THE VIRTUAL FRONTIER:

COMPUTER GRAPHICS CHALLENGES IN VIRTUAL REALITY

Dr. Morgan McGuire | NVIDIA Research

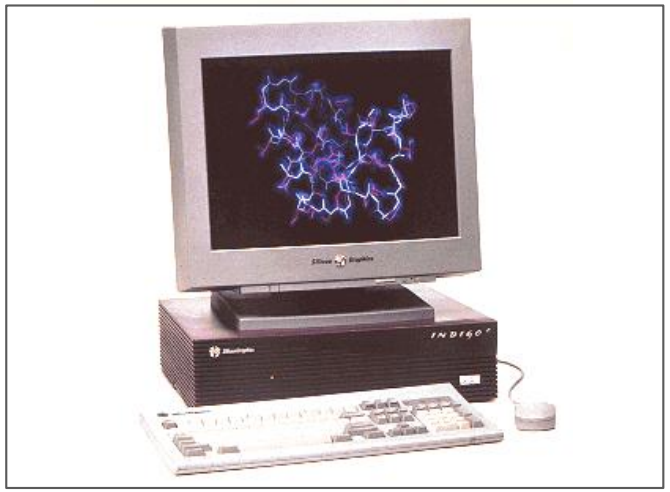
NVIDIA

NVIDIA RESEARCH

120 World-Class Ph.D. Researchers

VISION

1977 HPC



1997 HPC

2017 HPC

Today, everyone is a high-performance computer user, with GPUs in phones, tablets, desktops, game consoles, and cars

VISION

Power User Technology

Pervasive

FUTURE VR

1. Virtual reality will be the new interface to computing for everyone
2. Virtual reality requires a new graphics system

   sensors, algorithms, physics, rendering, AI, data structures, processors, optics, and displays

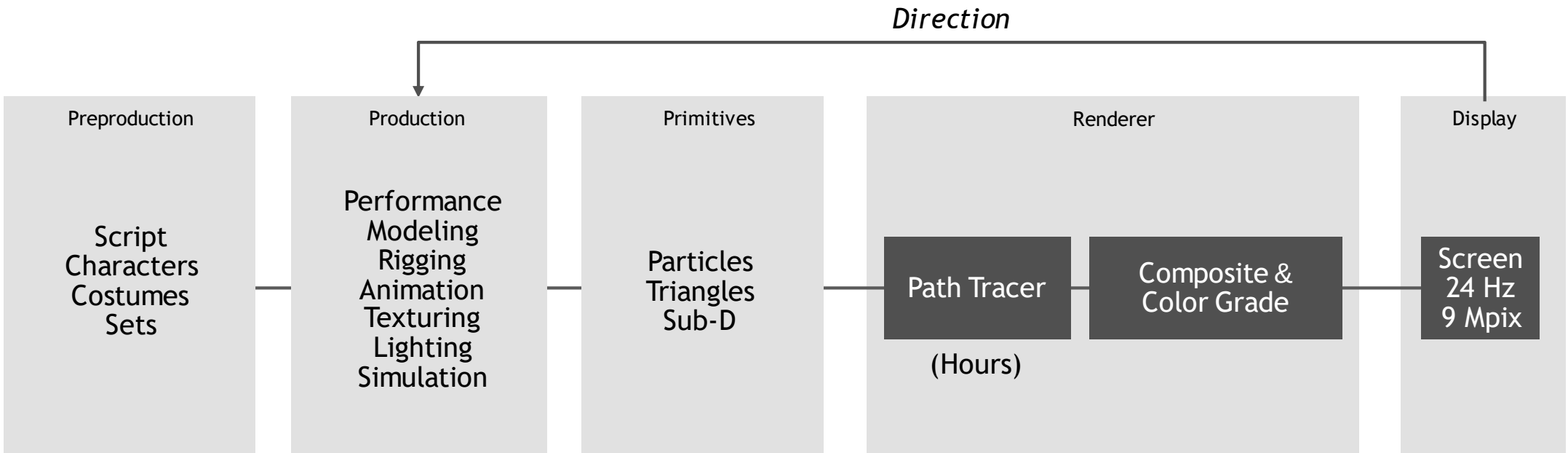
MODERN GRAPHICS SYSTEMS

VISUAL FIDELITY OF FILM CGI

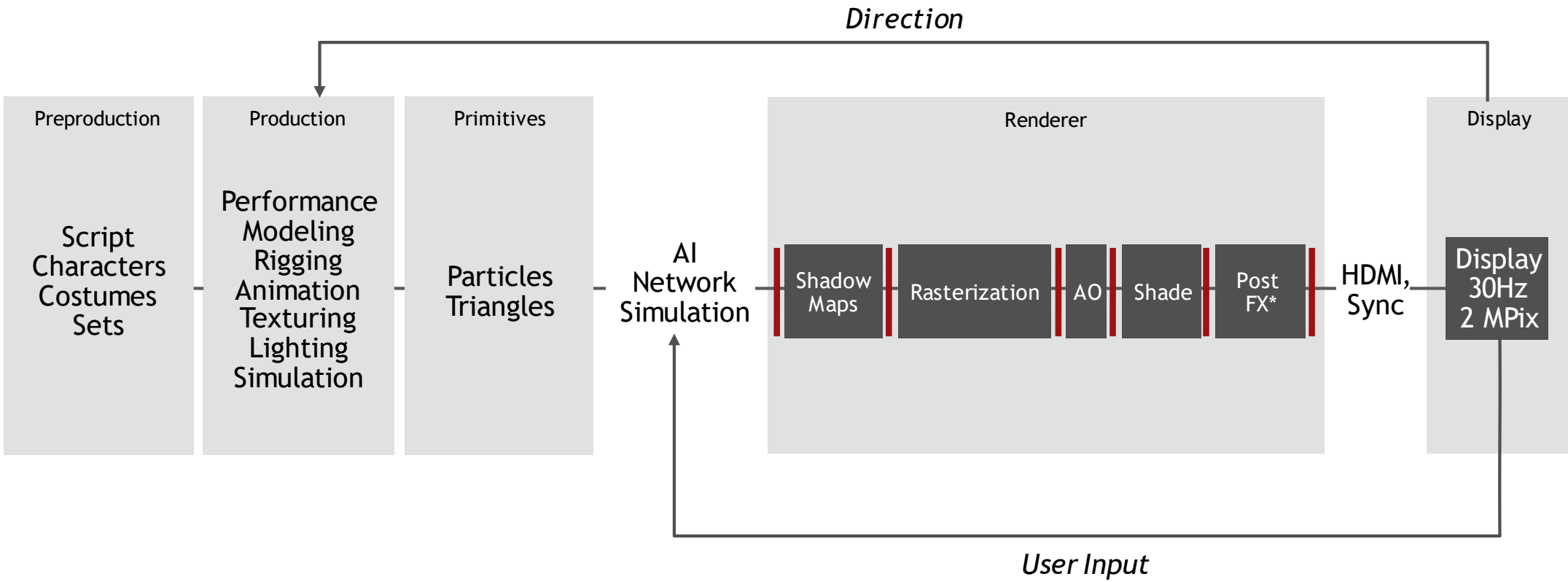
Deadpool (Marvel)

Deadpool (Marvel)

FILM CGI: CONCEPT TO PHOTONS

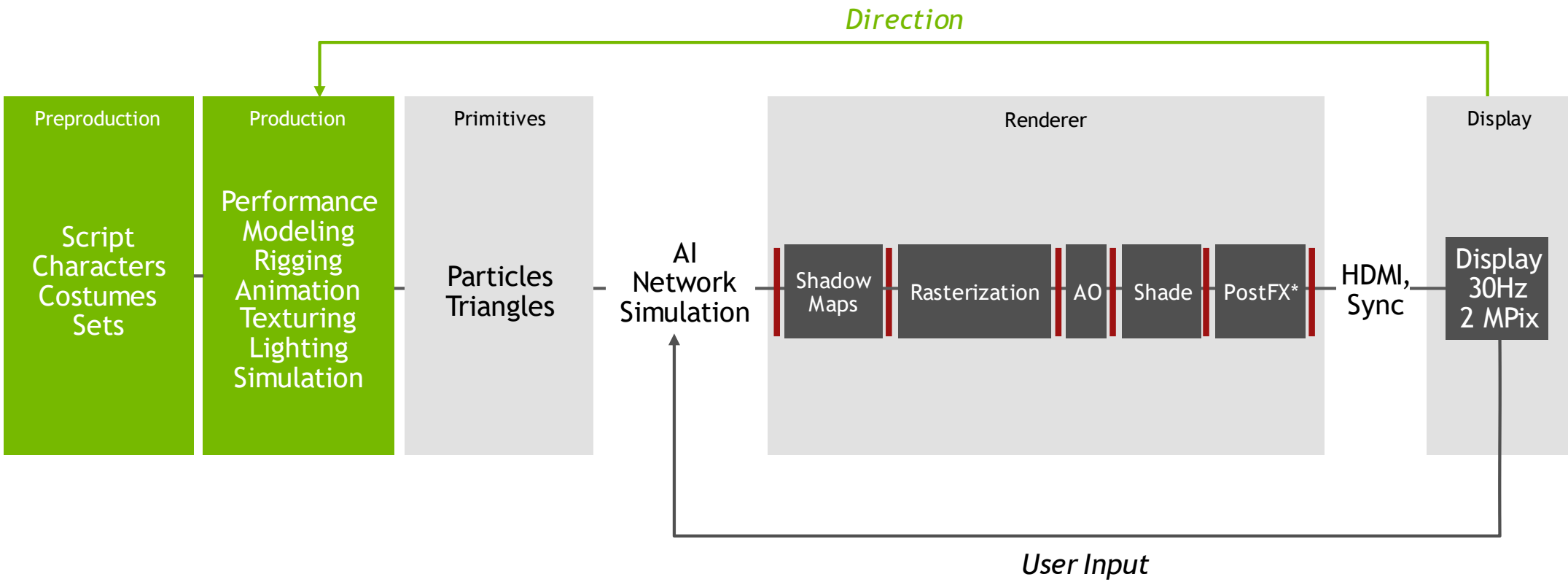


3D GAME SYSTEM



* *Includes depth of field, reflections, fog, color grading, motion blur, antialiasing*

3D GAME SYSTEM



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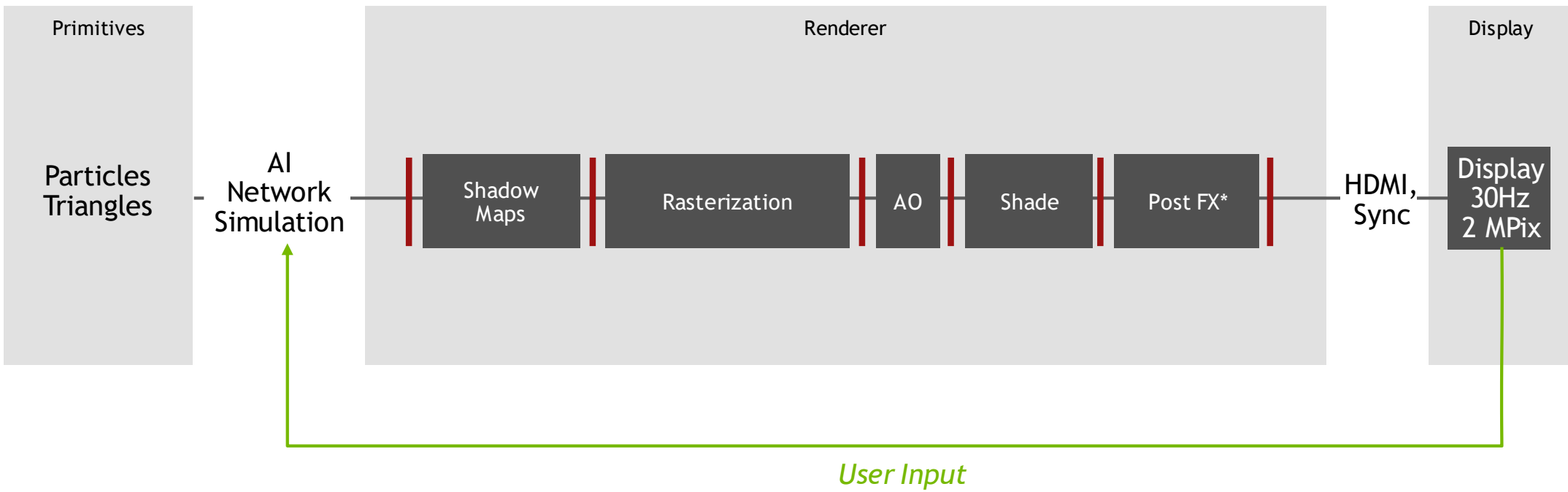

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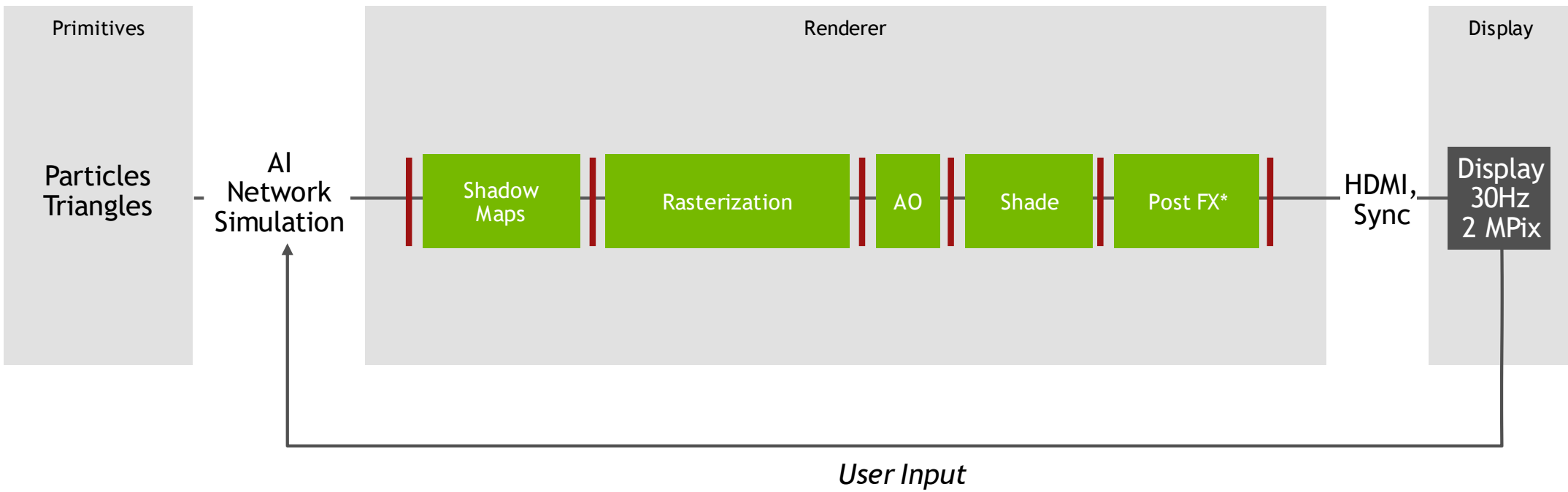


* Includes depth of field, reflections, fog, color grading, motion blur, antialiasing

Star Wars: Battlefront II (DICE)

Forza Motorsport 6 (Turn 10 Studios)

7X THROUGHPUT INCREASE

3D GAME = 60 MPIX/S

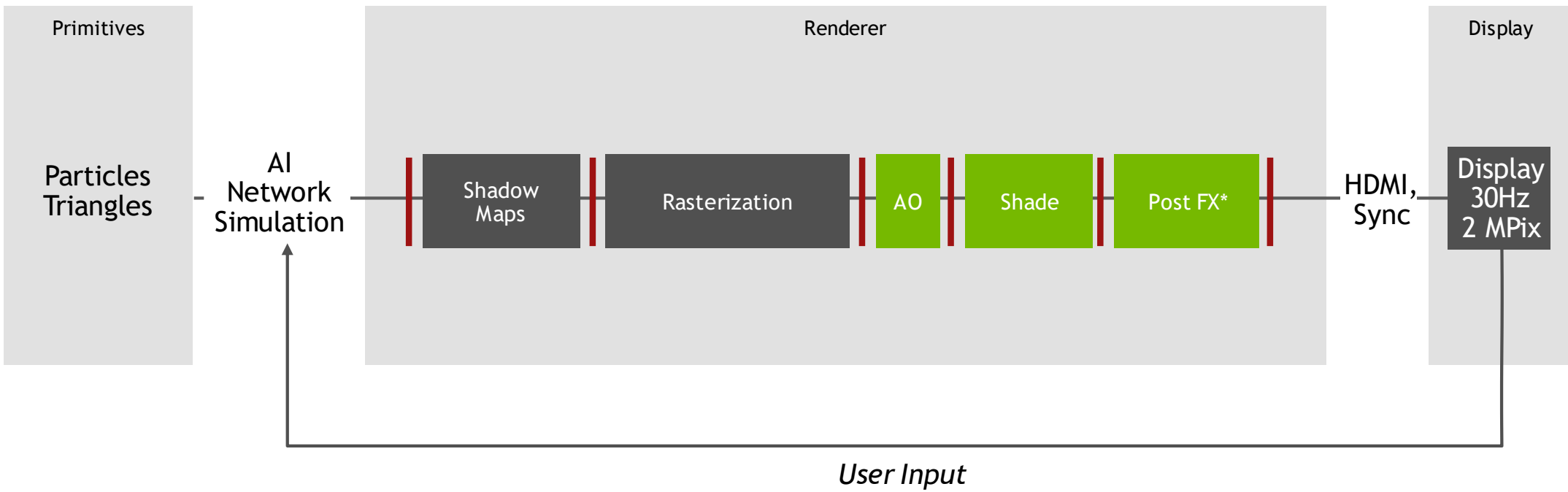
(1920 X 1080 @ MIN 30 FPS)

MODERN VR = 450 MPIX/S

(3024 X 1680 @ MIN 90 FPS)*

** VR render resolution*

3D GAME SYSTEM



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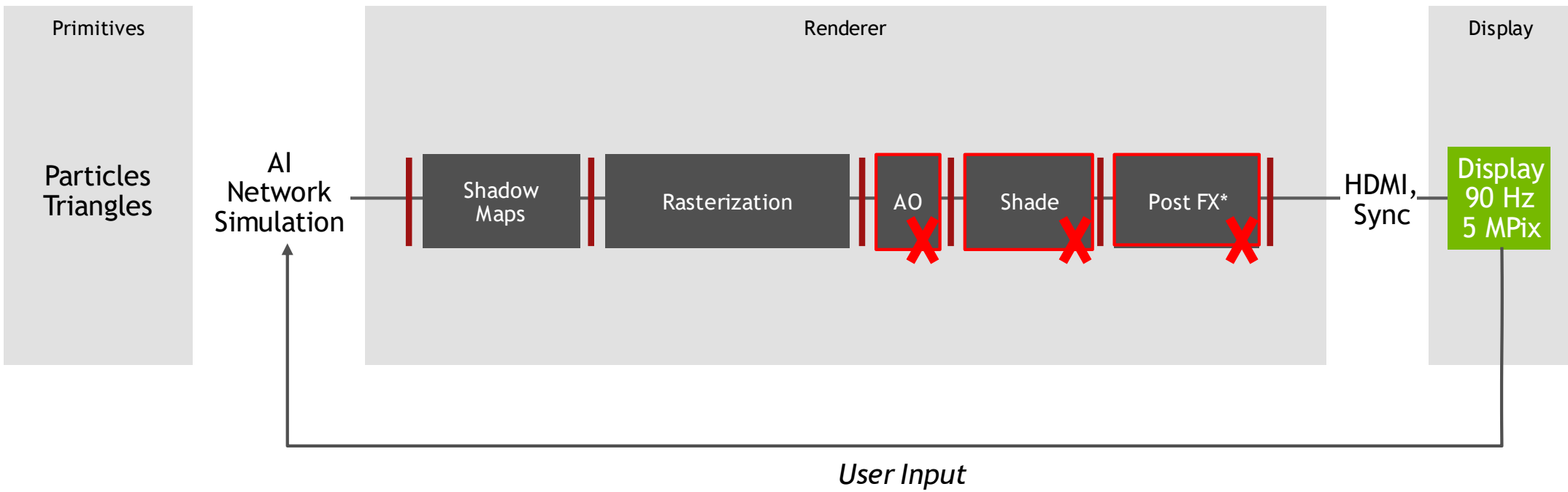
3D GAME SYSTEM



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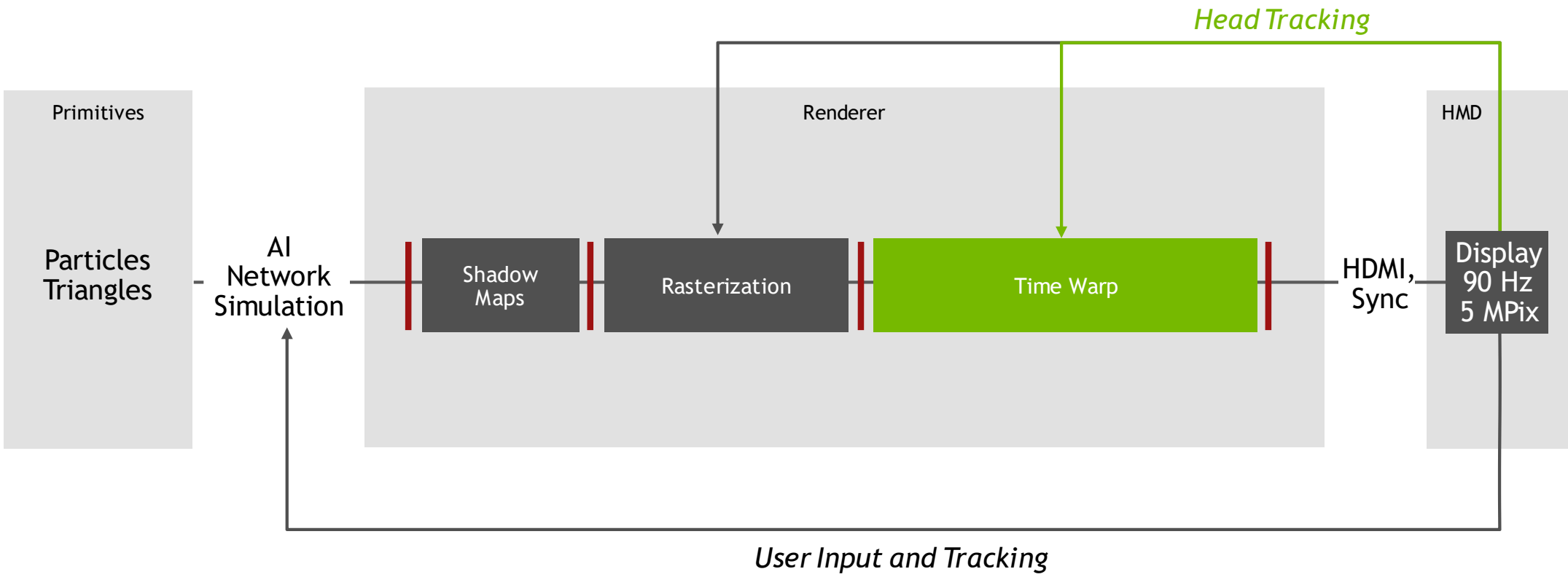
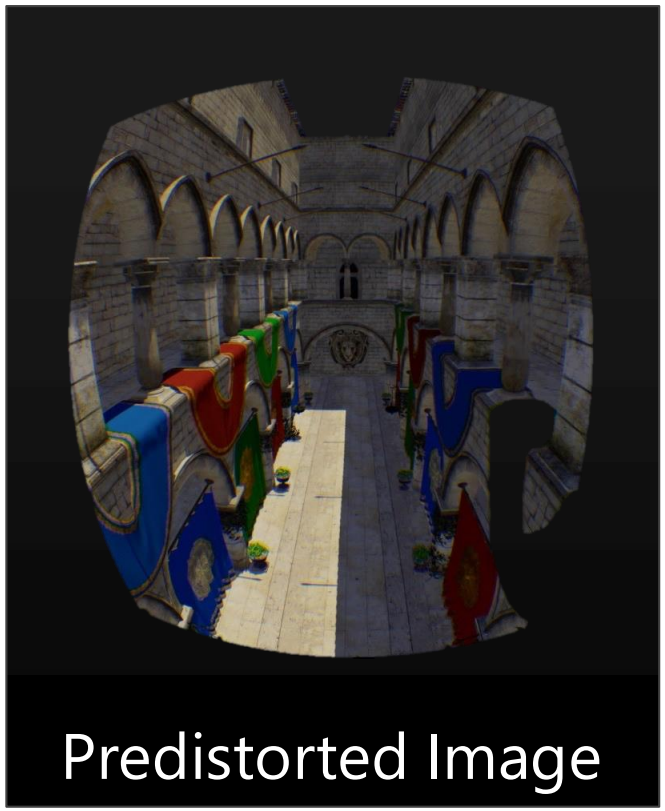
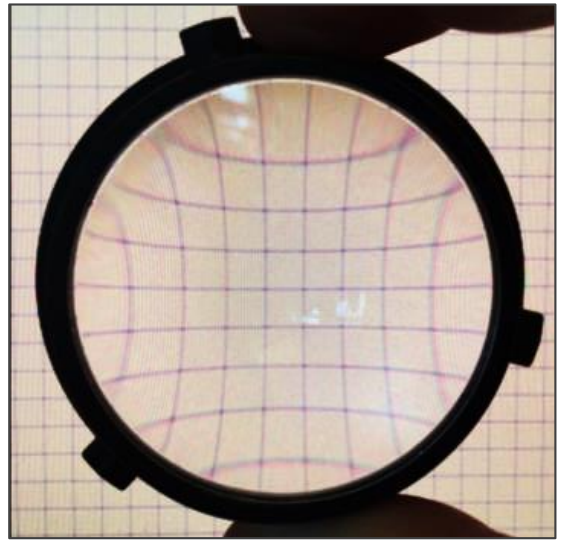
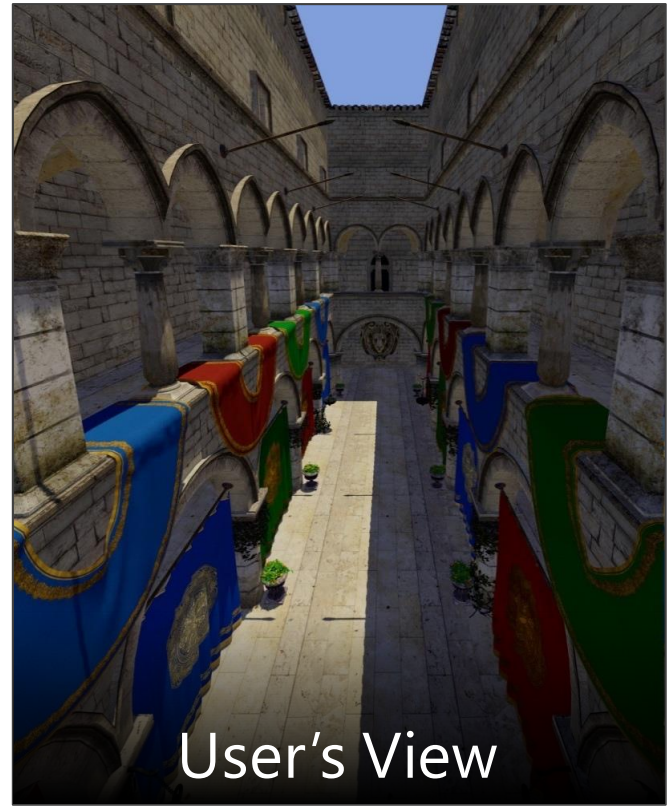
MODERN VR SYSTEM



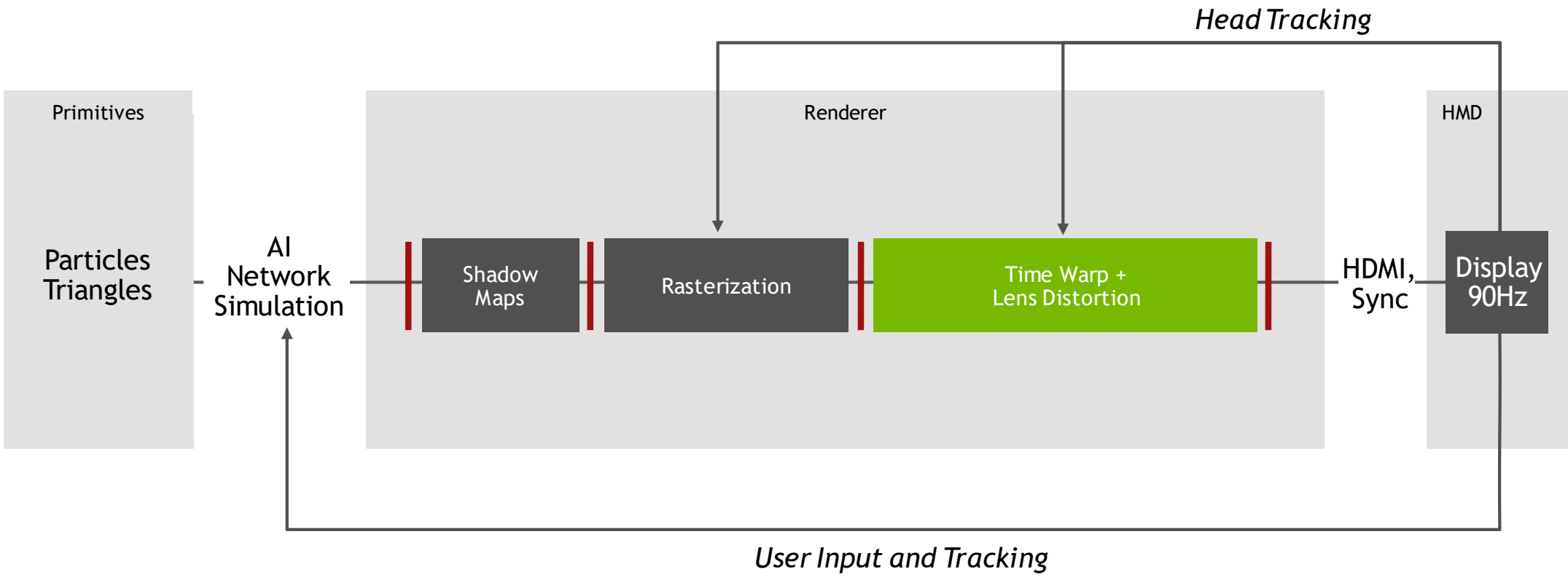
LENS DISTORTION







MODERN VR SYSTEM



1. Virtual reality will be the new interface to computing for everyone
2. Virtual reality requires a new graphics system
   sensors, algorithms, data structures, processors, and displays
3. Pascal architecture upgrades the gaming system to modern VR
   warping, lens matched shading, multiprojection, stereo projection, variable resolution

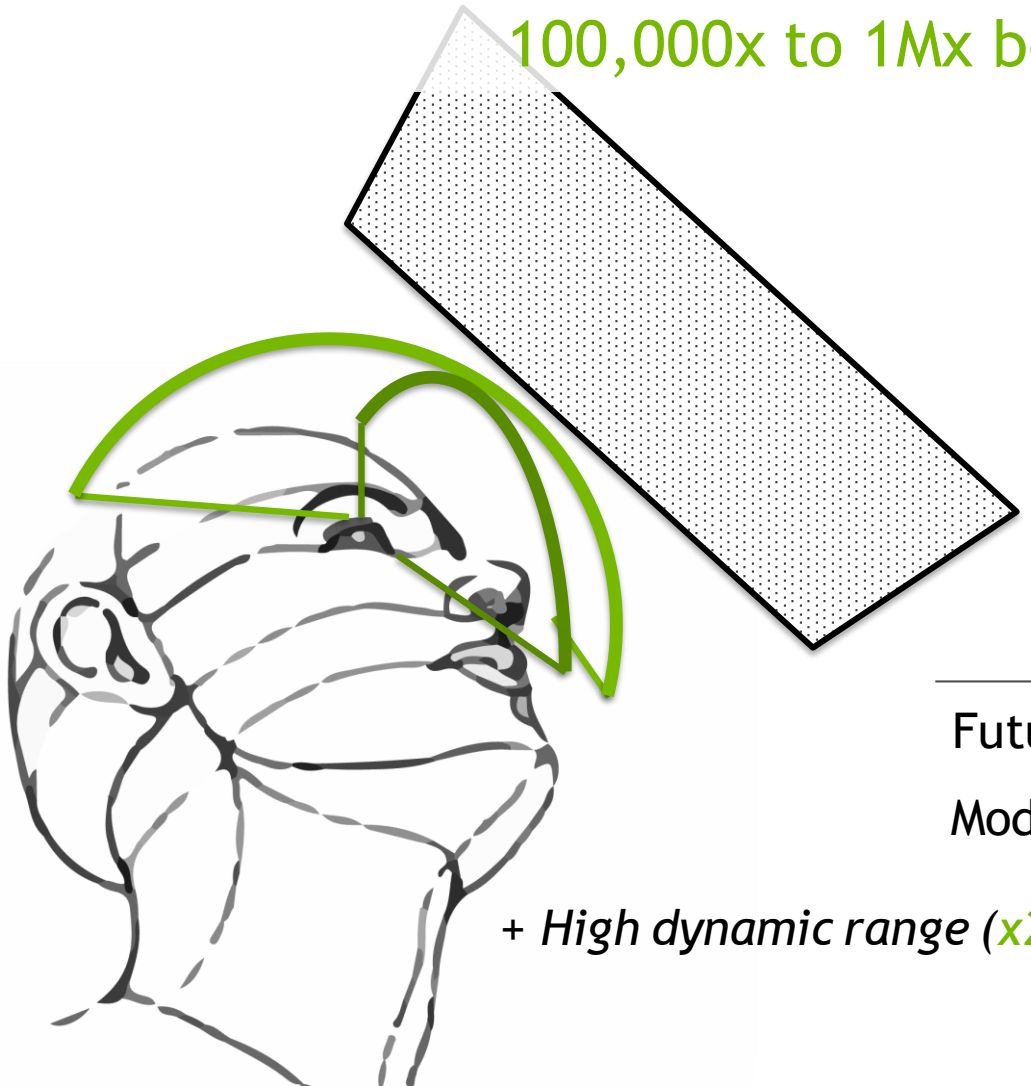
FUTURE GRAPHICS SYSTEMS

The remainder of the talk describes active research, including new results not previously presented in public.

These are not products.

LIMITS OF HUMAN PERCEPTION

100,000x to 1Mx beyond modern VR



220° Horizontal
x 135° Vertical

x (120 pixels/degree)^2

≈ 400,000,000 pixels
= 200 x 1080p TVs

x 240 Hz

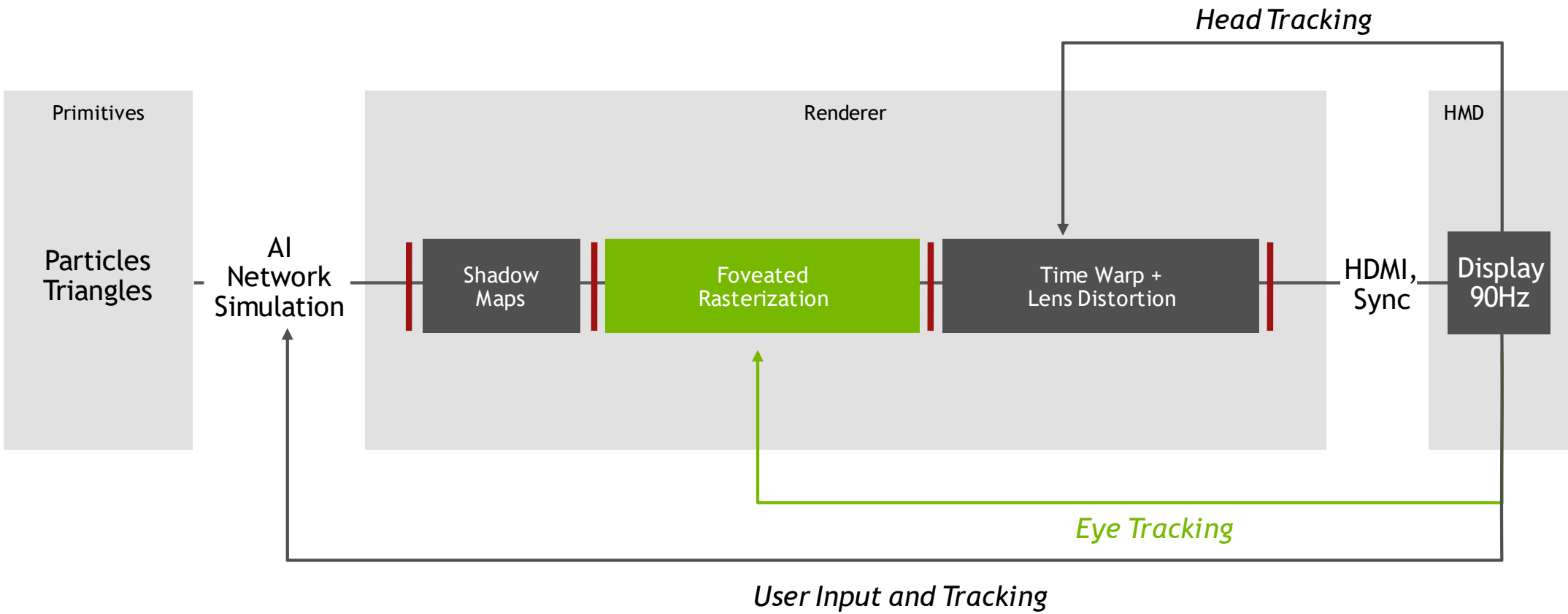
Future VR = **100,000** Mpix/s

Modern VR = **450** Mpix/s

+ High dynamic range (x2), photorealistic dynamic lighting (x10,000), …

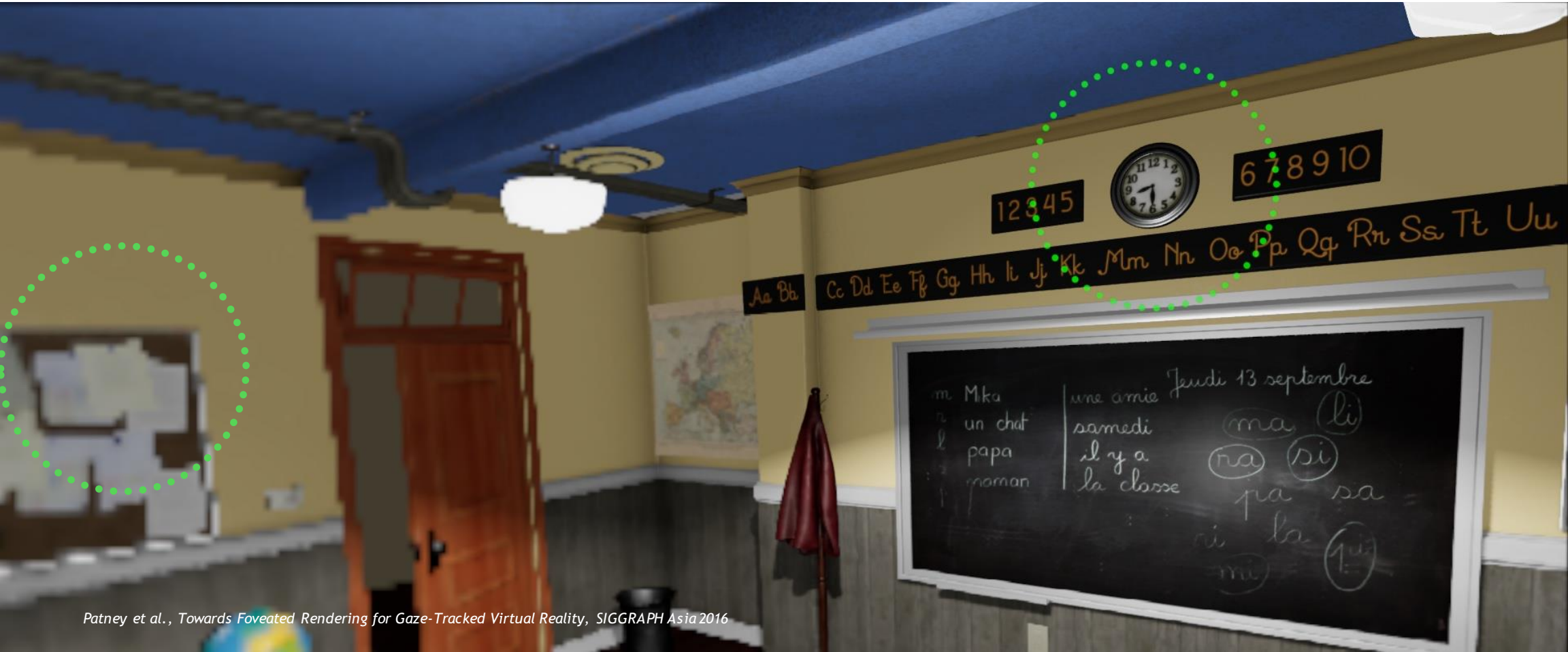
Head image from http://jeffsearle.blogspot.com/2015/09/drawing-head-from-different-angles.html

FOVEATED RENDERING



FOVEATED RENDERING

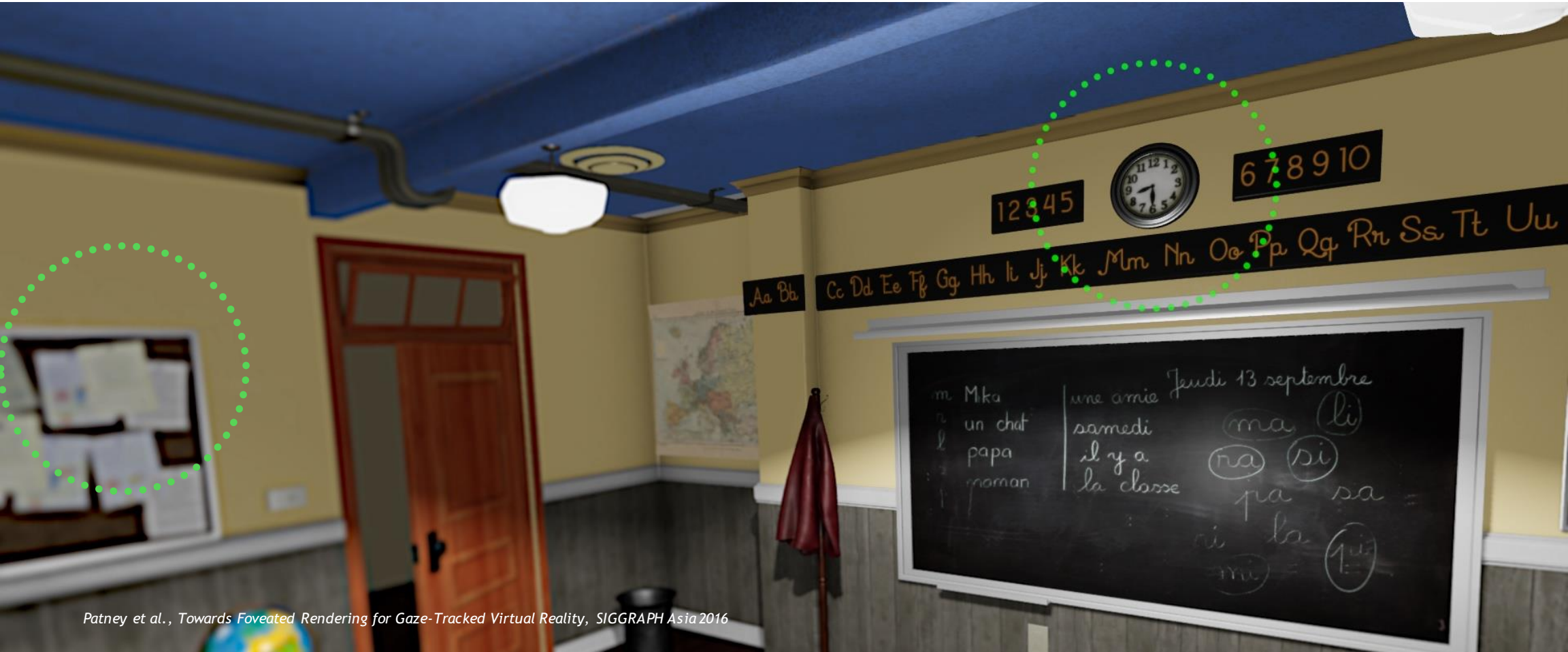
Conventional Approach: Aliasing



Patney et al., Towards Foveated Rendering for Gaze-Tracked Virtual Reality, SIGGRAPH Asia 2016

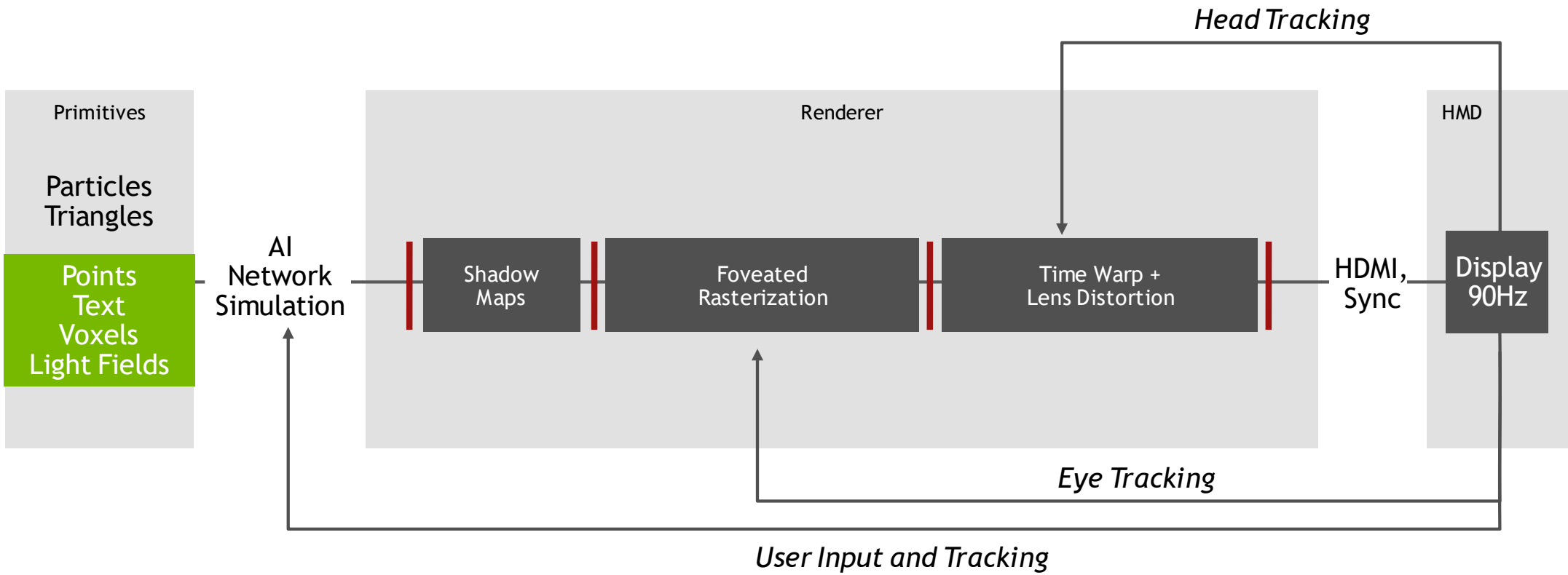
FOVEATED RENDERING

Our Approach: Perceptually Optimized



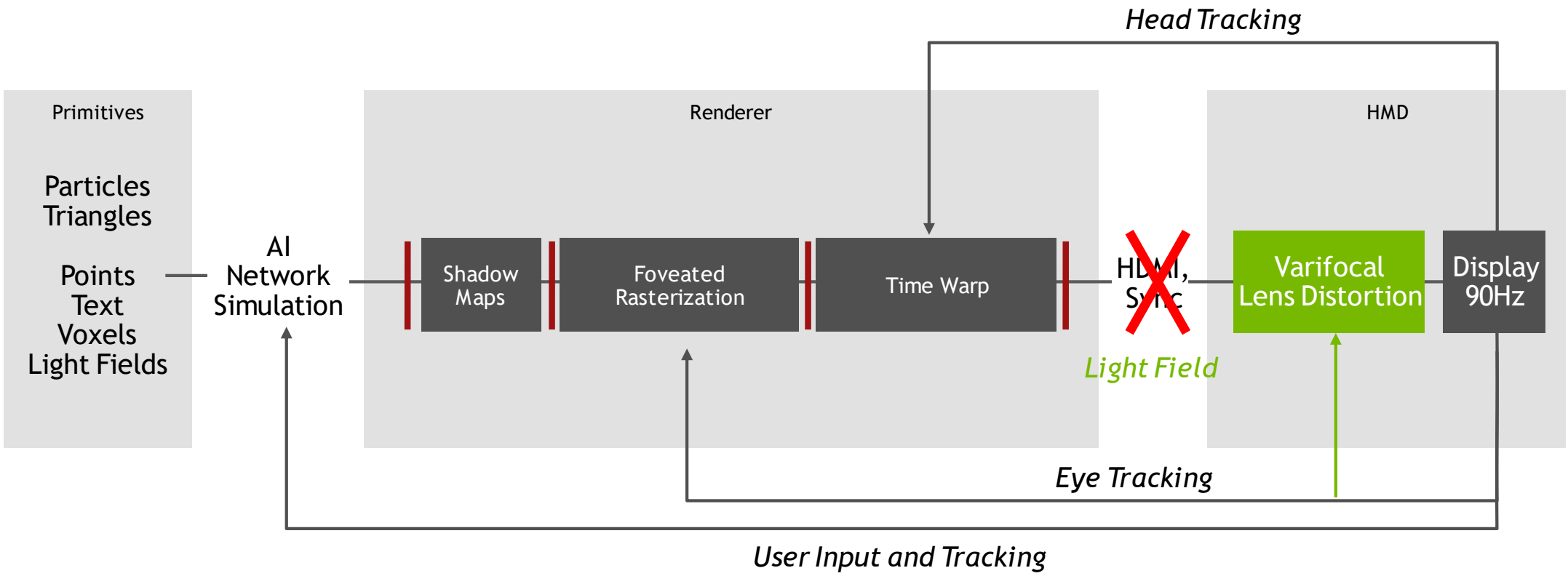
Patney et al., Towards Foveated Rendering for Gaze-Tracked Virtual Reality, SIGGRAPH Asia 2016

BEYOND TRIANGLES



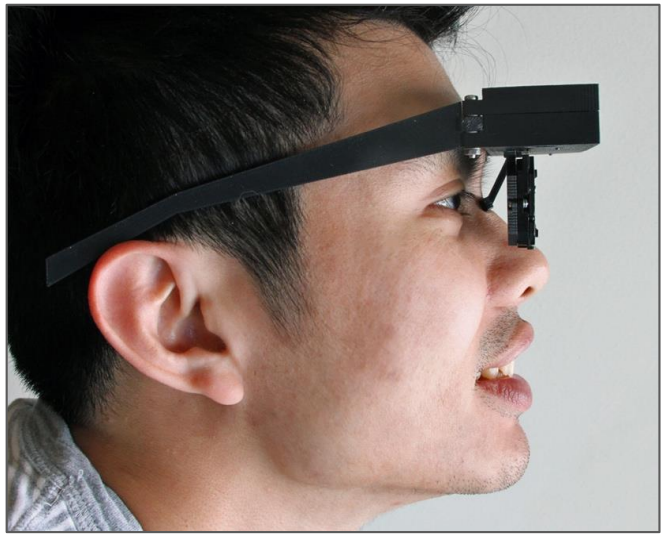
McGuire et al., Real-time global illumination with light field probes, I3D 2017

COMPUTATIONAL DISPLAYS

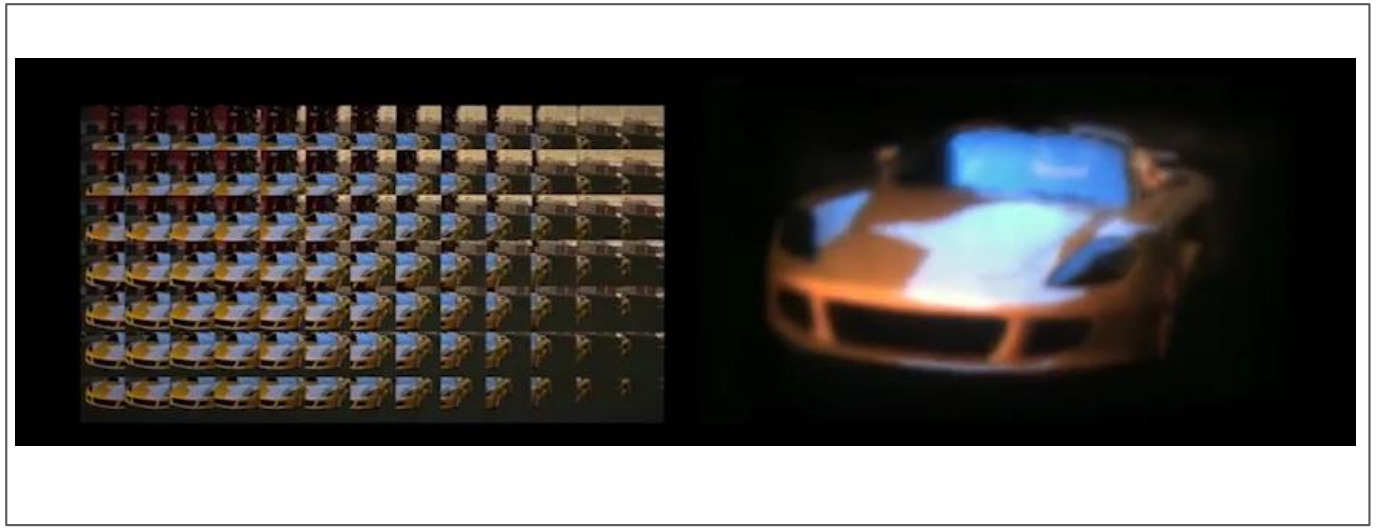


COMPUTATIONAL DISPLAYS

Light Field Display



Display Prototype



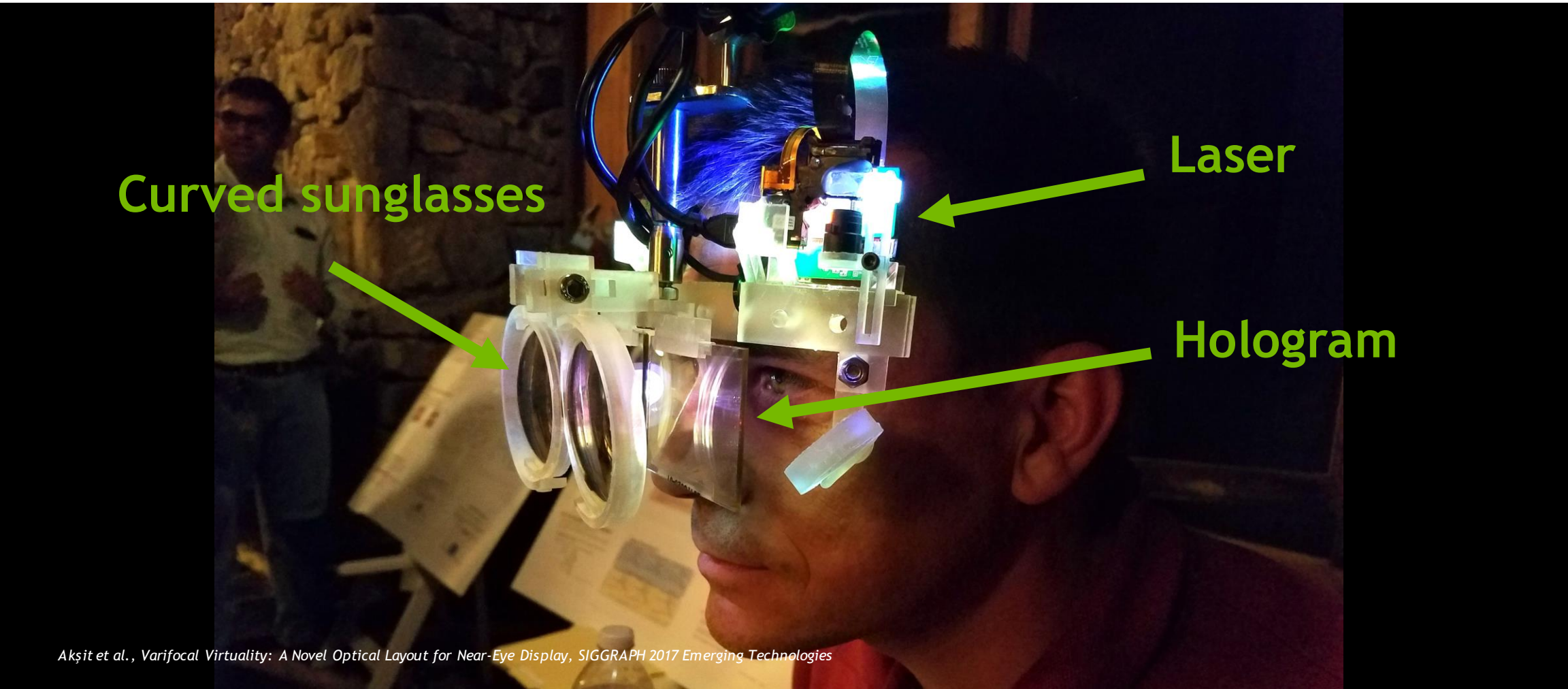
GPU Output

Observed Image

Lanman and Luebke, Near-Eye Light Field Displays, SIGGRAPH Asia 2013

COMPUTATIONAL DISPLAYS

Varifocal Optics



Akşit et al., Varifocal Virtuality: A Novel Optical Layout for Near-Eye Display, SIGGRAPH 2017 Emerging Technologies

COMPUTATIONAL DISPLAYS

Varifocal Optics

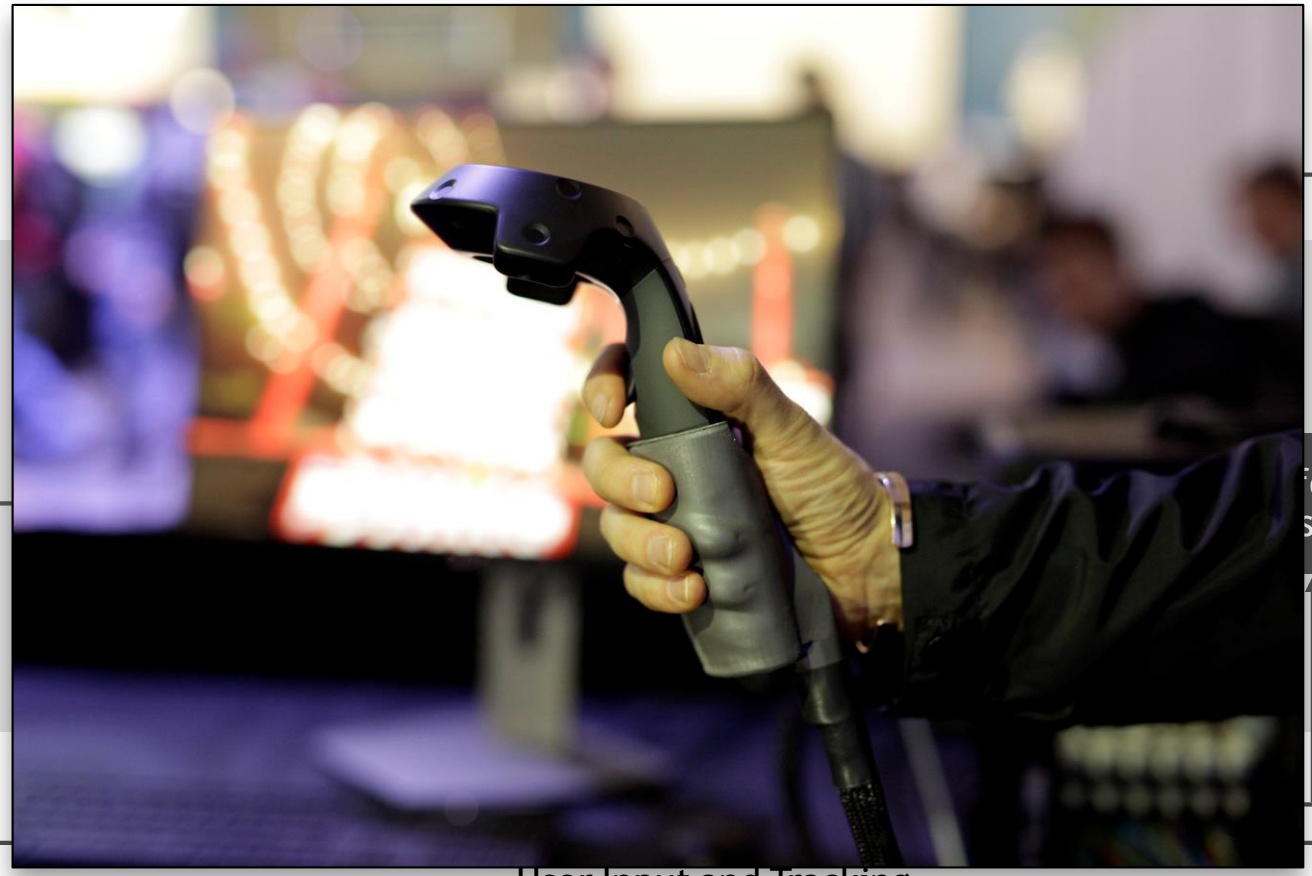
Dunn et al, Wide field of view varifocal near-eye display using see-through deformable membrane mirrors, Proc. of IEEE VR 2017

NVIDIA

MAX-PLANCK-GESELLSCHAFT

UNIVERSITÄT DES SAARLANDES

PNEUMATIC HAPTICS



Primitives

Particles
Triangles

Points
Text
2½D Video
Voxels
Light Fields

AI
Network
Simulation

HMD

ocal
stortion

Display
90Hz

User Input and Tracking

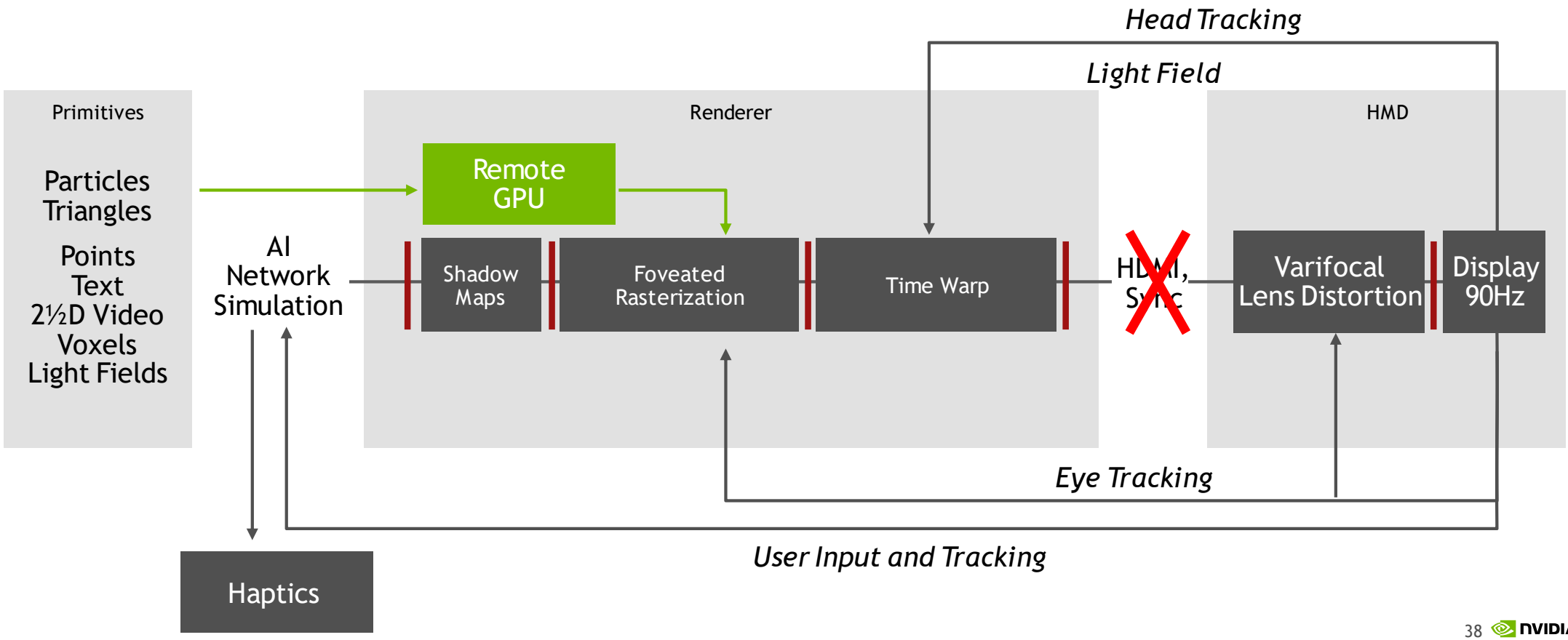
Haptics

NVIDIA

CORNELL UNIVERSITY FOUNDED A.D. 1865

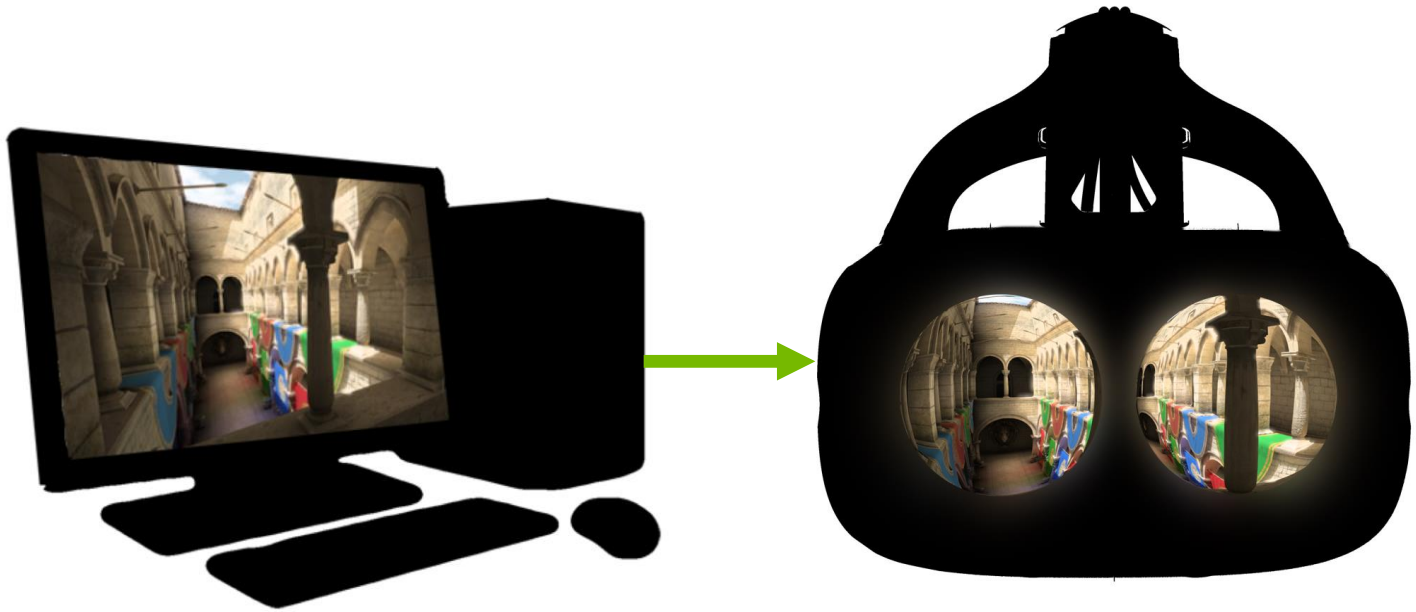
LOW LATENCY

Hierarchical Rendering



LOW LATENCY

Hierarchical Rendering



Local GeForce

Wearable Tegra

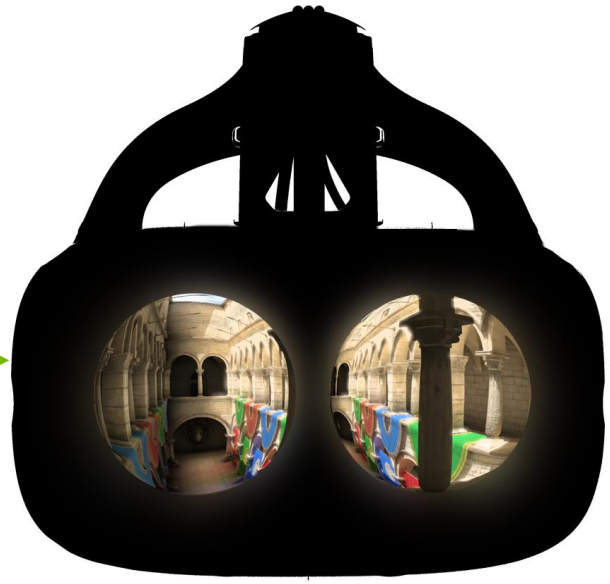
Crassin et al., CloudLight: A system for amortizing indirect lighting in real-time, JCGT 2015

LOW LATENCY

Hierarchical Rendering

Cloud GRID Platform
Tesla GPU

Local GeForce



Wearable Tegra

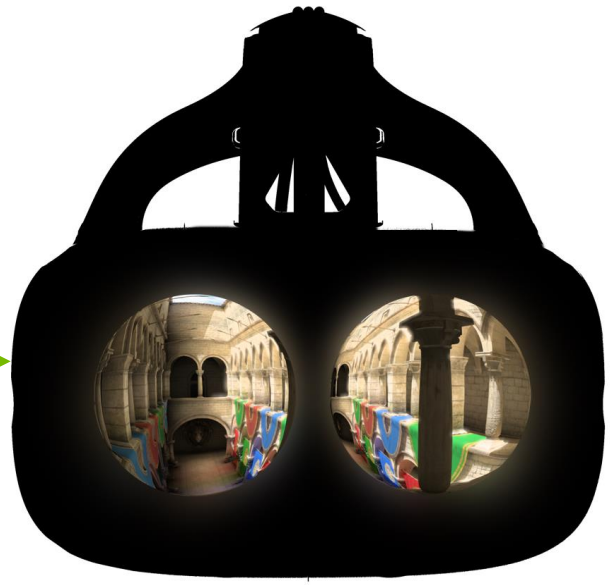
LOW LATENCY

Hierarchical Rendering

Cloud GRID Platform
Tesla GPU

High speed network

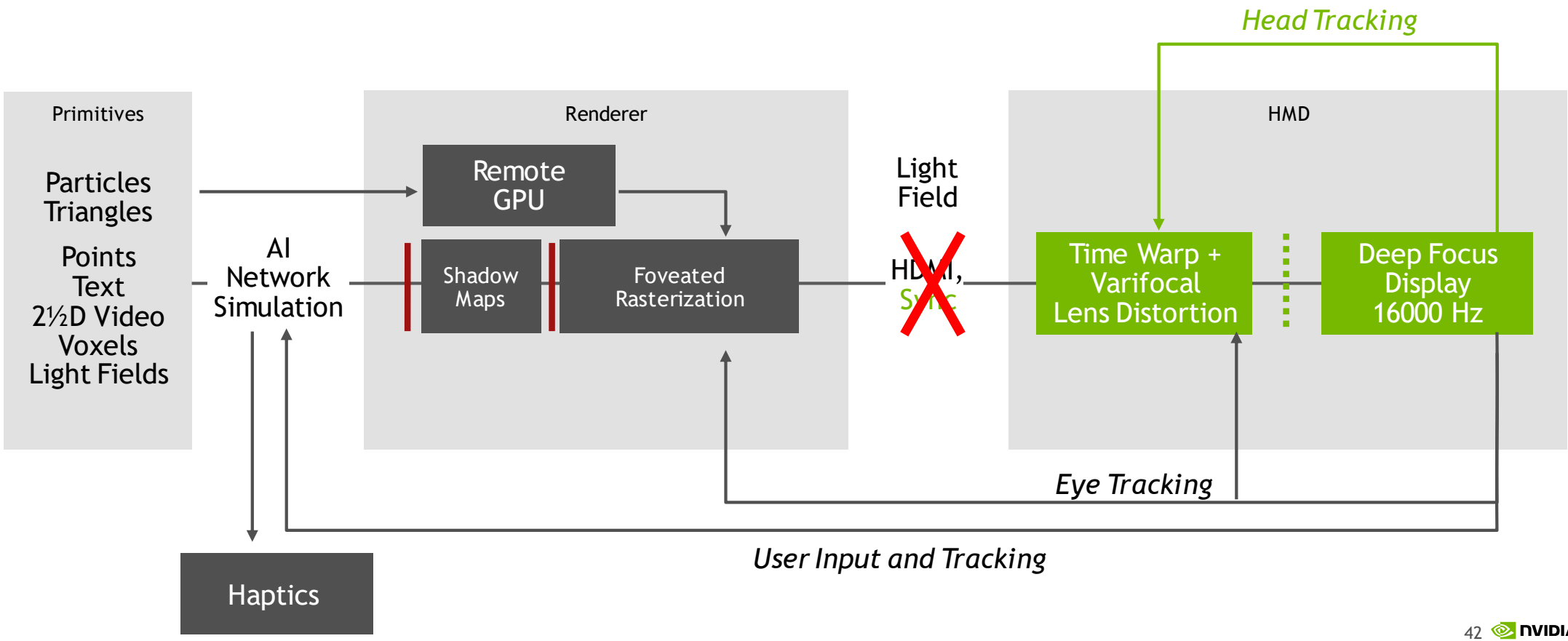
Compressed lighting data

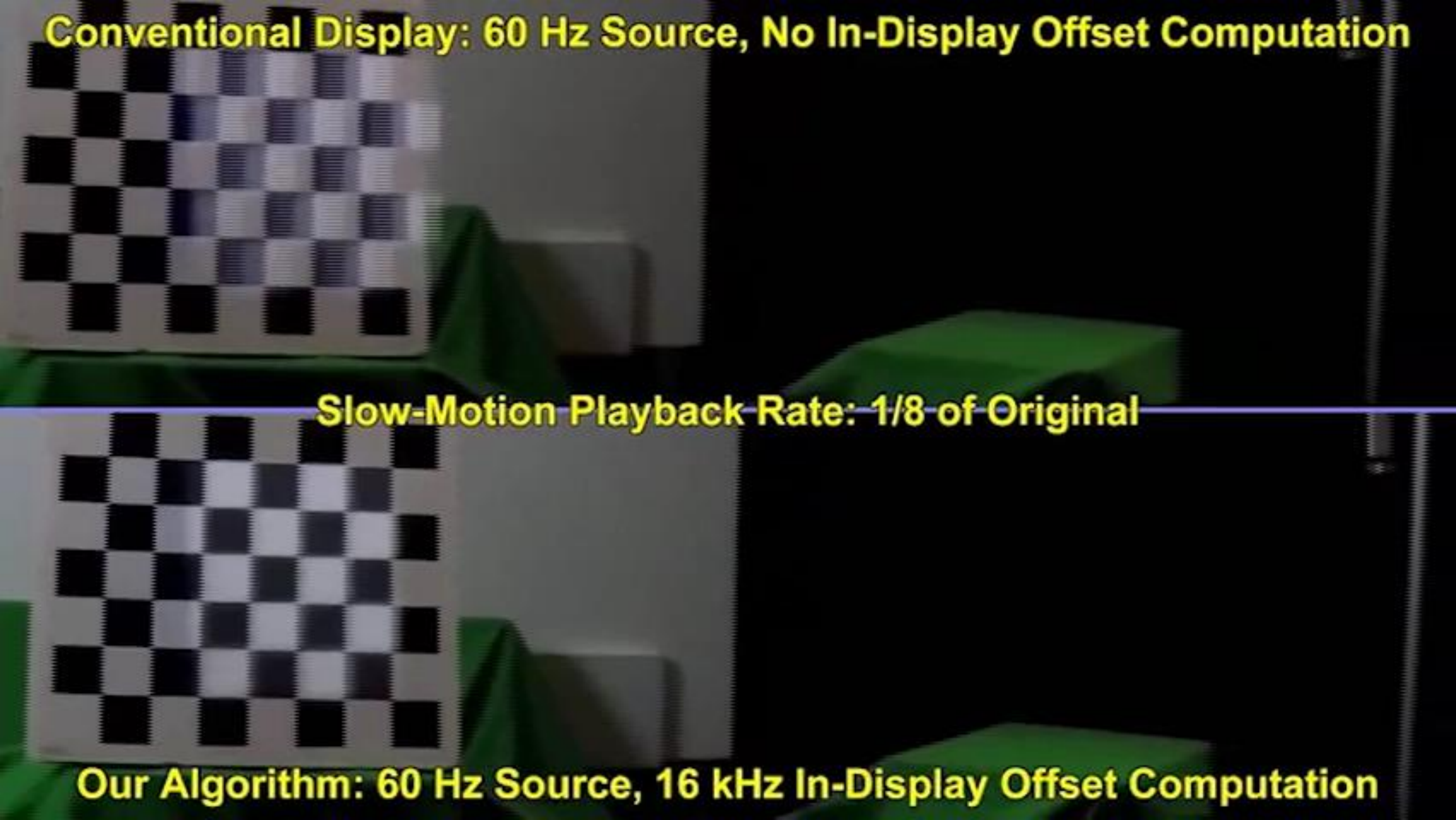


Wearable Tegra

LOW LATENCY

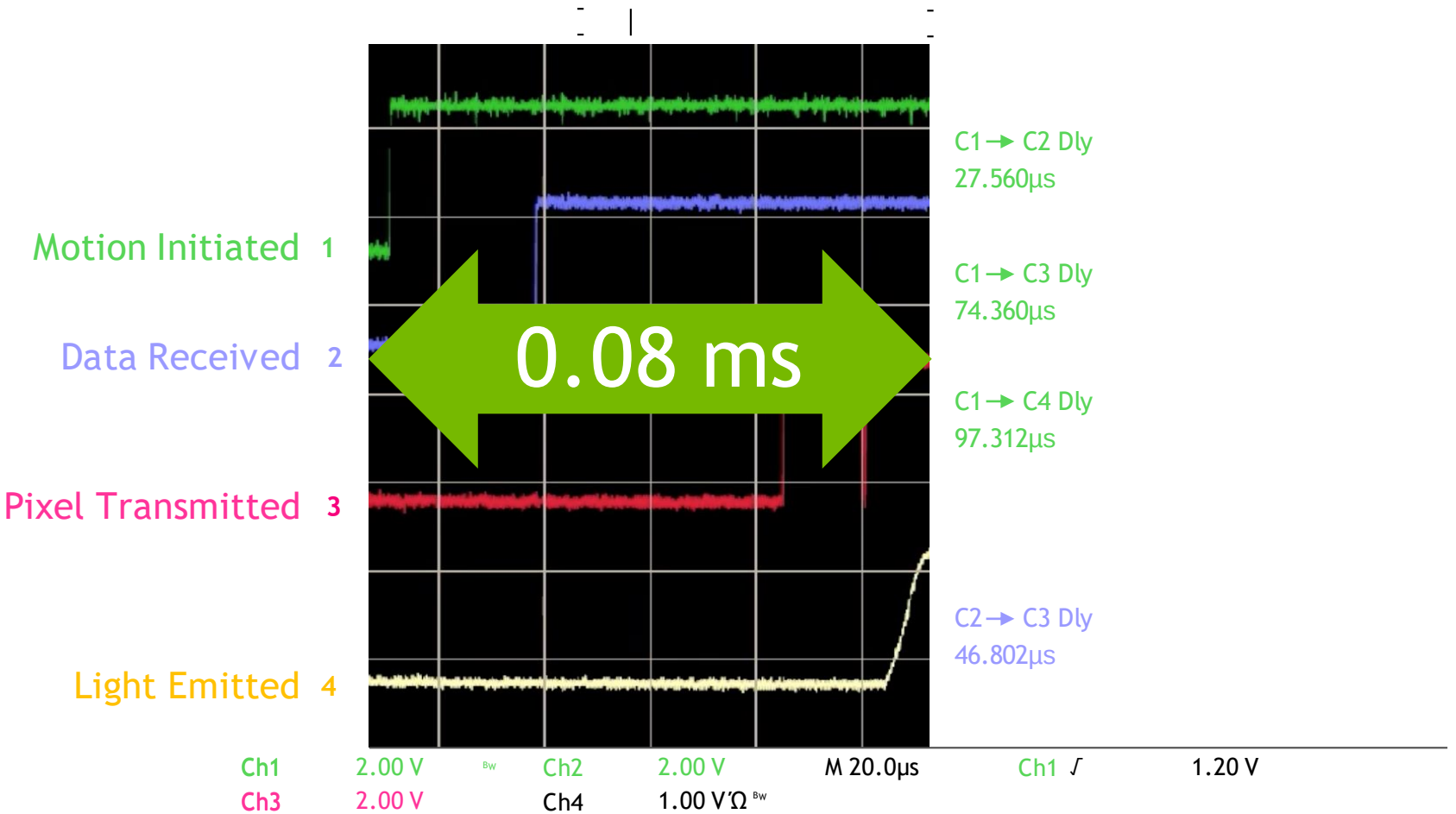
Binary Frames




Conventional Display: 60 Hz Source, No In-Display Offset Computation
Slow-Motion Playback Rate: 1/8 of Original
Our Algorithm: 60 Hz Source, 16 kHz In-Display Offset Computation

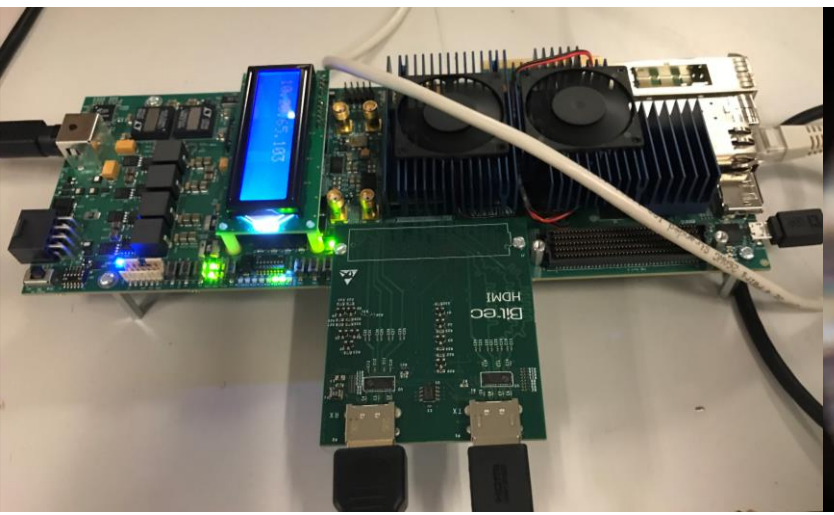
LOW LATENCY

Binary Frames

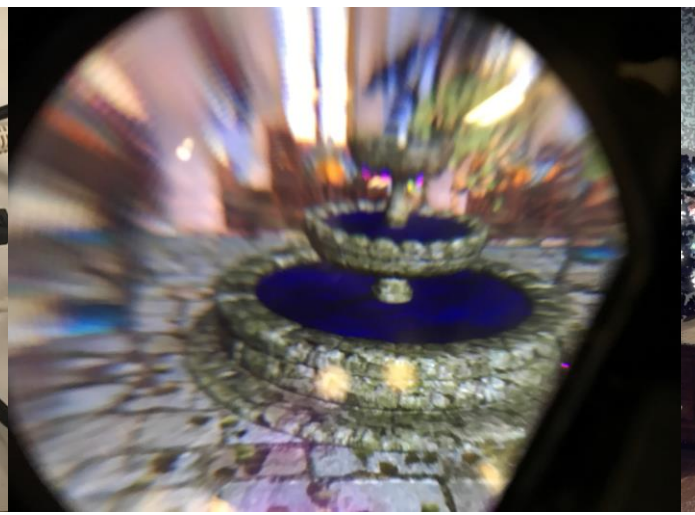


LOW LATENCY

On-HMD Warping



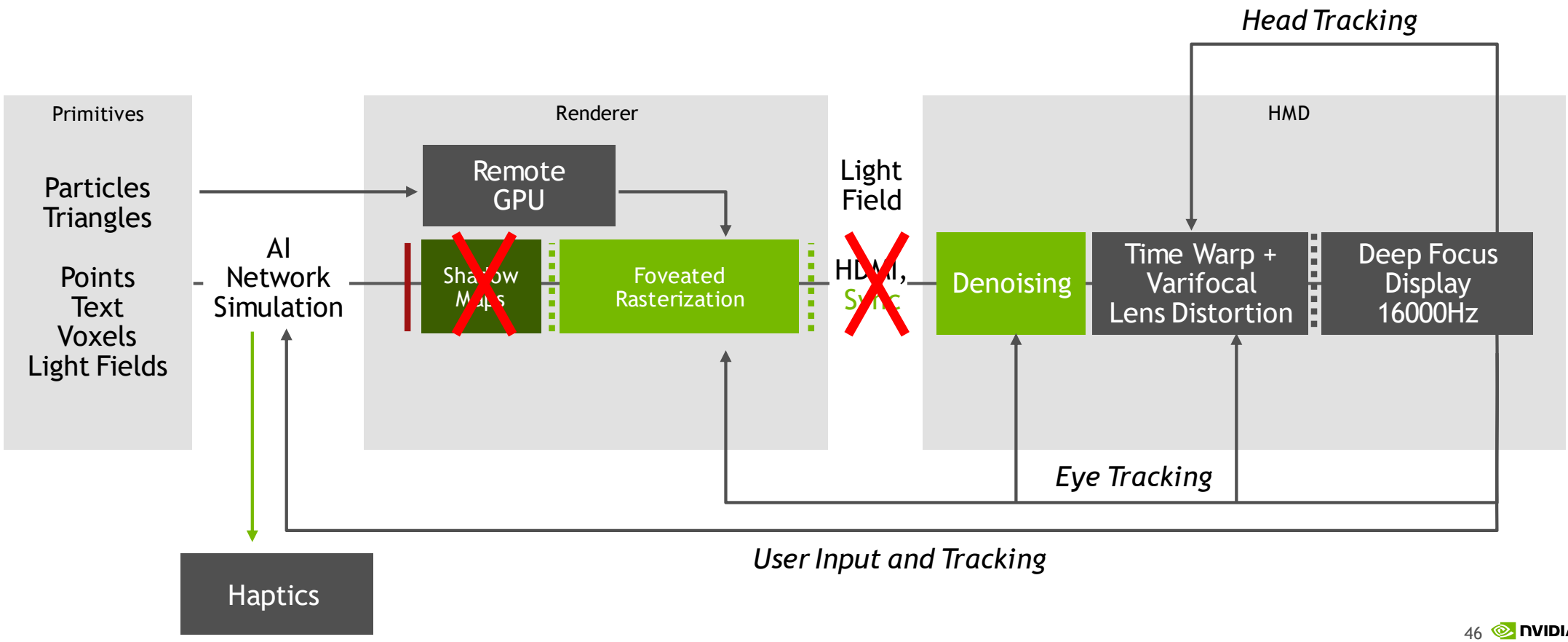
Hardware Warping Prototype

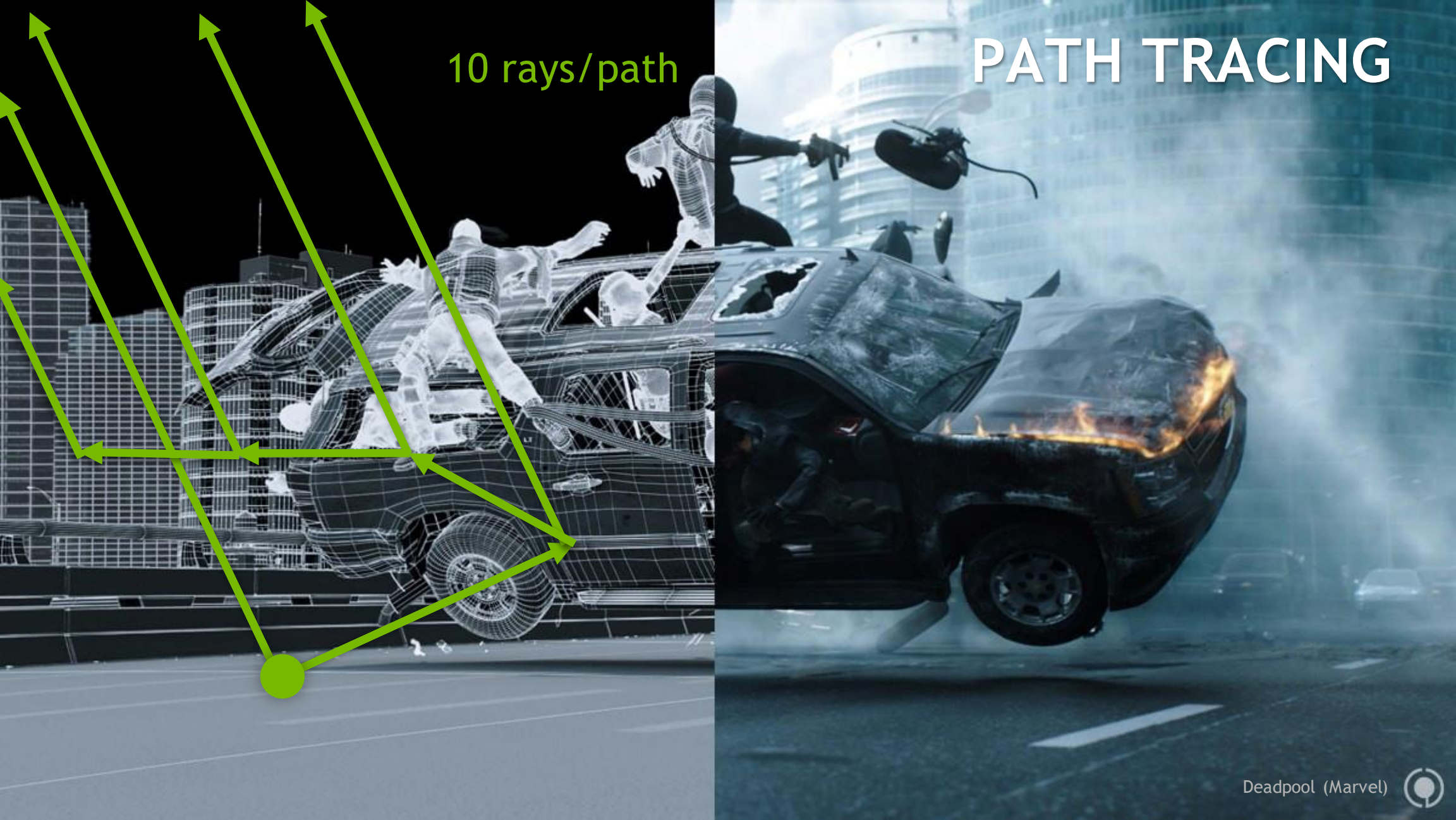


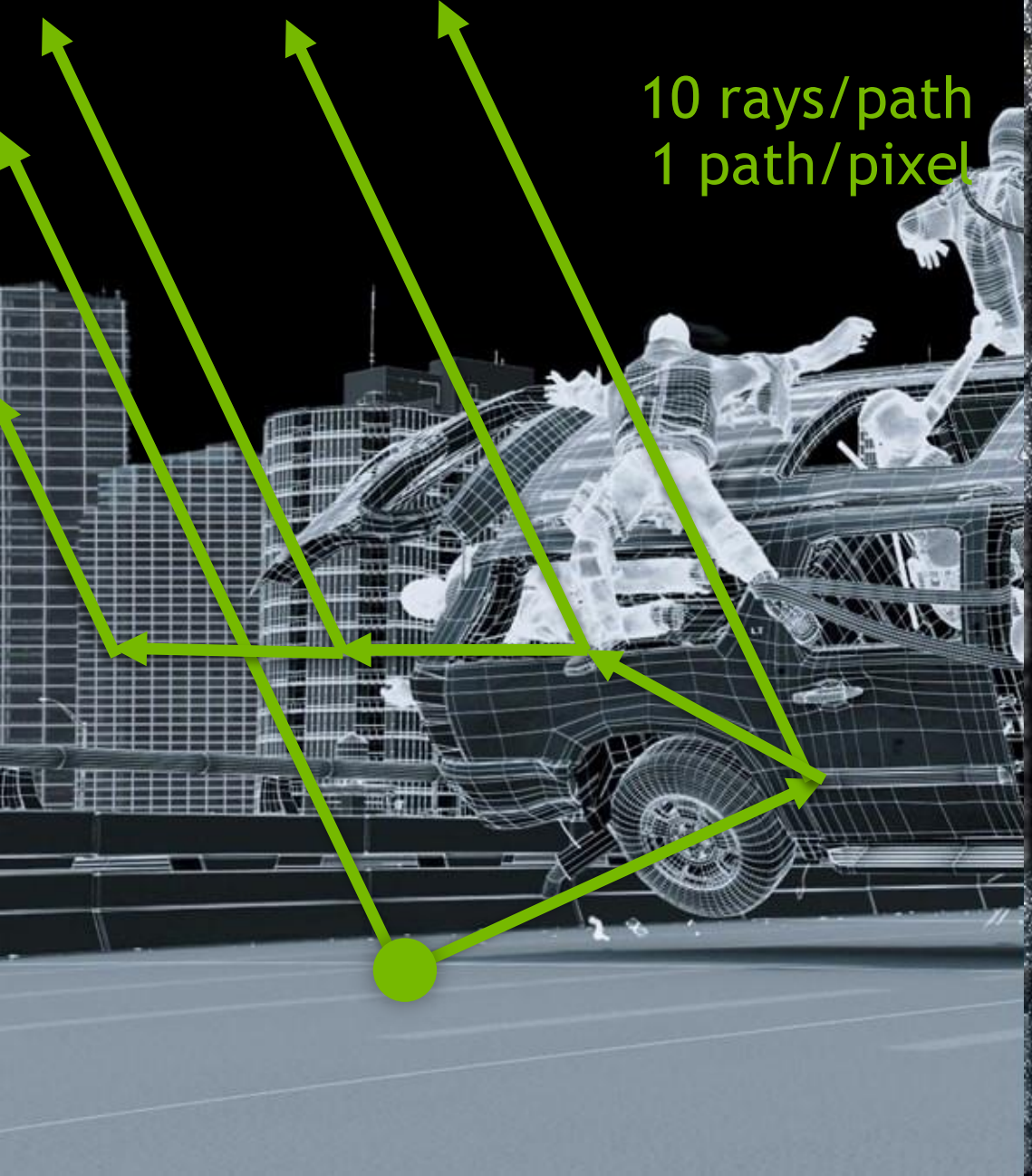
Photographed in HMD

Warped Static Point Set

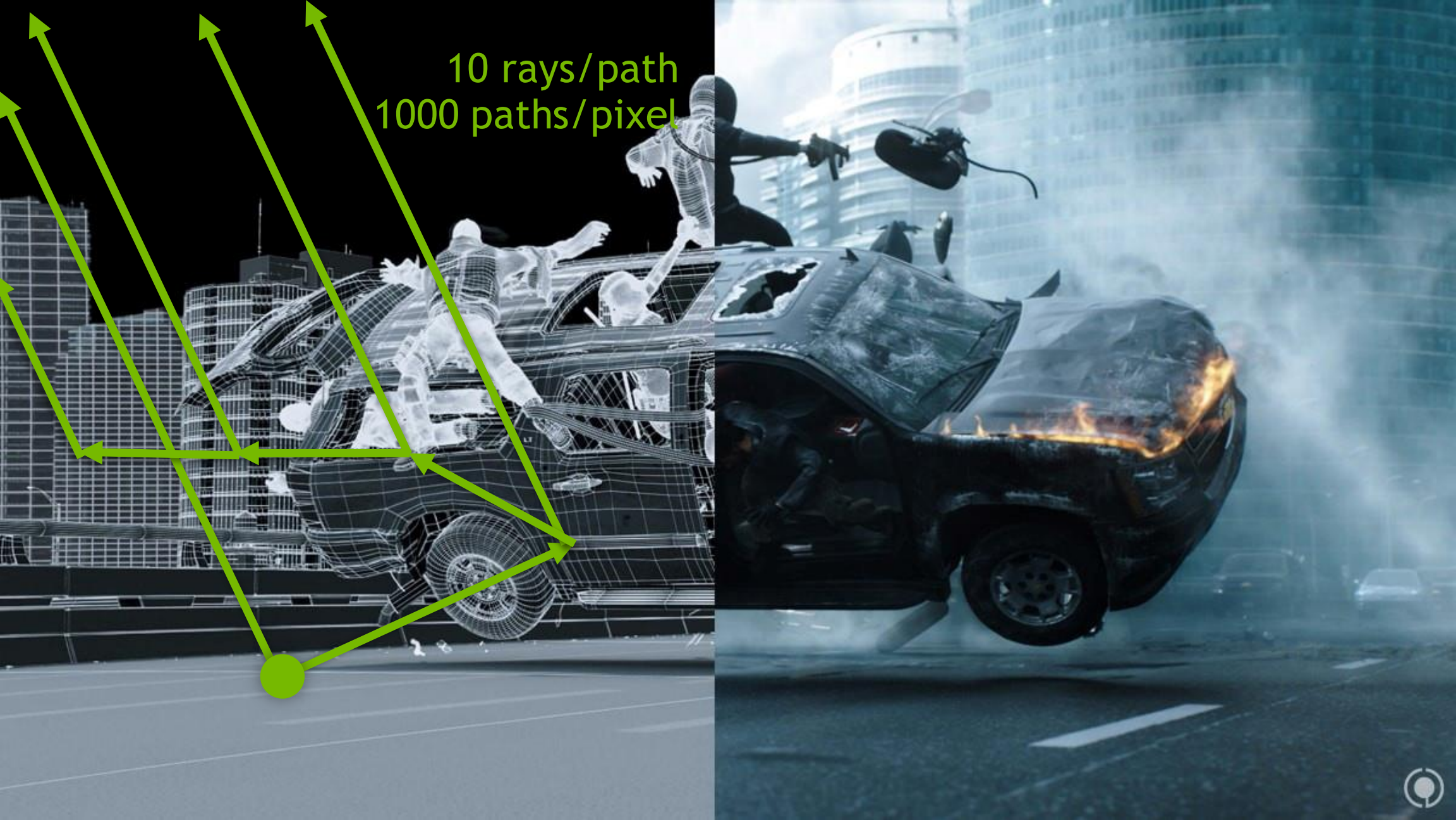
RAY & PATH TRACING




10 rays/path
PATH TRACING
Deadpool (Marvel)


10 rays/path
1 path/pixel


Visualization of path tracing noise


10 rays/path
1000 paths/pixel

DENOISING PATH TRACING

Naïve Real-time Result

Chaitanya et al., Interactive reconstruction of Monte Carlo image sequences using a recurrent denoising autoencoder, SIGGRAPH 2017
Schied et al., Spatiotemporal variance guided filtering: real-time reconstruction for path tracing, High Performance Graphics 2017
Mara et al., An efficient denoising algorithm for global illumination, High Performance Graphics 2017

DENOISING PATH TRACING

Denoised Real-Time Result

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DENOISING PATH TRACING

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AI GRAPHICS NVIDIA RESEARCH

SIGGRAPH 2017

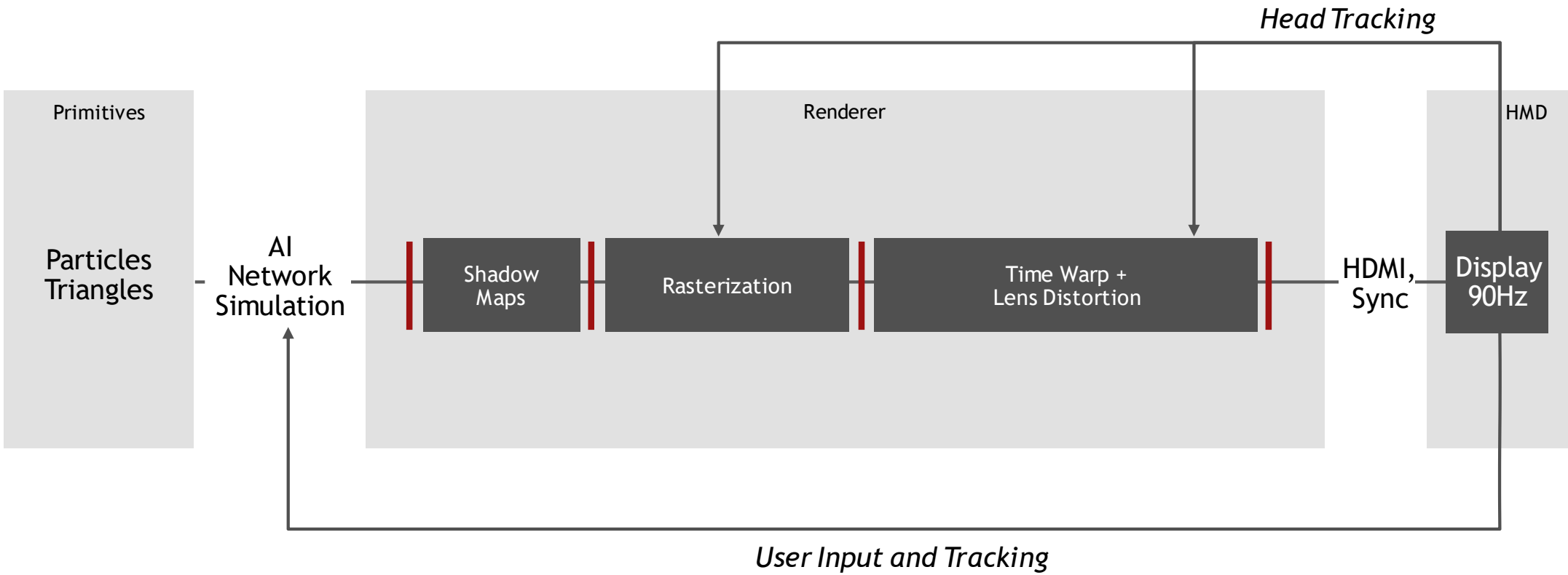
AI Facial Animation

AI Denoising

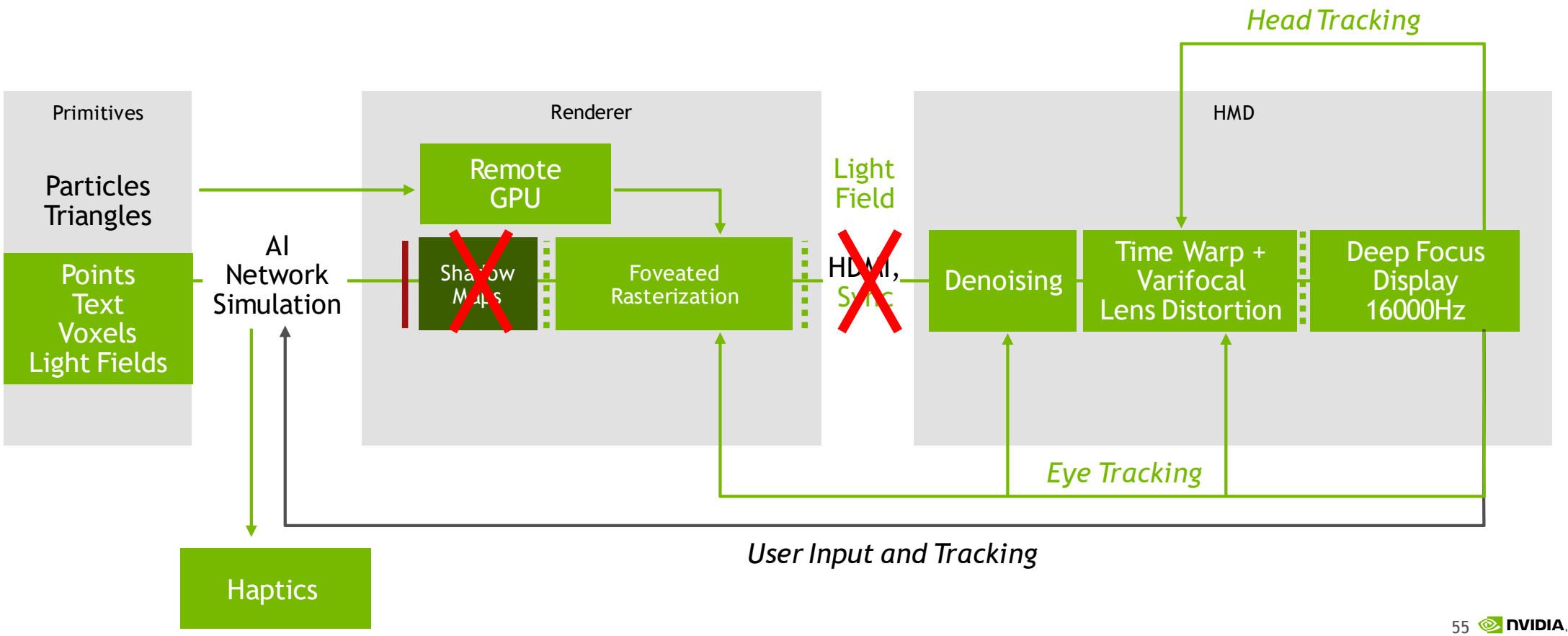
AI Anti-Aliasing

AI Light Transport

MODERN VR SYSTEM



FUTURE VR SYSTEM



1. Virtual reality will be the new interface to computing for everyone
2. Pascal architecture upgrades the gaming system to modern VR

   GPU warping, lens matched shading, multiprojection, stereo projection, variable resolution

3. NVIDIA is innovating for a revolutionary new future VR system

   computational displays, varifocal optics, foveated & cloud rendering, light fields, binary frames, on-display warping, beam racing, haptics, path tracing, denoising


http://research.nvidia.com

MODERN VR EXPERIENCES

+Batman replacing Aperture

Mechanics & Design

The Climb (Crytek)
SUPERHOT (Superhot Team)

Narrative & Characters

The Labs (Valve)

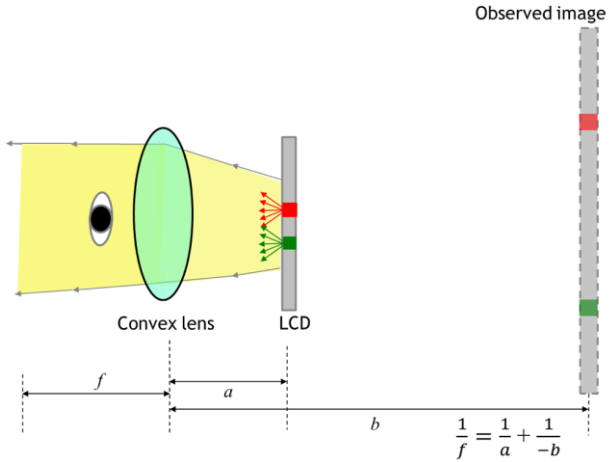
Simulation & Performance

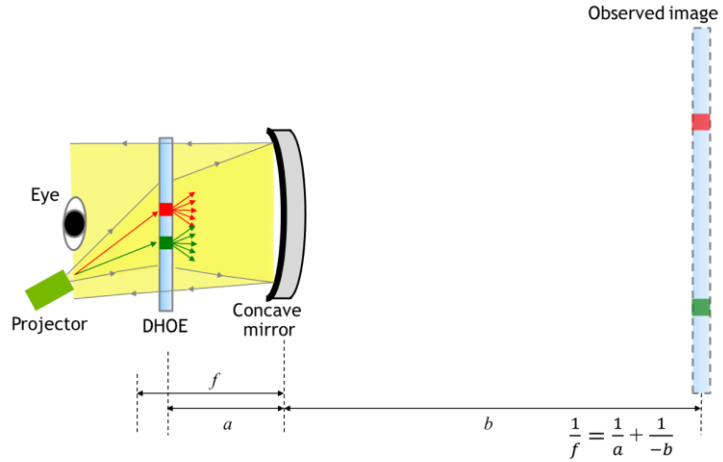
NVIDIA VR Funhouse

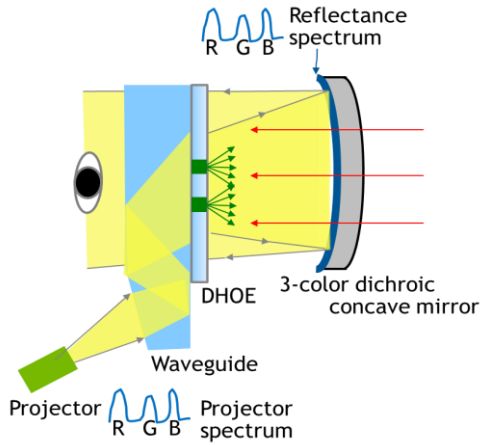
Content

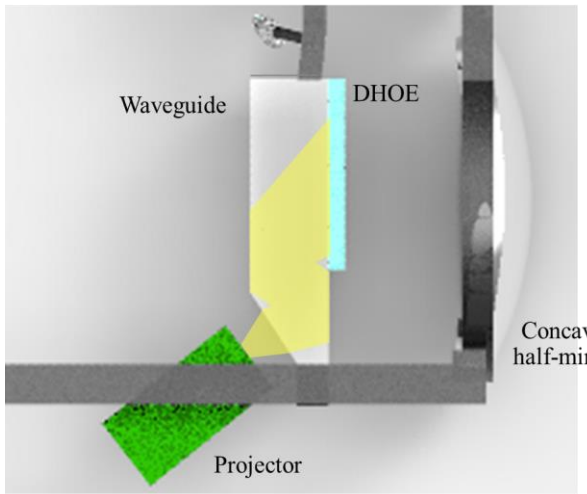
Google Earth VR

PROJECTOR-BASED DISPLAY

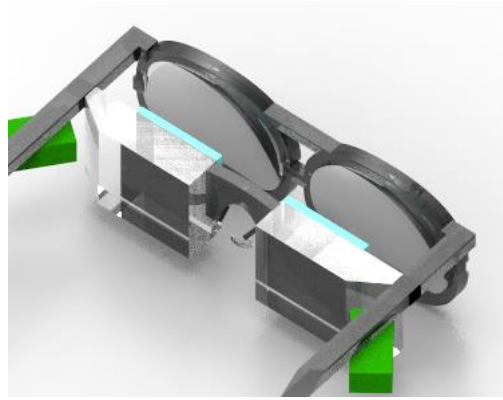






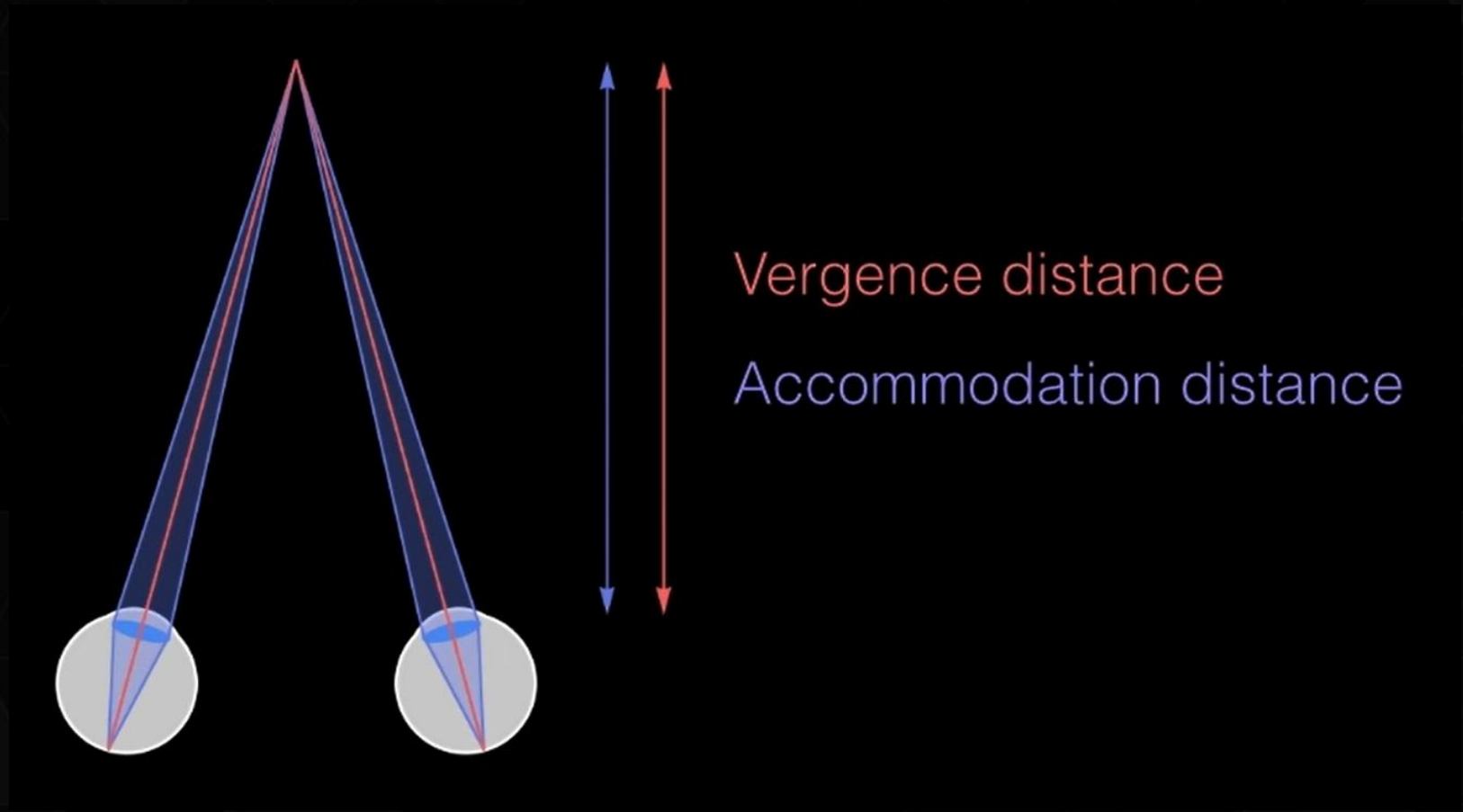


< Top view >




The Vanishing of Ethan Carter (The Astronauts)

CHALLENGE: FOCUS CUES



Video from Narain et al., *Optimal Presentation of Imagery with Focus Cueson Multi-Plane Displays, SIGGRAPH 2015*

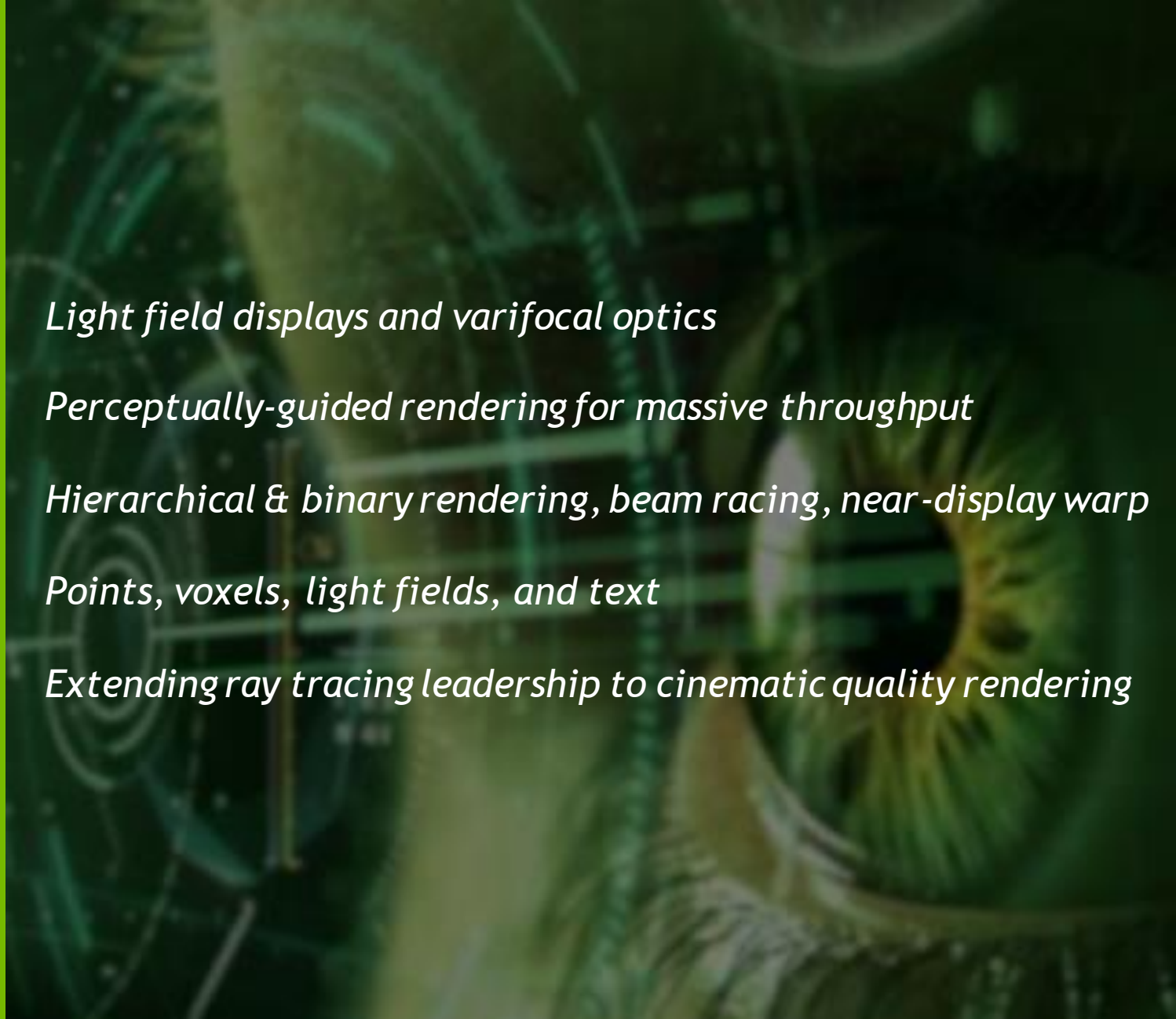
BEYOND TRIANGLES

Light Fields

McGuire et al., Real-time global illumination with light field probes, I3D 2017

NVIDIA AR/VR RESEARCH

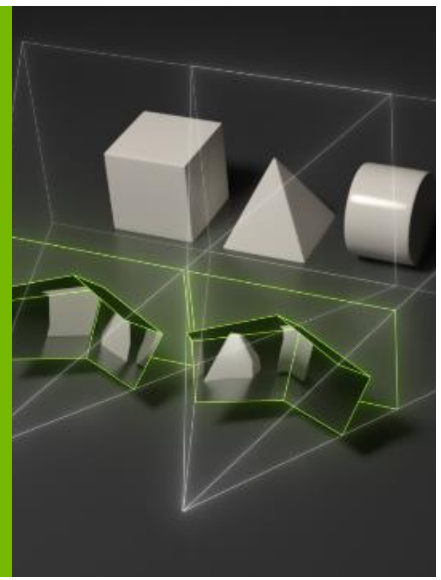
Computational Displays	*Light field displays and varifocal optics*
Foveated Rendering	*Perceptually-guided rendering for massive throughput*
Ultra-Low Latency	*Hierarchical & binary rendering, beam racing, near-display warp*
Beyond Triangles	*Points, voxels, light fields, and text*
Path Tracing	*Extending ray tracing leadership to cinematic quality rendering*



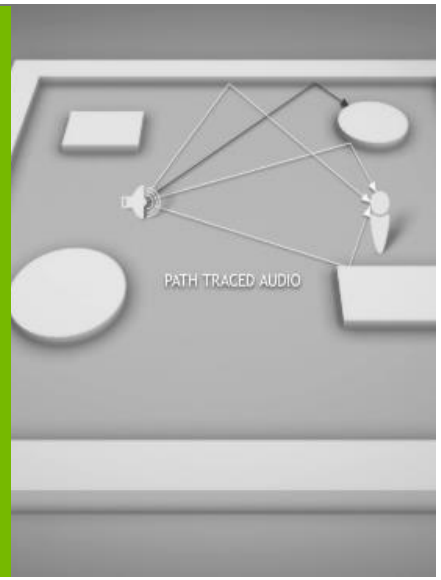
NVIDIA VRWORKS SDK

BRINGING REALITY TO VR

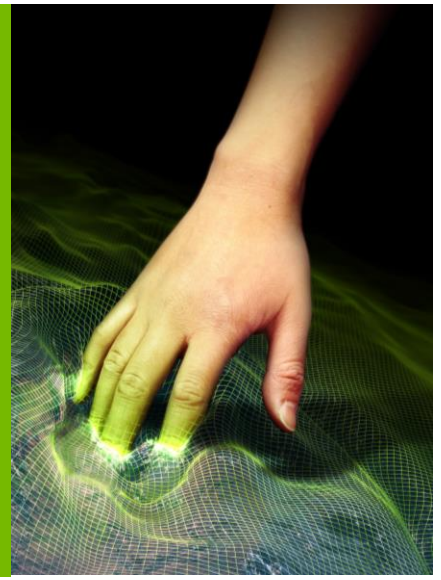
SIGHT



SOUND



PHYSICS & TOUCH



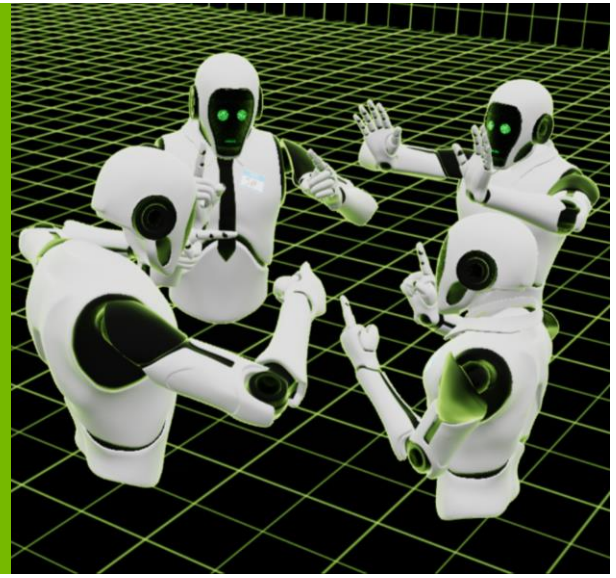
CAPTURE

NVIDIA HOLODECK
HANDS-ON DEMO AT SIGGRAPH

NVIDIA PROJECT HOLODECK

PHOTOREALISTIC MODELS

COLLABORATION



INTERACTIVE PHYSICS

NVIDIA VRWORKS & PASCAL

Accelerating Modern VR

GRAPHICS

LENS MATCHED SHADING

SINGLE PASS STEREO

MULTIRES SHADING

VR SLI

HEADSET

CONTEXT PRIORITY

DIRECT MODE

FRONT BUFFER RENDERING

TOUCH & PHYSICS

PHYSX

PROFESSIONAL

WARP & BLEND

SYNCHRONIZATION

GPU AFFINITY

AUDIO

VRWORKS AUDIO

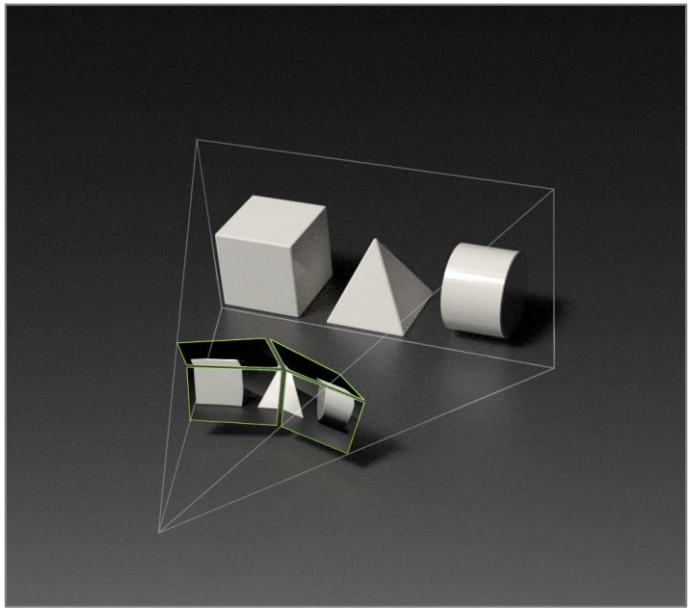
VIDEO

VRWORKS 360 VIDEO

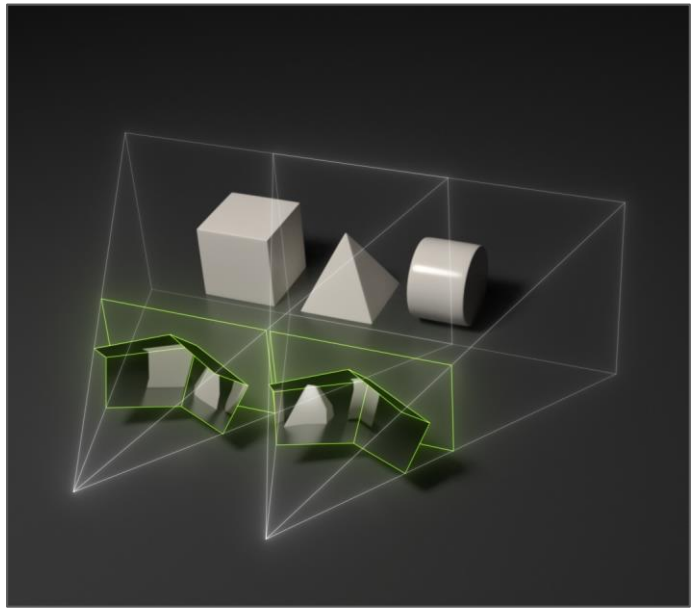
GPUDIRECT FOR VIDEO

VRWORKS & PASCAL

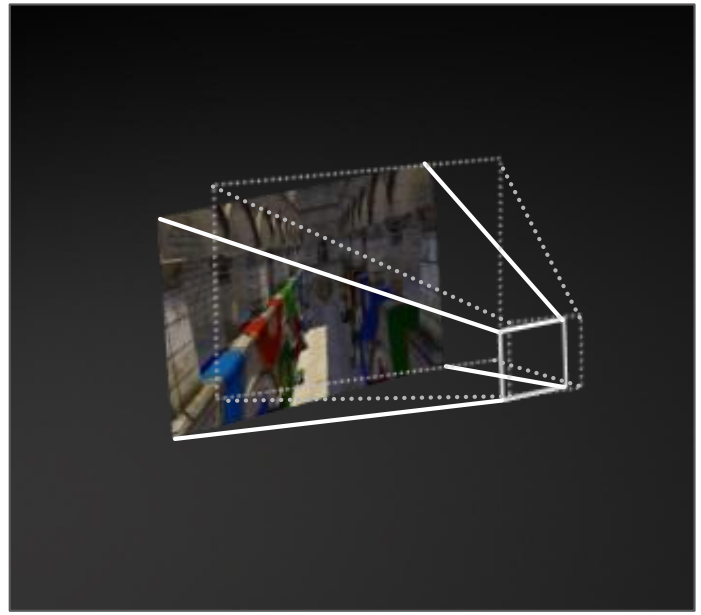
Hardware Acceleration for Modern VR



Lens Matched Shading & Multiprojection



Single-Pass Stereo

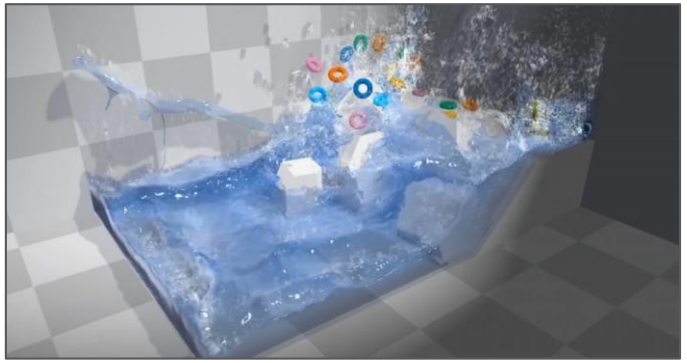


Preemption for Timewarp

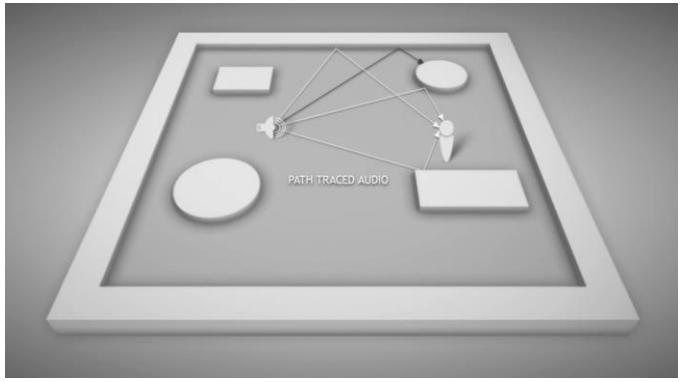
VRWORKS & PASCAL

Hardware Acceleration for Modern VR

PhysX

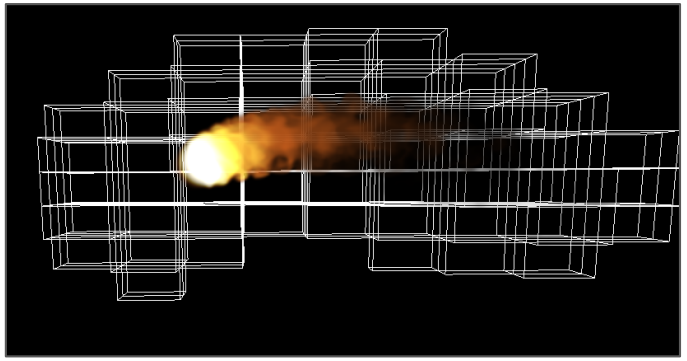


Flex



VRWorks Audio

Hairworks



Flow

Cloth

FOVEATED RENDERING