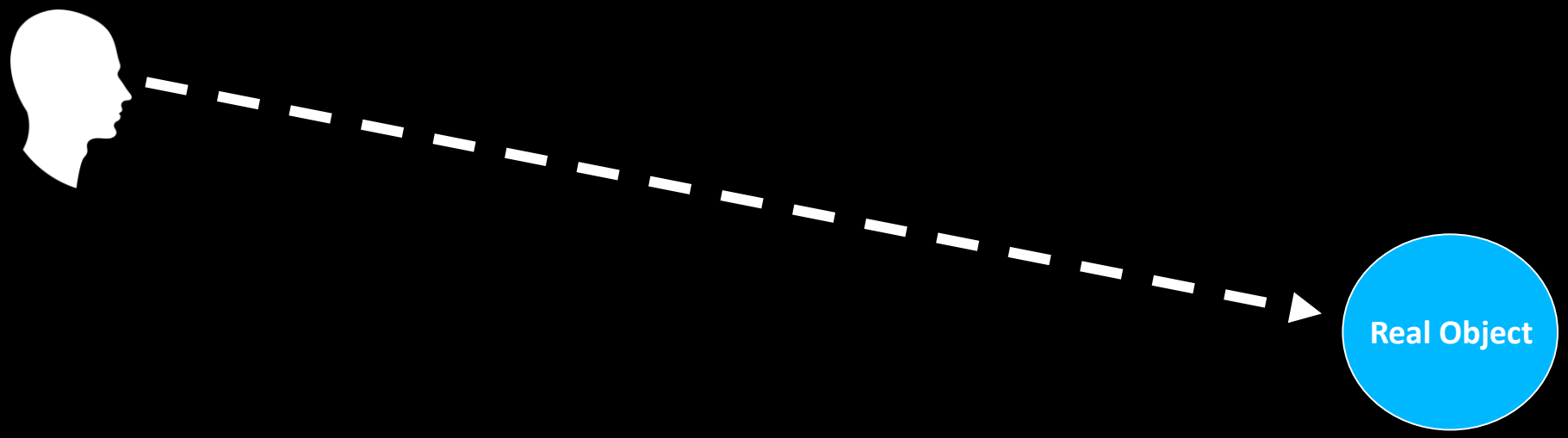
从现实到虚拟现实
- 虚实融合呈现技术

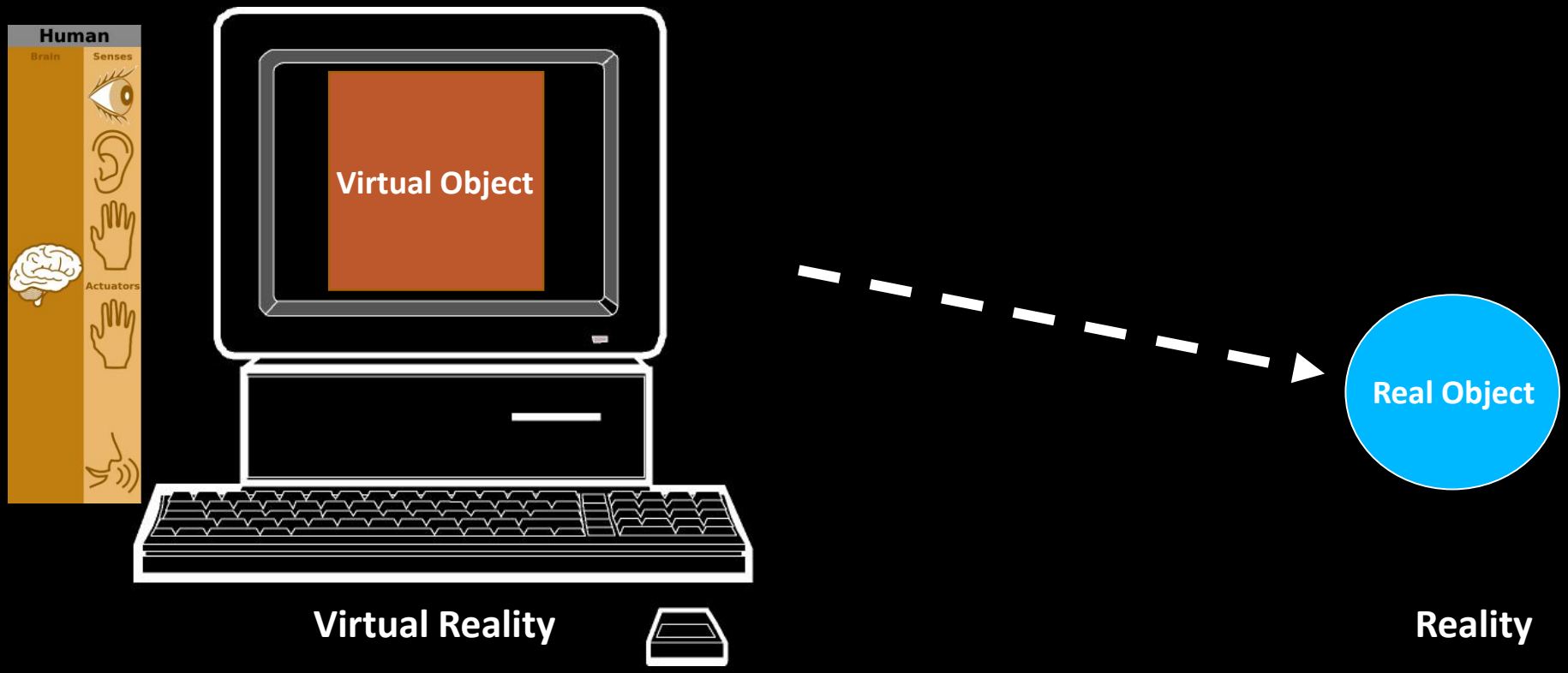
王锐 Rui Wang
浙江大学CAD&CG国家重点实验室
rwang@cad.zju.edu.cn
http://www.cad.zju.edu.cn/home/rwang

从现实到虚拟现实

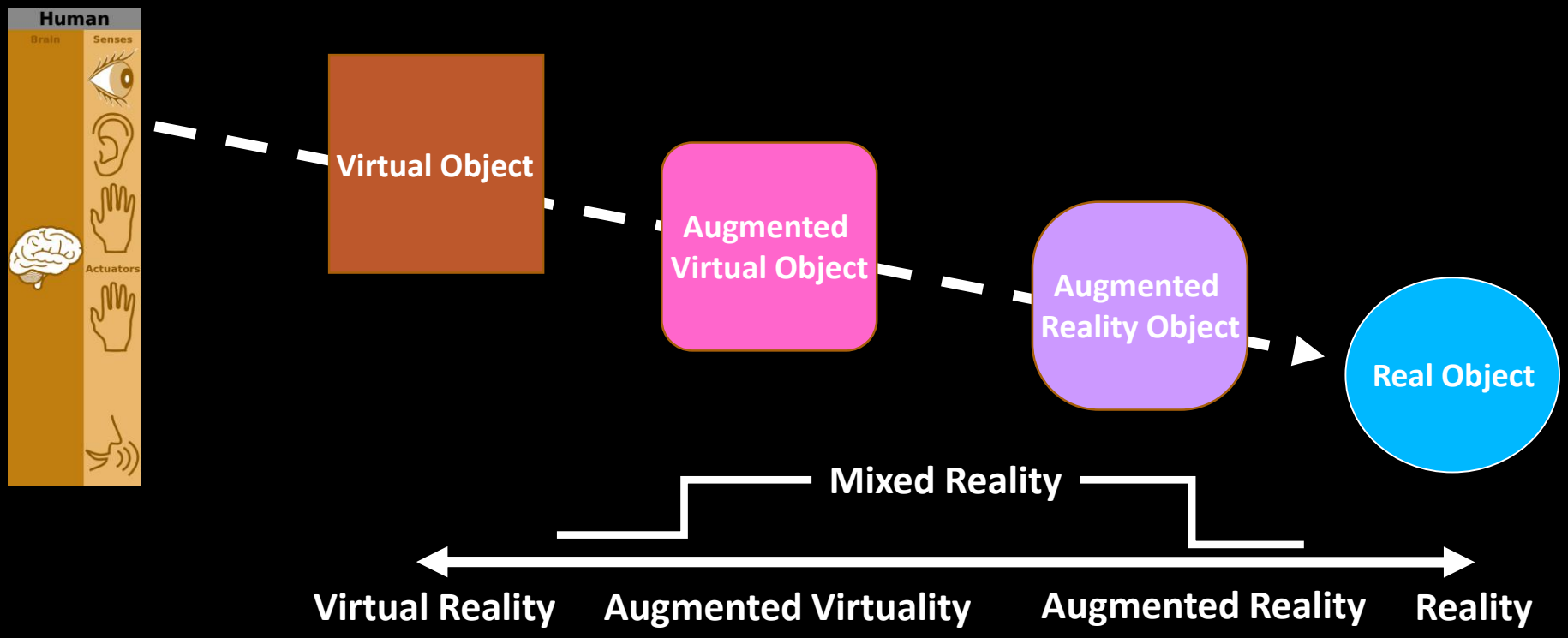


Reality

从现实到虚拟现实


Human
Brain
Senses
Actuators
Virtual Object
Real Object
Virtual Reality
Reality

从现实到虚拟现实


Human
Brain
Senses
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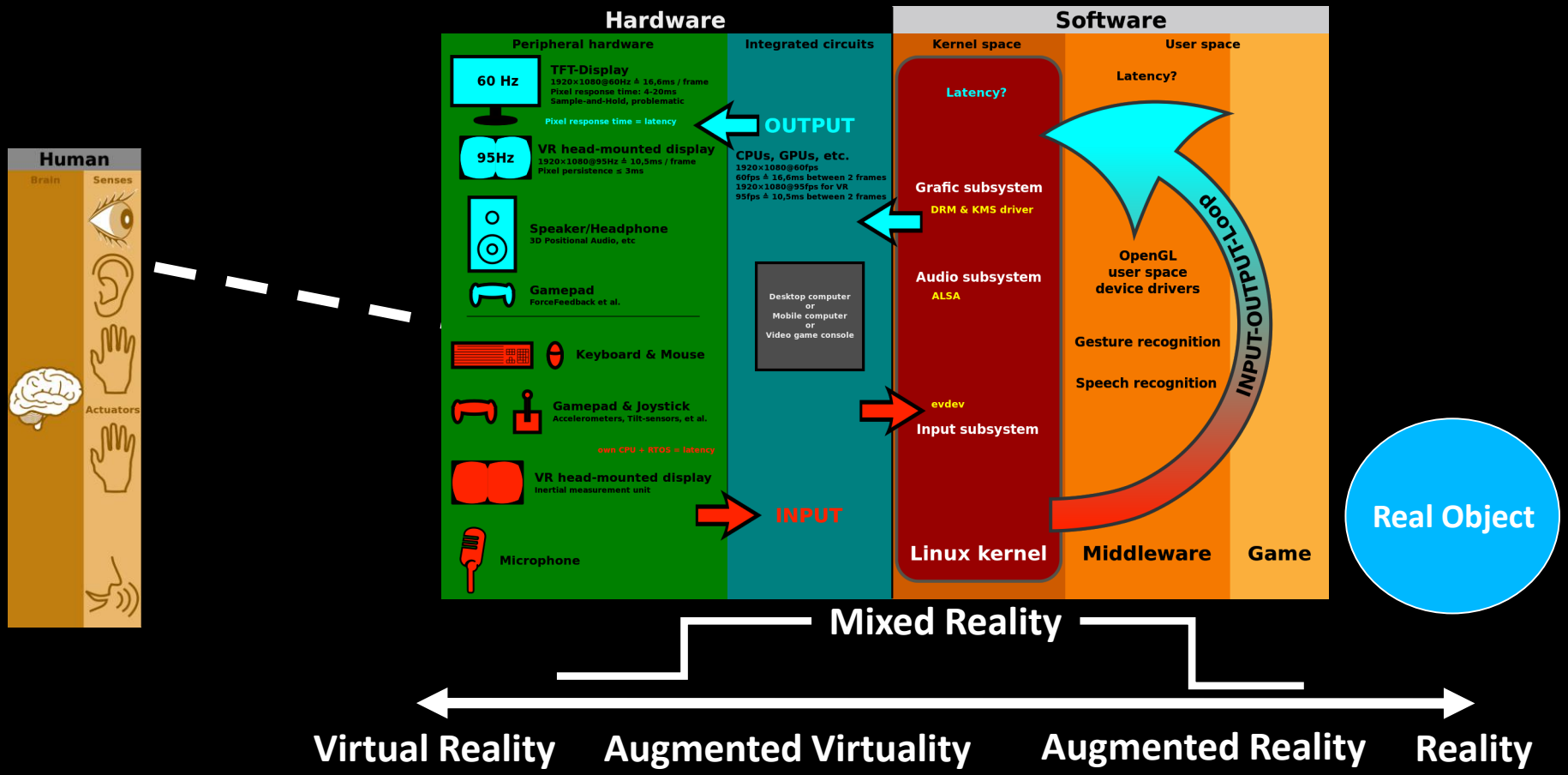
Virtual Object
Augmented Virtual Object
Augmented Reality Object
Real Object
Mixed Reality
Virtual Reality
Augmented Virtuality
Augmented Reality
Reality

从现实到虚拟现实


Human
Brain
Senses
Actuators
Hardware
Peripheral hardware
Integrated circuits
60 Hz
TFT-Display
1920×1080@60Hz ≙ 16,6ms / frame
Pixel response time: 4-20ms
Sample-and-Hold, problematic
Pixel response time = latency
95Hz
VR head-mounted display
1920×1080@95Hz ≙ 10,5ms / frame
Pixel persistence ≤ 3ms
Speaker/Headphone
3D Positional Audio, etc
Gamepad
ForceFeedback et al.
Keyboard & Mouse
Gamepad & Joystick
Accelerometers, Tilt-sensors, et al.
own CPU + RTOS = latency
VR head-mounted display
Inertial measurement unit
Microphone
OUTPUT
CPUs, GPUs, etc.
1920×1080@60fps
60fps ≙ 16,6ms between 2 frames
1920×1080@95fps for VR
95fps ≙ 10,5ms between 2 frames
Desktop computer
or
Mobile computer
or
Video game console
INPUT
Software
Kernel space
User space
Latency?
Latency?
Grafic subsystem
DRM & KMS driver
Audio subsystem
ALSA
evdev
Input subsystem
Linux kernel
OpenGL
user space
device drivers
Gesture recognition
Speech recognition
Middleware
Game
INPUT-OUTPUT-LOOP
Real Object
Mixed Reality
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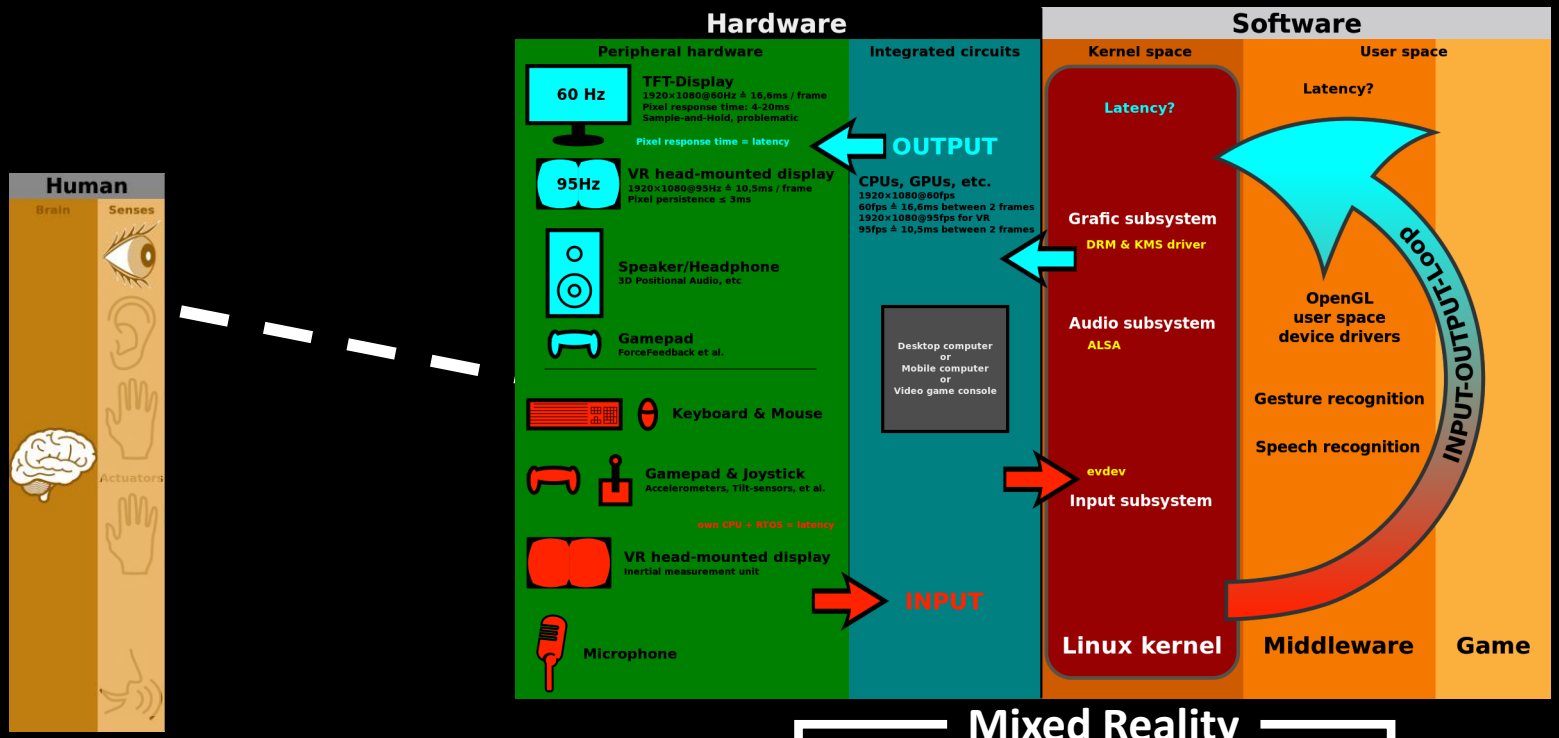
从视觉现实到视觉虚拟现实



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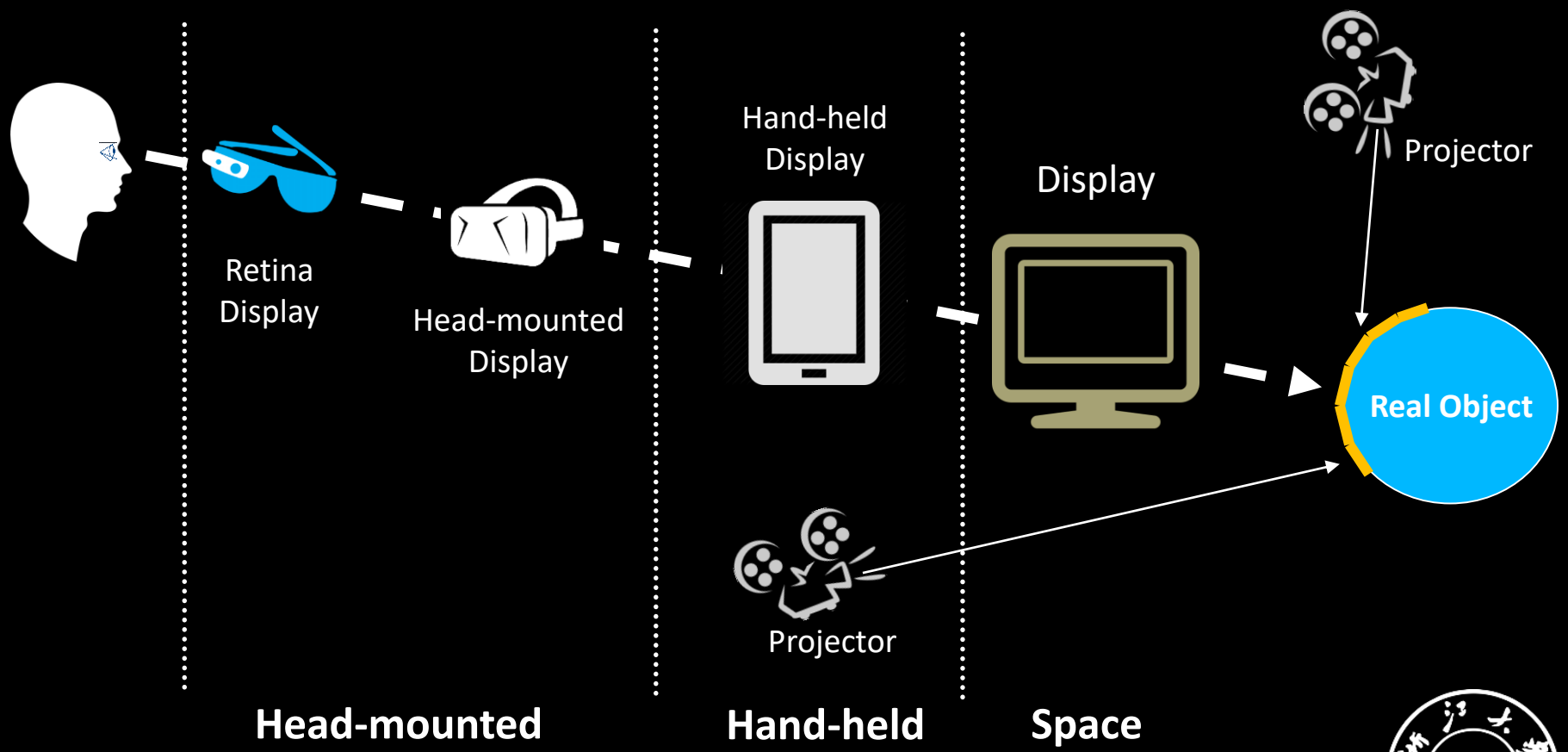

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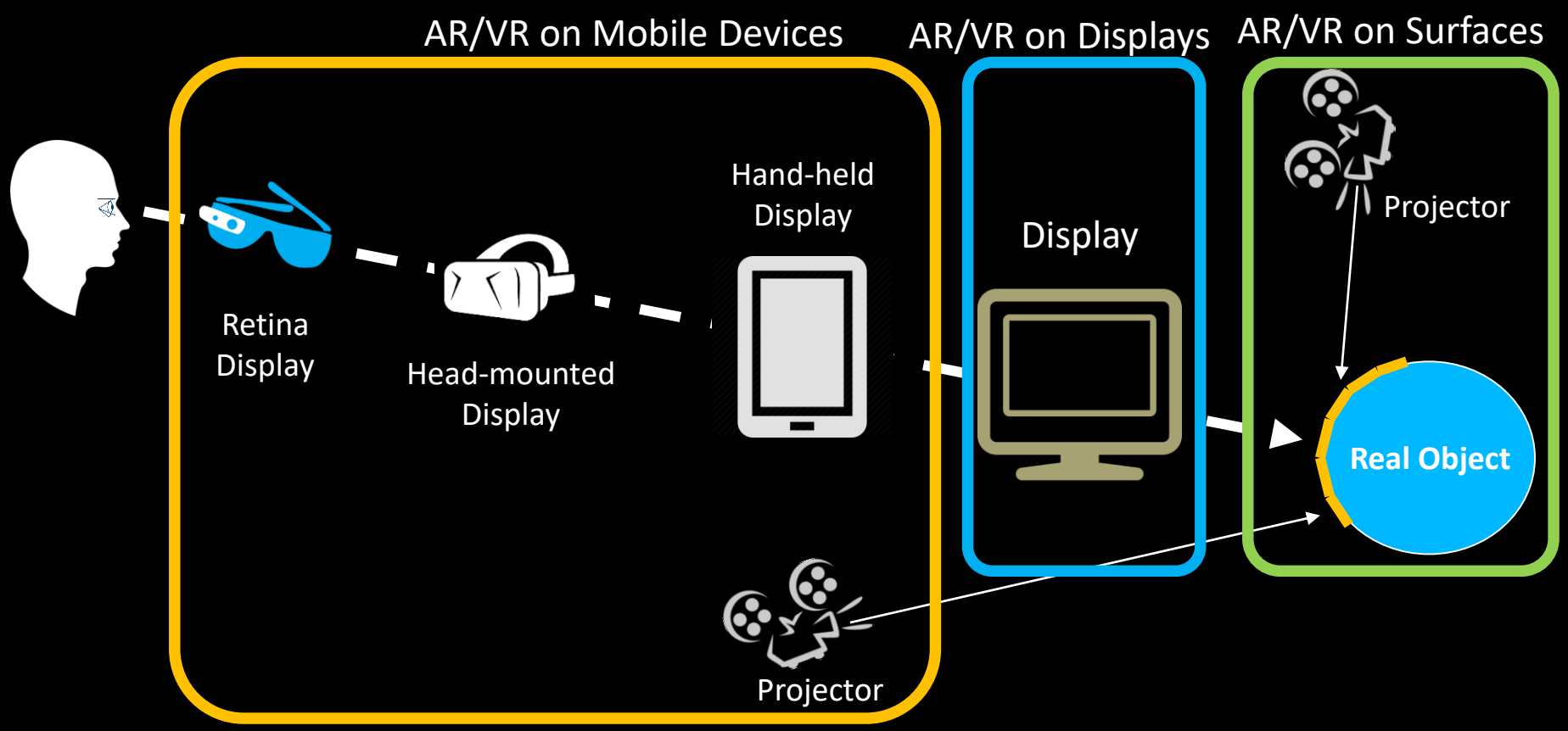

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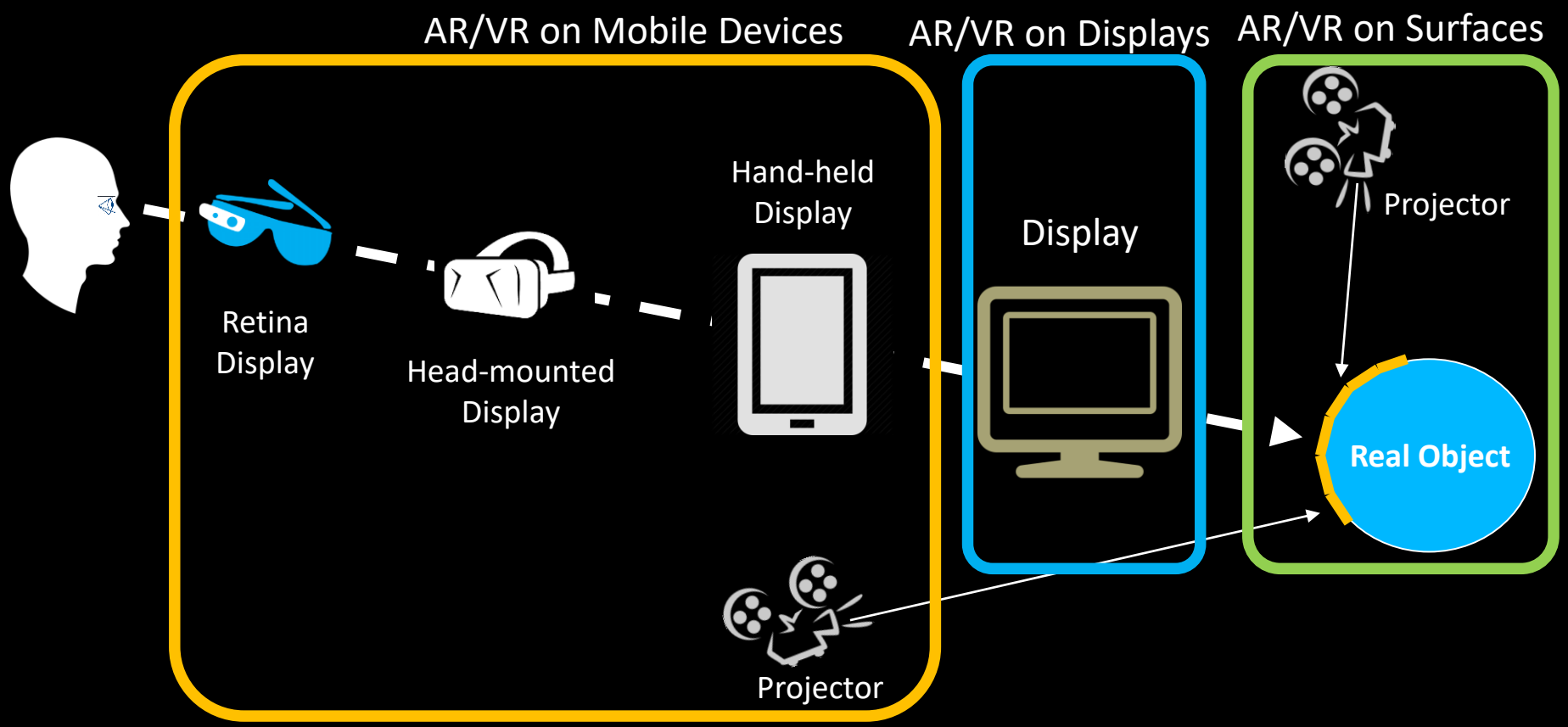

- 硬件 – 虚拟物体呈现原理与方案
- 软件 – 虚拟物体绘制技术

提纲

- 基于物体表面投影的VR/AR呈现技术
- 基于3D显示器的VR/AR呈现技术
- 基于穿戴式头盔眼镜的VR/AR呈现技术
- 总结

总结

- 不同的VR/AR呈现技术与方案
  - 基于物体表面的VR/AR方案
  - 基于3D显示器的VR/AR方案
  - 基于穿戴式头盔眼镜的VR/AR方案

- 基于显示硬件的绘制流失线

基于物体表面投影的VR/AR呈现技术

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    (project virtual scene on surface)
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  - **视差式 Parallax-based**
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    - 光场式 Lightfield
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    - 动态全息 Dynamic
      (holovideo)

- **基于眼镜的显示设备 Glasses-bound Stereoscopic**
  - **头戴式 head mounted**
    (eyepiece-objective and microdisplay)
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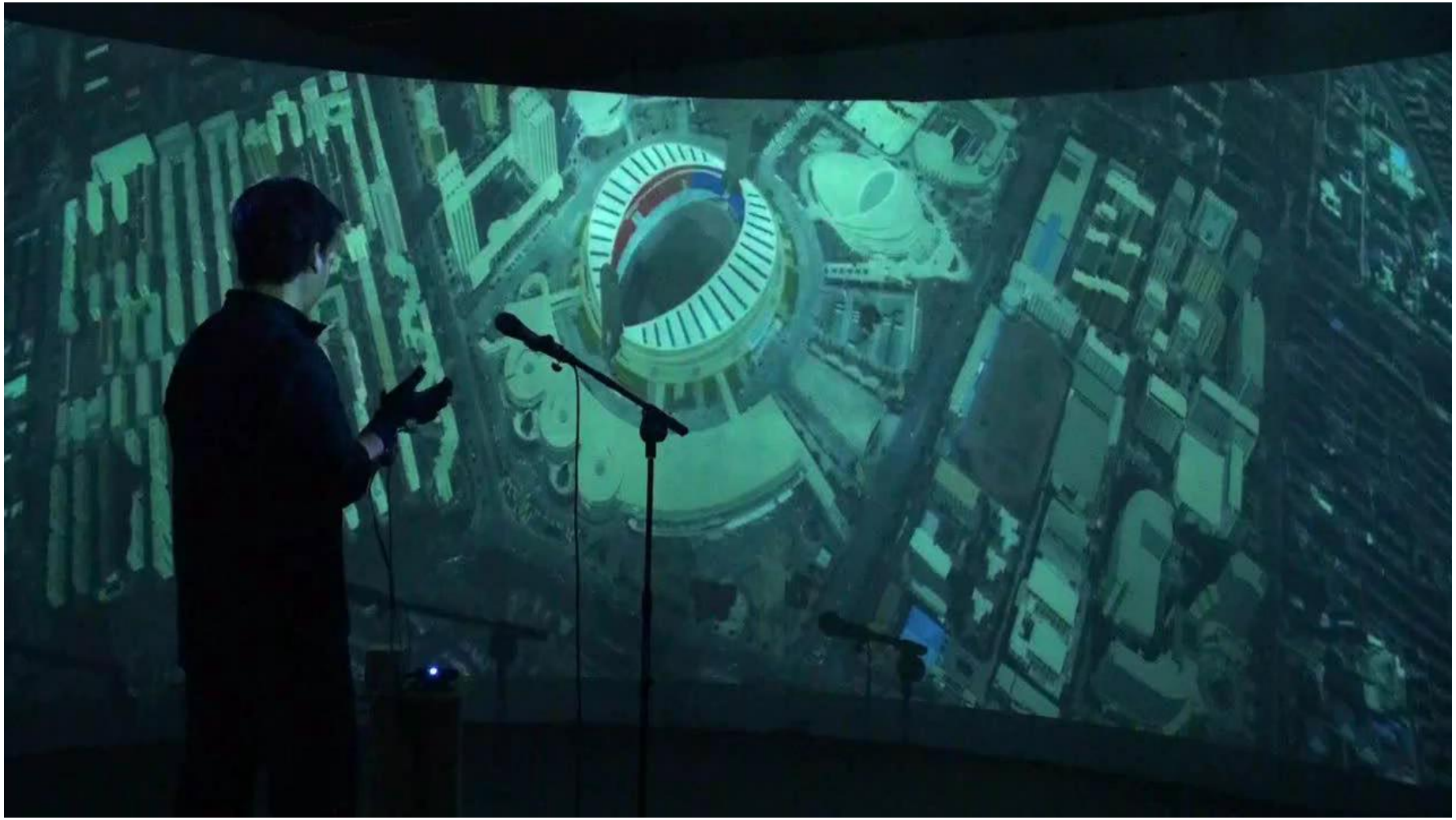
      (blocks direct-viewing of real world)
    - 穿透式 See-through
      (superimposes synthetic images onto real world)
  - **像素重用 multi-pixels**
    (stereo pair with same display surface)
    - 基于空域的像素重用
      Spatially-multiplexed (field-concurrent)
      (color filters, polarizers, autostereograms, etc.)
    - 基于时域的像素重用
      Temporally-multiplexed (field-sequential)
      (LCD shutter glasses)

Taxonomy adapted from Hong Hua

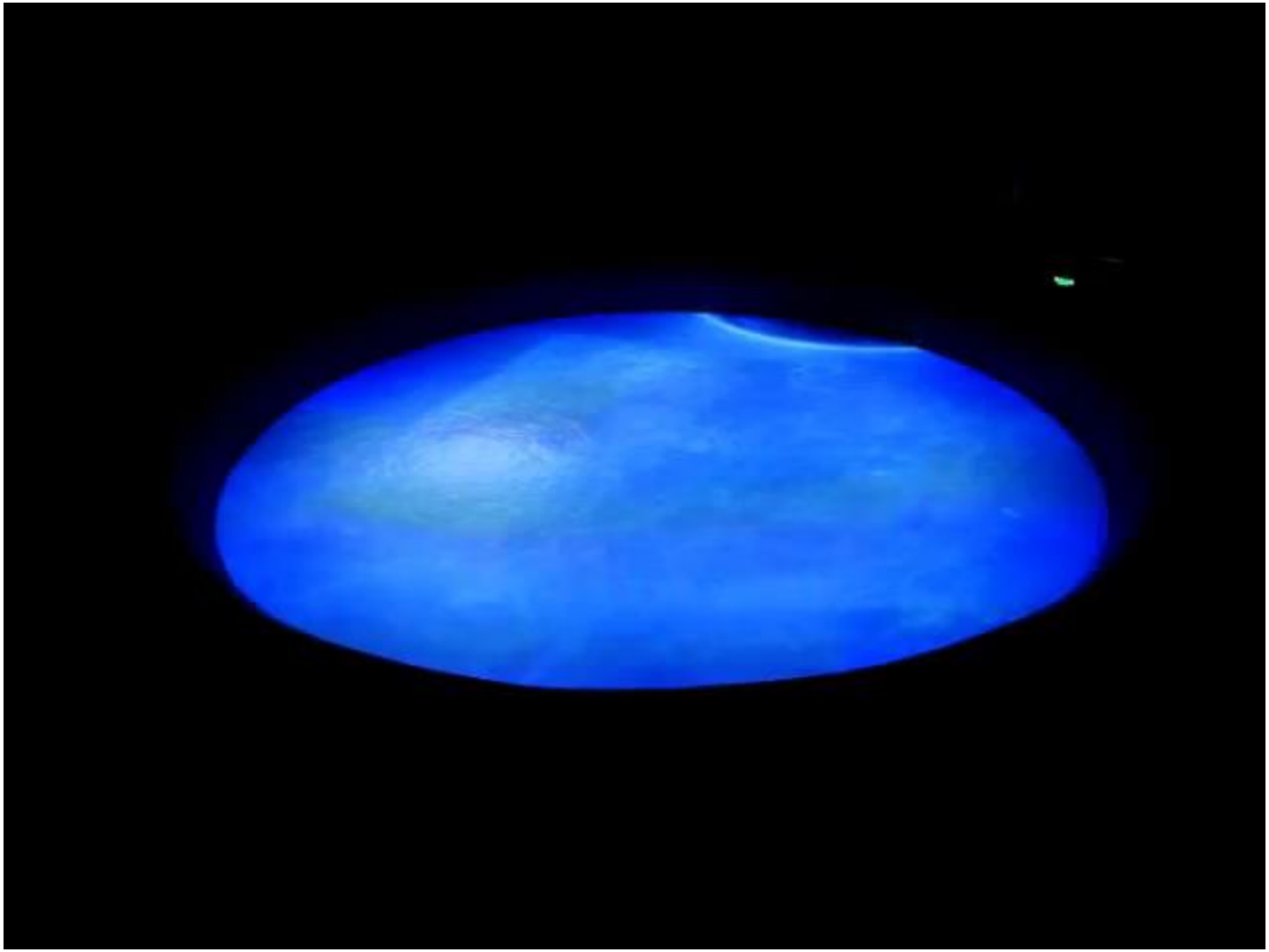
基于表面的VR呈现技术-示例

- 360°沉浸式交互显示系统



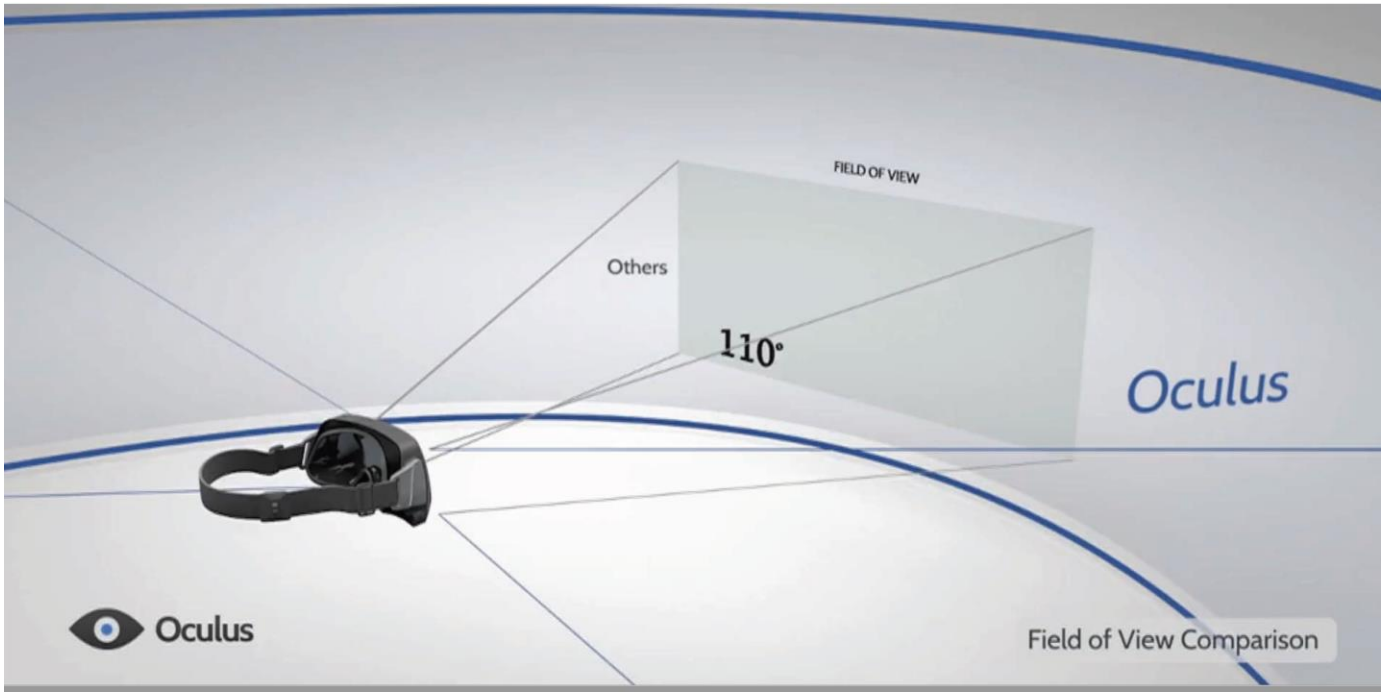
基于表面的VR呈现技术-示例

- 世博浙江馆

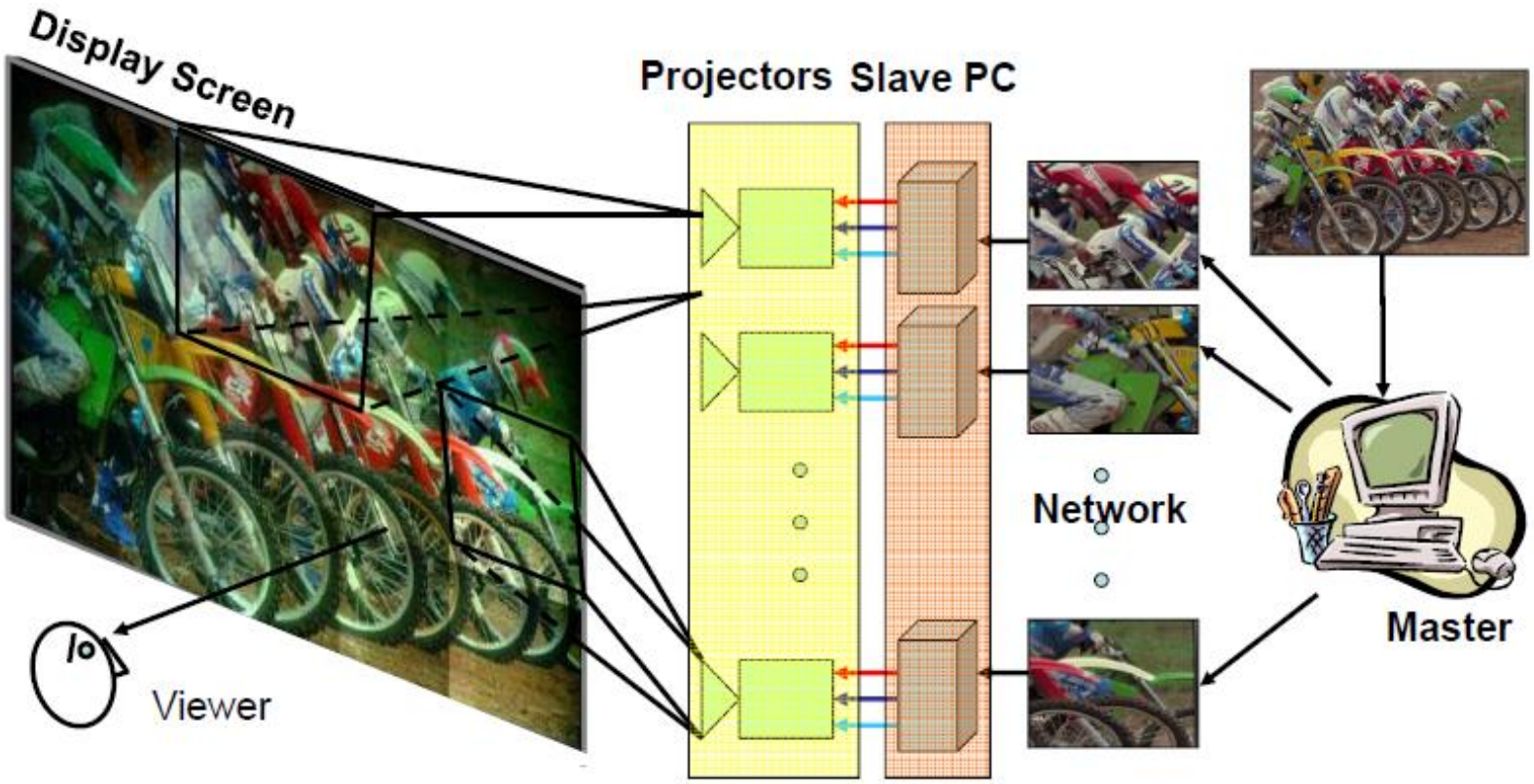


基于表面的VR呈现技术

- 更大的视域
- 较少的聚焦辐辏矛盾
- 较低的延迟误差



多投影显示系统构成

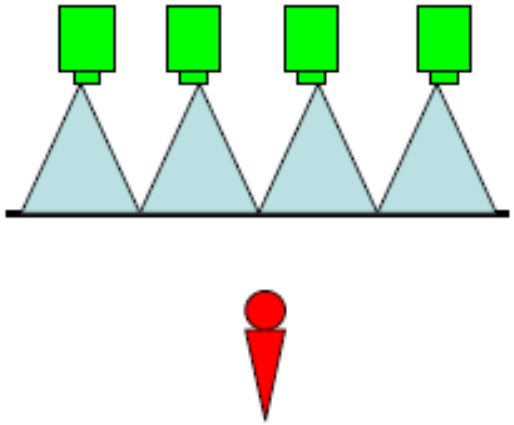


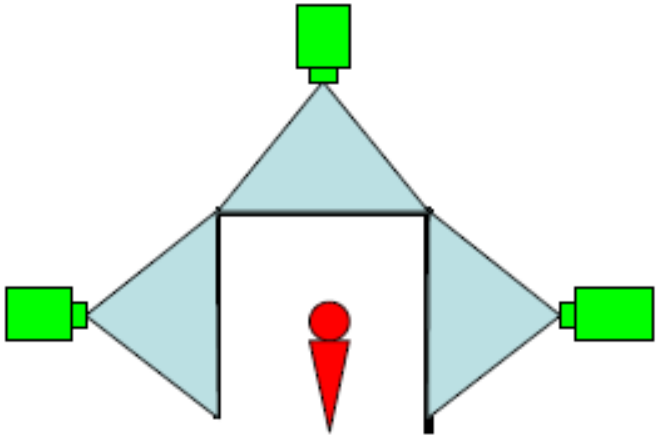
多投影显示系统构成

- 硬件
  - 计算机（集群）
  - 投影仪阵列
  - 网络
- 软件
  - 多投影仪投影画面拼接技术
  - 多投影仪网络绘制驱动技术

第一代多投影仪显示系统

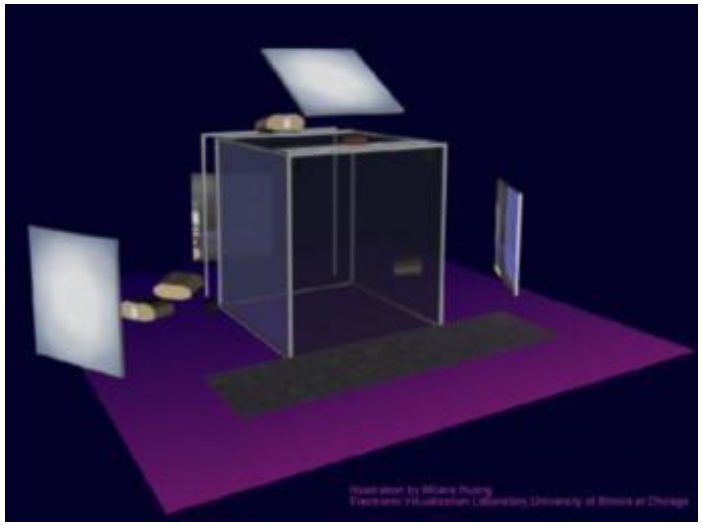
- 分片对齐
- 硬件化的绘制方法（将校准固化于硬件设备中）





多投影显示系统-示例

- CAVE



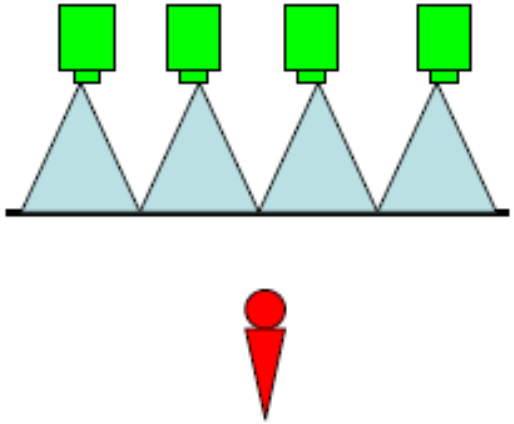
Design of a CAVE

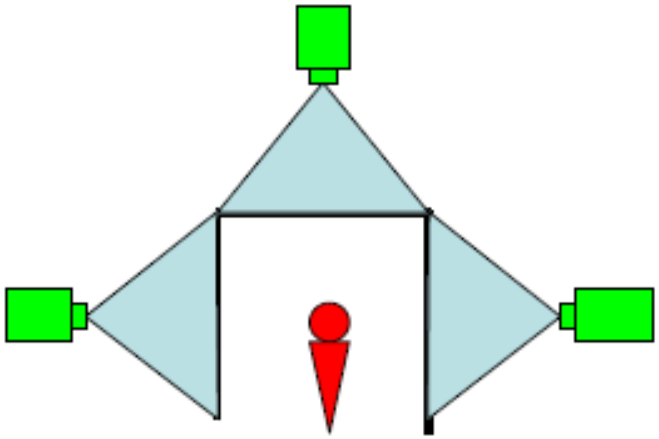
第一代多投影仪显示系统

- 专用的拼接投影仪，价格昂贵
  - Projectors ($75,000)
  - SGI Infinite Reality ($1,000,000)
- 手动校准
  - Expensive 6 DOF mounts
  - Fresnel lens
  - Manual manipulation
  - Projector and mount controls

第一代多投影仪显示系统

- 局限性：
  - 受限制的拼接方式
  - 扩展性很差、配置方式受限
  - 需要大量的人工工作





第二代（当前）多投影仪显示系统

- 技术特征（与第一代最大的不同）
  - 能够利用廉价设备
    - 普通投影仪、普通计算机（集群）驱动
  - 方便配置、具有较好的扩展性
  - 尽量减少人工的工作，能自动拼接
- 硬件技术的发展
  - 硬件越来越便宜

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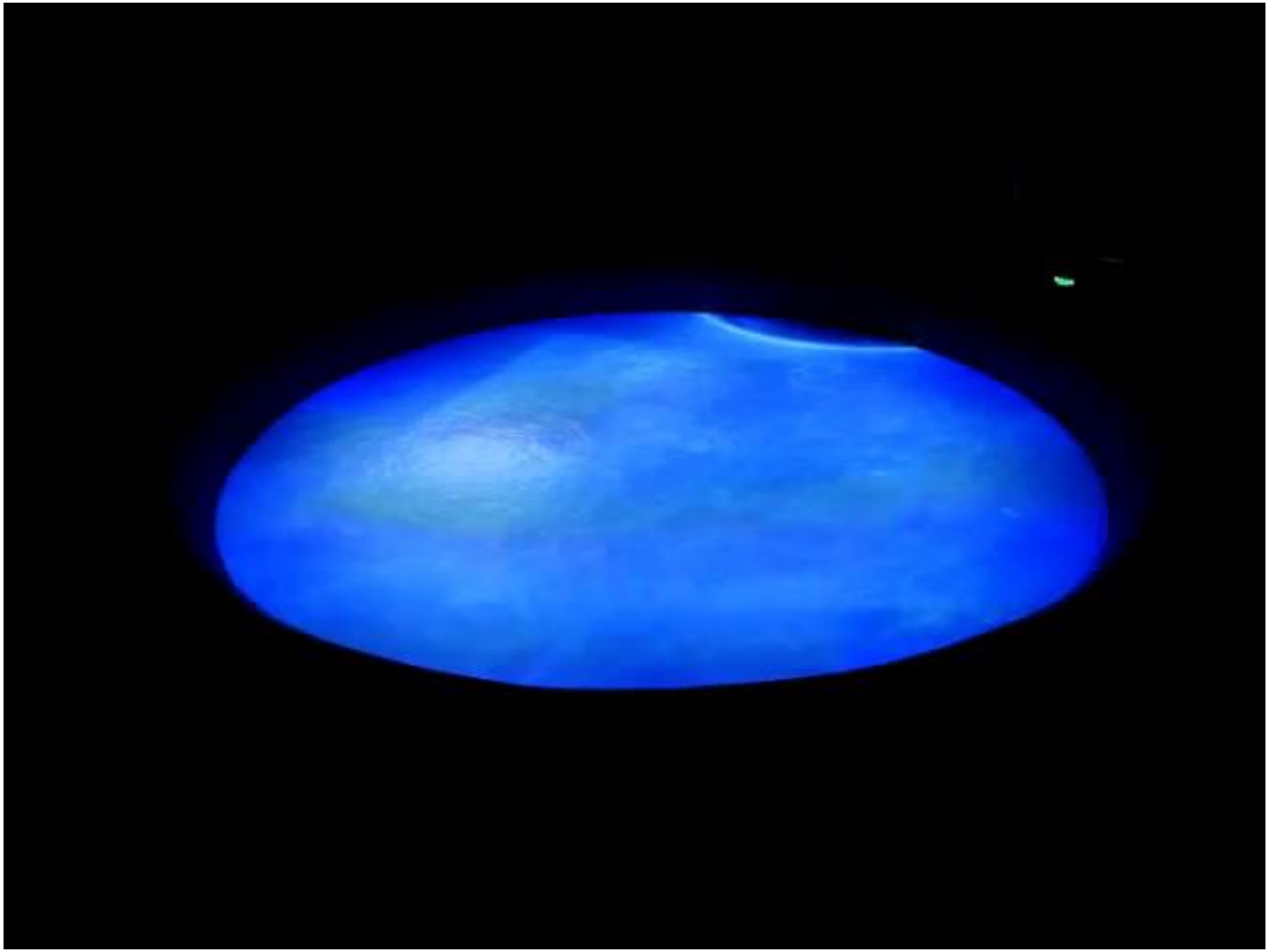
- 硬件技术的发展
  - 硬件越来越便宜
- 软件技术的发展
  - 采用了基于照相机（视觉）的解决方案

基于表面的VR呈现技术-示例

- 世博浙江馆



多投影显示系统-示例

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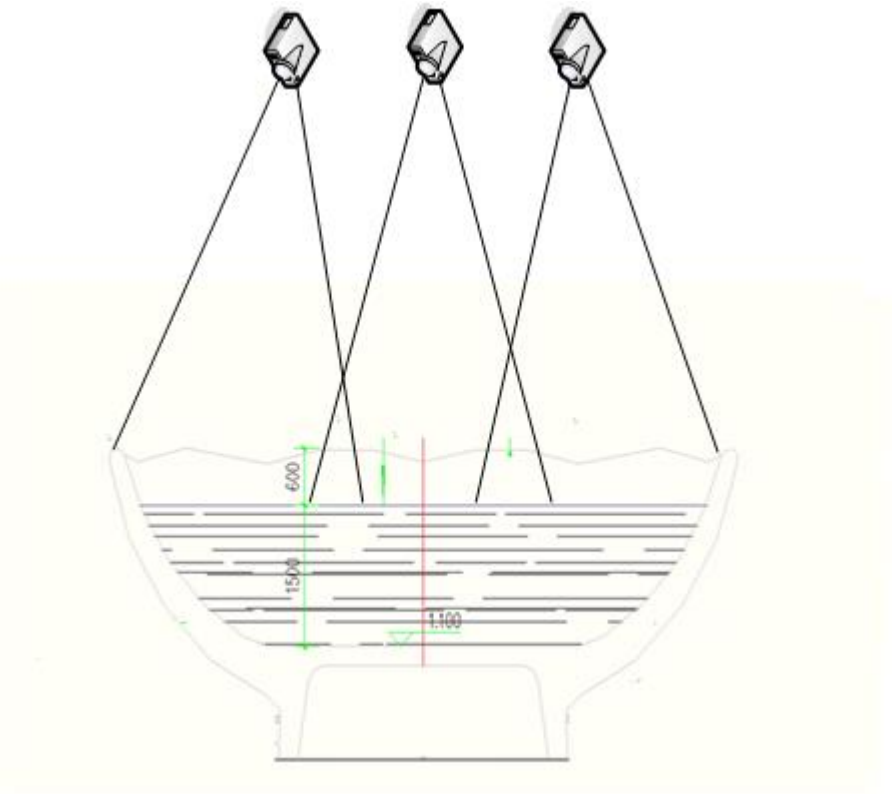
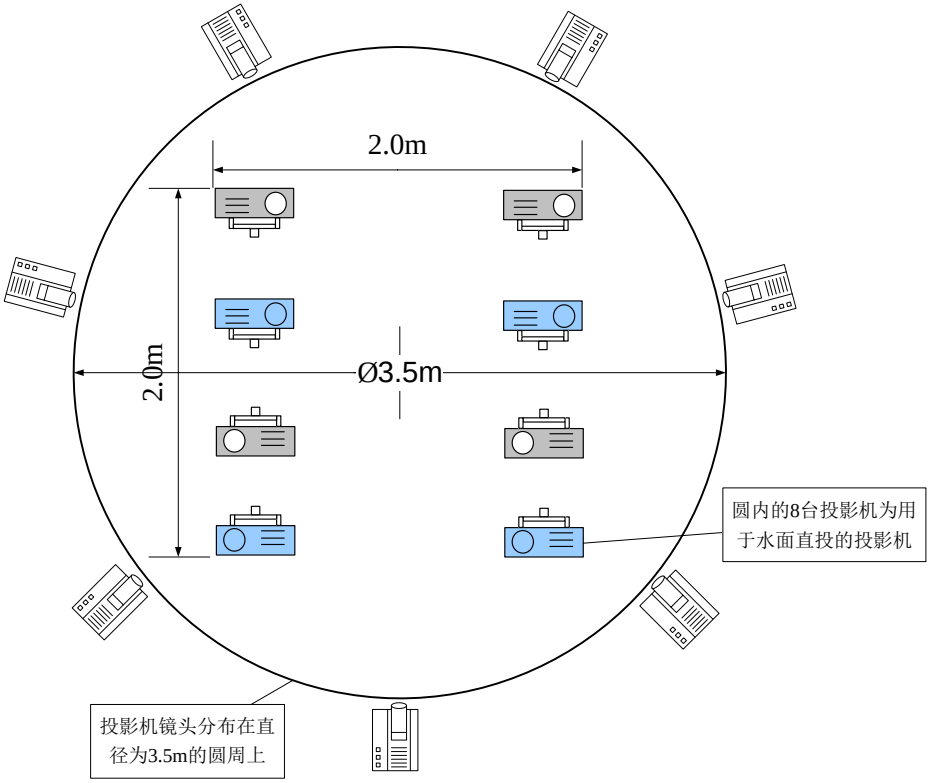
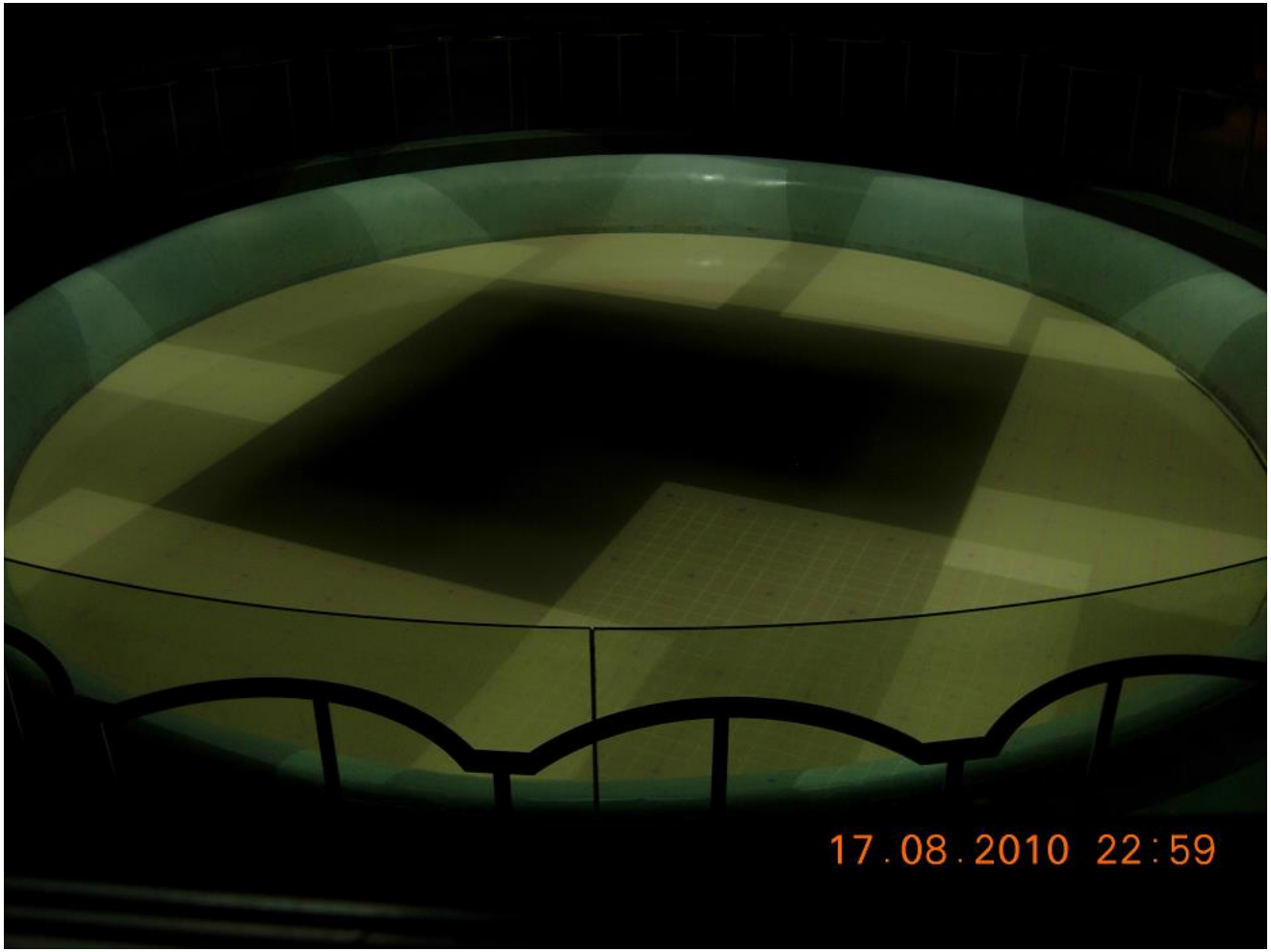
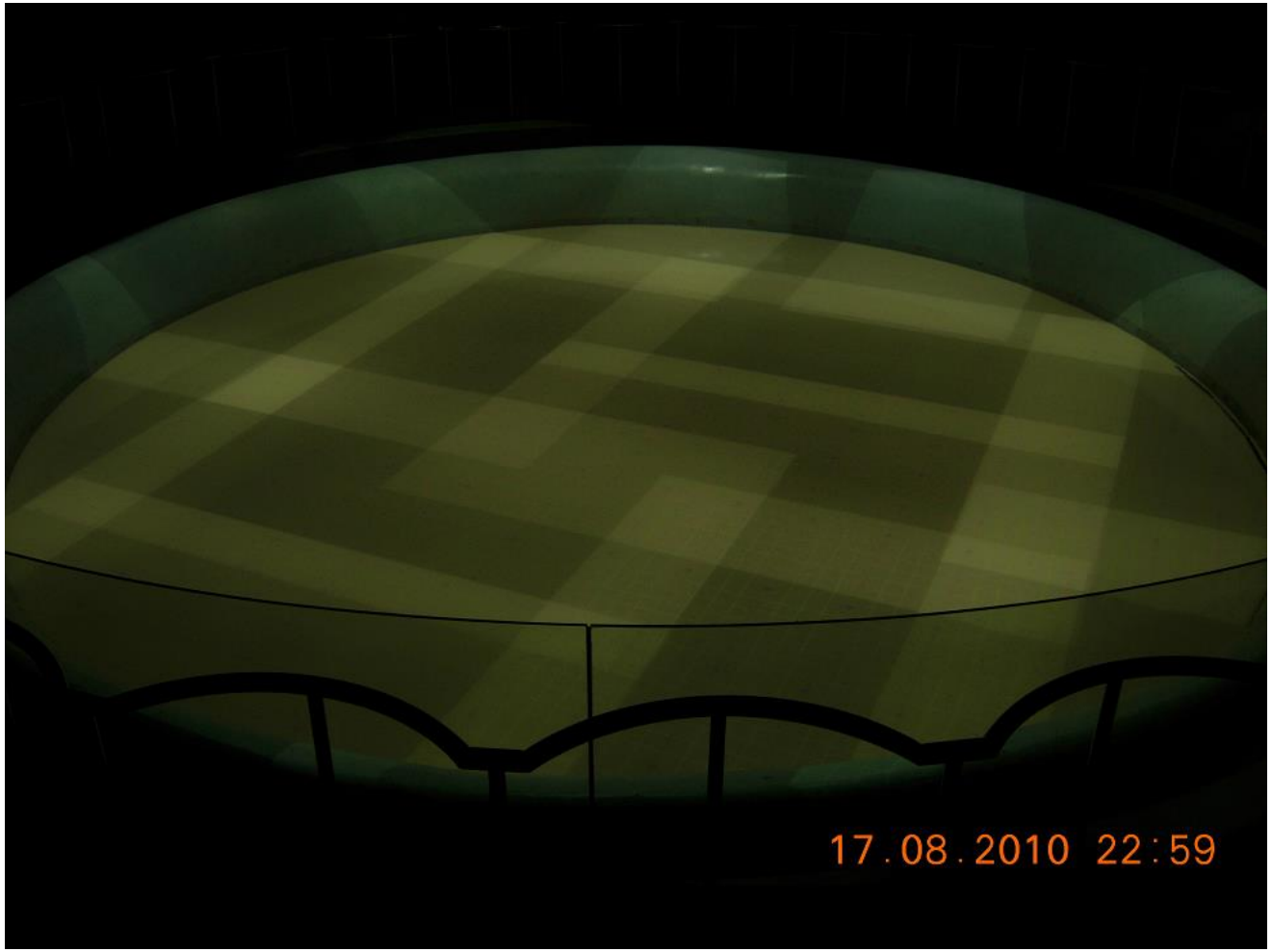




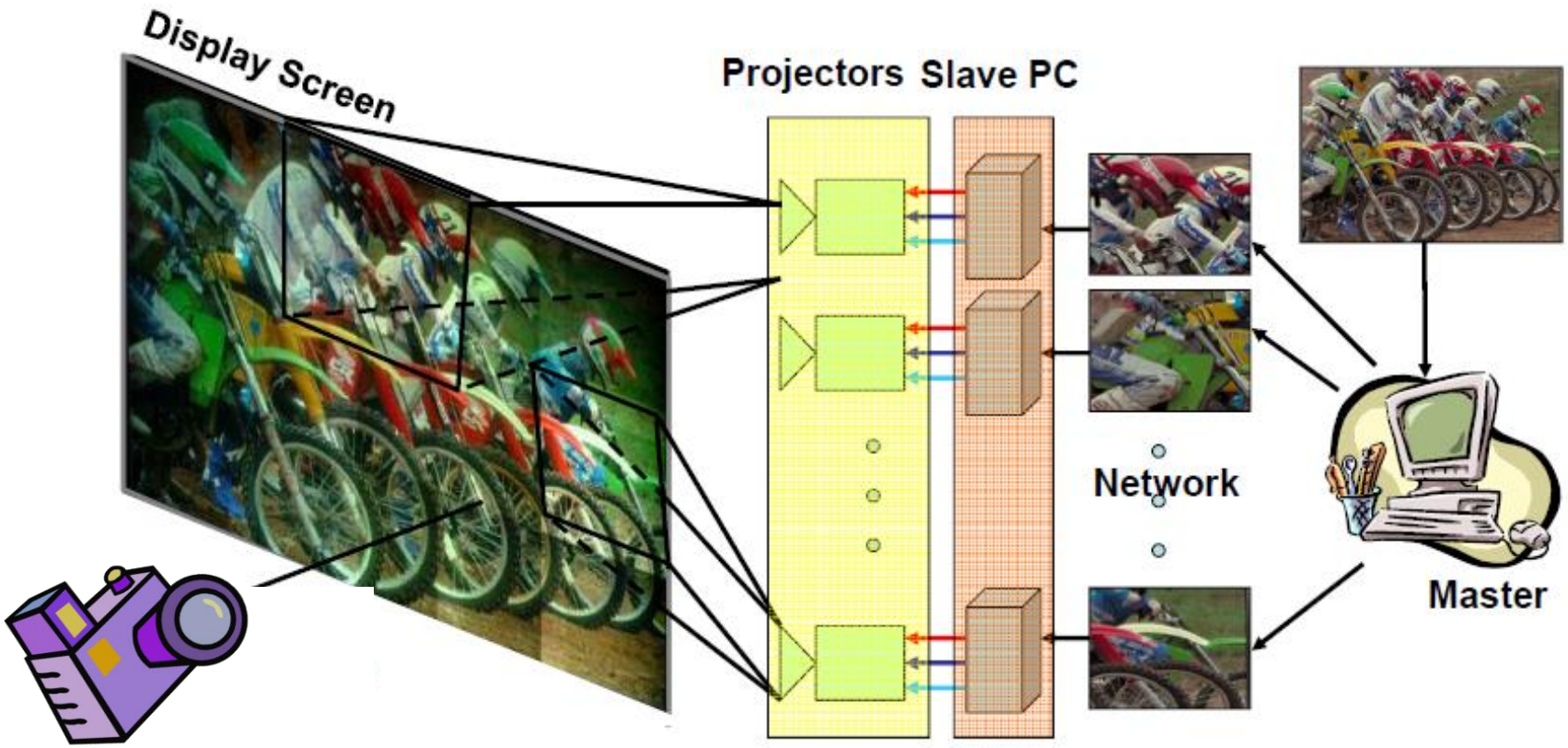
存在的主要问题—几何存在误差



存在的主要问题—颜色存在误差



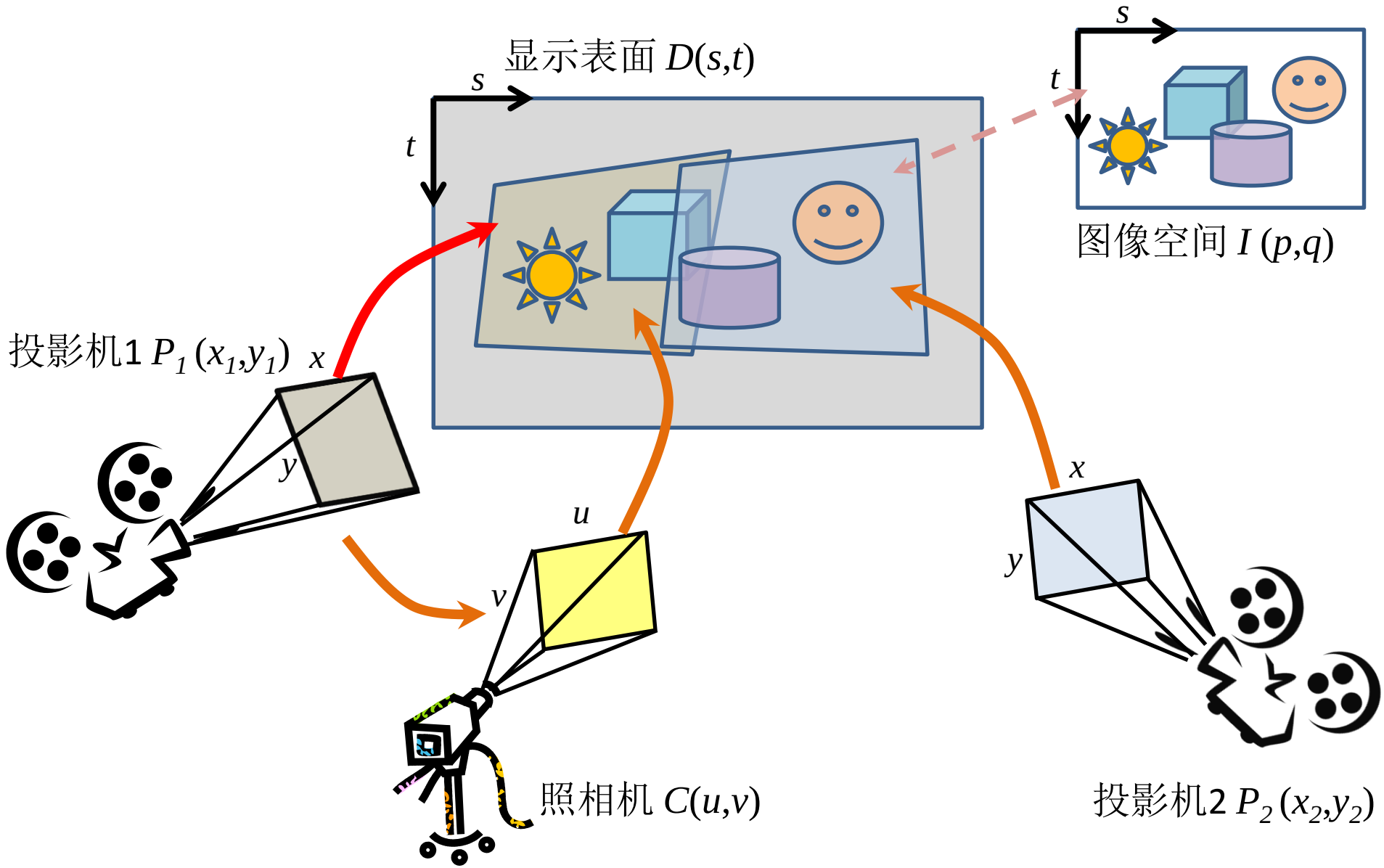
基于照相机（视觉）的解决方案



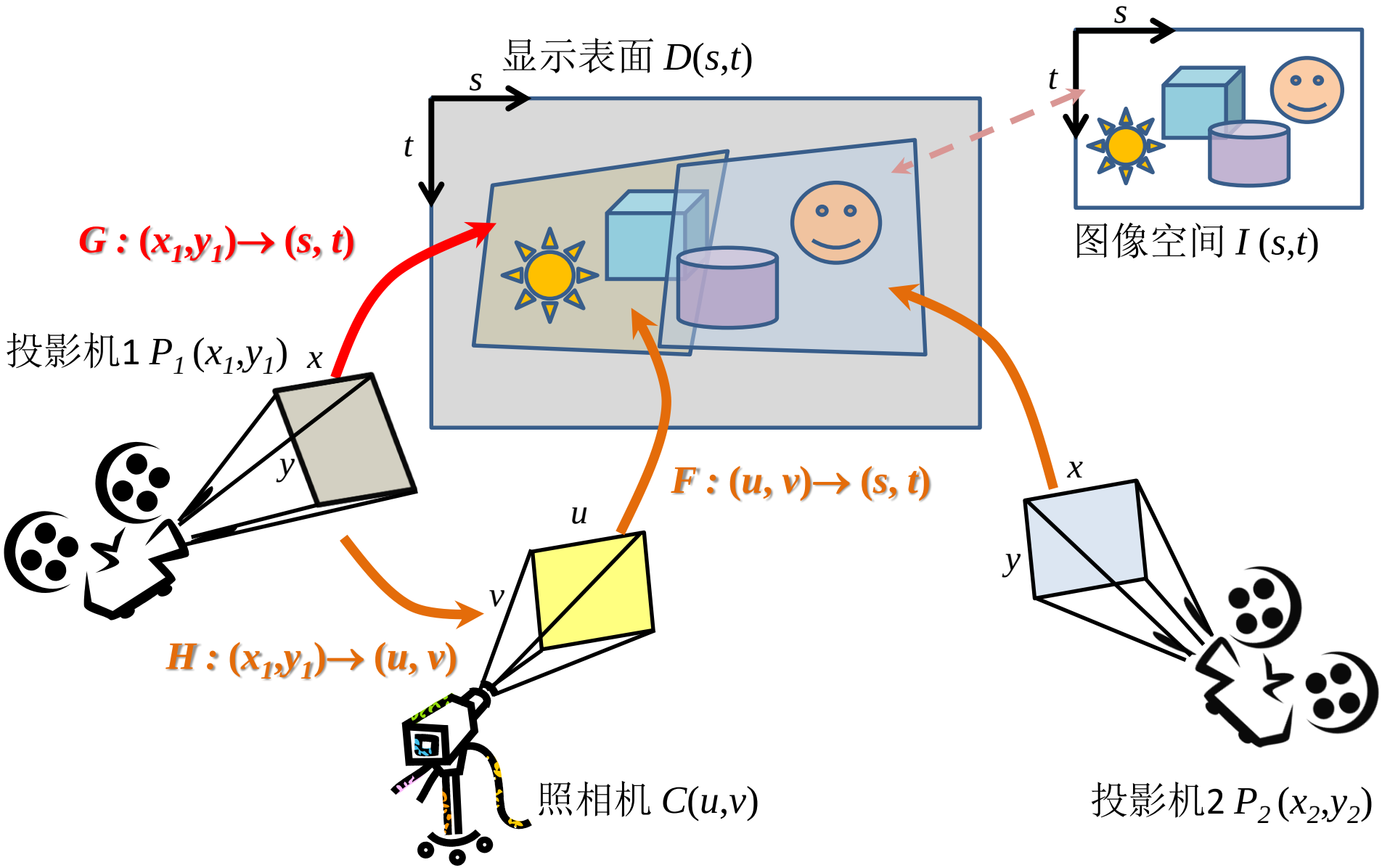
基于照相机（视觉）的解决方案

- 利用照相机检测不一致
  - 几何不一致
  - 颜色不一致
- 将不一致用函数表示（通过计算得到）
  - 几何矫正函数
  - 颜色校正函数
- 将计算得到的函数应用于投影拼接中
  - 将逆函数应用到投影中消除不一致
  - 保证拼接的实时性（预扭曲或GPU-based solution）

基于照相机的解决方案


显示表面 $D(s,t)$
s
t
图像空间 $I(p,q)$
s
t
投影机1 $P_1(x_1,y_1)$
x
y
u
v
照相机 $C(u,v)$
x
y
投影机2 $P_2(x_2,y_2)$

几何矫正的基本思路


显示表面 $D(s,t)$
s
t
图像空间 $I(s,t)$
s
t
$G:(x_1,y_1)\rightarrow(s,t)$
投影机1 $P_1(x_1,y_1)$
x
y
$F:(u,v)\rightarrow(s,t)$
u
v
$H:(x_1,y_1)\rightarrow(u,v)$
照相机 $C(u,v)$
x
y
投影机2 $P_2(x_2,y_2)$

平面显示

- 几何矫正前

平面显示

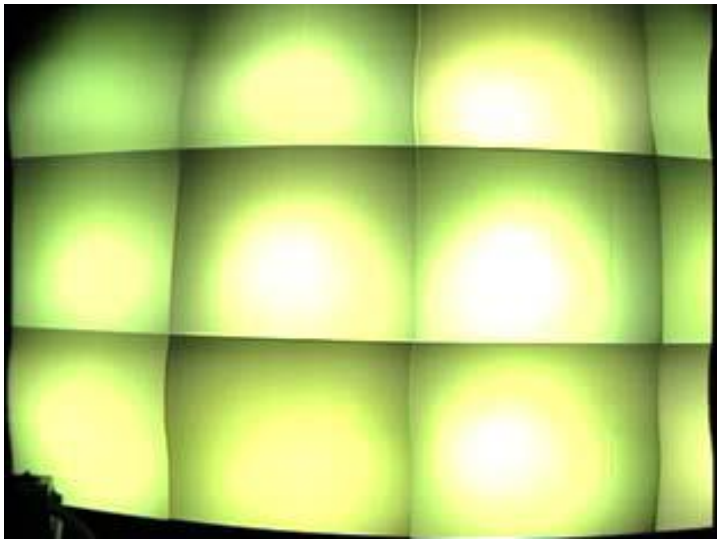
- 几何矫正后

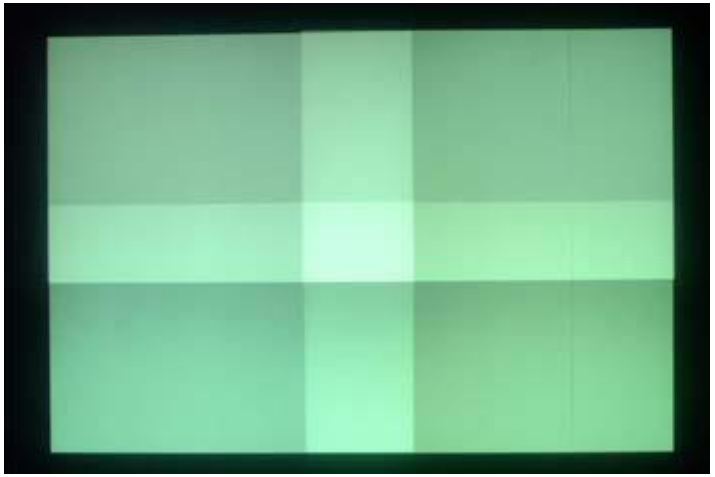
构建多通道投影技术

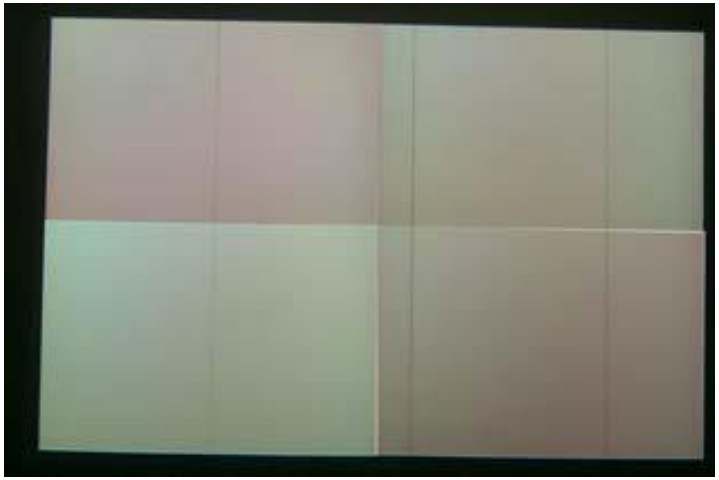
- 几何矫正
- **颜色校正**

多投影的颜色不一致问题种类

- 内部不一致
  - 单投影机内
- 外部不一致
  - 不同投影仪间的
- 重叠区域







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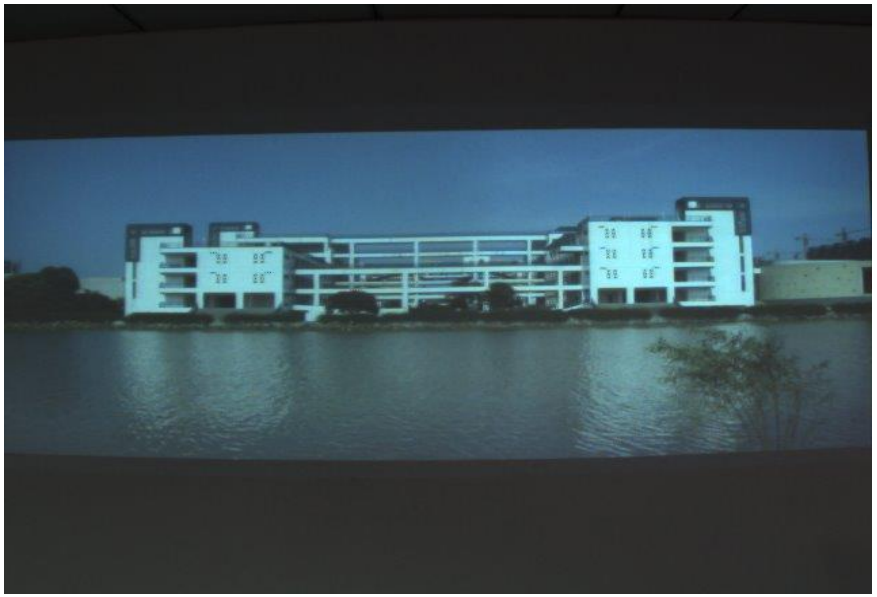
投影机颜色重构与调整

边缘融合

边缘融合

- 结果

校正前



校正后

基于裸眼3D显示器的VR/AR呈现技术

王锐 Rui Wang
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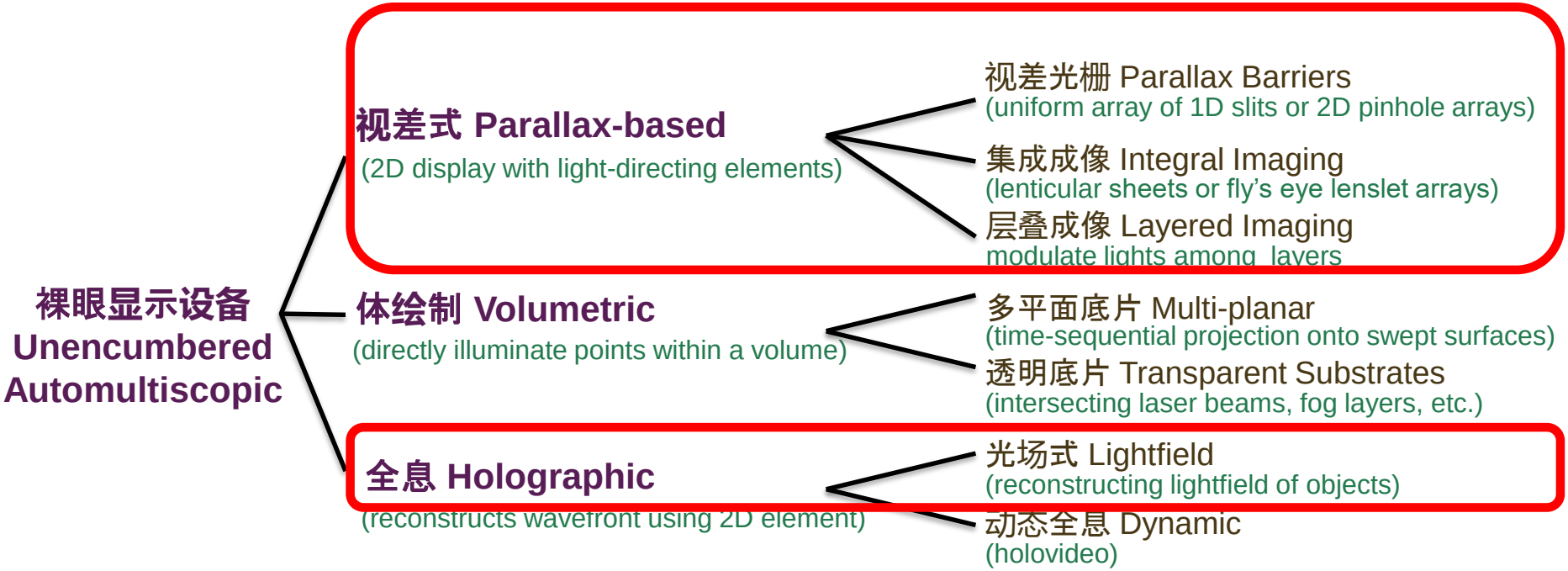
    (stereo pair with same display surface)
    - 基于空域的像素重用
      Spatially-multiplexed (field-concurrent)
      (color filters, polarizers, autostereograms, etc.)
    - 基于时域的像素重用
      Temporally-multiplexed (field-sequential)
      (LCD shutter glasses)

Taxonomy adapted from Hong Hua

裸眼3D显示设备原理



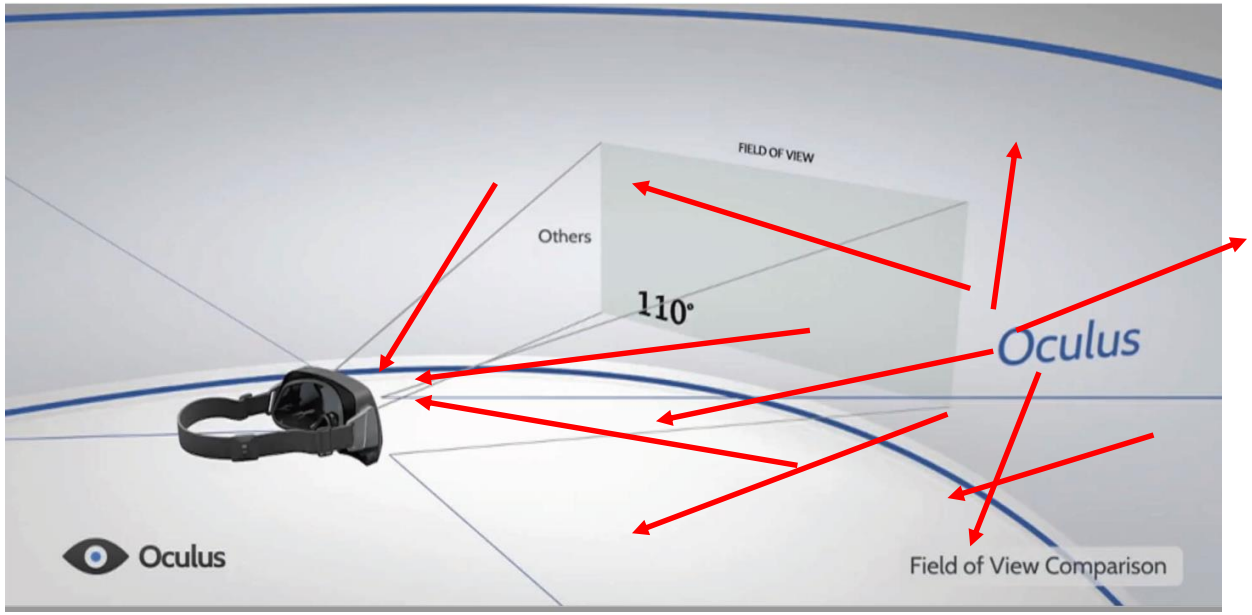
- 视差式显示器
  - 视差光栅
  - 集成成像
- 光场式

视差式显示器

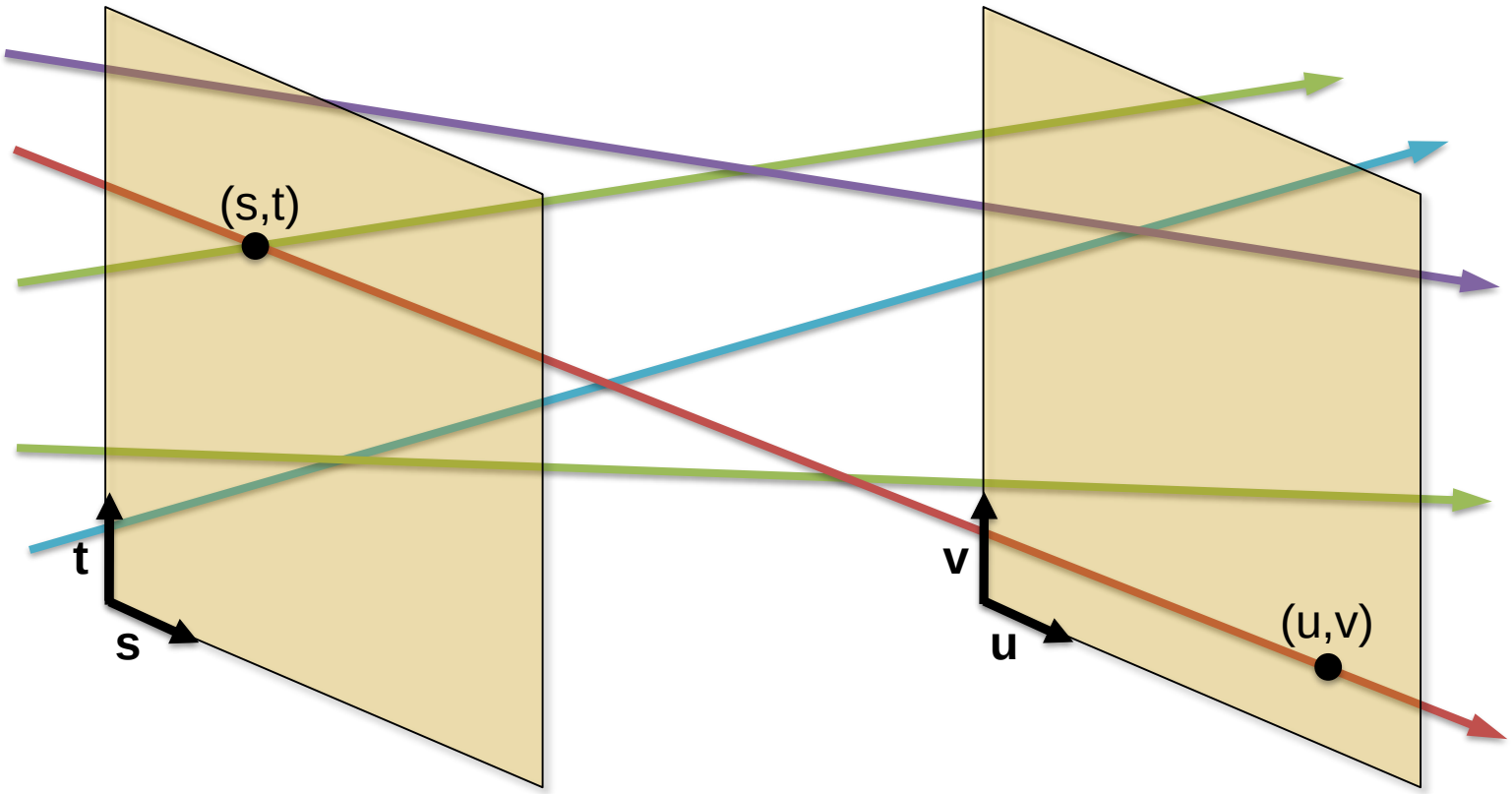
全光函数

- 3D 为视点
- 2D 为视线方向
- 1D 为波长（颜色）
- 1D 为时间

$$R(X, Y, Z, \theta, \phi, \lambda, t)$$



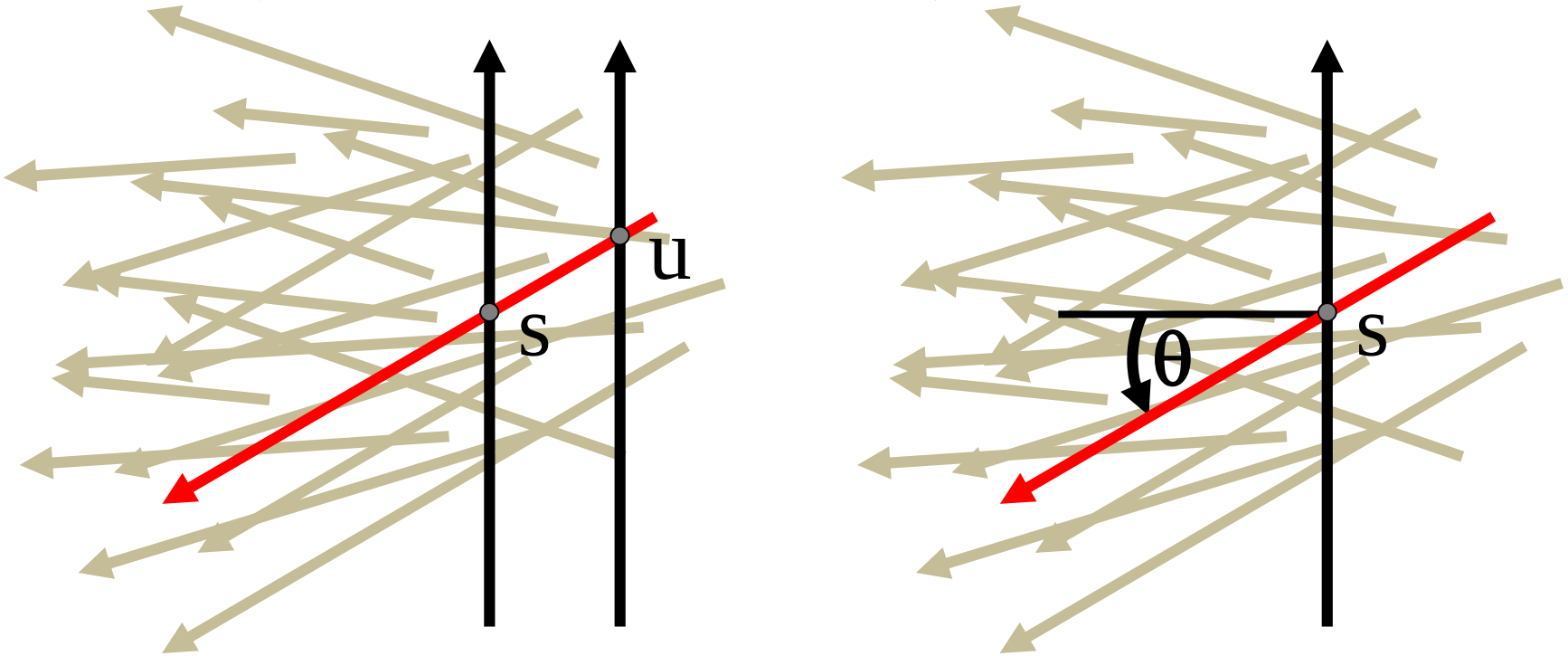
光场的一种参数化形式



光场表示

- 用两个参数化的平面表示，任一根光线都可以用这两个平面上的两个点表示。因此光场是一个4维的空间

光场的一种参数化形式

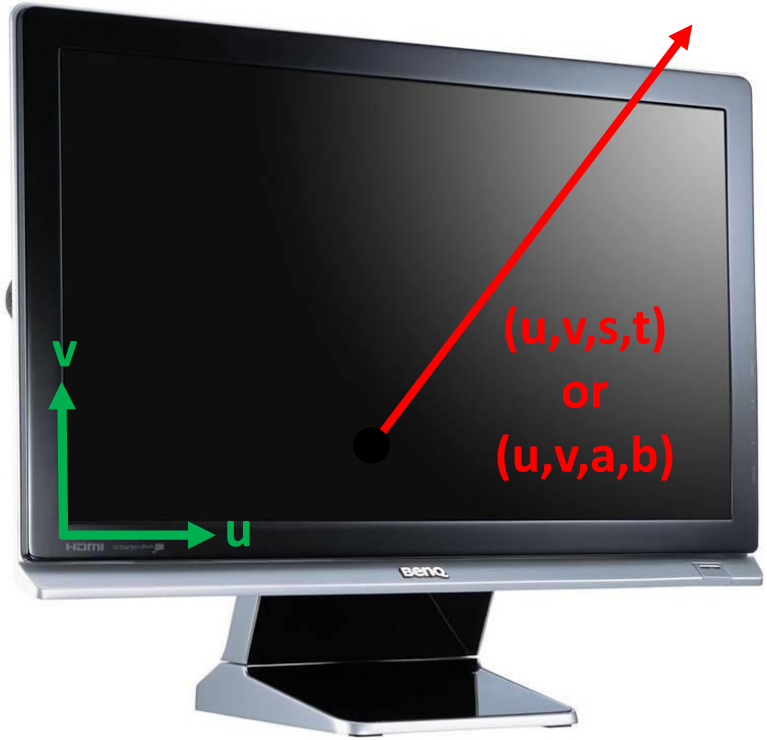


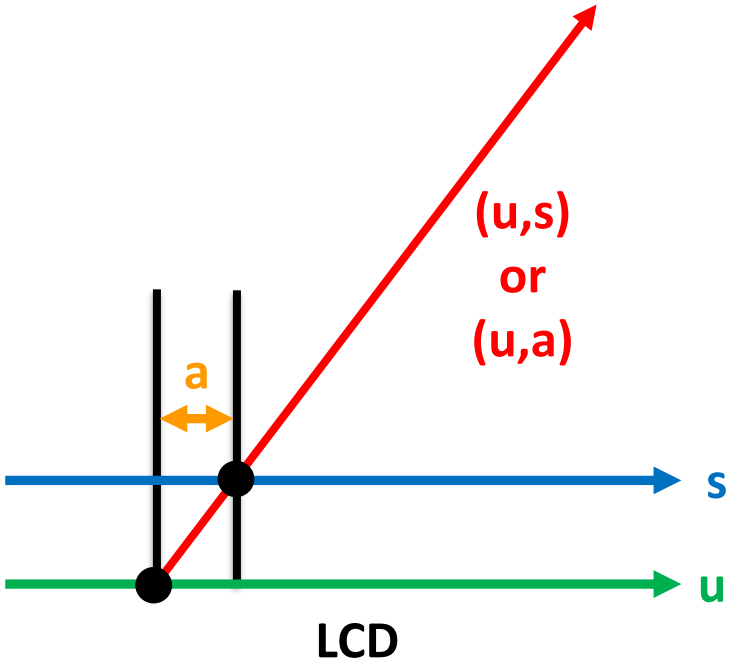
Two Plane Parameterization **Position-Angle Parameterization**

光场表示

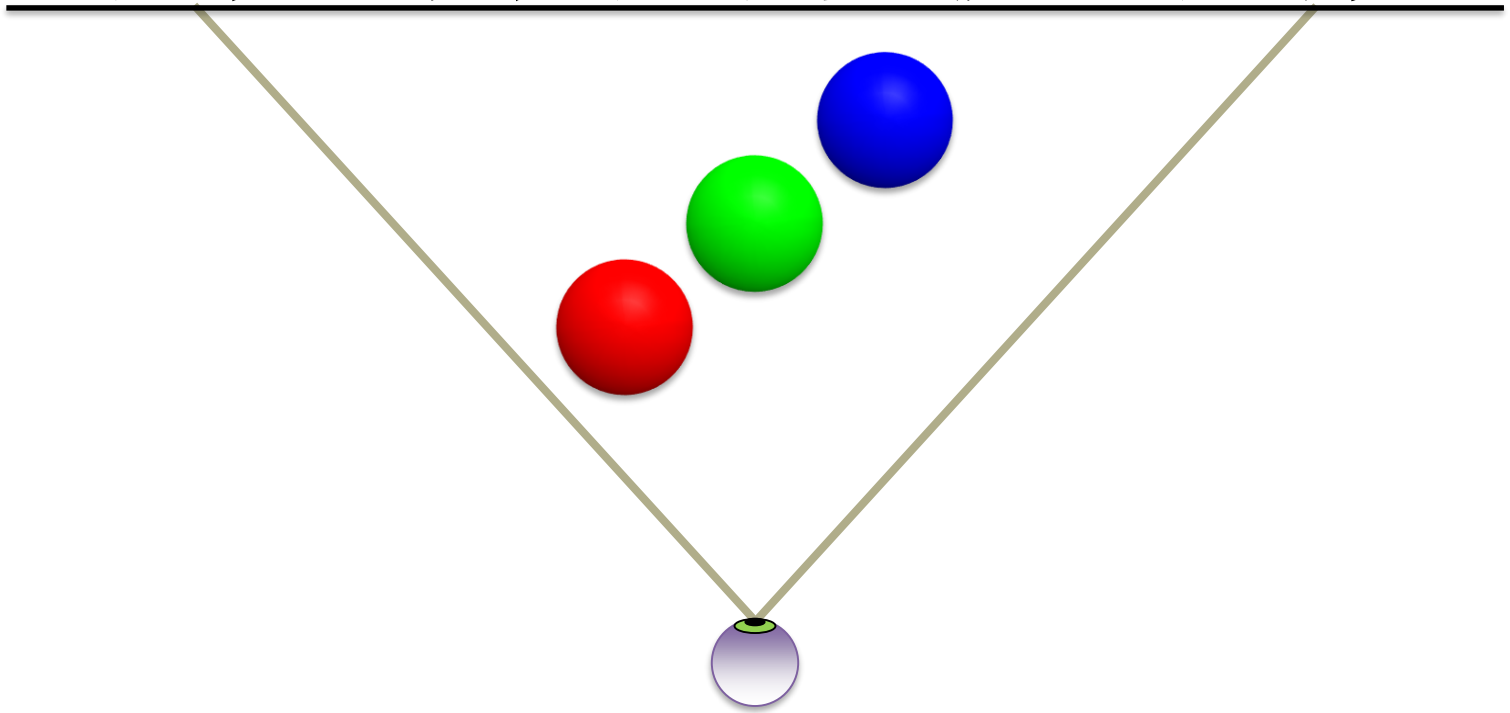
- 另一种表示方式，空间位置+角度，也是4维的表示

用光场来表示3D显示

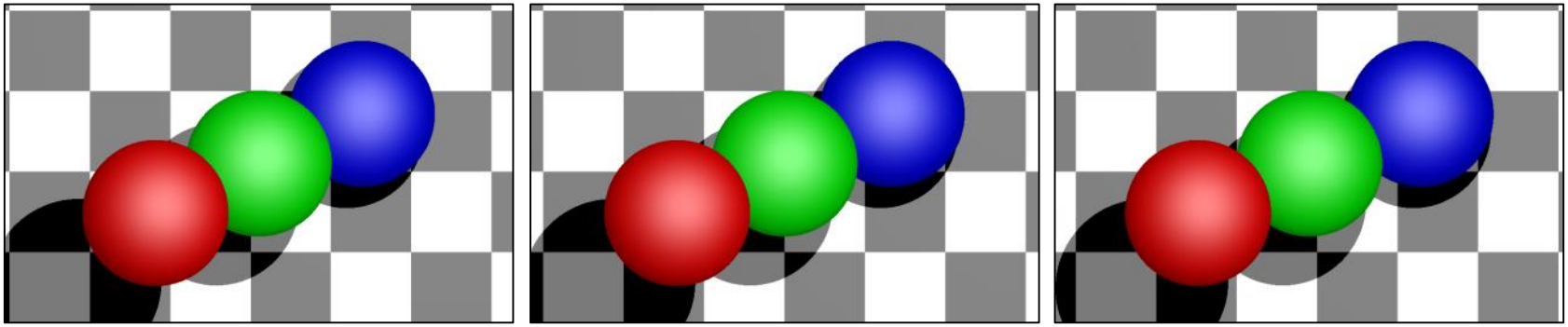




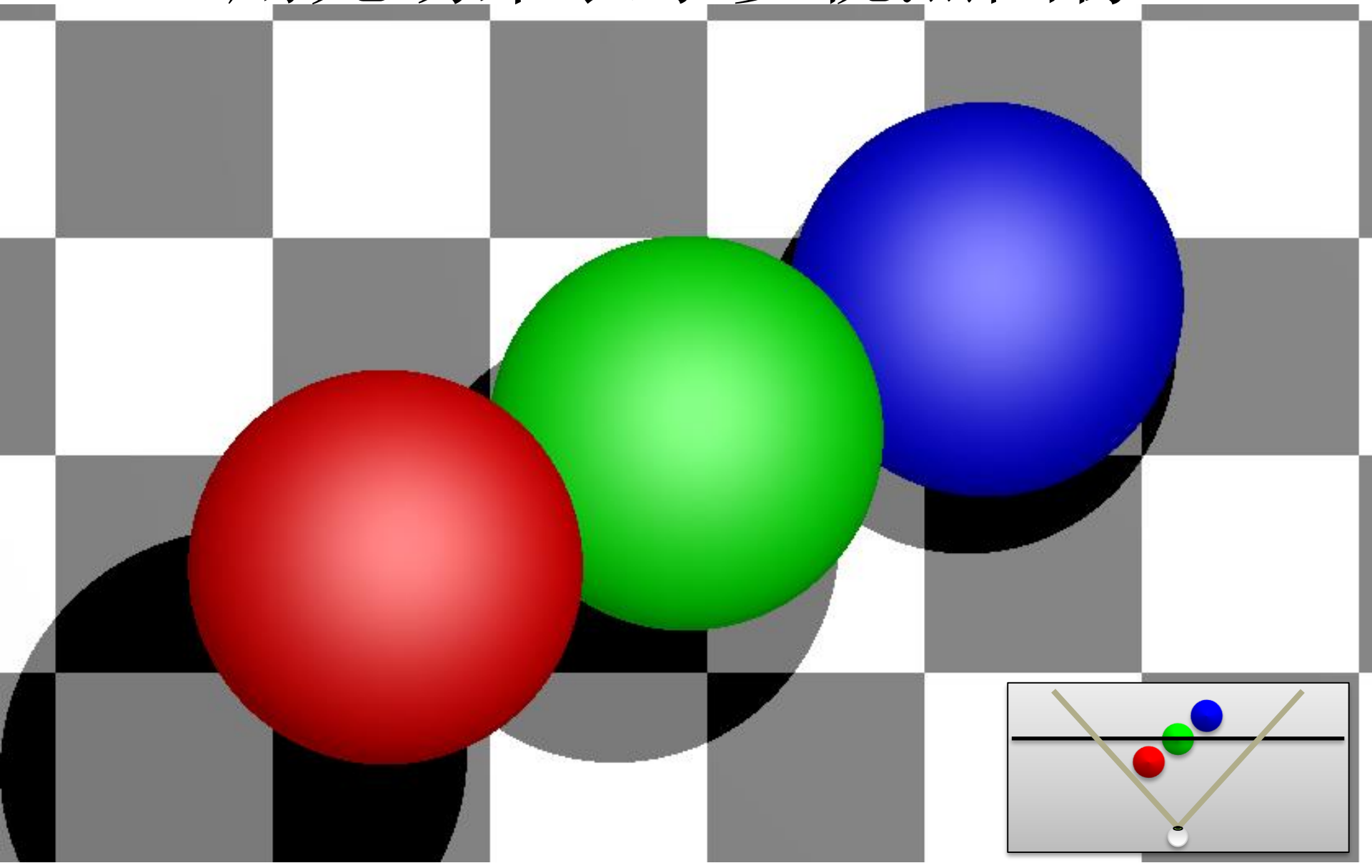
用光场来表示多视点图像



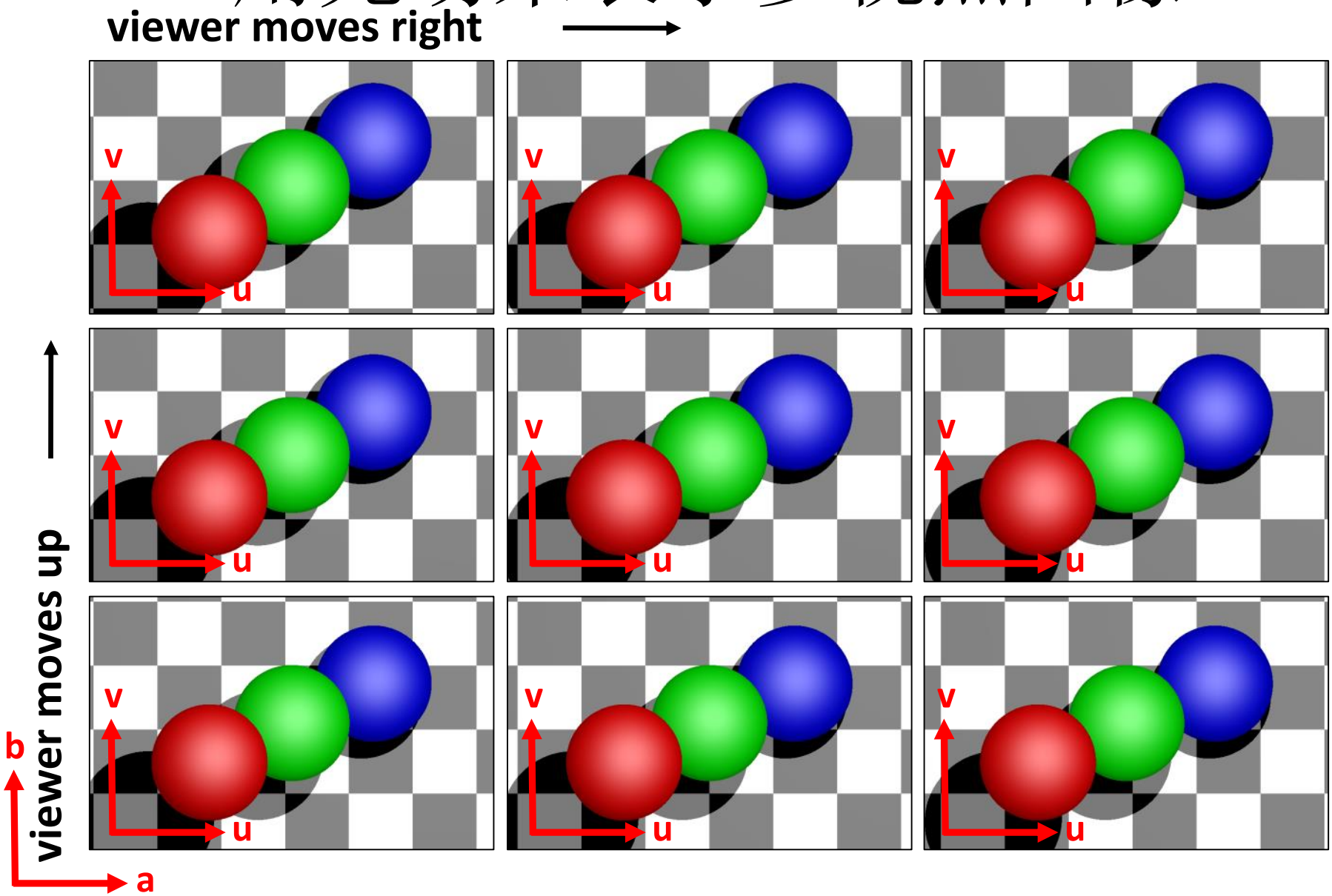
viewer moves right



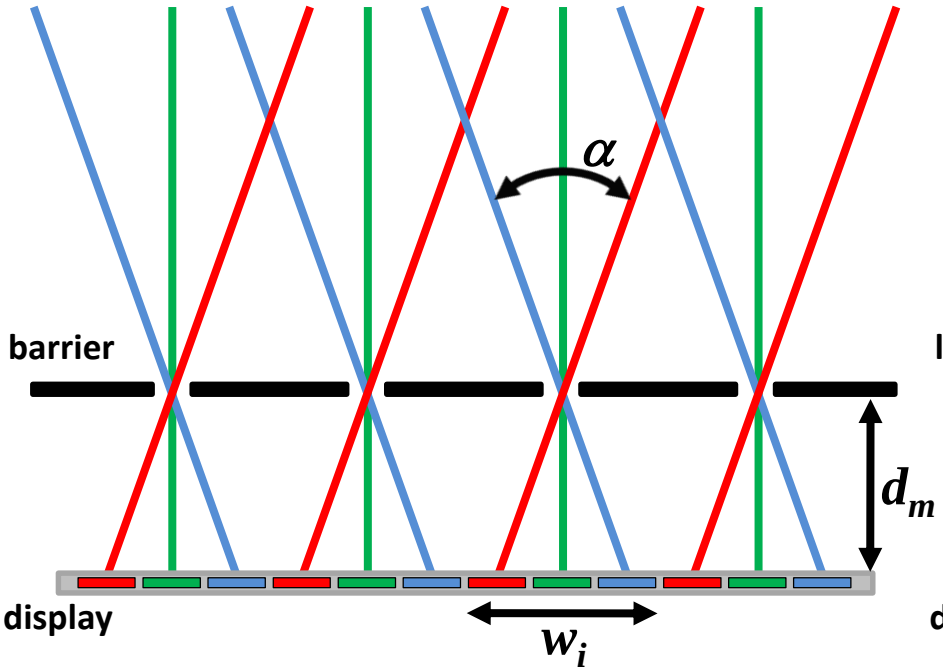
用光场来表示多视点图像



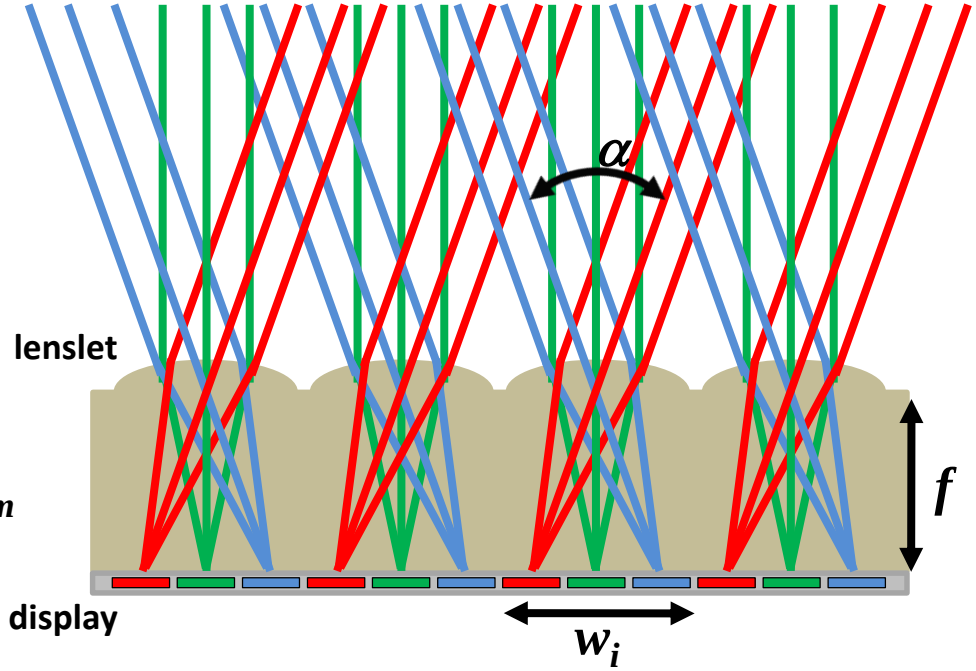
用光场来表示多视点图像



视差光栅 vs. 微透镜阵列



Parallax Barrier



Lenselet Array

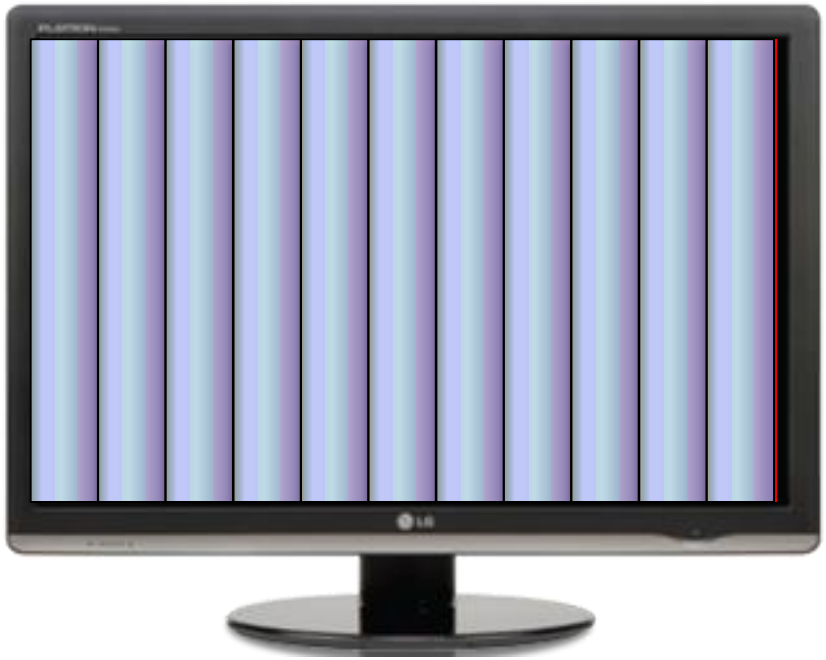
视差式显示器 Parallax-based Displays

- 视差光栅 Parallax Barriers ，光栅式 **[Ives, 1903]**
- 集成成像 Integral Imaging，微透镜阵列 **[Lippmann, 1908]**

- 光栅的问题 – 昏暗（对光的遮挡造成）
- 微透镜的问题 – 在角度范围与解析度间折中

1D vs. 2D 视差

1D Parallax Barrier



1D Lenslet Array

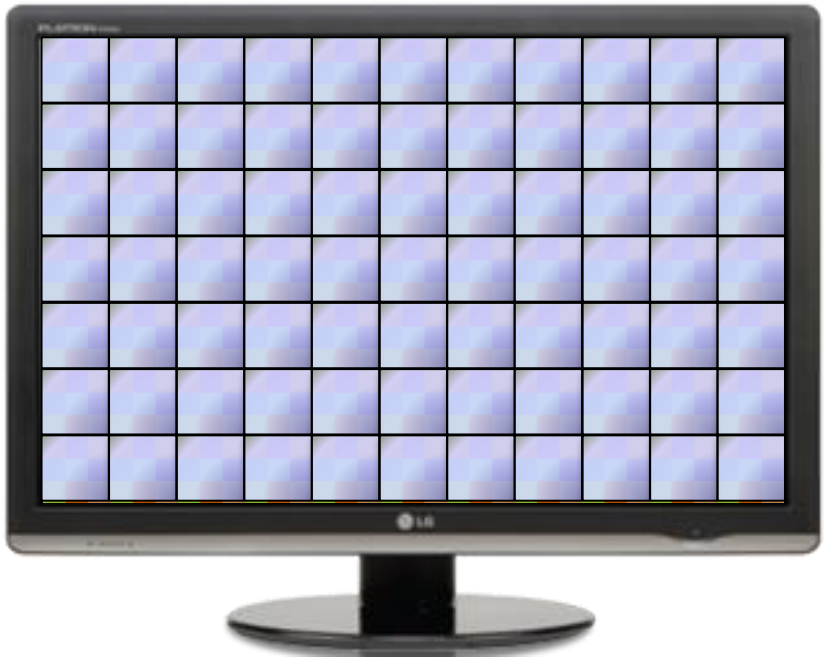
只支持水平的视差

- 垂直分布的视差光栅
- 微透镜阵列由柱状镜组成

无法支持垂直方向的深度感知

1D vs. 2D 视差

2D Parallax Barrier



2D Lenslet Array

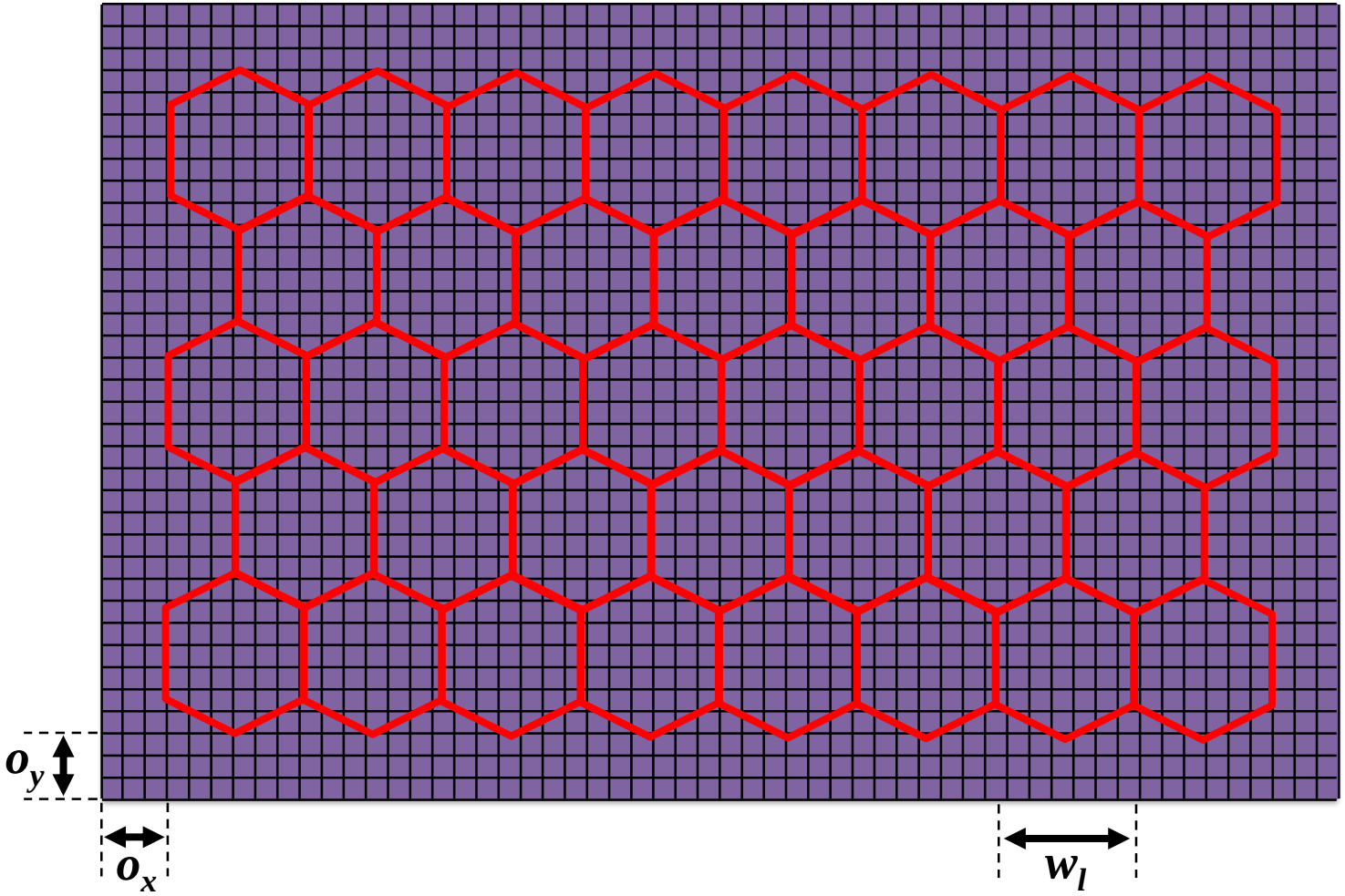
支持2D视差的显示器

- 光栅分布是二维的
- 微透镜由二维的透镜阵列组成（类似苍蝇的复眼）

能带来更好的3D效果，但是需要生成更多光线，而解析度会更低

视差光栅的小孔会带来亮度的损失。

六面体微透镜分布



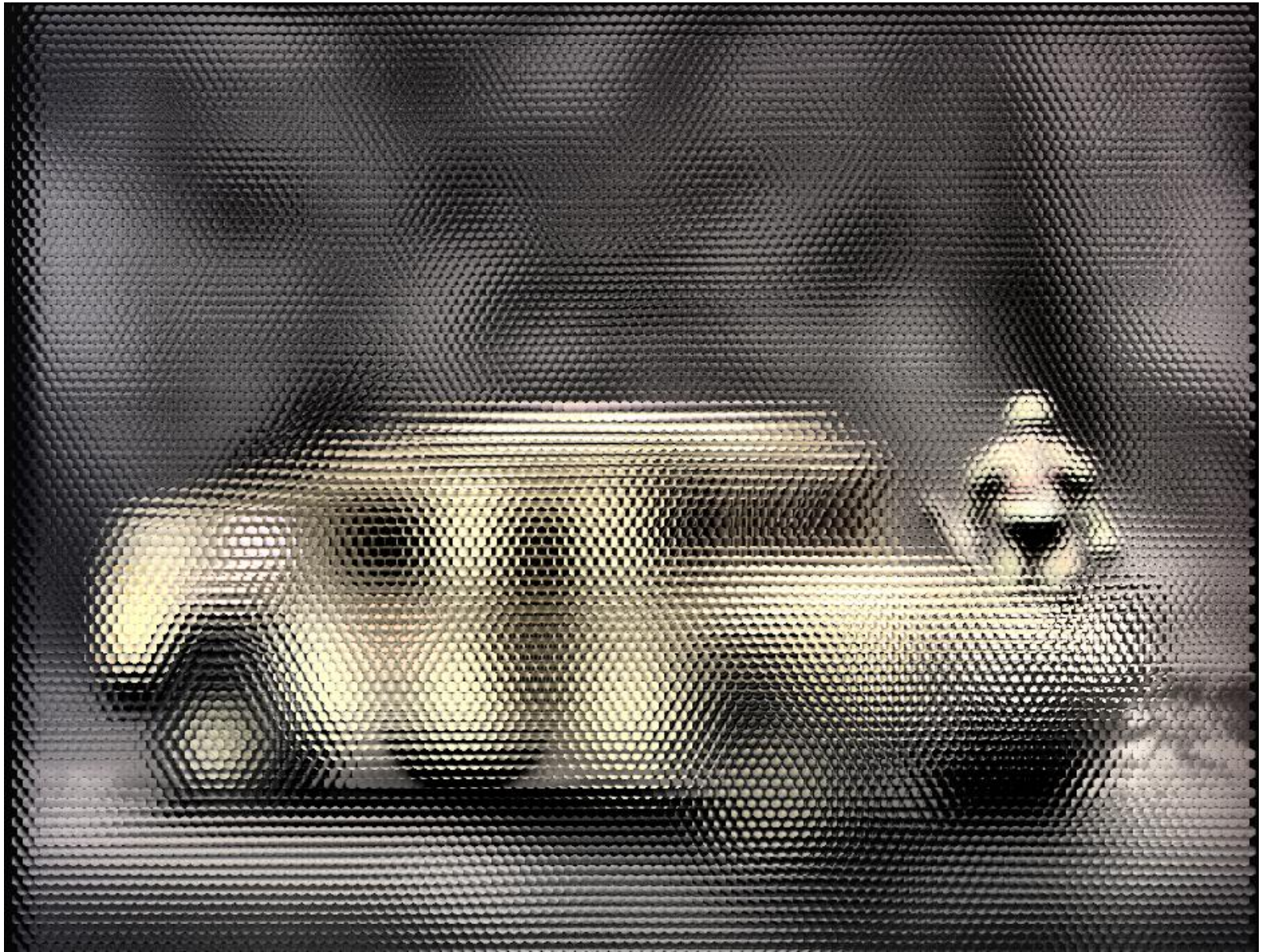
显示实例-多视点图像

viewer moves right →

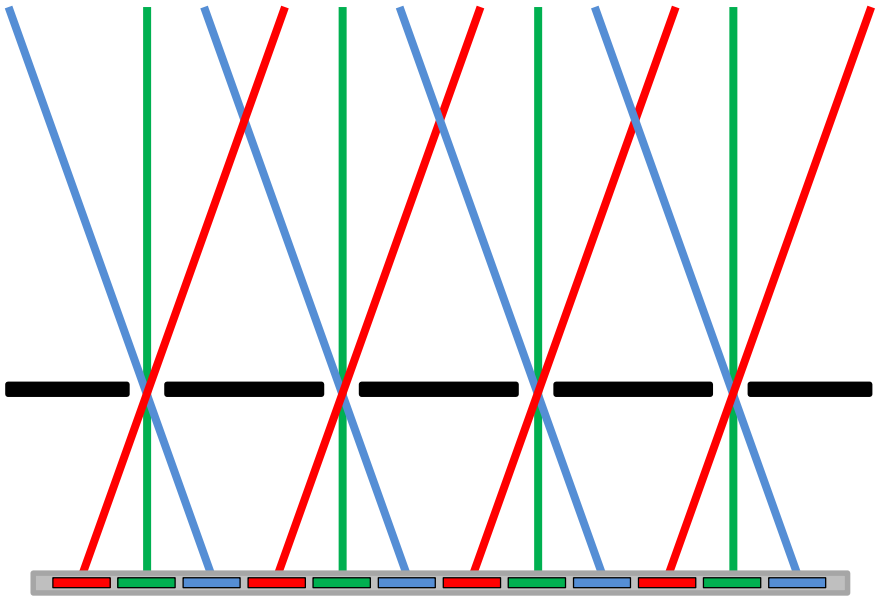
viewer moves up ↑

Sample Image

显示实例-屏幕显示像素



静-动态光栅

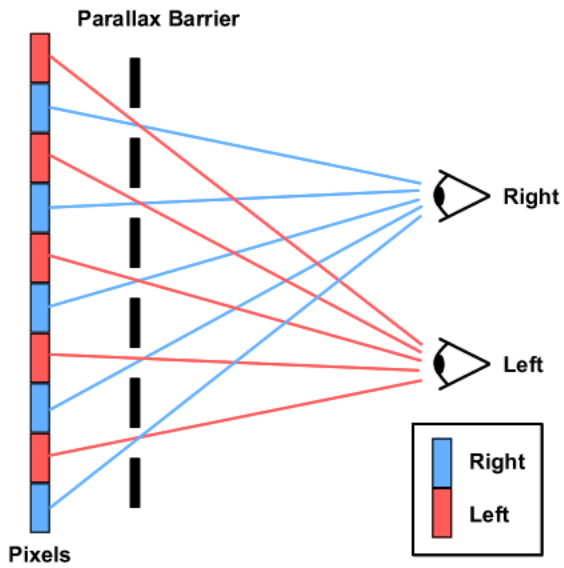


Parallax Barrier

静态 vs. 动态视差光栅显示器

- 静态光栅的问题是带来解析度与亮度的损失
- 动态光栅可以减少解析度的损失
  - 必须快速的移动（> 60 Hz)

视差光栅



NewSight MV-42AD3 42"
(1920x1080, 1x8 views)

视差光栅 Parallax Barriers
(uniform array of 1D slits or 2D pinhole arrays)

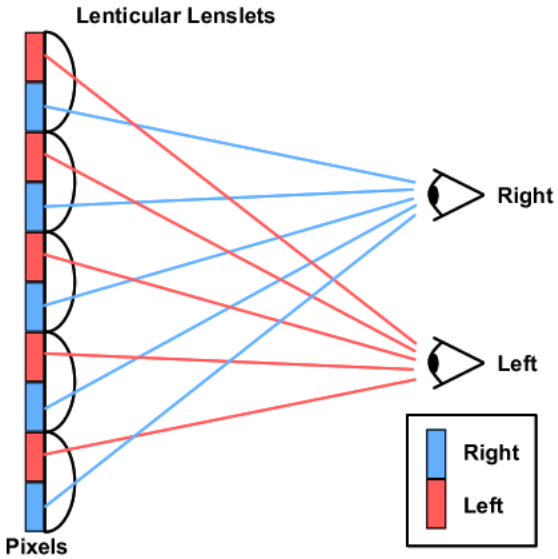
裸眼显示设备
Unencumbered
Automultiscopic

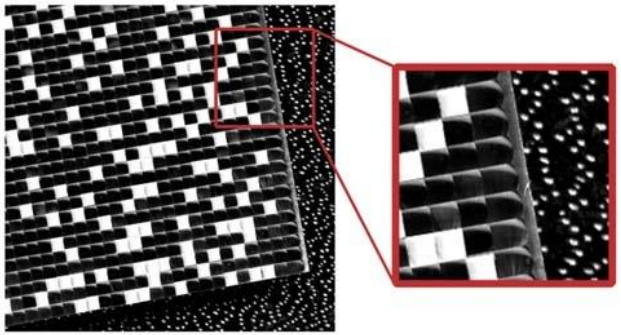
视差式 Parallax-based
(2D display with light-directing elements)

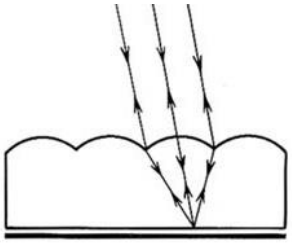
体绘制 Volumetric
(directly illuminate points within a volume)

全息 Holographic
(reconstructs wavefront using 2D element)

集成成像





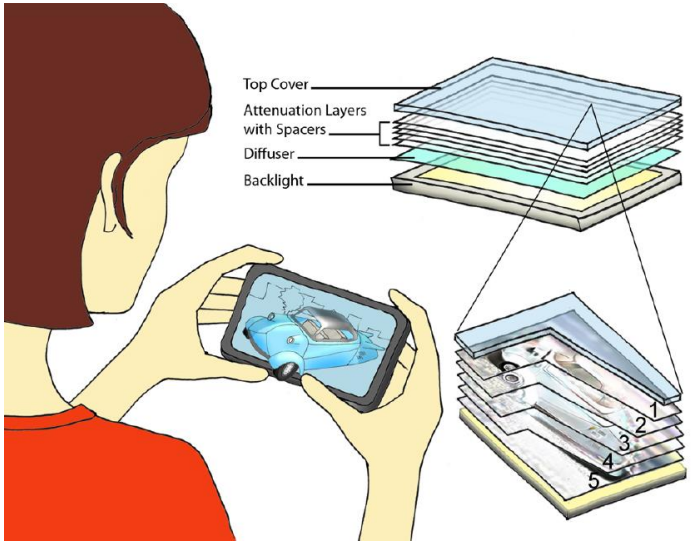


Alioscopy 3DHD 42"
(1920x1200, 1x8 views)

裸眼显示设备
Unencumbered Automultiscopic

- **视差式 Parallax-based**
  (2D display with light-directing elements)
  - 视差光栅 Parallax Barriers
    (uniform array of 1D slits or 2D pinhole arrays)
  - 集成成像 Integral Imaging
    (lenticular sheets or fly's eye lenslet arrays)
- **体绘制 Volumetric**
  (directly illuminate points within a volume)
- **全息 Holographic**
  (reconstructs wavefront using 2D element)

层叠成像



裸眼显示设备 Unencumbered Automultiscopic

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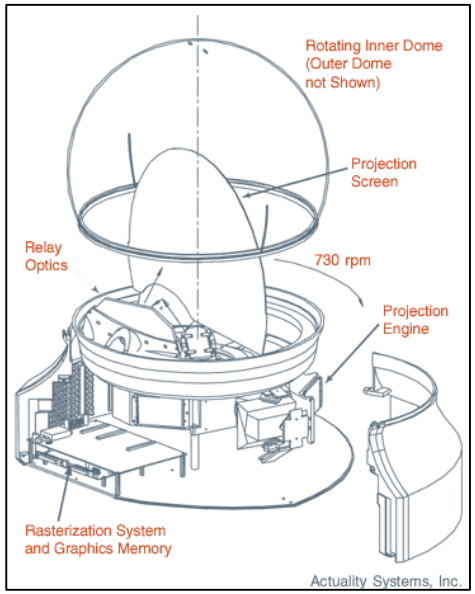
  - 层叠成像 Layered Imaging
    modulate lights among layers
- **体绘制 Volumetric**
  (directly illuminate points within a volume)
- **全息 Holographic**
  (reconstructs wavefront using 2D element)

多平面底片



裸眼显示设备
Unencumbered
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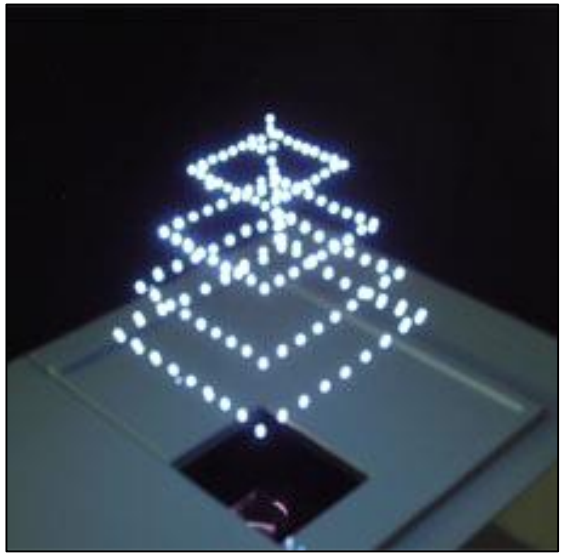
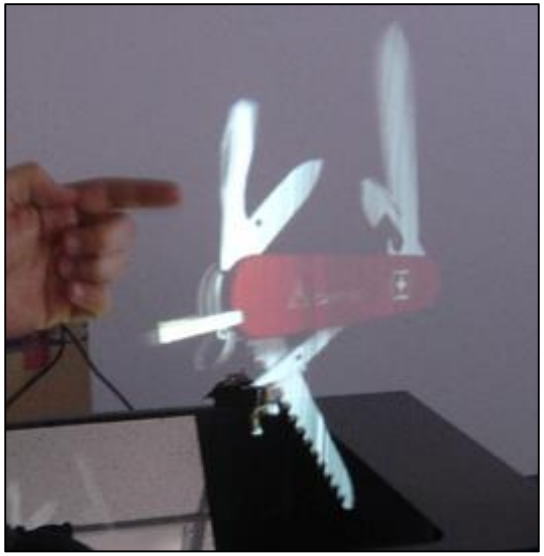
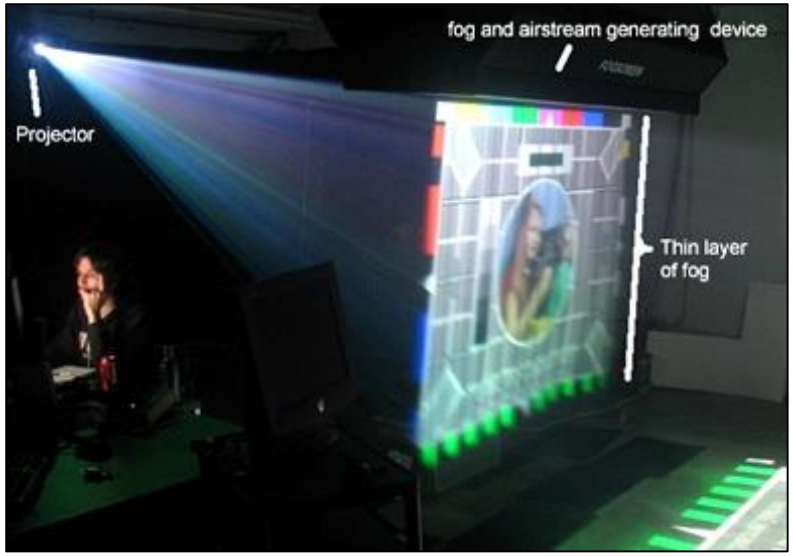
  - 多平面底片 Multi-planar
    (time-sequential projection onto swept surfaces)
- **全息 Holographic**
  (reconstructs wavefront using 2D element)

透明底片







裸眼显示设备 Unencumbered Automultiscopic

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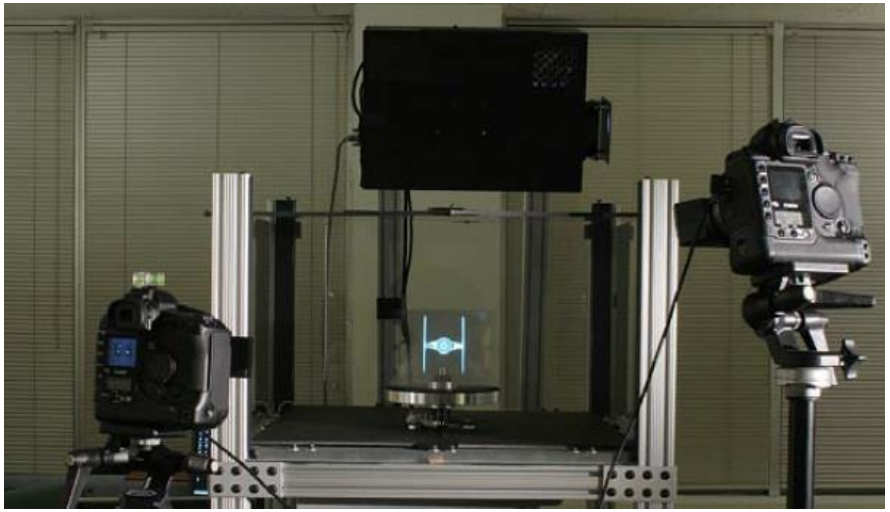
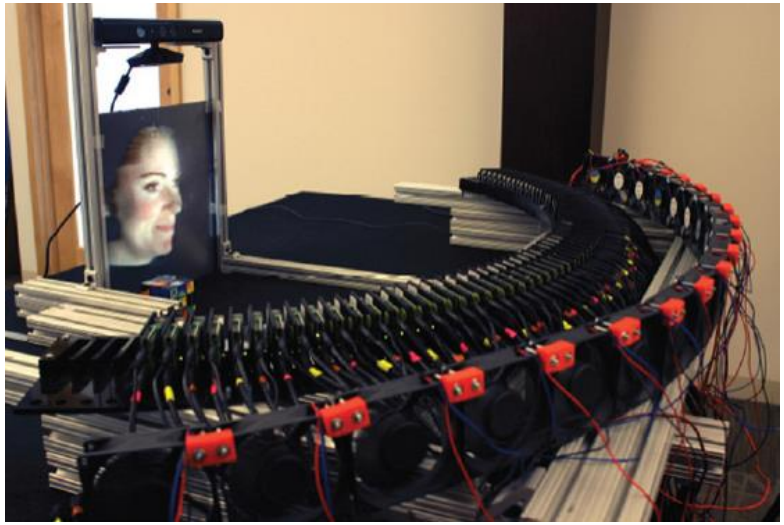
    modulate lights among layers
- **体绘制 Volumetric**
  (directly illuminate points within a volume)
  - 多平面底片 Multi-planar
    (time-sequential projection onto swept surfaces)
  - 透明底片 Transparent Substrates
    (intersecting laser beams, fog layers, etc.)
- **全息 Holographic**
  (reconstructs wavefront using 2D element)

光场式





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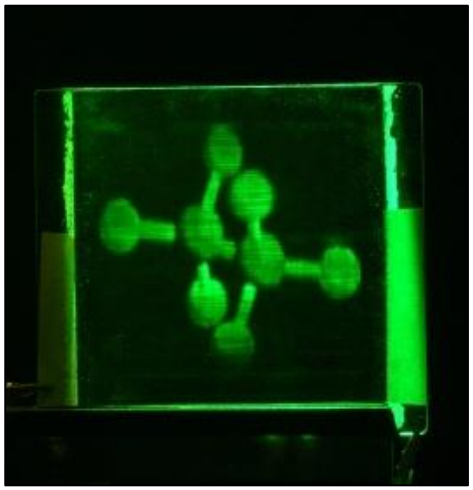
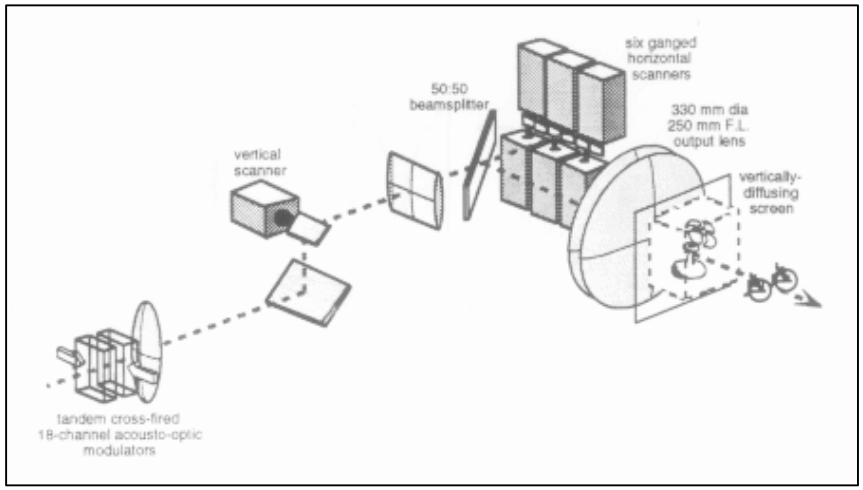
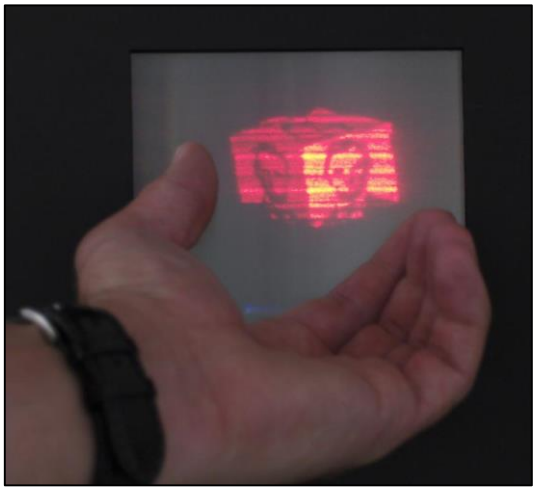
    (time-sequential projection onto swept surfaces)
  - 透明底片 Transparent Substrates
    (intersecting laser beams, fog layers, etc.)
- **全息 Holographic**
  (reconstructs wavefront using 2D element)
  - 光场式 Lightfield
    (reconstructing lightfield of objects)

动态全息



Tay et al.
[Nature, 2008]





MIT Media Lab Spatial Imaging Group
[Holovideo, 1989 – present]

裸眼显示设备
Unencumbered Automultiscopic

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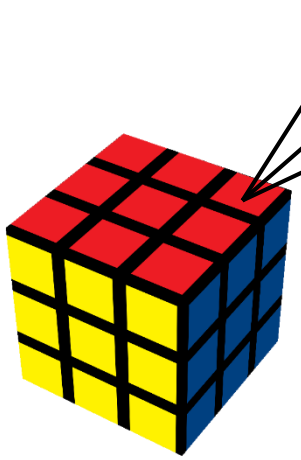
  - 透明底片 Transparent Substrates
    (intersecting laser beams, fog layers, etc.)
- **全息 Holographic**
  (reconstructs wavefront using 2D element)
  - 光场式 Lightfield
    (reconstructing lightfield of objects)
  - 动态全息 Dynamic
    (holovideo)

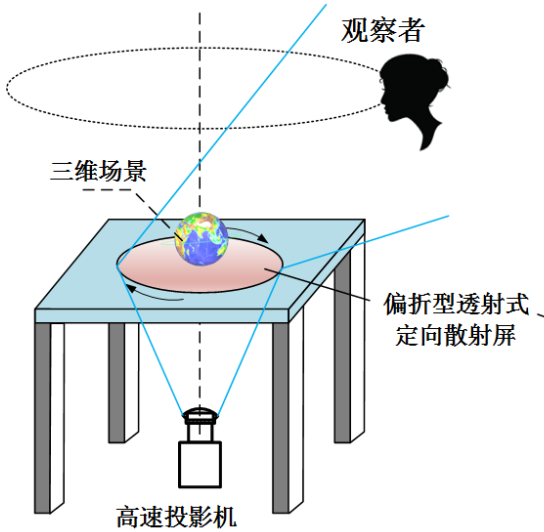
光场式

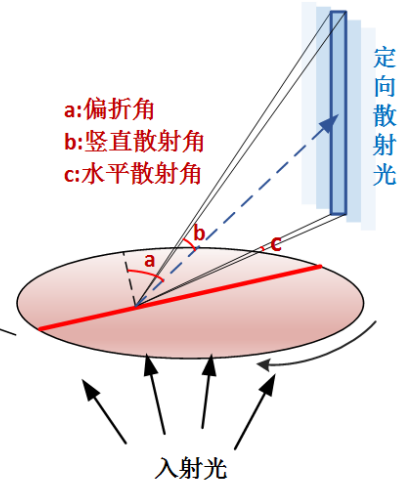
光场的另一种参数化形式

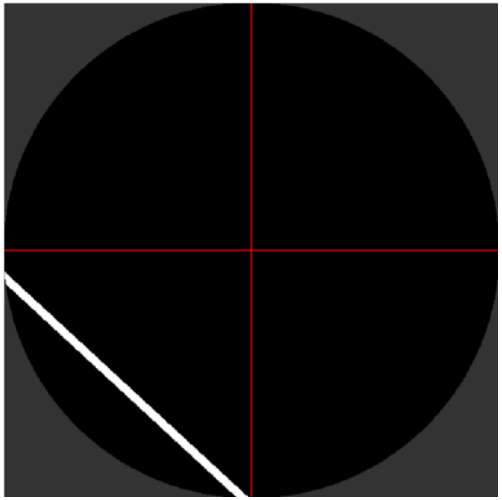


扫描光场显示设备

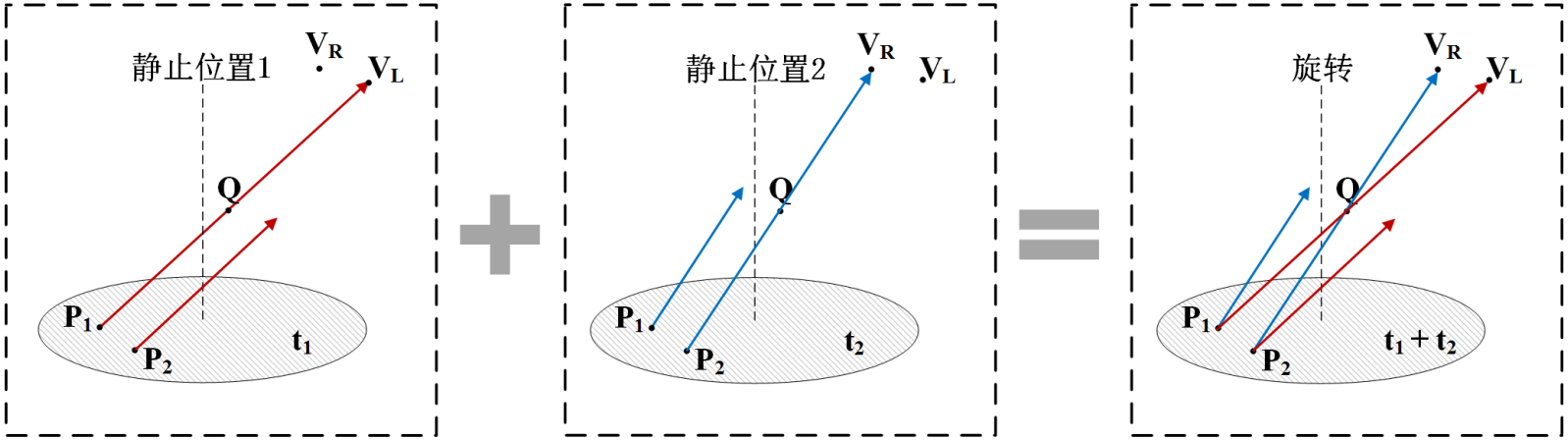
高速投影图像 + 旋转定向散射屏 = 扫描光场显示





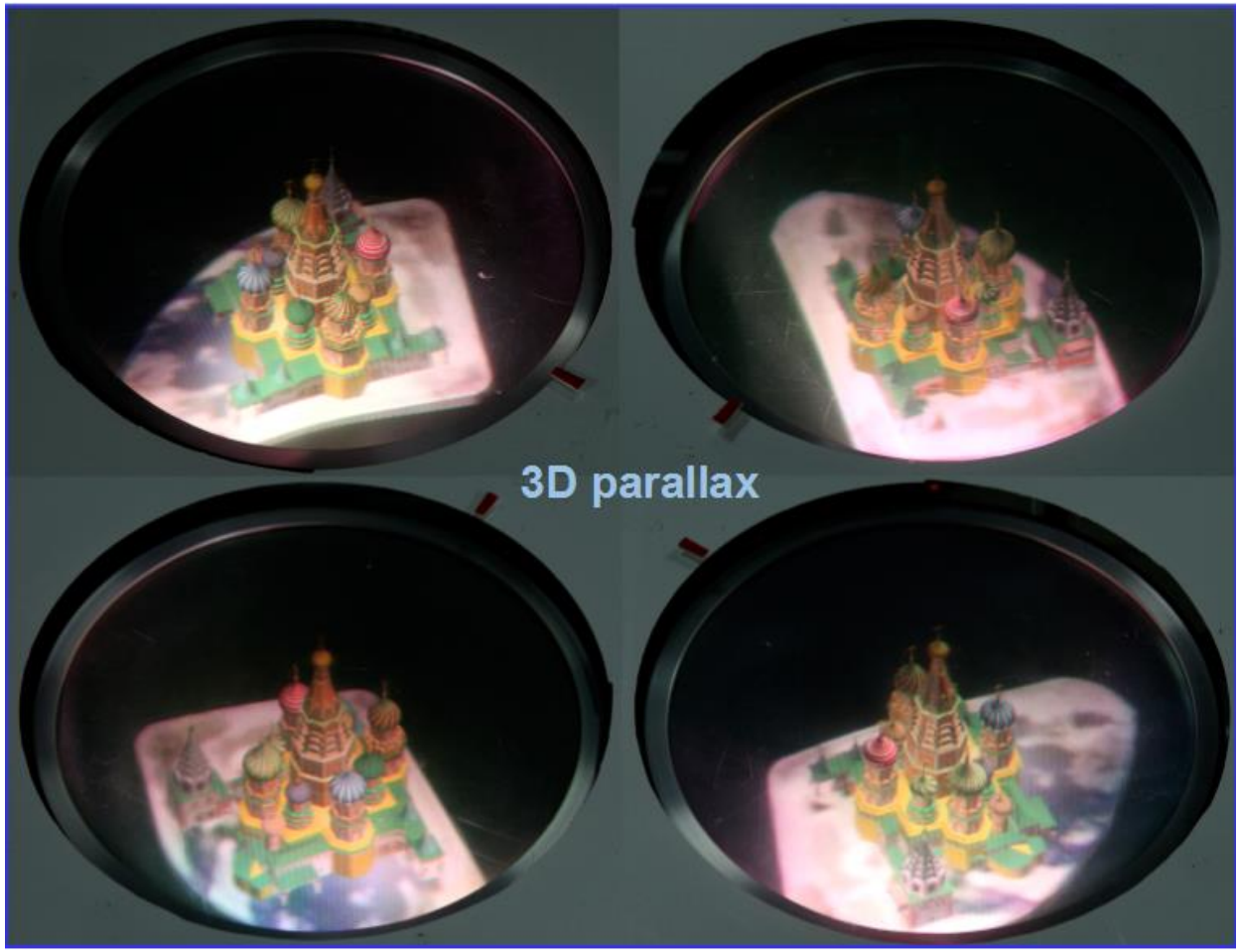


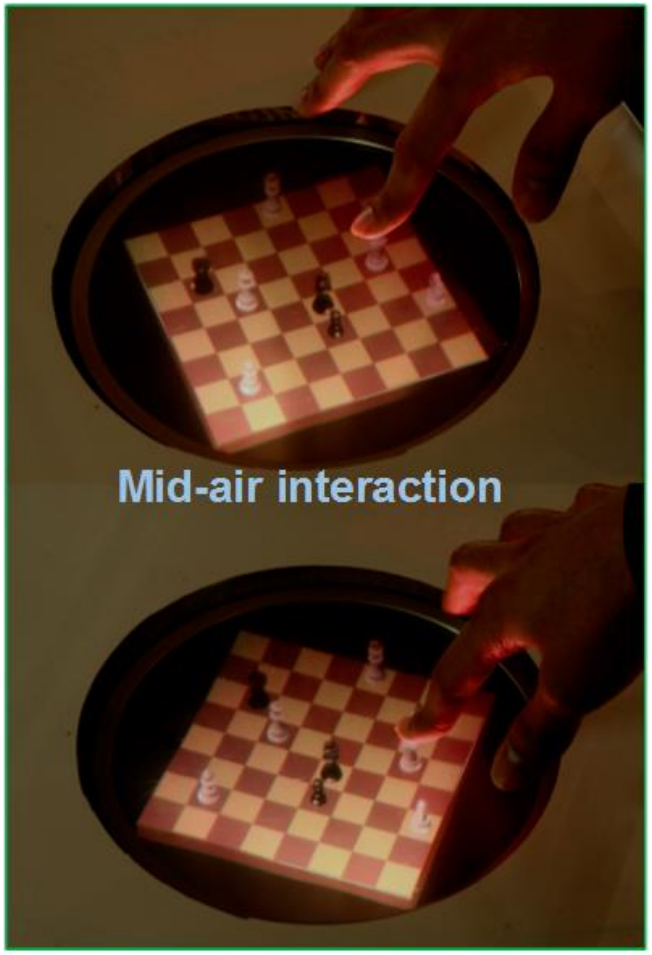
立体视觉
实现原理



扫描光场显示设备

- 结果





基于穿戴式头盔眼镜的VR/AR呈现技术

王锐 Rui Wang
浙江大学CAD&CG国家重点实验室
rwang@cad.zju.edu.cn
http://www.cad.zju.edu.cn/home/rwang

- **基于表面的显示设备 Surface-based Stereoscopic**
  - **投影式 Projector-based**
    (project lightfield on surface)
    - 沉浸式 Immersive
      (blocks direct-viewing of real world)
- **裸眼显示设备 Unencumbered Automultiscopic**
  - **视差式 Parallax-based**
    (2D display with light-directing elements)
    - 视差光栅 Parallax Barriers
      (uniform array of 1D slits or 2D pinhole arrays)
    - 集成成像 Integral Imaging
      (lenticular sheets or fly's eye lenslet arrays)
  - **体绘制 Volumetric**
    (directly illuminate points within a volume)
    - 多平面底片 Multi-planar
      (time-sequential projection onto swept surfaces)
    - 透明底片 Transparent Substrates
      (intersecting laser beams, fog layers, etc.)
  - **全息 Holographic**
    (reconstructs wavefront using 2D element)
    - 光场式 Lightfield
      (reconstructing lightfield of objects)
    - 动态全息 Dynamic
      (holovideo)
- **基于眼镜的显示设备 Glasses-bound Stereoscopic**
  - **头戴式 head mounted**
    (eyepiece-objective and microdisplay)
    - 沉浸式 Immersive
      (blocks direct-viewing of real world)
    - 穿透式 See-through
      (superimposes synthetic images onto real world)
  - **像素重用 multi-pixels**
    (stereo pair with same display surface)
    - 基于空域的像素重用
      Spatially-multiplexed (field-concurrent)
      (color filters, polarizers, autostereograms, etc.)
    - 基于时域的像素重用
      Temporally-multiplexed (field-sequential)
      (LCD shutter glasses)

Taxonomy adapted from Hong Hua

头戴显示器

沉浸式 Immersive
(blocks direct-viewing of real world)

头戴式 head mounted
(eyepiece-objective and microdisplay)

基于眼镜的显示设备
Glasses-bound Stereoscopic

像素重用 multi-pixels
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穿透式头戴显示器

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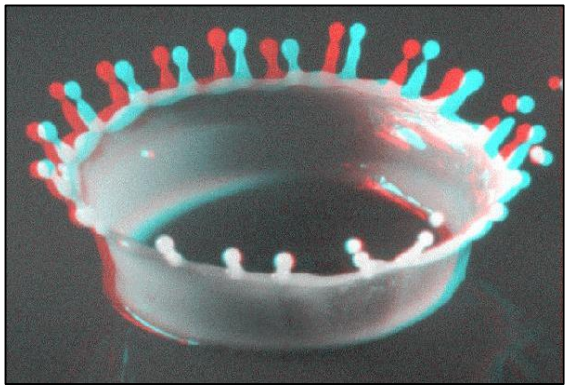
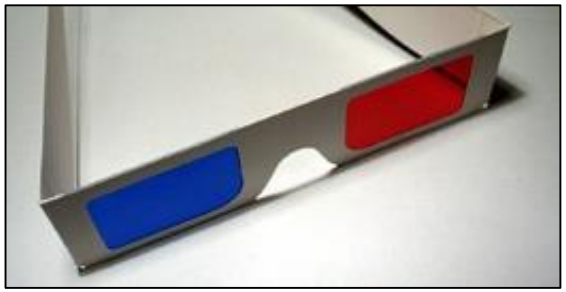
基于空域的像素重用





基于眼镜的显示设备
Glasses-bound Stereoscopic

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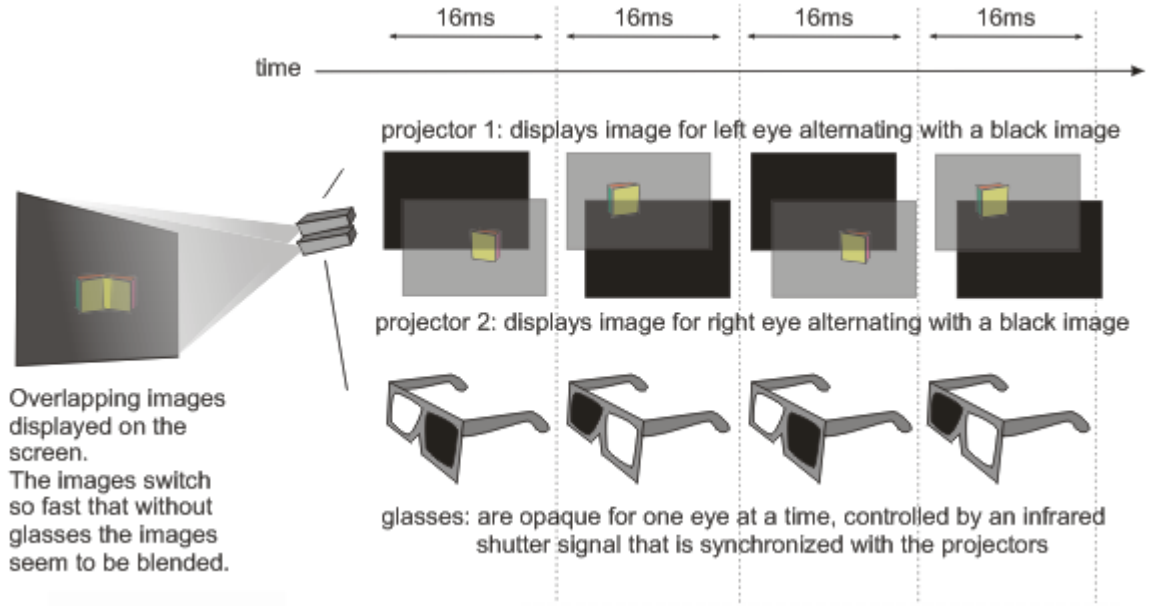
基于时域的像素重用



基于眼镜的显示设备
Glasses-bound Stereoscopic

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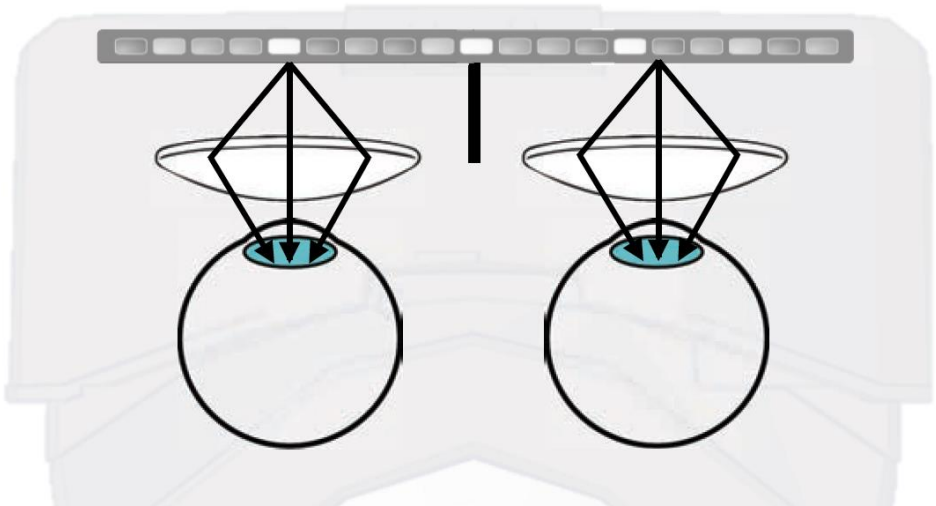
    Temporally-multiplexed (field-sequential)
    (LCD shutter glasses)

头盔显示器原理

- 显示器部分与裸眼3D显示器类似



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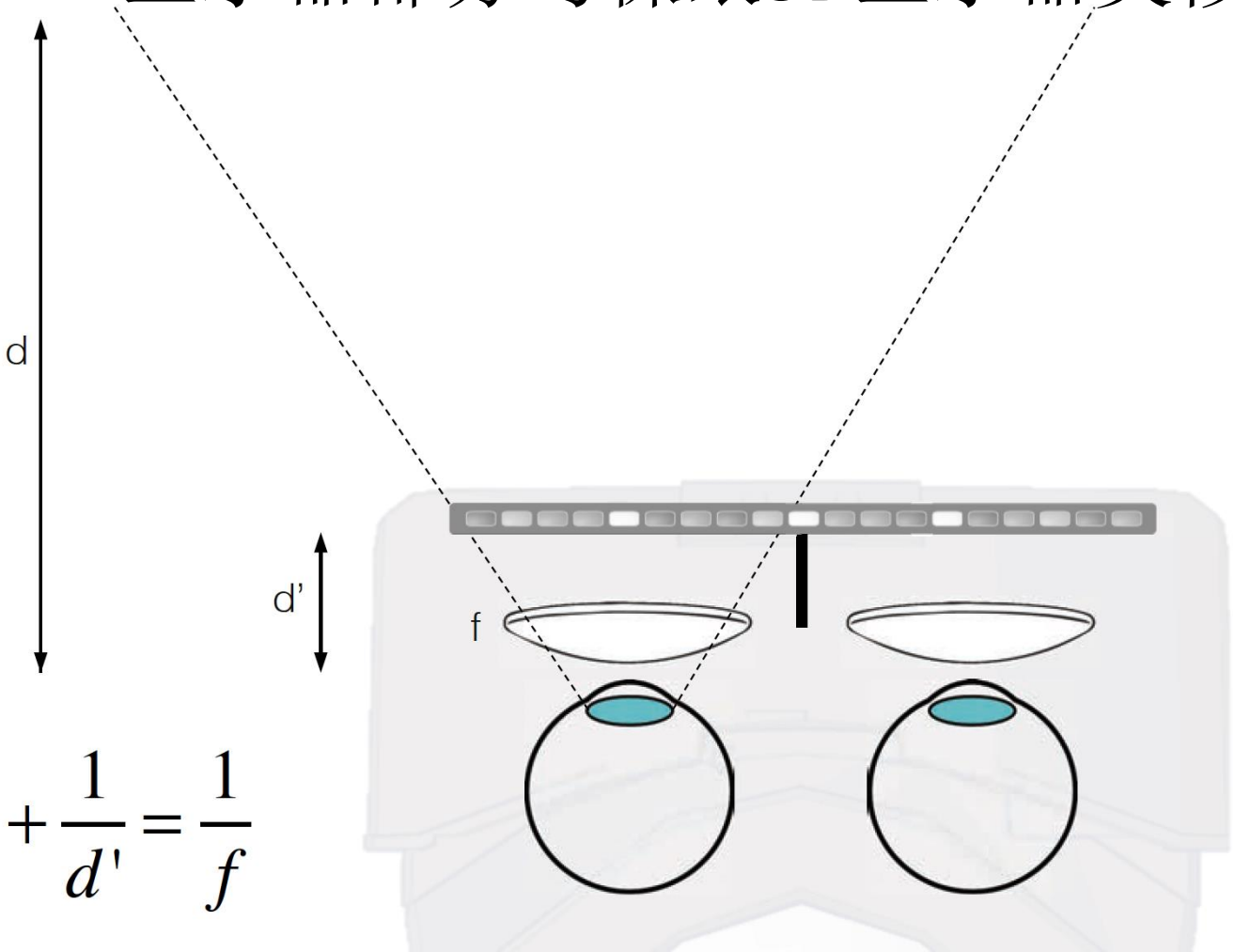
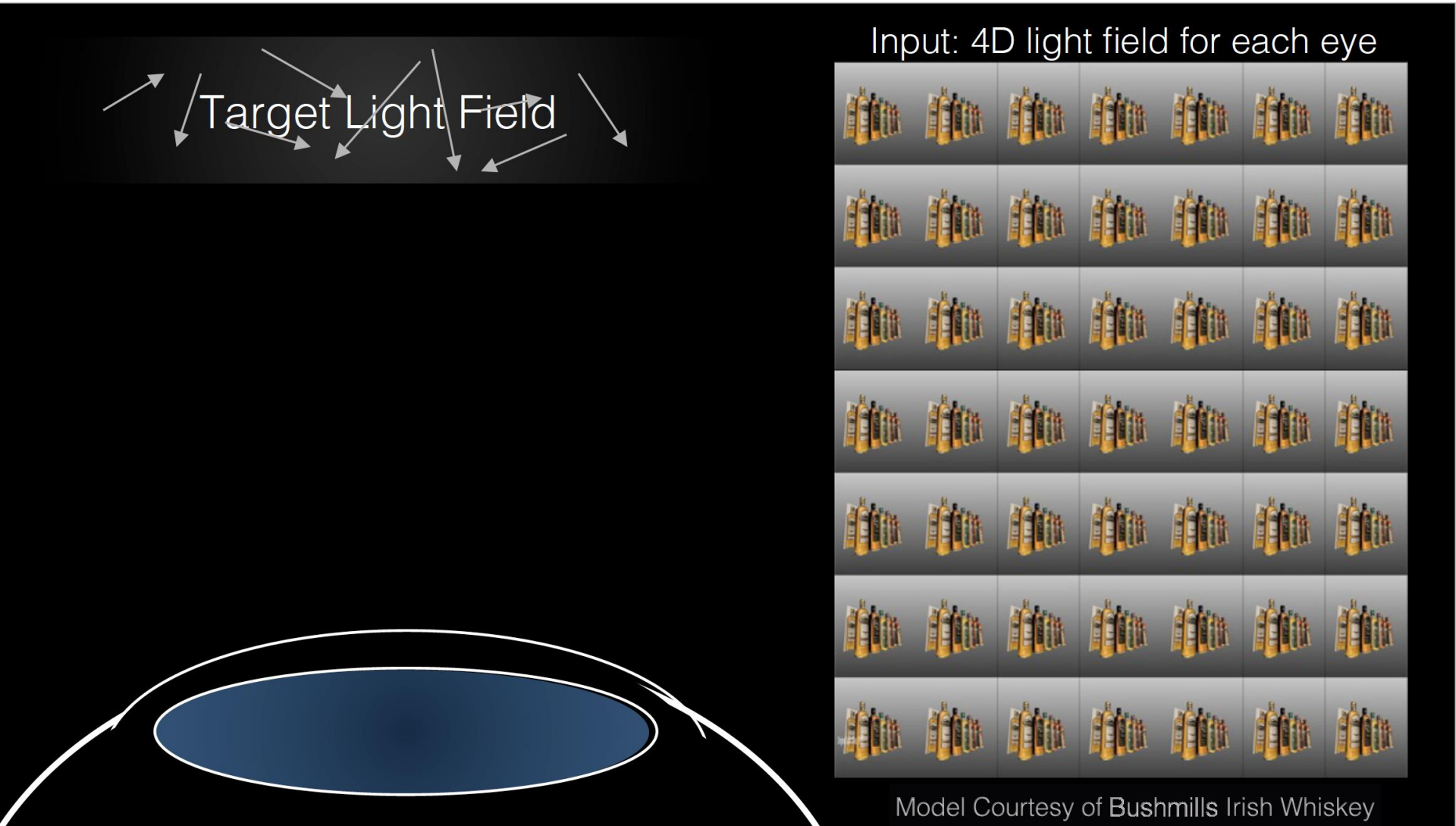


$$\frac{1}{d}+\frac{1}{d'}=\frac{1}{f}$$

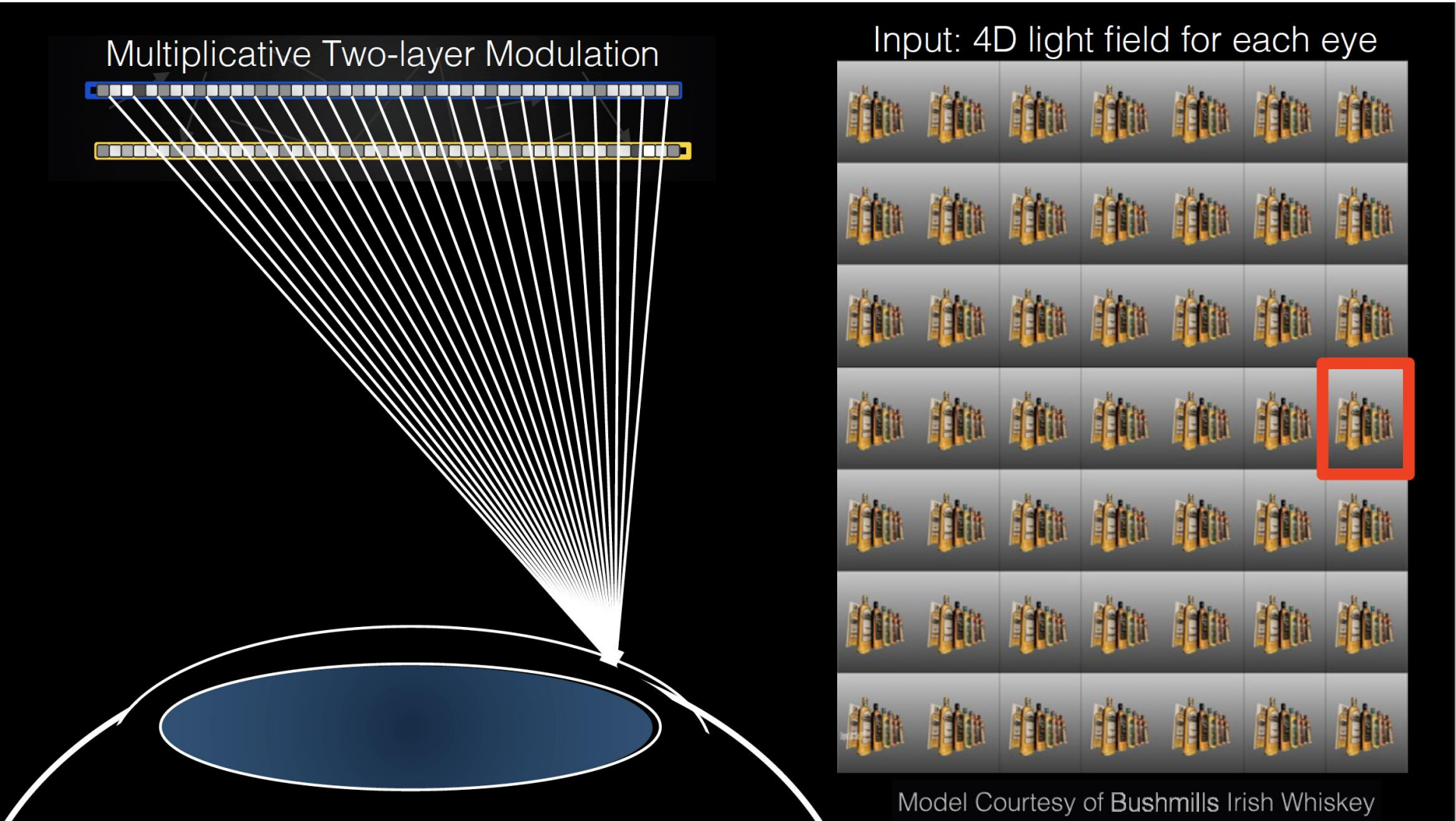
头盔显示器原理


Target Light Field
Input: 4D light field for each eye
Model Courtesy of Bushmills Irish Whiskey

头盔显示器原理

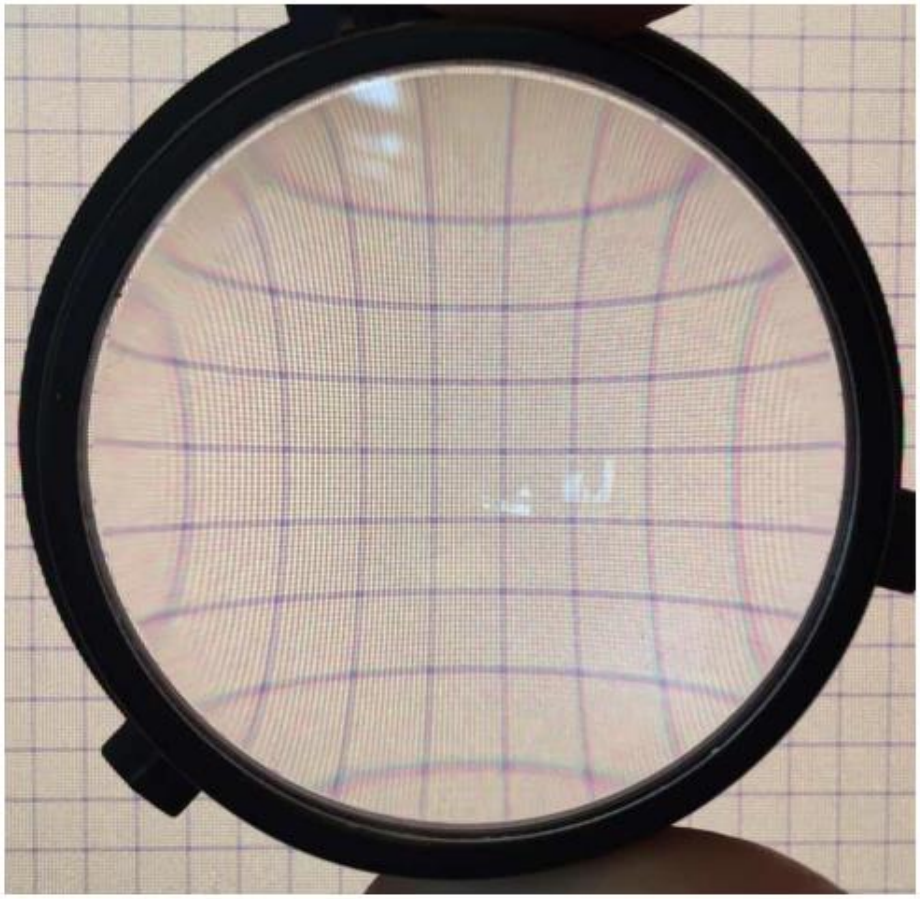
Multiplicative Two-layer Modulation
Input: 4D light field for each eye
Model Courtesy of Bushmills Irish Whiskey

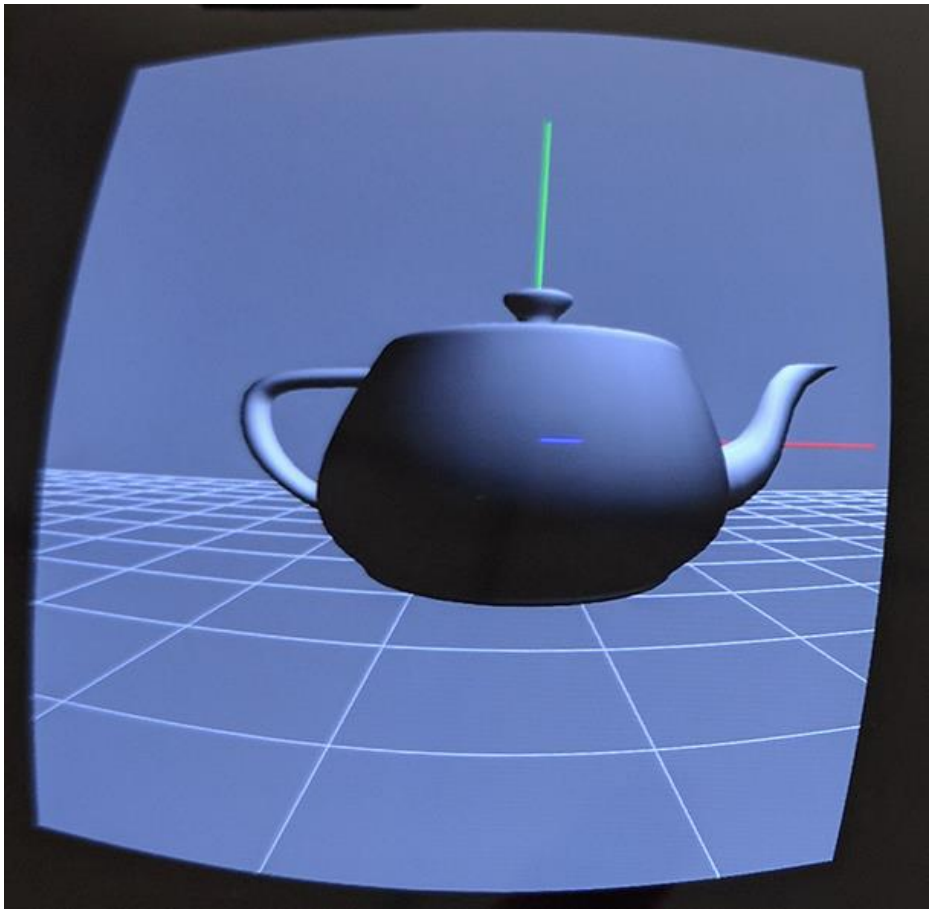
头盔显示器原理


Multiplicative Two-layer Modulation
Input: 4D light field for each eye
Model Courtesy of Bushmills Irish Whiskey

头盔显示器原理

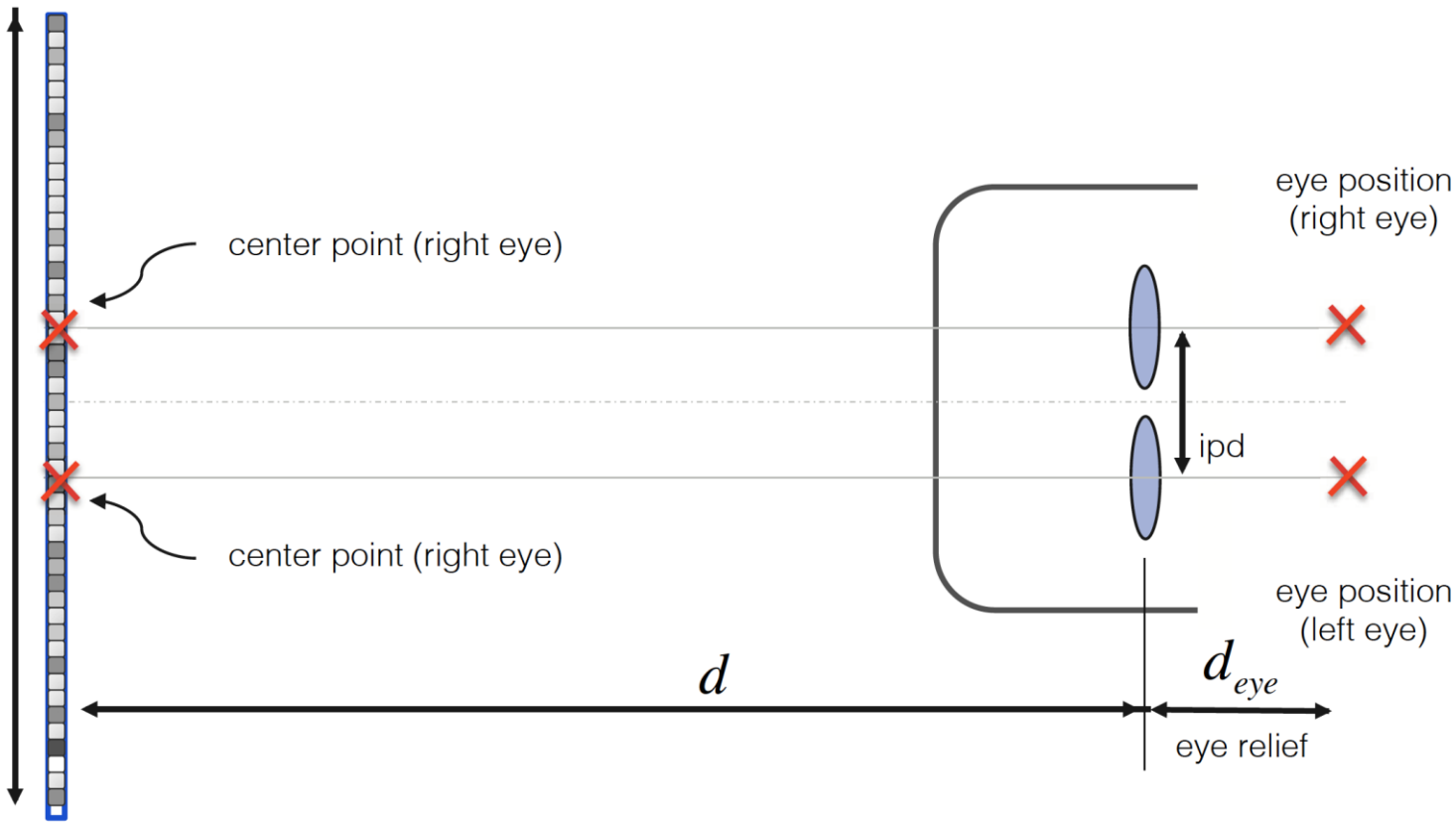
- 透镜矫正





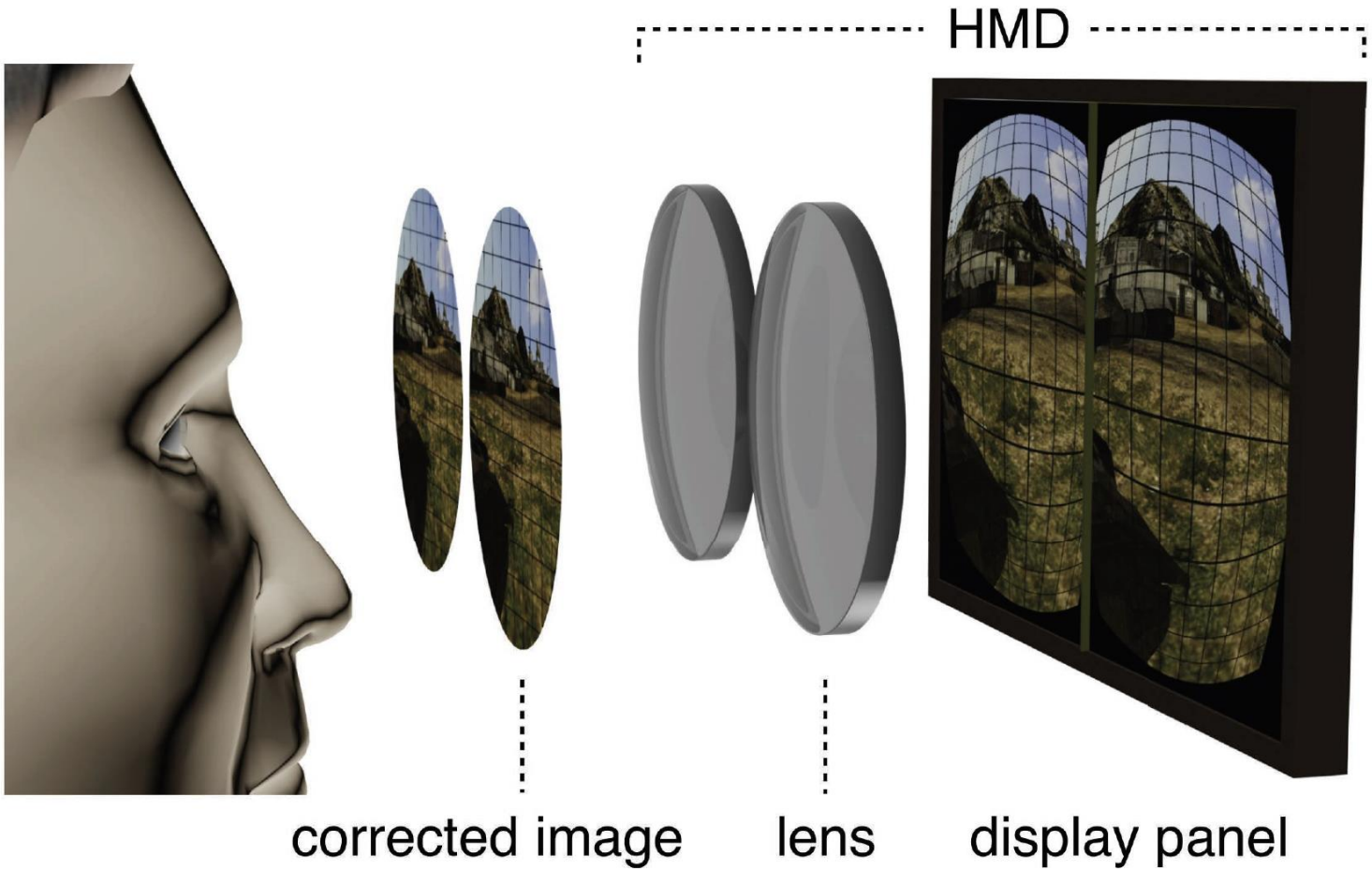
头盔显示器原理

- 透镜矫正

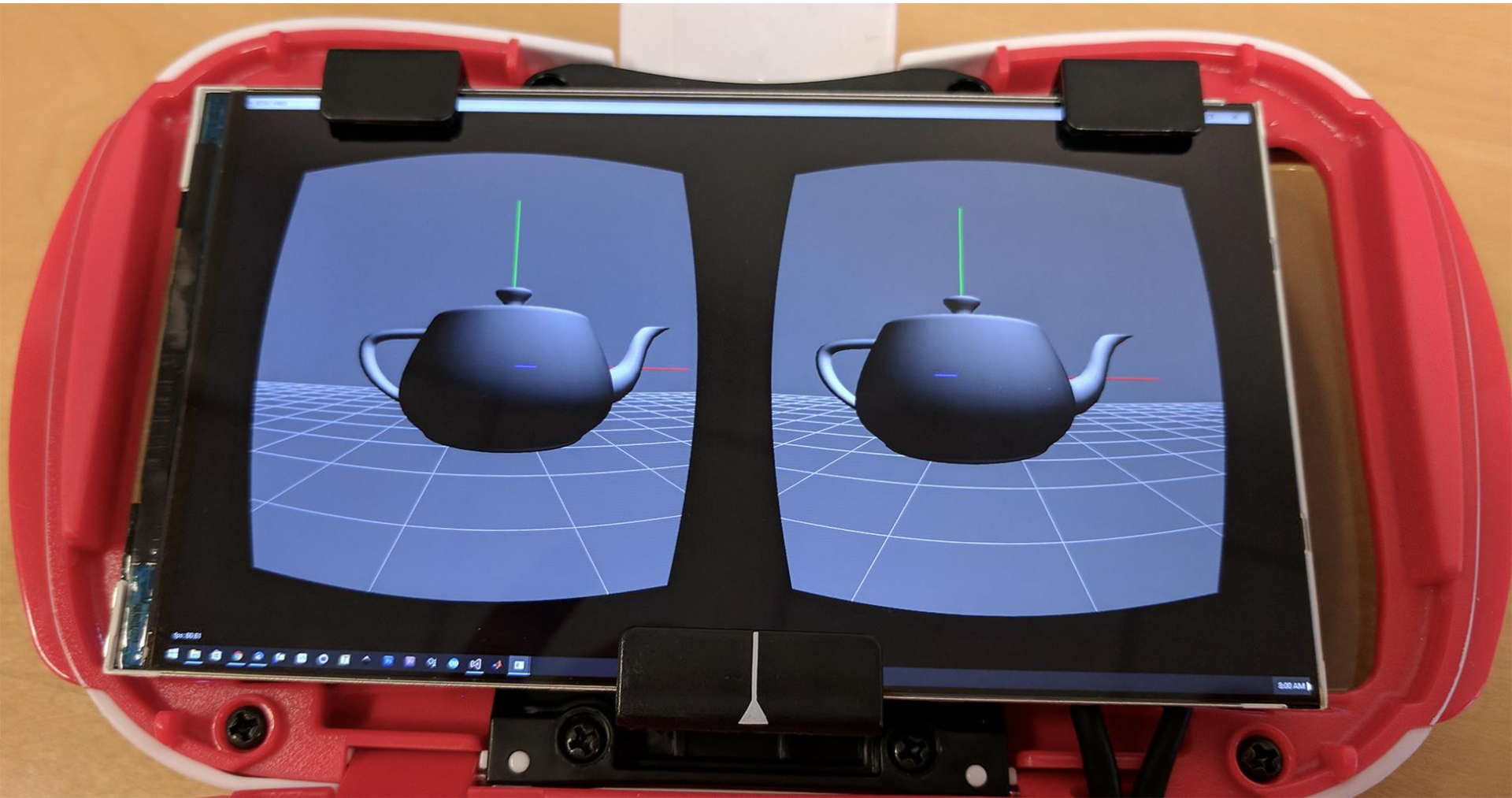


头盔显示器原理

- 透镜矫正

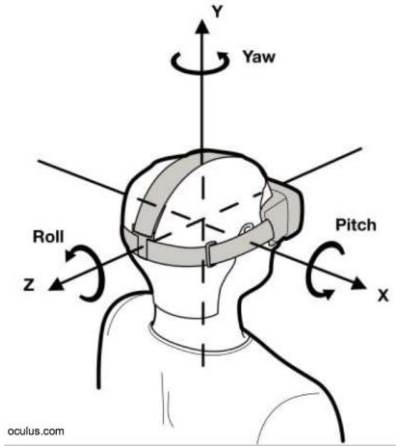


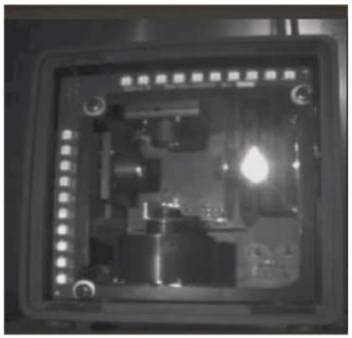
头盔显示器原理

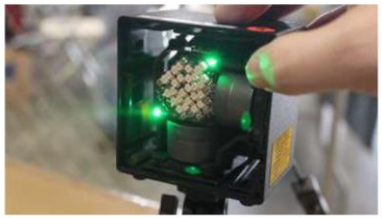


头盔显示器原理

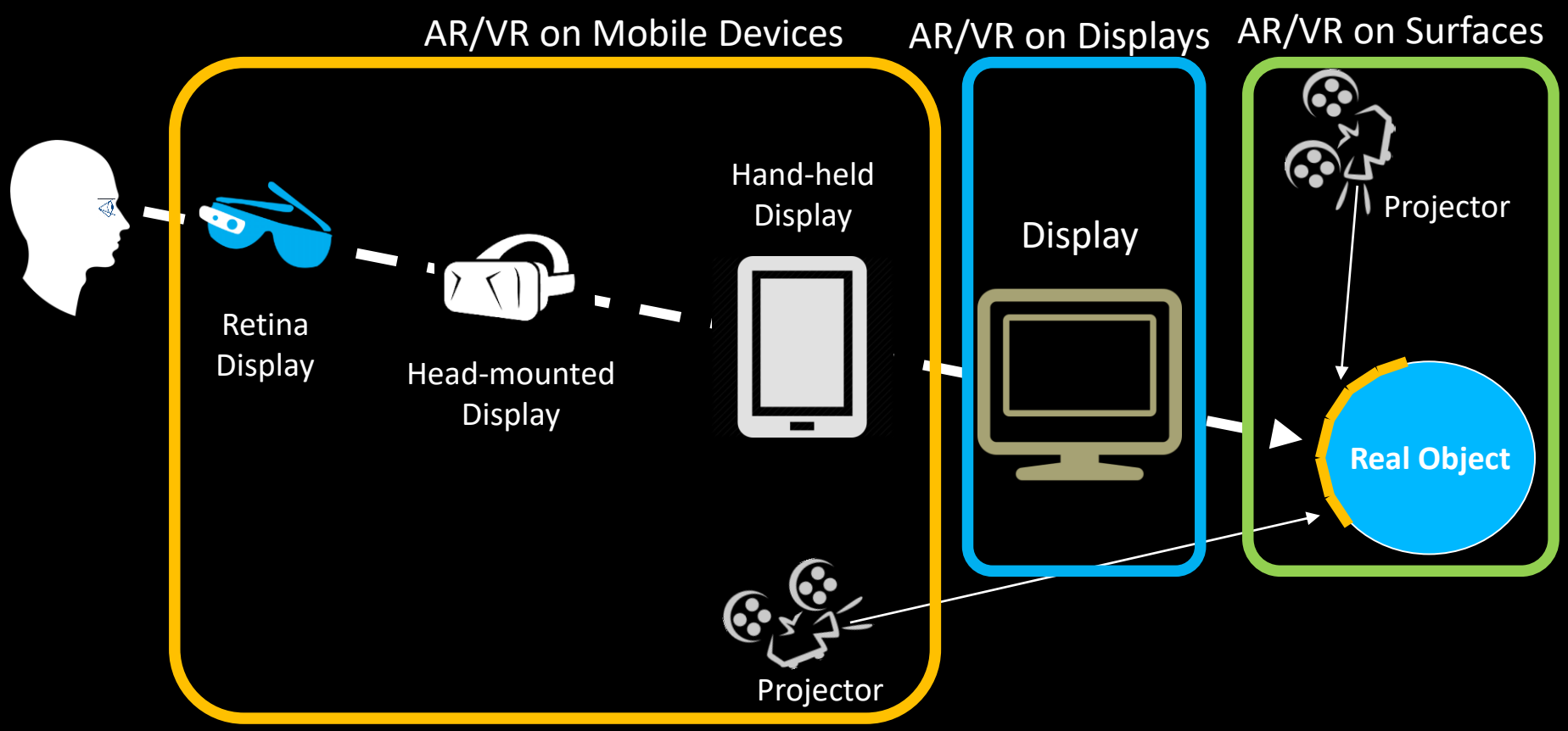
- 空间定位
  - IMU
  - SLAM
  - Marker
  - HTC Lighthouse



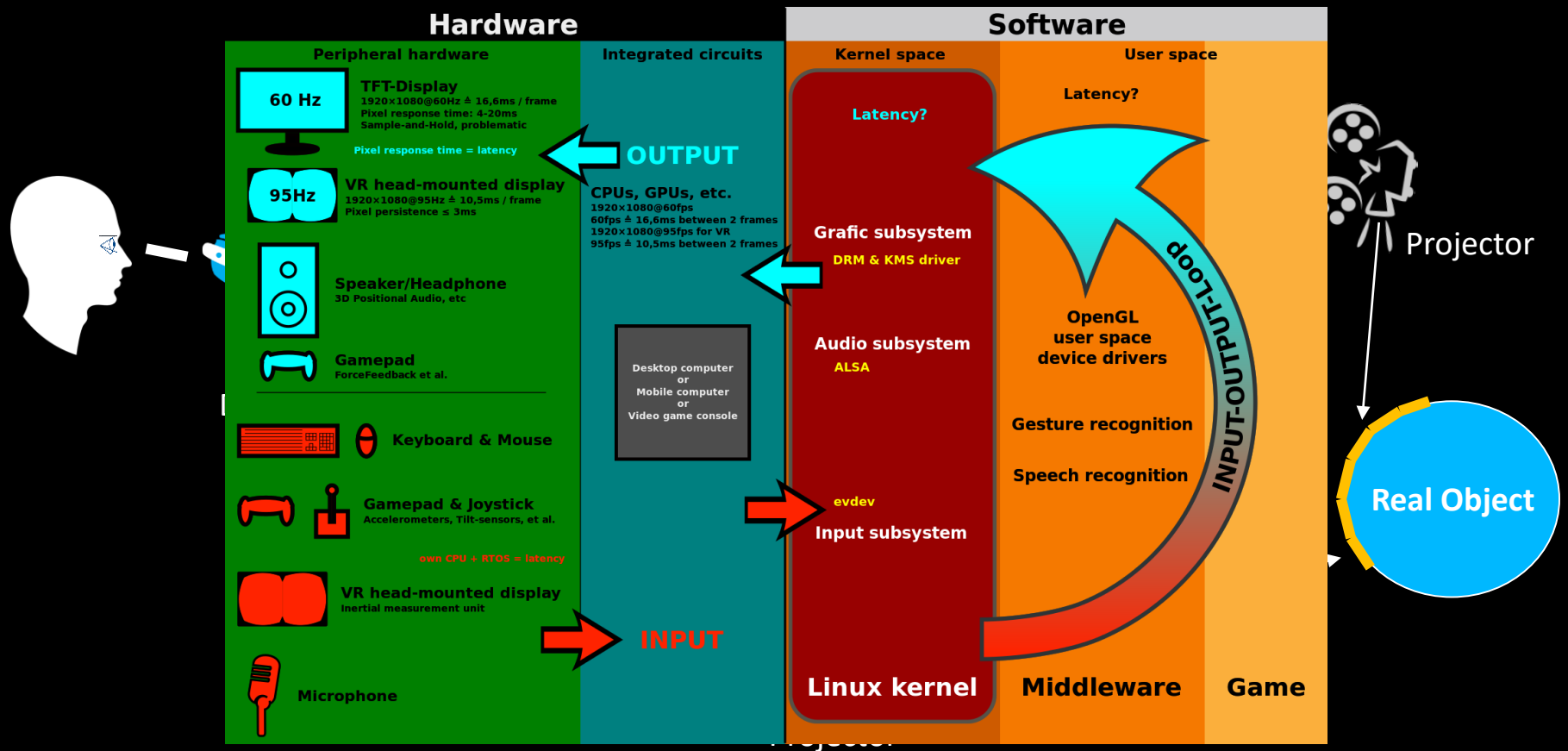




从视觉现实到视觉虚拟现实



从视觉现实到视觉虚拟现实

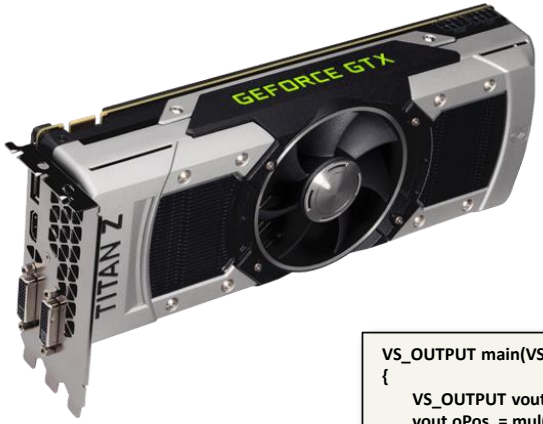


- 硬件 – 虚拟物体呈现原理与方案
- 软件 – 虚拟物体实时绘制技术

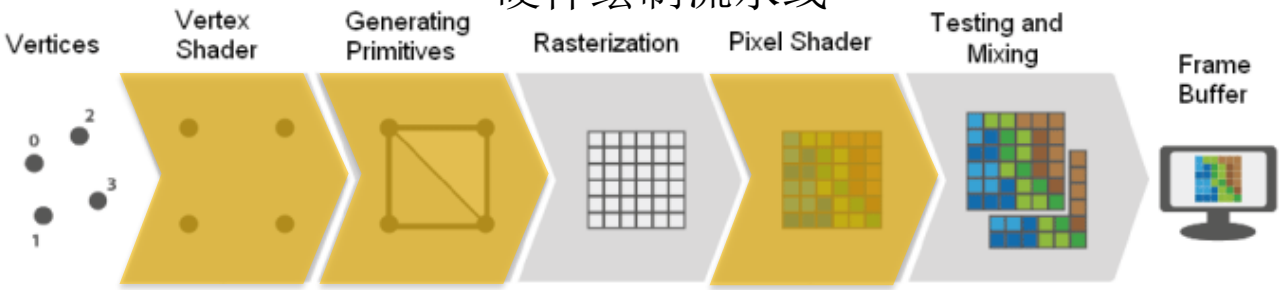
实时绘制技术

硬件绘制流水线

实时绘制技术



硬件绘制流水线

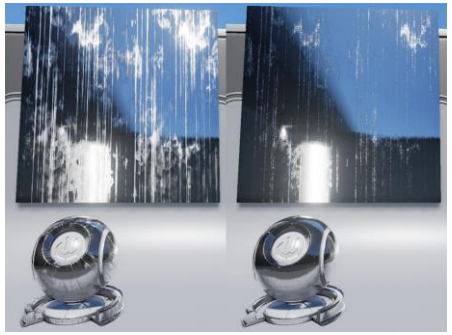



```
VS_OUTPUT main(VS_INPUT in)
{
    VS_OUTPUT vout;
    vout.oPos  = mul(wVP, invPos);
    vout.wPos = mul(wM, in.vPos).xyz;
    return vout;
}
```

```
PS_OUTPUT main(VS_OUTPUT in)
{
    PS_OUTPUT pout;
    float3 N = normalize(in.N);
    float3 P = in.wPos.xyz;
    float3 L = normalize(lightPos – P);
    pout.diffuse = Kd * Ic* dot(N,L);
    return pout;
}
```

```
GS_OUTPUT main(VS_INPUT in)
{
    GS_OUTPUT out;
    out.oPos  = mul(wVP, invPos);
    float3 N = normalize(in.N);
    float3 P = in.wPos.xyz;
    return out;
}
```

模型

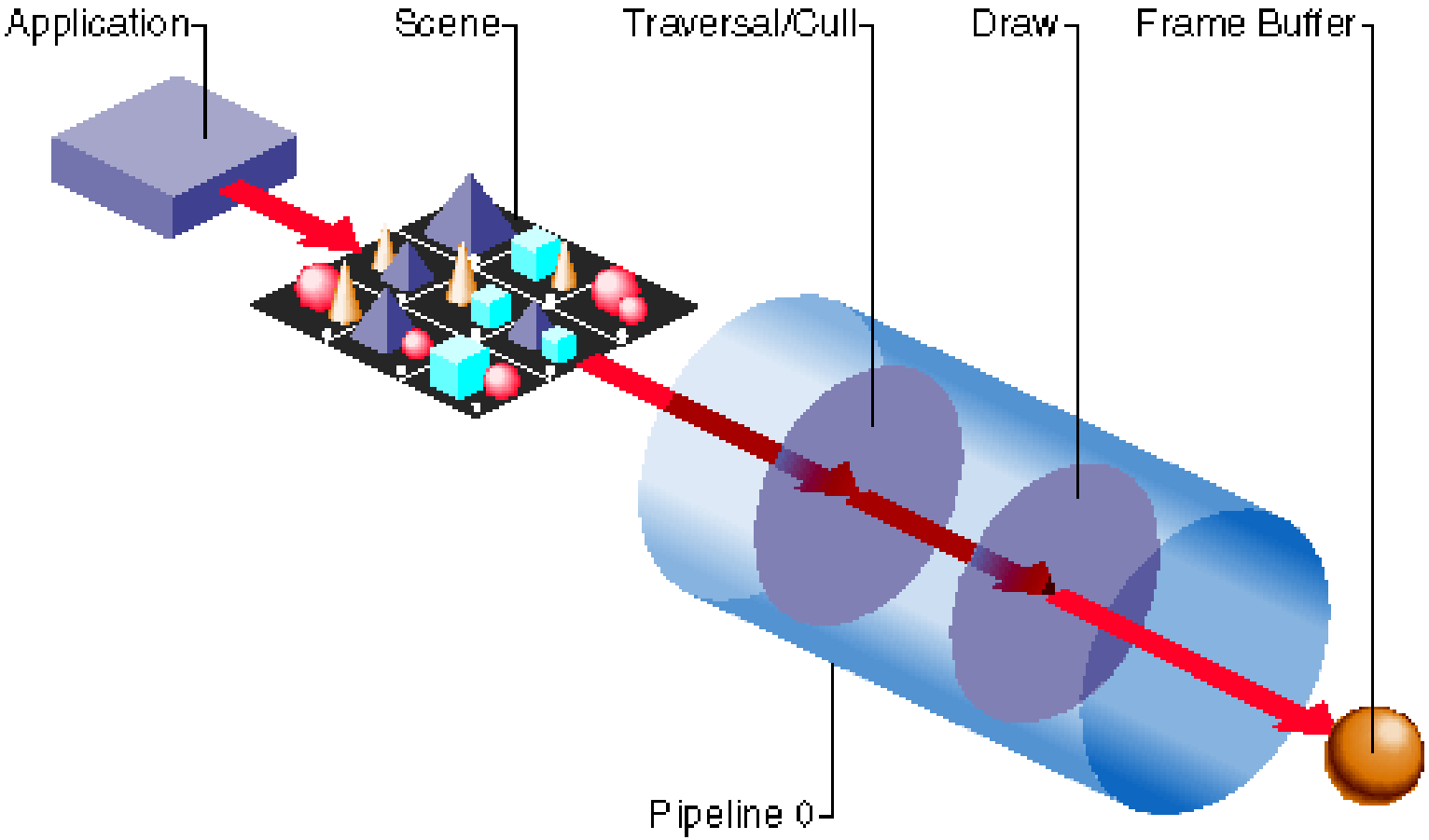


Reflection

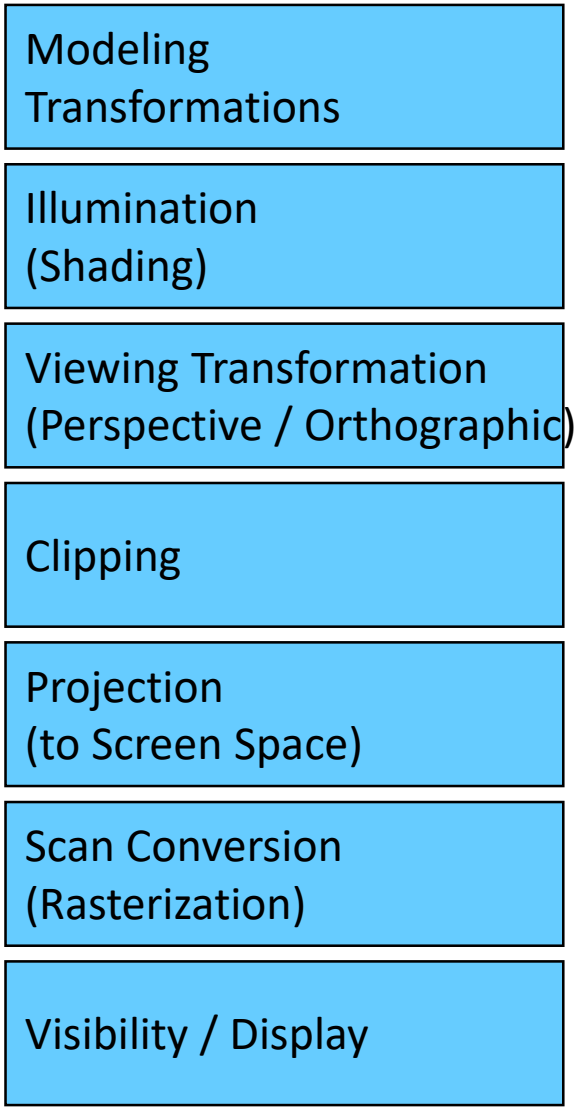
Resolution scale

Shaft

绘制流水线


Application
Scene
Traversal/Cull
Draw
Frame Buffer
Pipeline 0

绘制流水线



- 现在的图形API和3D硬件已经把接下来介绍的大部分细节隐藏了。
- 了解底层技术对开发者还是必要的，特别是对那些API还不支持的效果进行开发时。
- 绘制流水线的目的是将三维空间中的场景表示投影映射到屏幕上。（空间变换贯穿其中）

绘制流水线

Modeling Transformations

Illumination (Shading)

Viewing Transformation (Perspective / Orthographic)

Clipping

Projection (to Screen Space)

Scan Conversion (Rasterization)

Visibility / Display

Input:

Geometric model:
Description of all object, surface, and light source geometry and transformations

Lighting model:
Computational description of object and light properties, interaction (reflection)

Synthetic Viewpoint (or *Camera*):
Eye position and viewing frustum

Raster Viewport:
Pixel grid onto which image plane is mapped

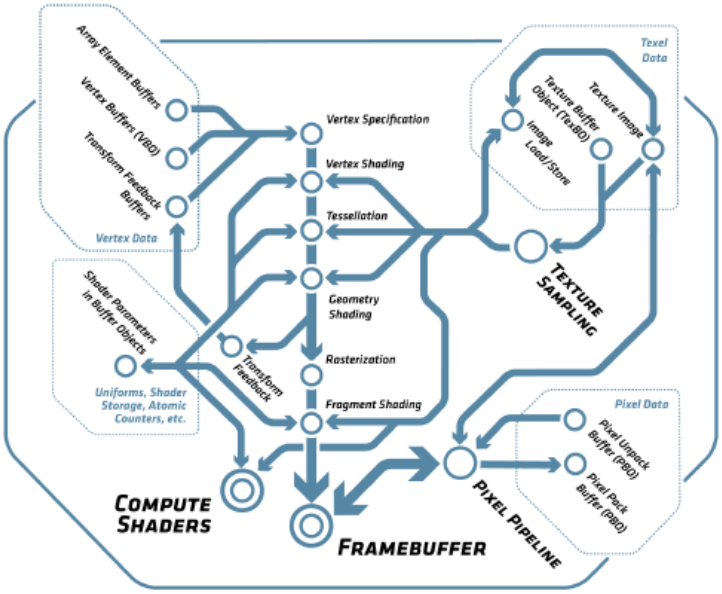
Output:

Colors/Intensities suitable for framebuffer display
(For example, 24-bit RGB value at each pixel)

流水线的演化

Khronos

Continuing OpenGL Innovation



Bringing state-of-the-art functionality to cross-platform graphics

OpenGL 4.5
OpenGL 4.4
OpenGL 4.3
OpenGL 4.2
OpenGL 4.1
OpenGL 3.3/4.0
OpenGL 3.2
OpenGL 3.1
OpenGL 2.0
OpenGL 2.1
OpenGL 3.0

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
DirectX 9.0c		DirectX 10.0		DirectX 10.1		DirectX 11		DirectX 11.1		DirectX 11.2

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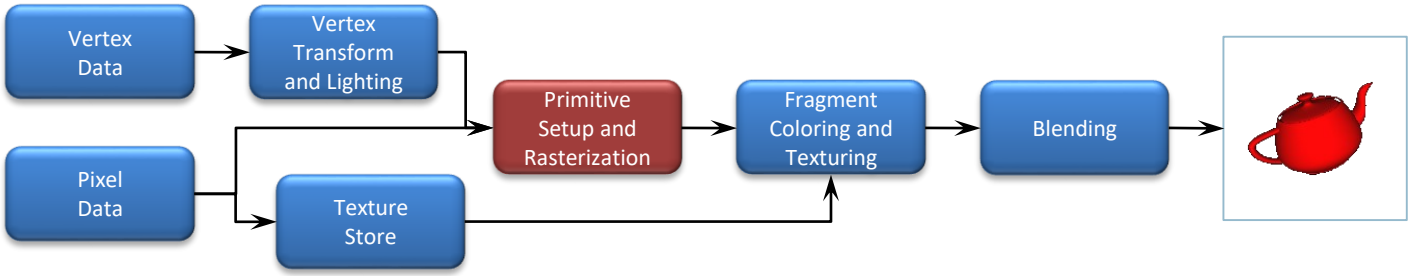
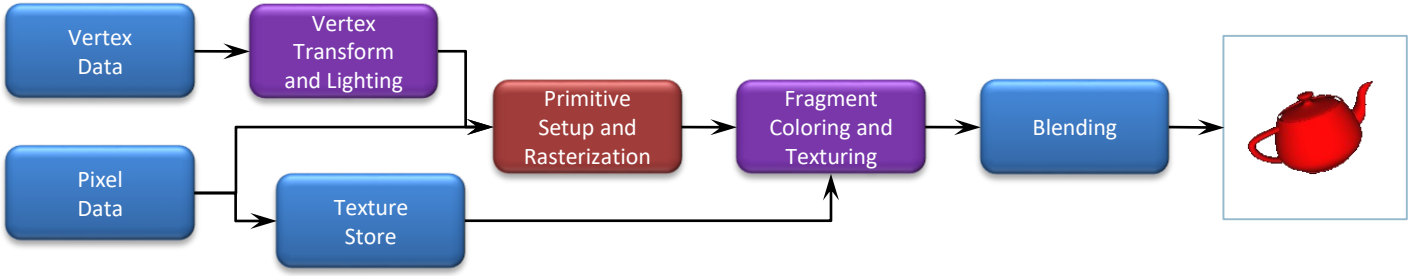
固定流水线 OpenGL 1.0

- OpenGL 1.0 于1994年7月1日发布
- 完全固定的流水线



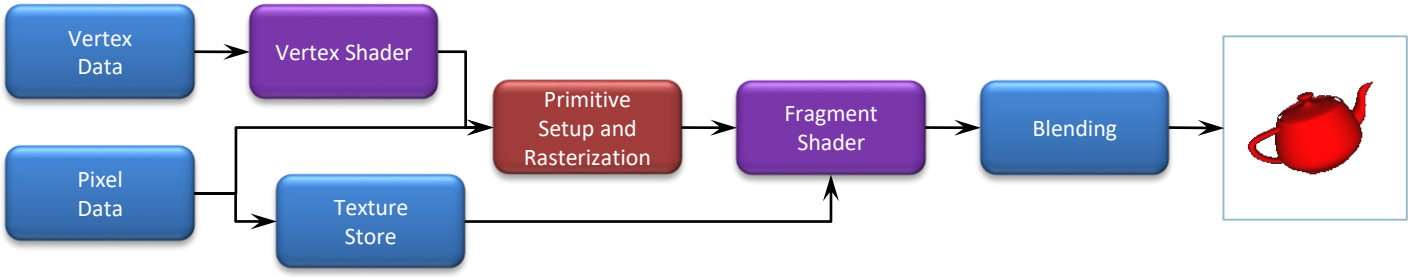
可编程流水线 OpenGL 2.0

- OpenGL 2.0支持可编程(programmable)流水线
  - *vertex shading*
  - *fragment shading*



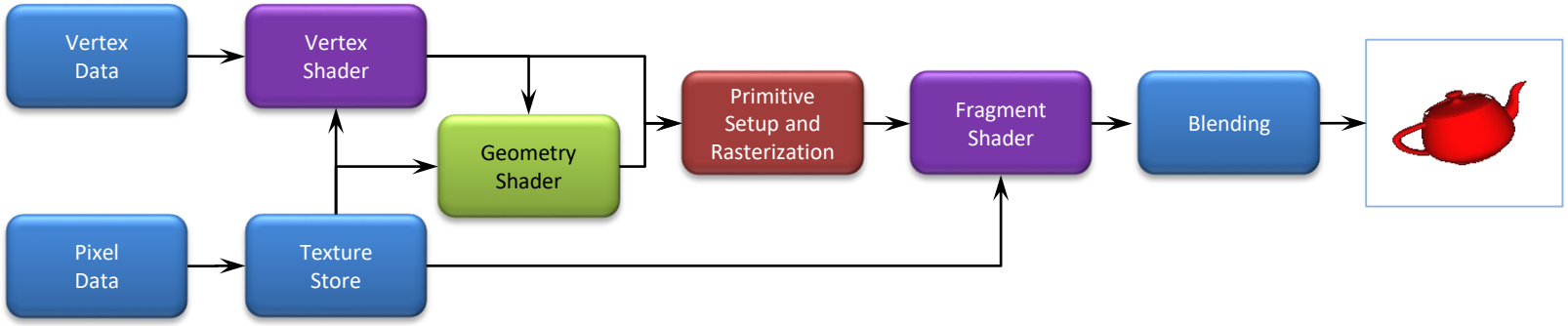
可编程流水线 OpenGL 3.1

- OpenGL 3.1 (released March 24th, 2009) 完全移除了固定流水线
  - OpenGL程序必须使用shaders



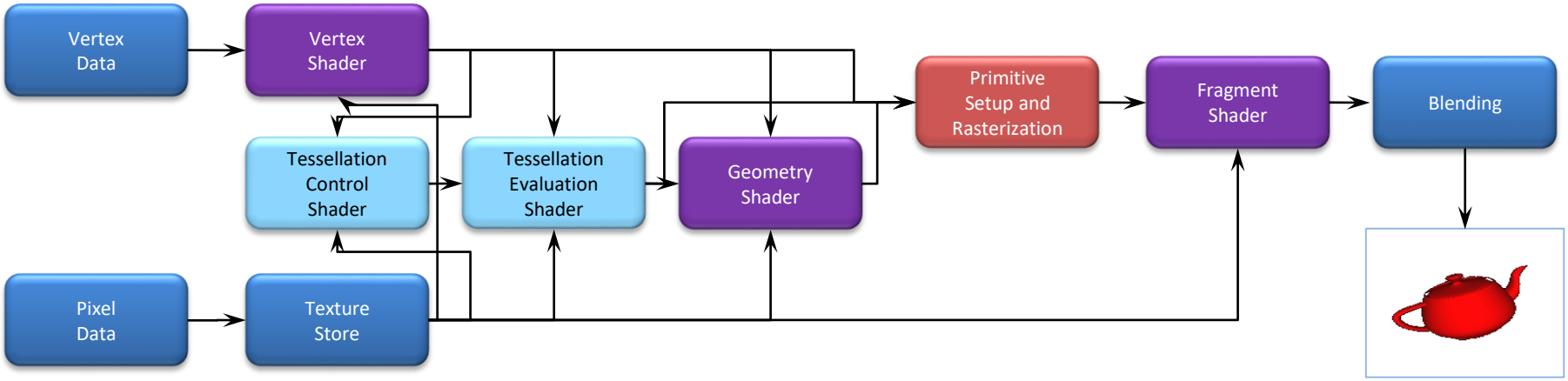
可编程流水线 OpenGL 3.2

- OpenGL 3.2 (released August 3rd, 2009) 添加了一个新的shader – geometry shaders
  - 可以在流水线中修改几何对象



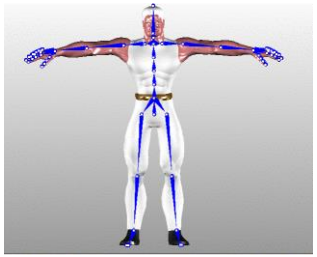
可编程流水线 OpenGL 4.5

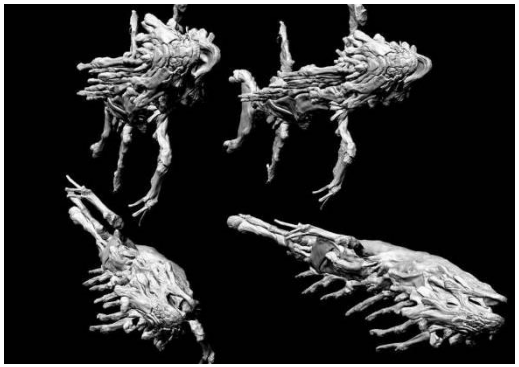
- OpenGL 4.1 (released July 25th, 2010) 添加了新的shader– *tessellation-control* 和 *tessellation-evaluation* shaders
- 最新的OpenGL版本是 4.6 (released July 30, 2017)

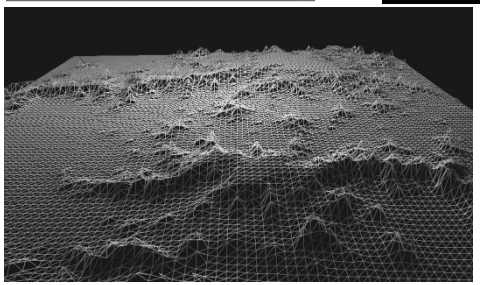


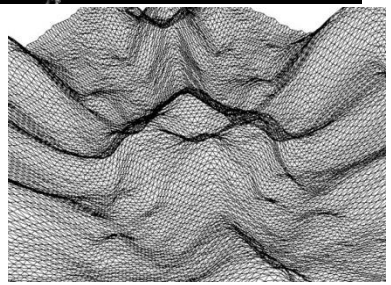
Shaders

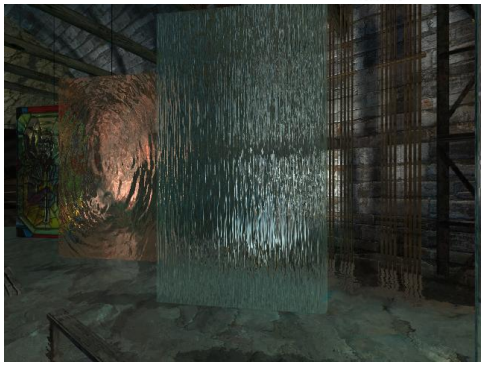
- Vertex Shader
  - Skinning Mesh
- Tessellation
  - Terrain Generation
- Geometry Shader
  - Surface details
- Fragment Shader
  - Advance shading











OpenGL

The OpenGL Family: 3D Everywhere!

The Leading Cross-Platform API for 3D Graphics on Desktop

OpenGL

Mobile-friendly OpenGL subset deployed on billions of devices

OpenGL|ES

OpenGL ES 2.0 functionality made available on the web via HTML5

WebGL

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下一代的APIs

- Vulkan, D3D12, and Metal
  - Coming to platforms you care about

- Why do we want new APIs?
- How are they different?

- An Overview of Next-Generation Graphics APIs (http://nextgenapis.realtimerendering.com/)

谢谢！