- Automotive
- Architecture
- Military





APPS AND SOFTWARE

- 3D Teleconferencing
- 3D Telexistence
- 3D Telemedicine
- Design & CAD
- Simulation

CONCLUSIONS

Light Field Displays		
Significant area of research	Early models reaching consumers	Assisted by current GPU VR/AR/mobile trends

Holographic Displays		
Focus drawn away by light field displays	Mostly research driven	Requires new technology

THANK YOU!

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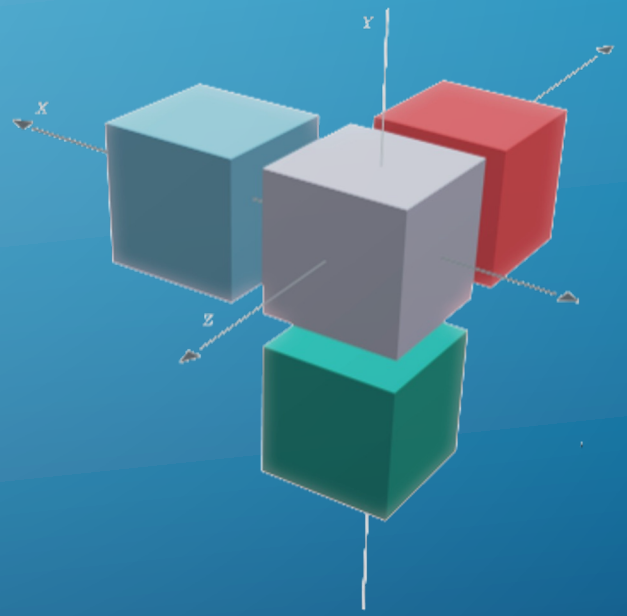

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