

Towards real-time photorealistic 3D holography with deep neural networks

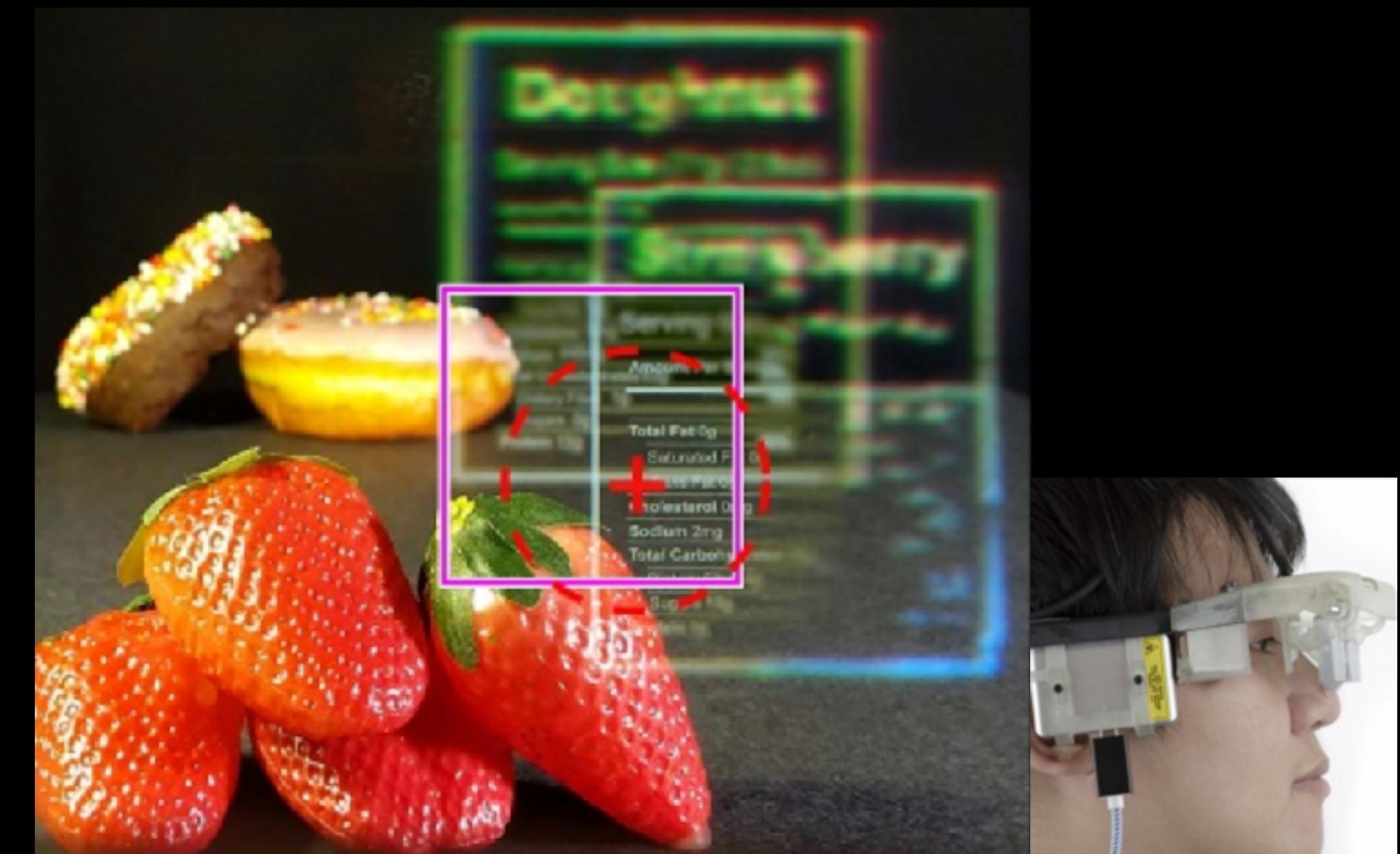
Presentor : Liang Shi



Background & Motivation

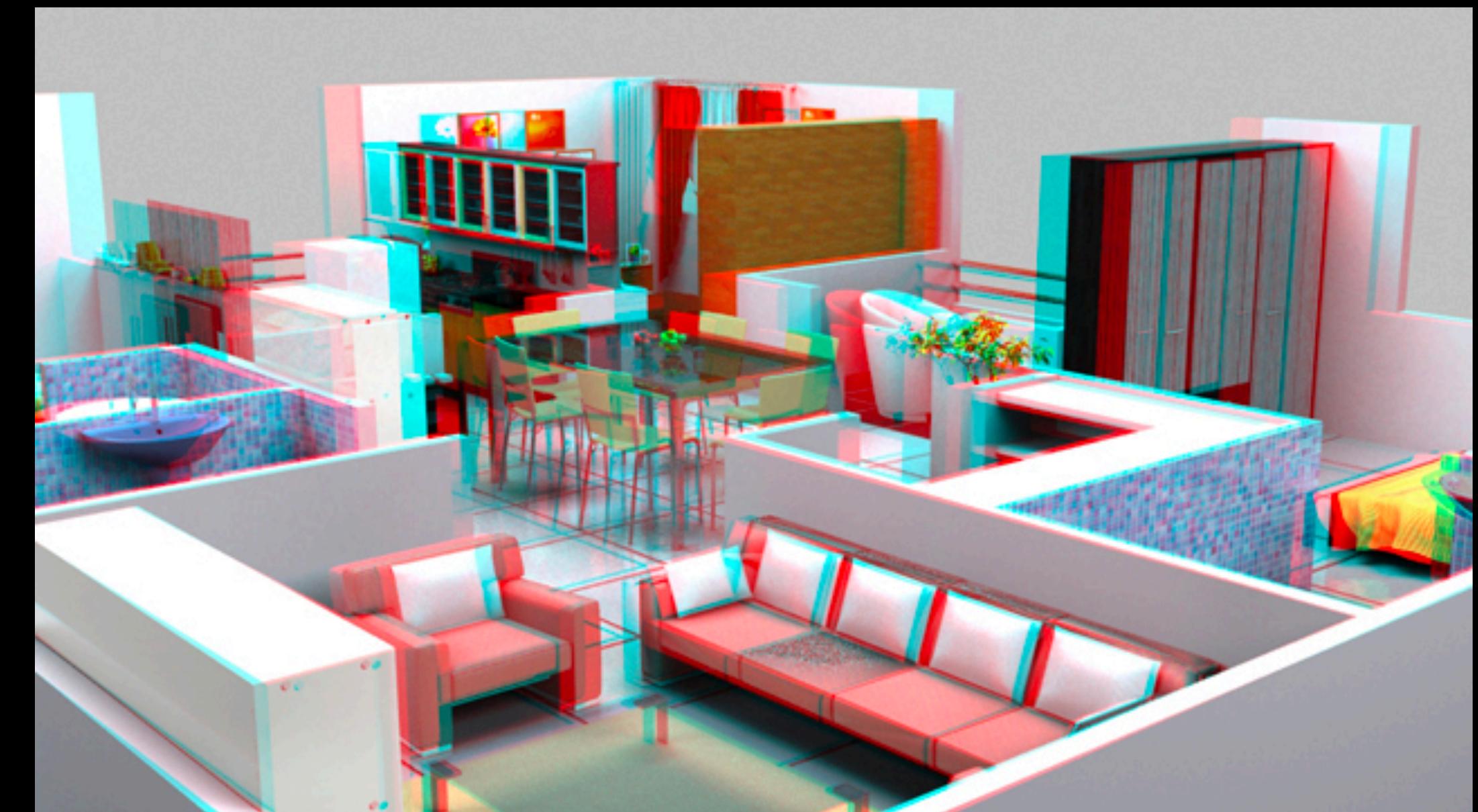
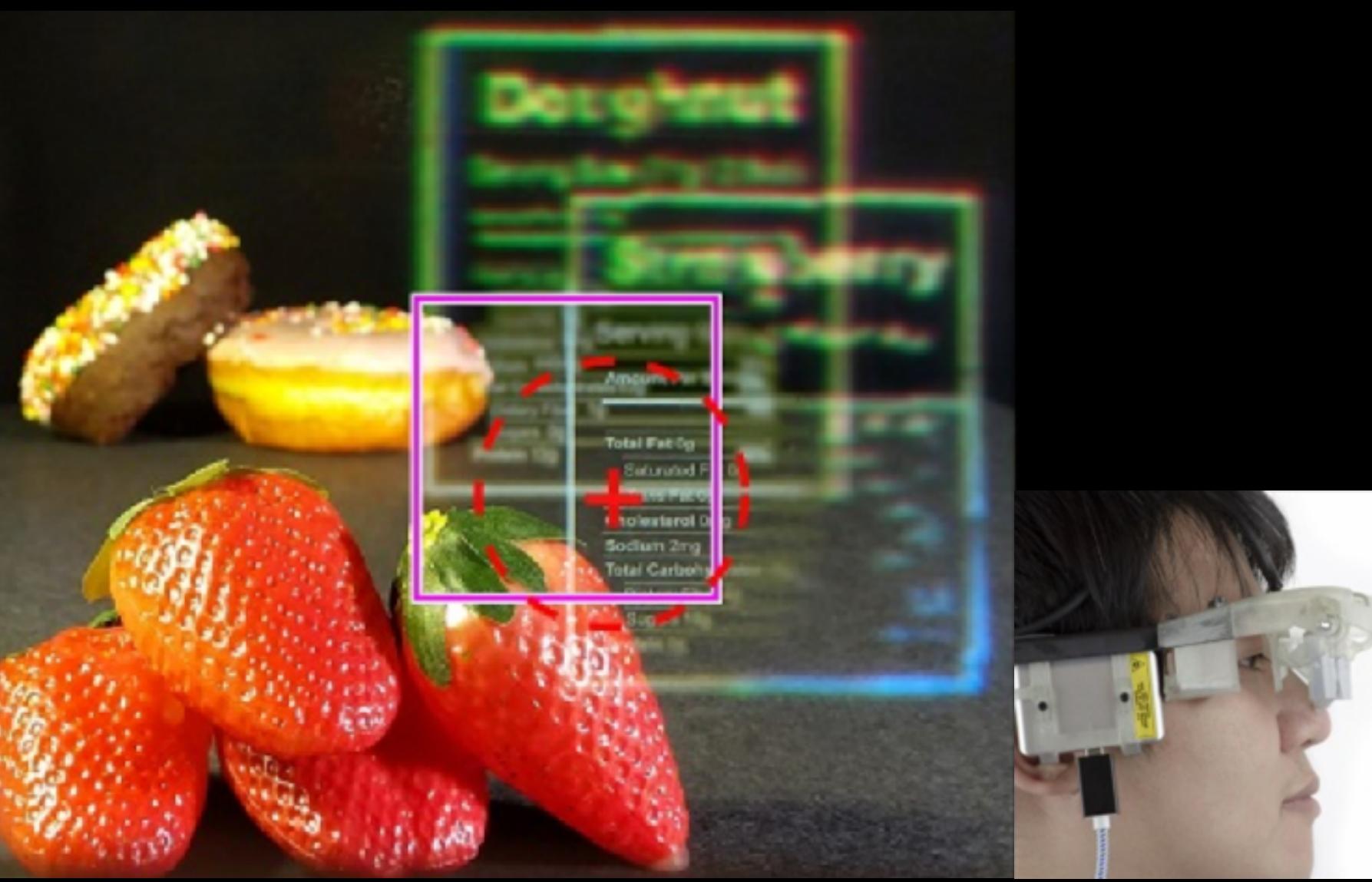


Virtual Reality (VR)



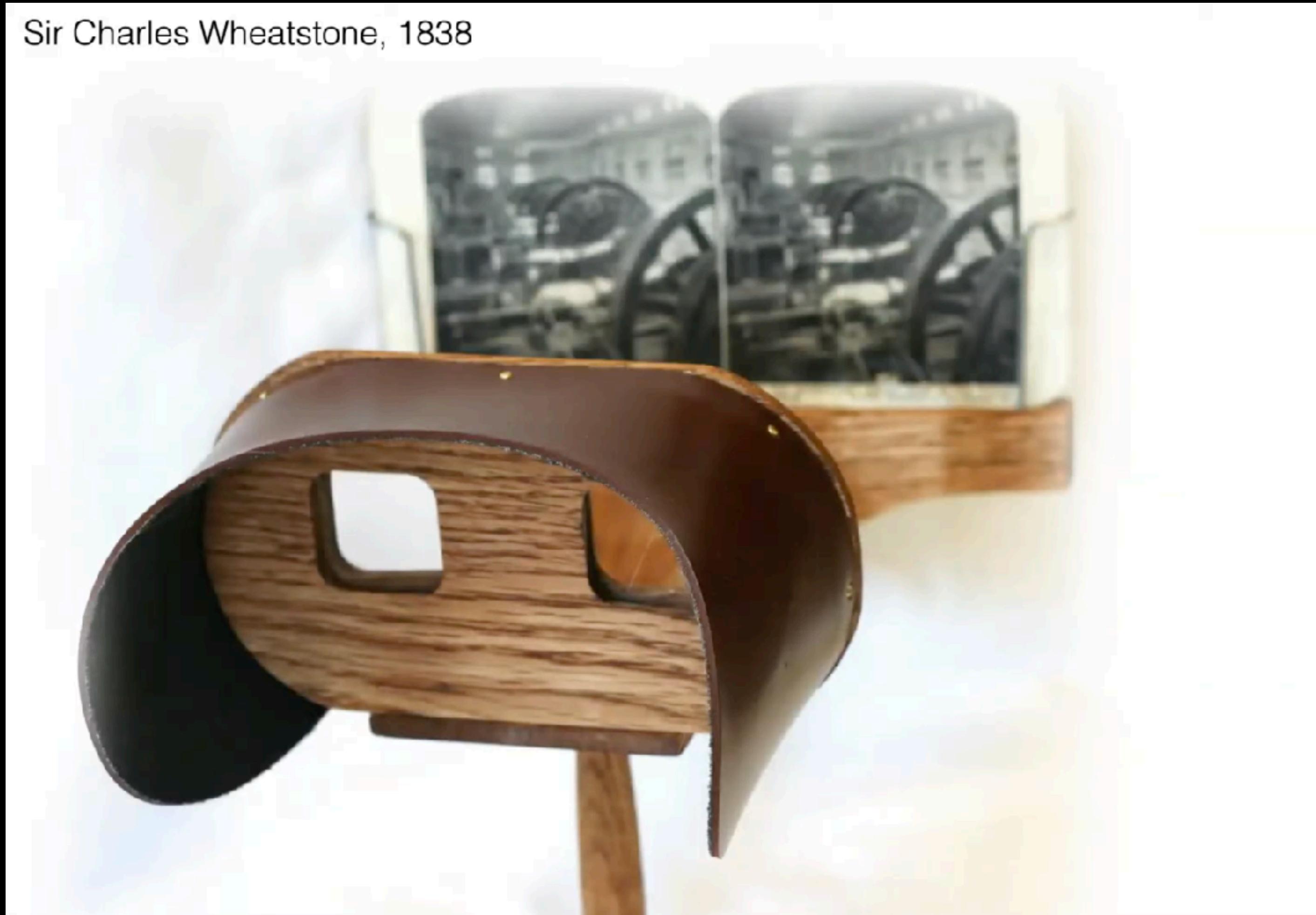
Augmented Reality (AR)

Background & Motivation



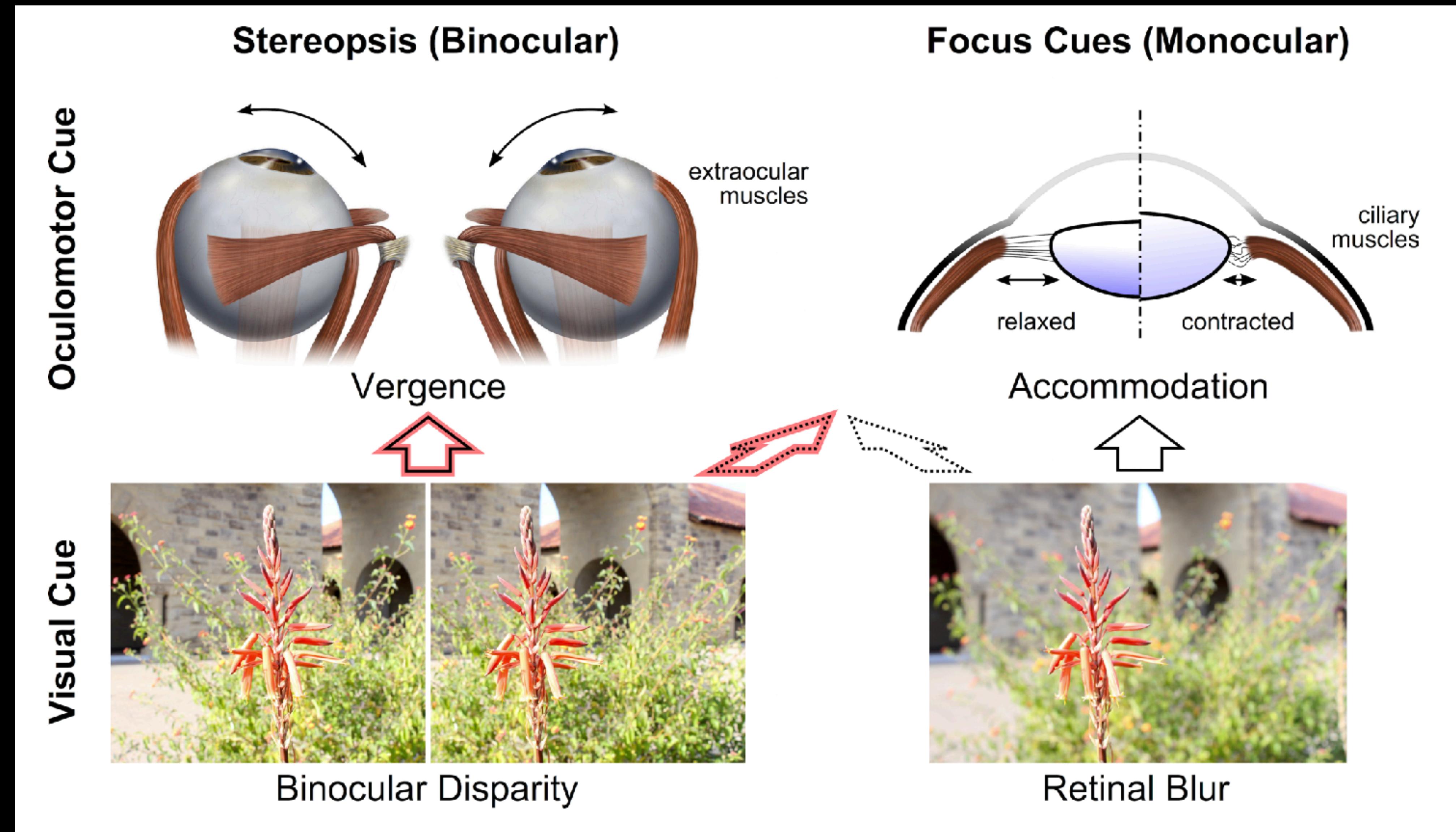
Stereoscopic Rendering

Background & Motivation

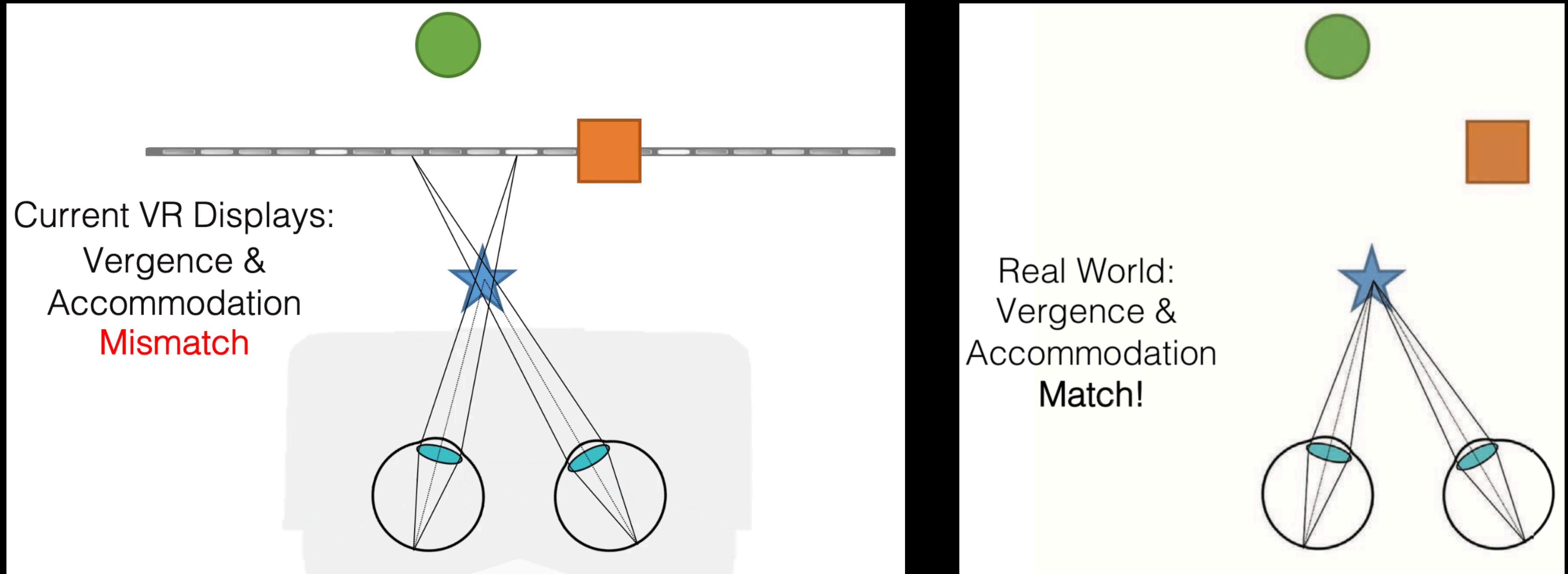


Invented more than 170 years ago

Background & Motivation



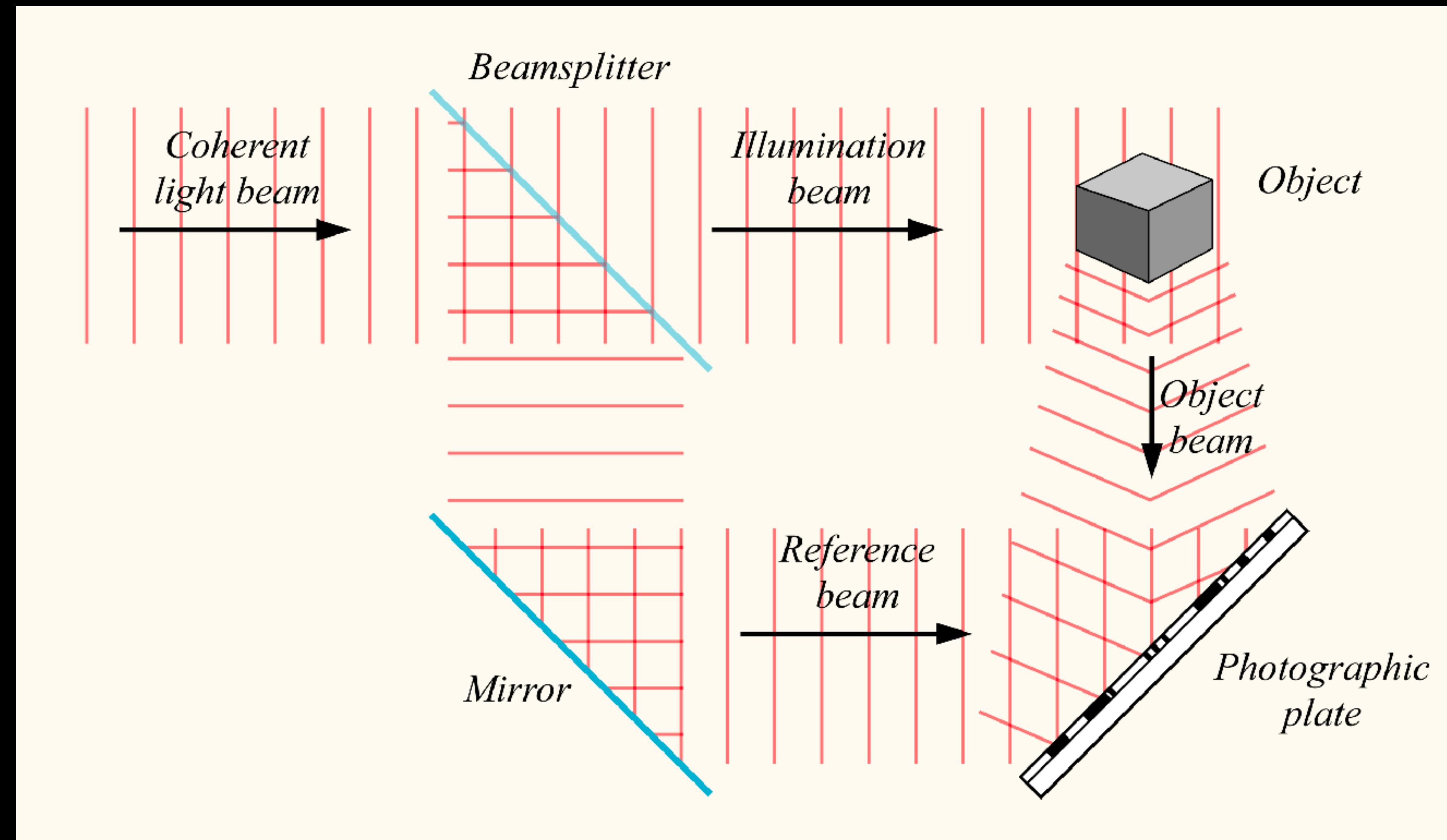
Background & Motivation



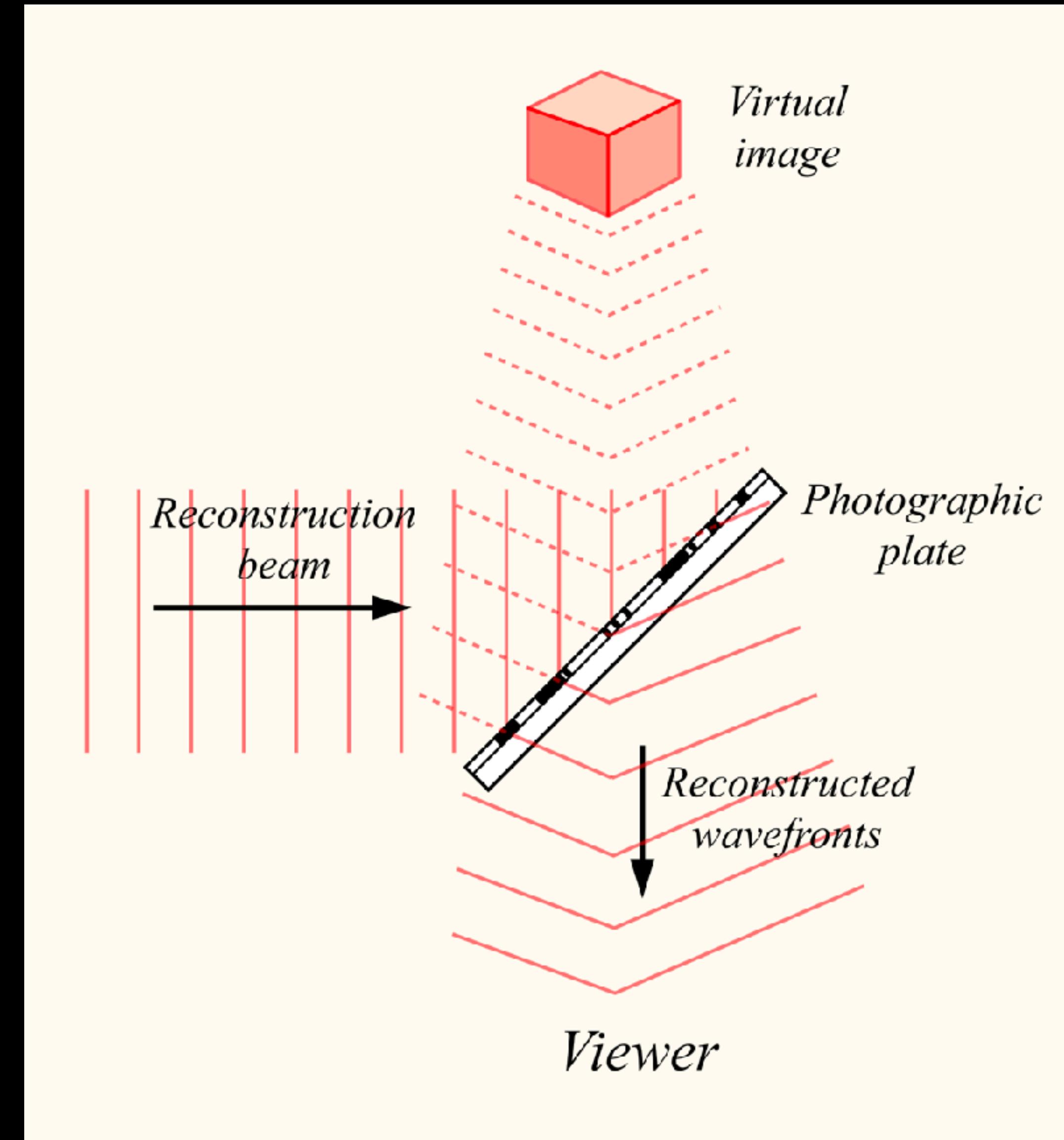
Holography



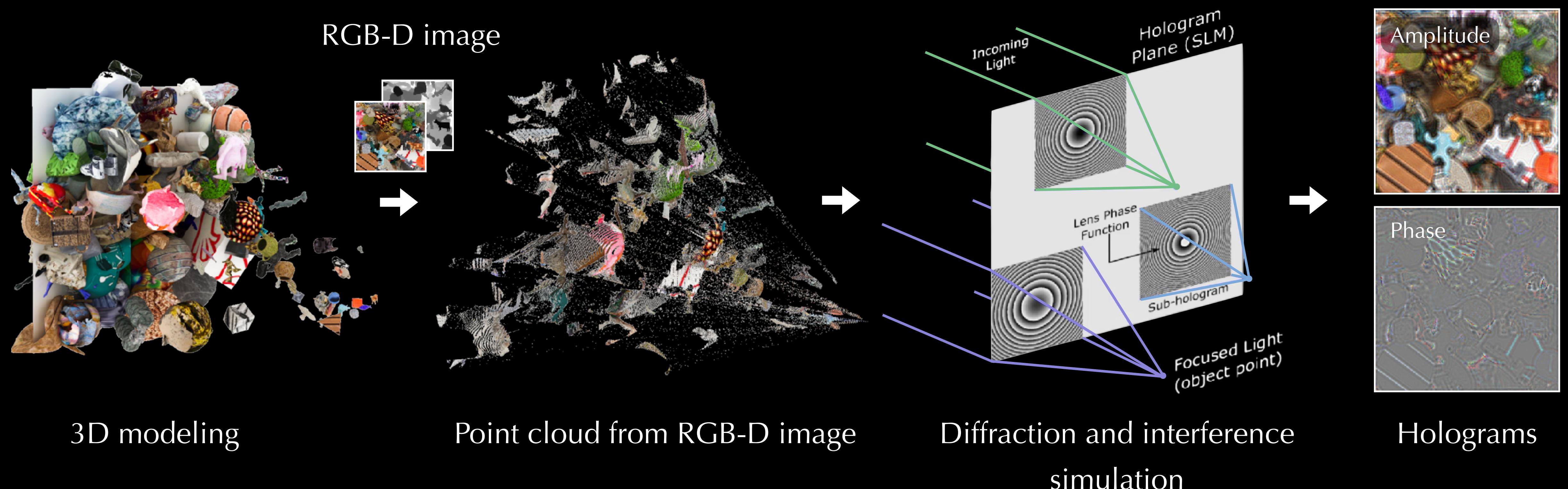
Holography



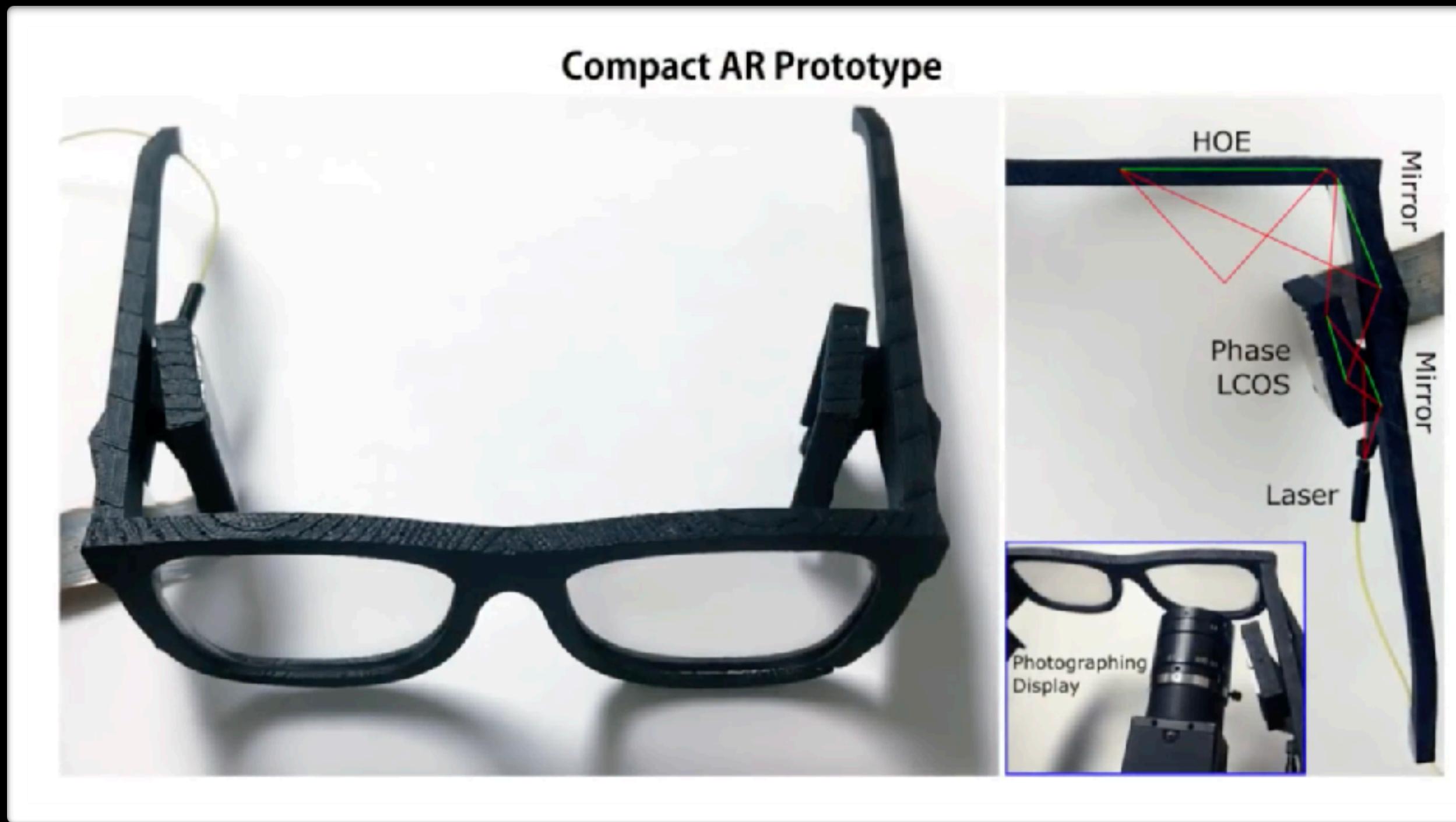
Holography



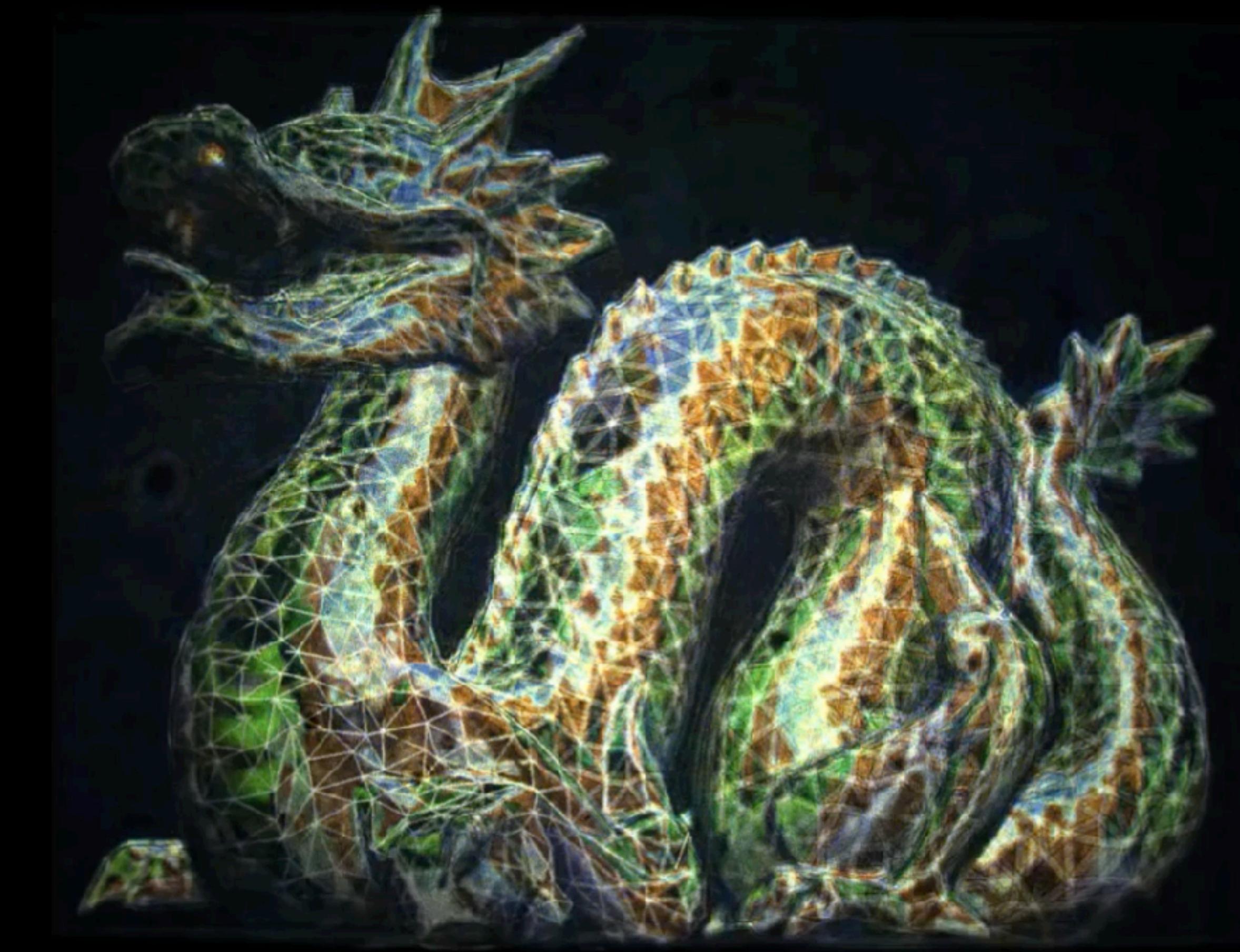
Computing True 3D Hologram



Holographic Near-Eye Display

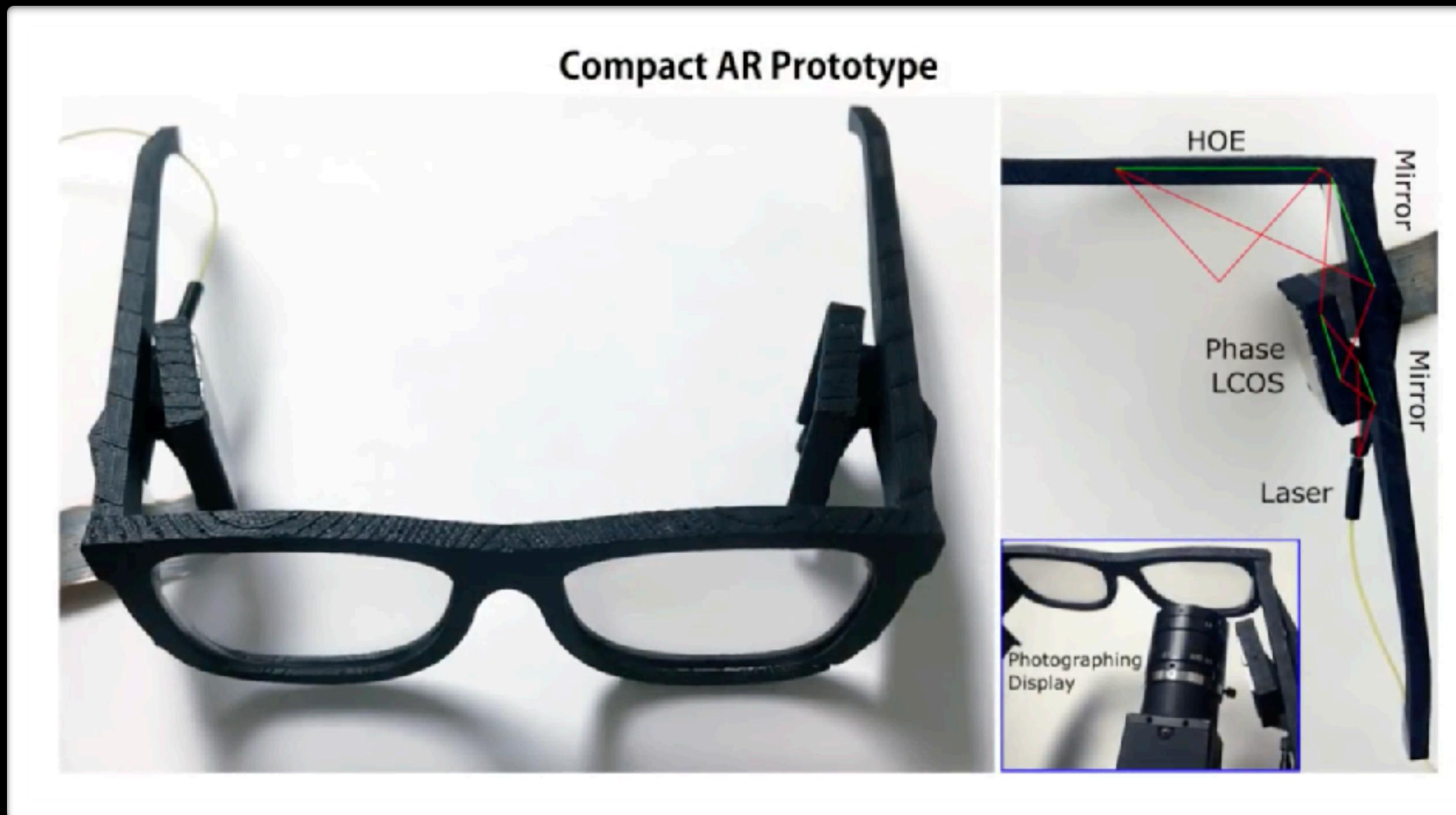


Compact form factor

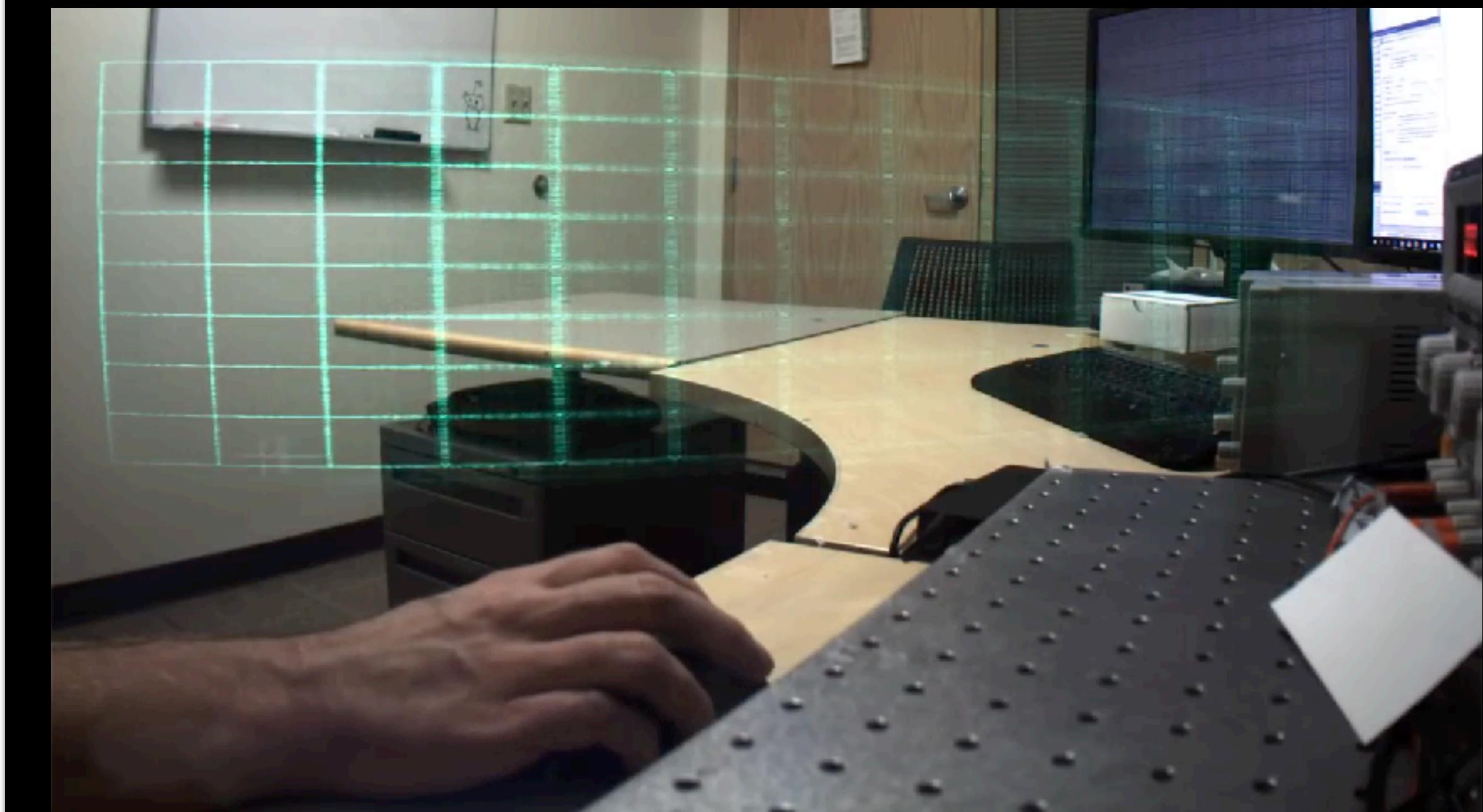


True 3D projection

Holographic Near-Eye Display

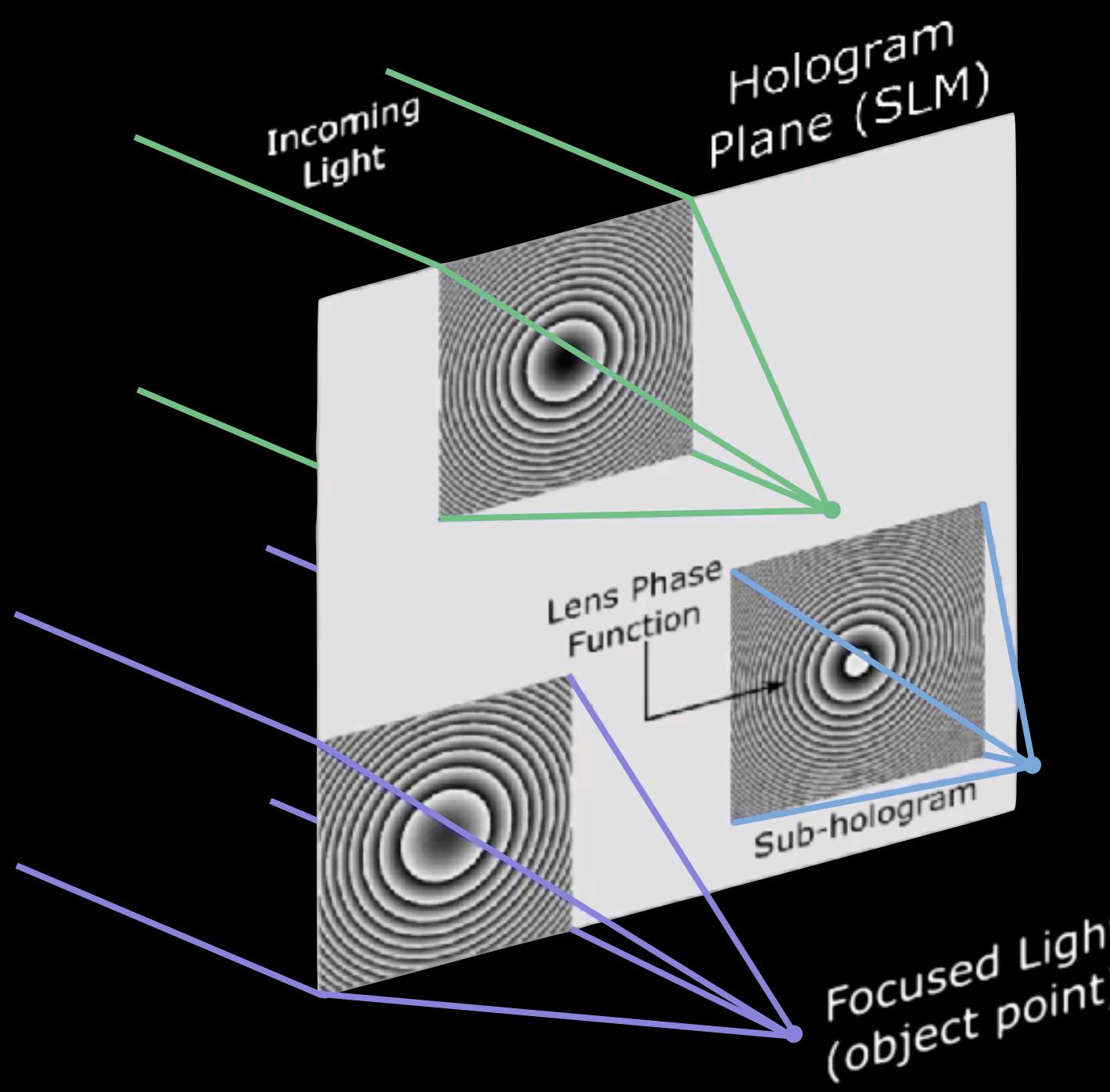


Compact form factor



Aberration correction

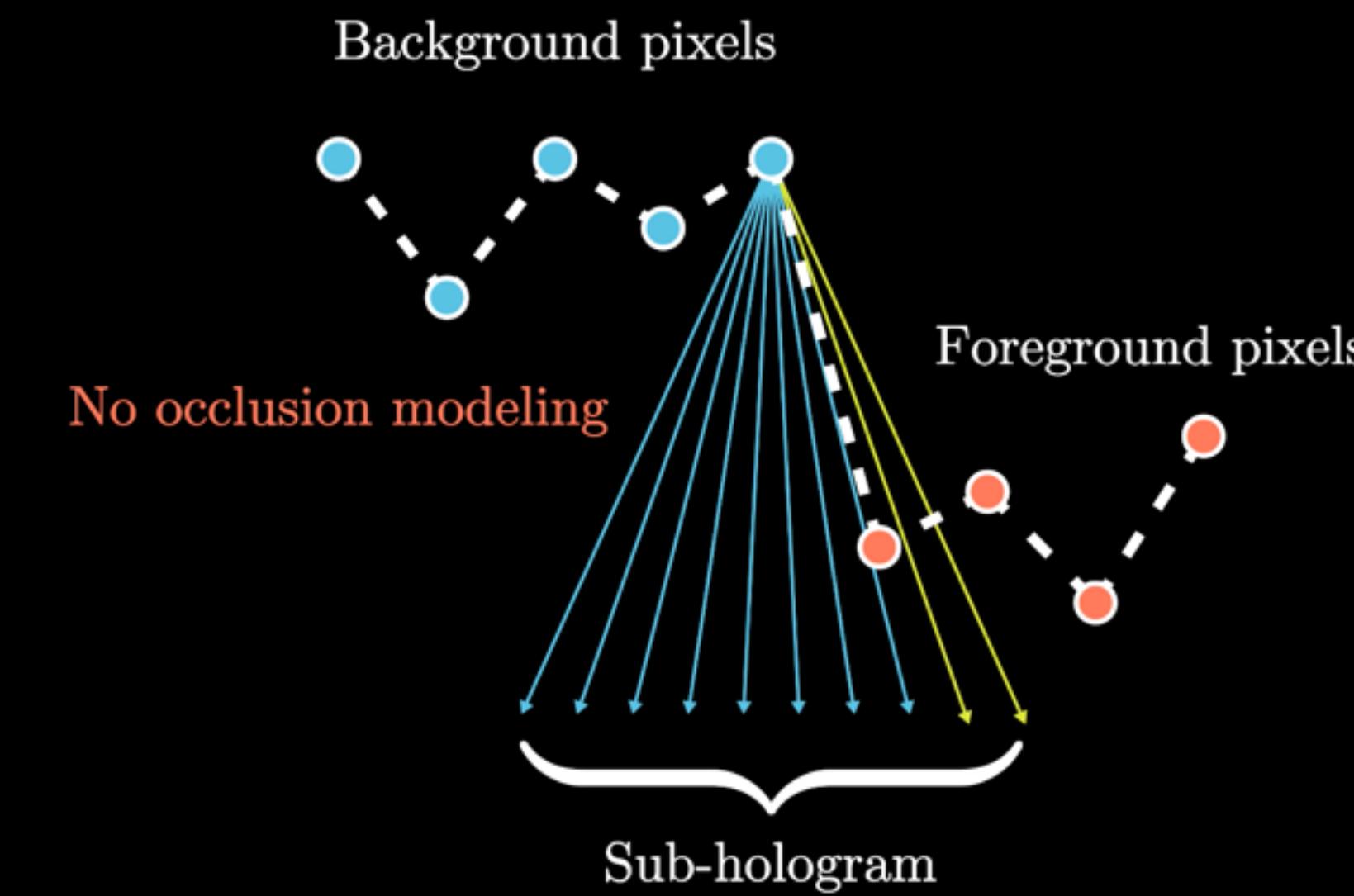
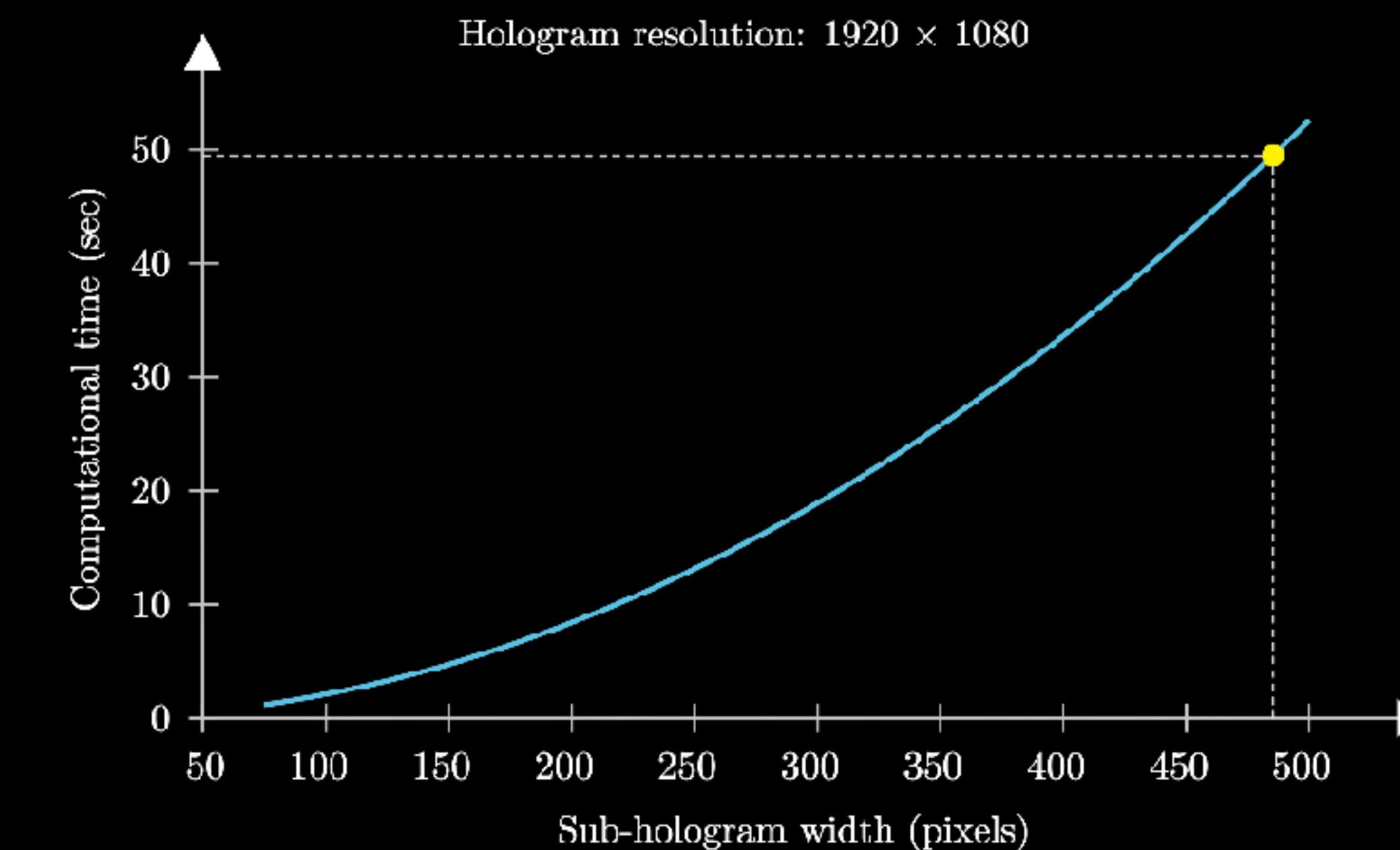
Computing True 3D Hologram



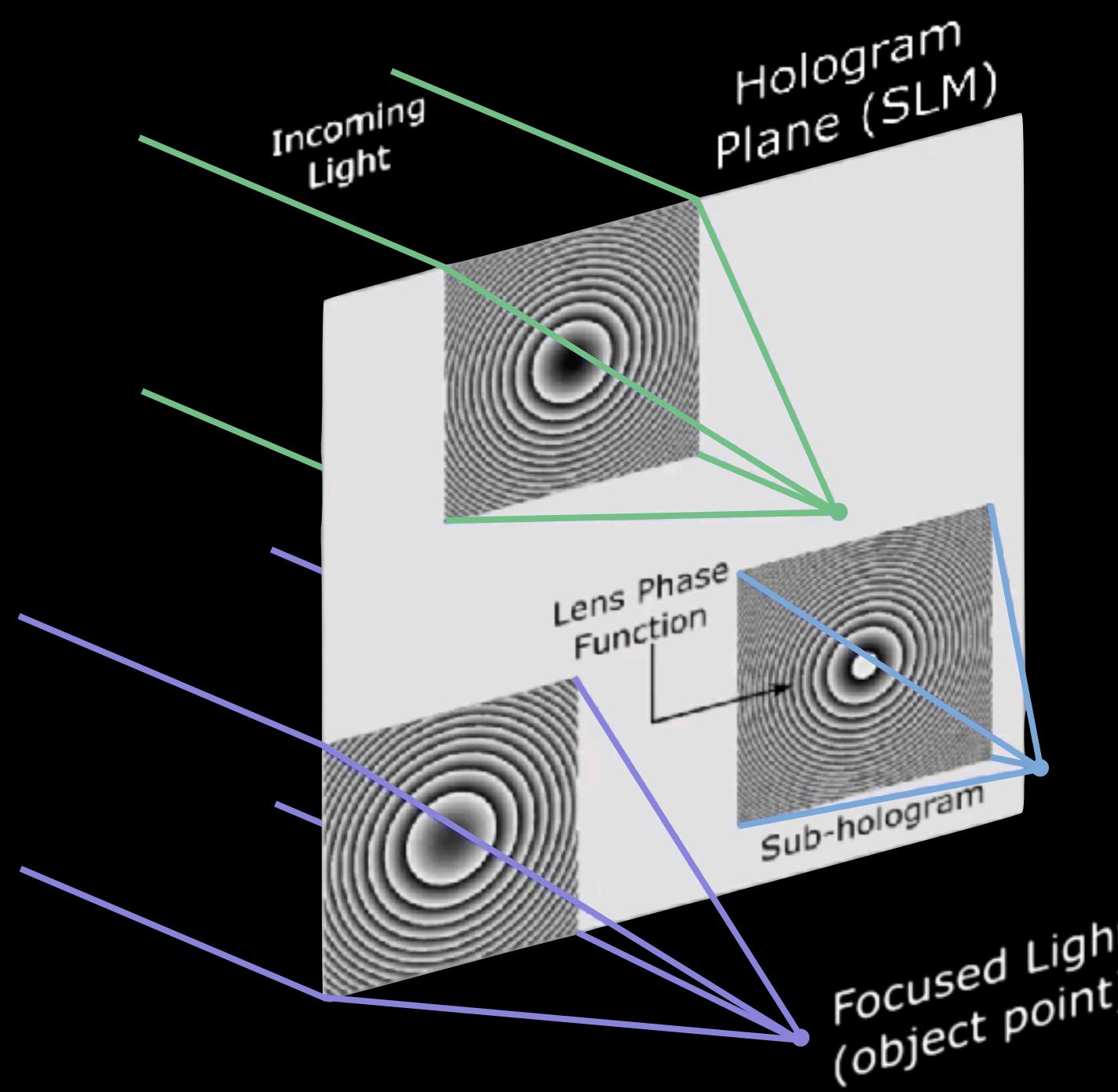
$$O(N^2 M^2)$$

N : spatial resolution (one axis)

M : maximum sub-hologram width



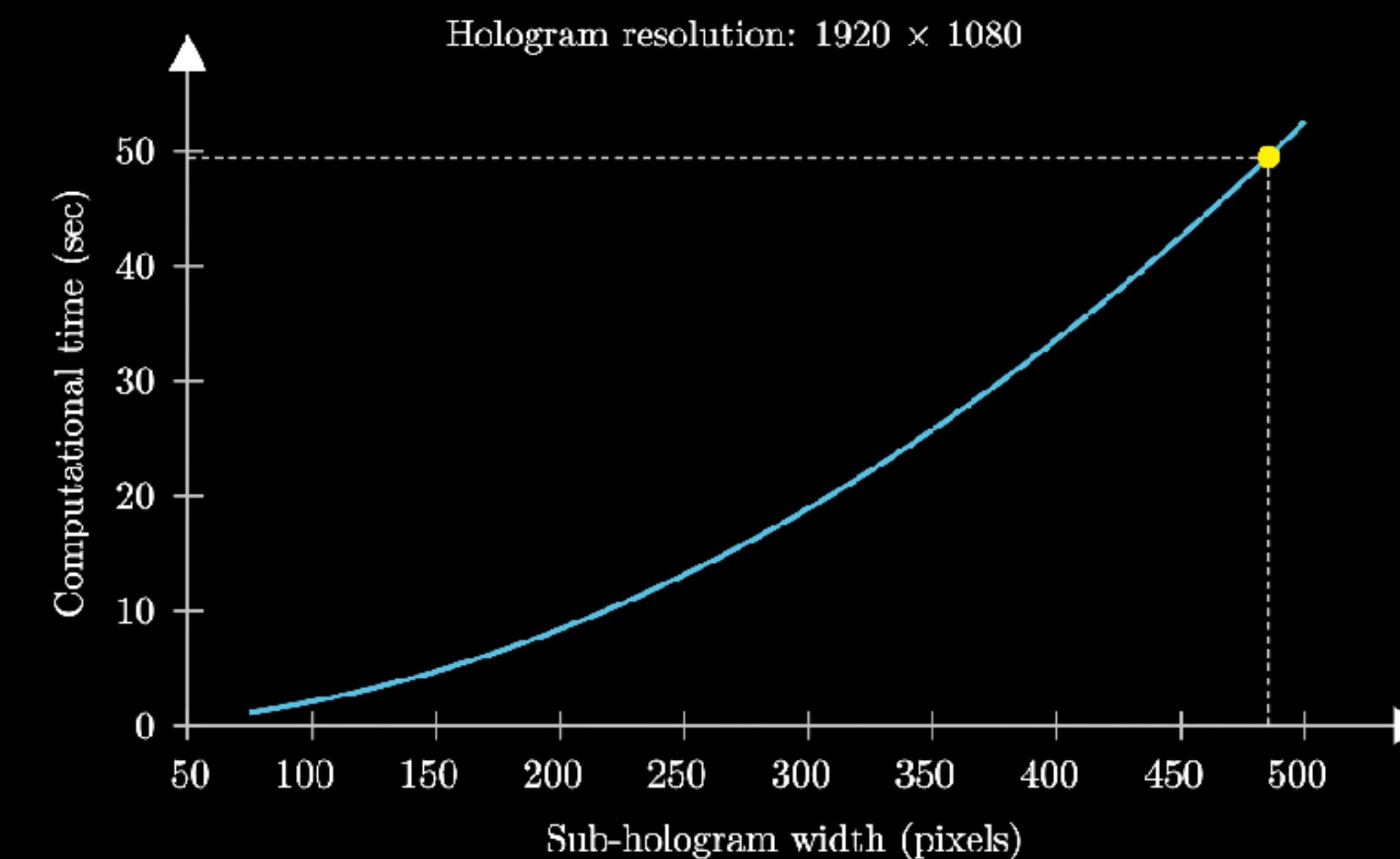
Computing True 3D Hologram



$$O(N^2 M^2)$$

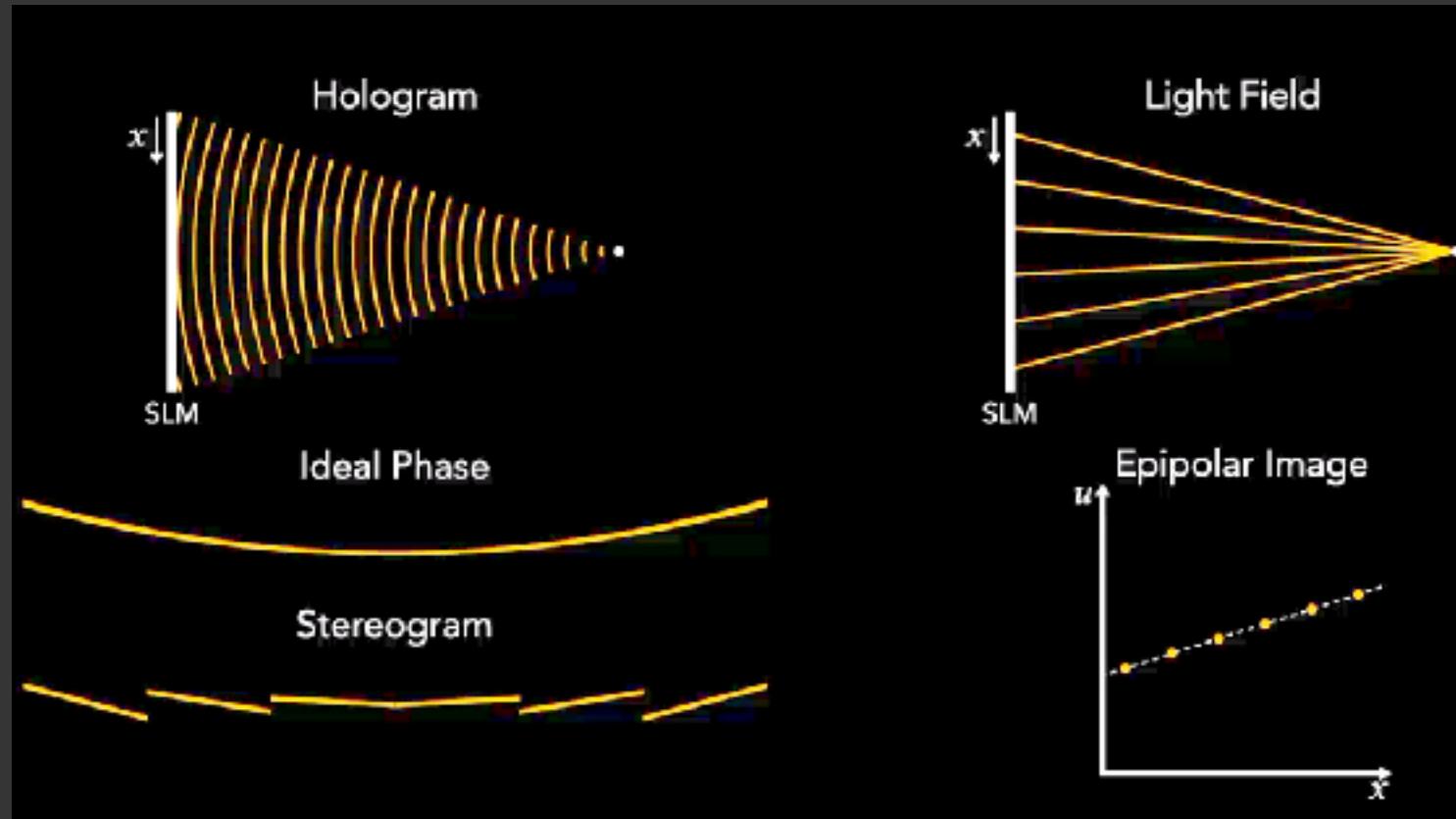
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Algorithms for Accelerating 3D CGH Computation

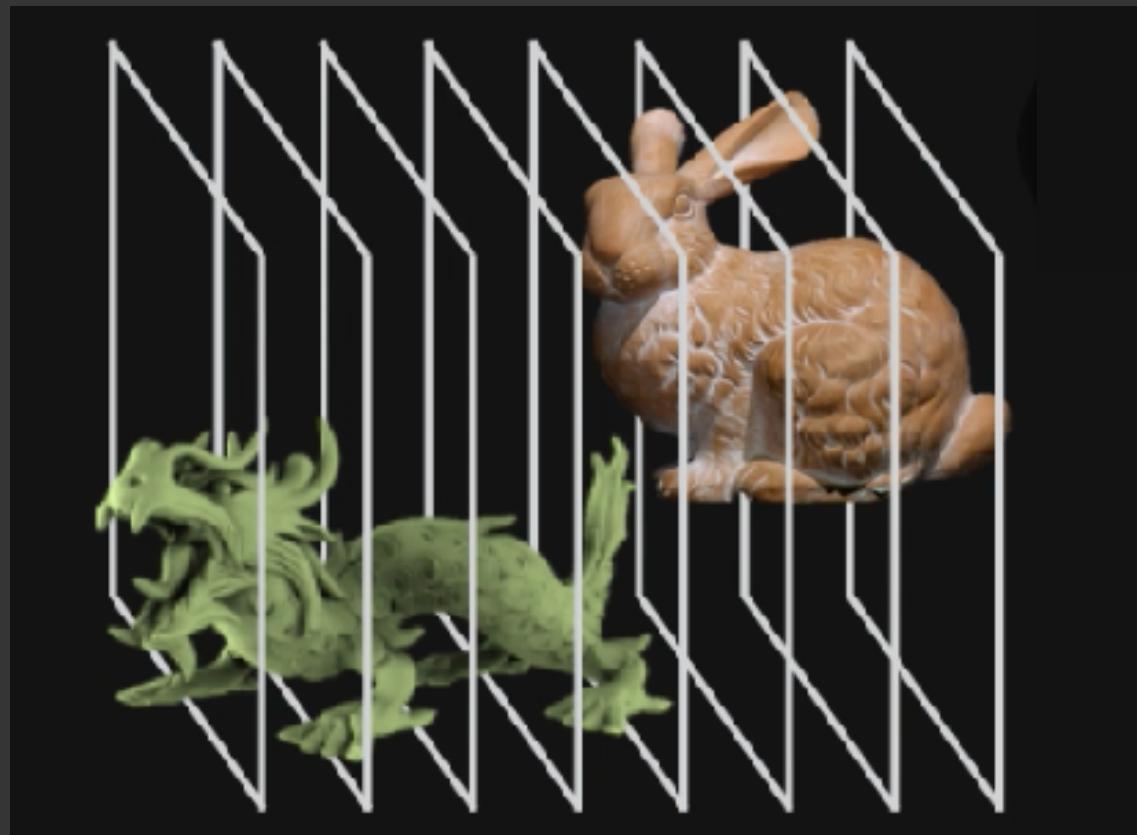
Light Field Approximation



- Moderately fast
- Support view-dependent effect
- Support occlusion
- High depth precision
- High rendering, data and I/O cost

[Padmanaban et al. 2019; Shi et al. 2017; Zhang et al. 2015]

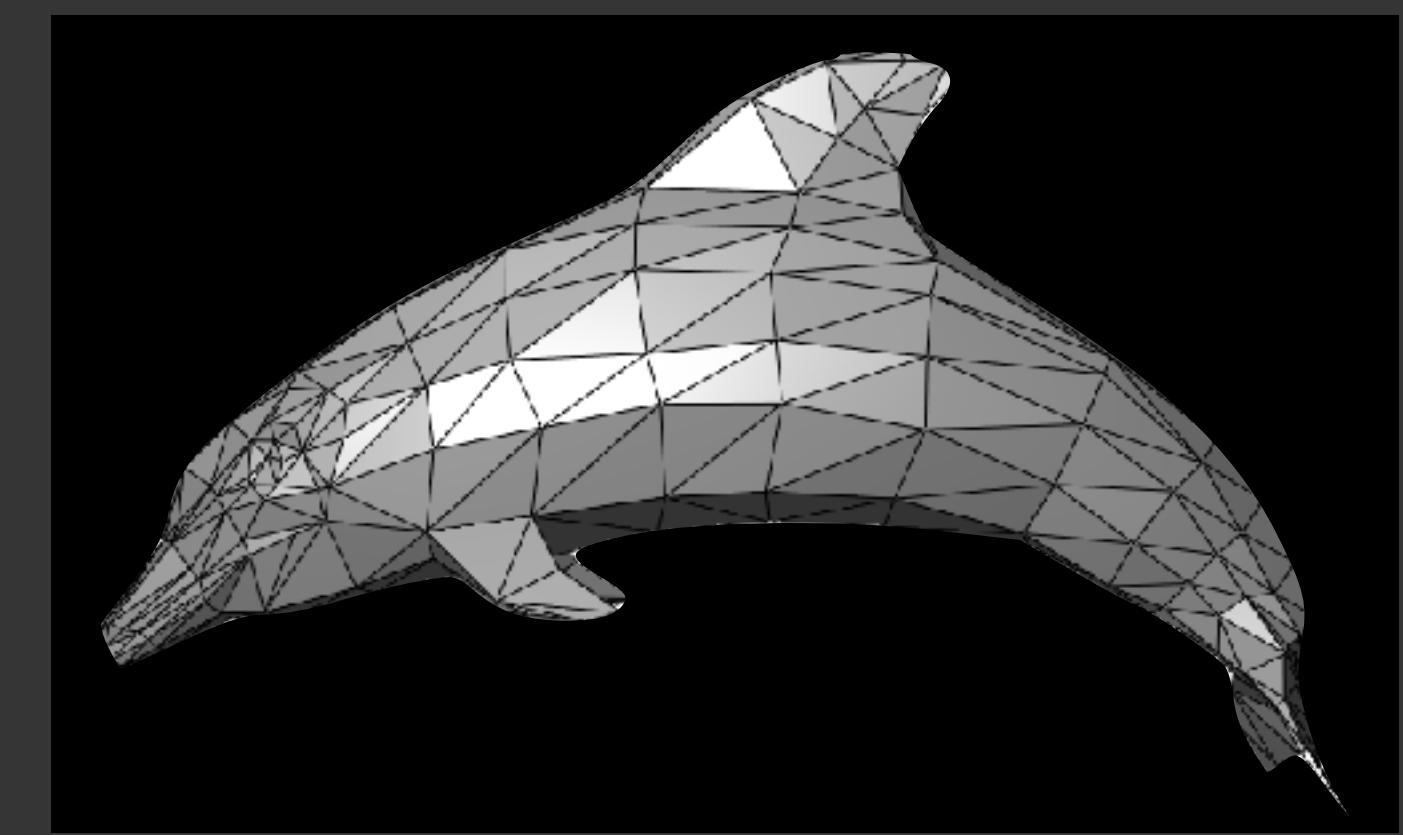
Multi-layer Approximation



- Very fast
- Low rendering, data and I/O cost
- Support occlusion
- No view-dependent effect
- Low depth precision

[Makey et al. 2019, Zhang et al. 2017, Chen et al. 2015]

Polygonal Tile Approximation



- Moderately fast
- Low rendering, data and I/O cost
- High depth precision
- No occlusion
- No view-dependent effect

[Kim et al 2018/2015, Zhang et al. 2018
Matsushima et al. 2005]

Algorithms for Accelerating 3D CGH Computation

Light Field Approximation



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[Padmanaban et al. 2019; Shi et al. 2017; Zhang et al. 2015]

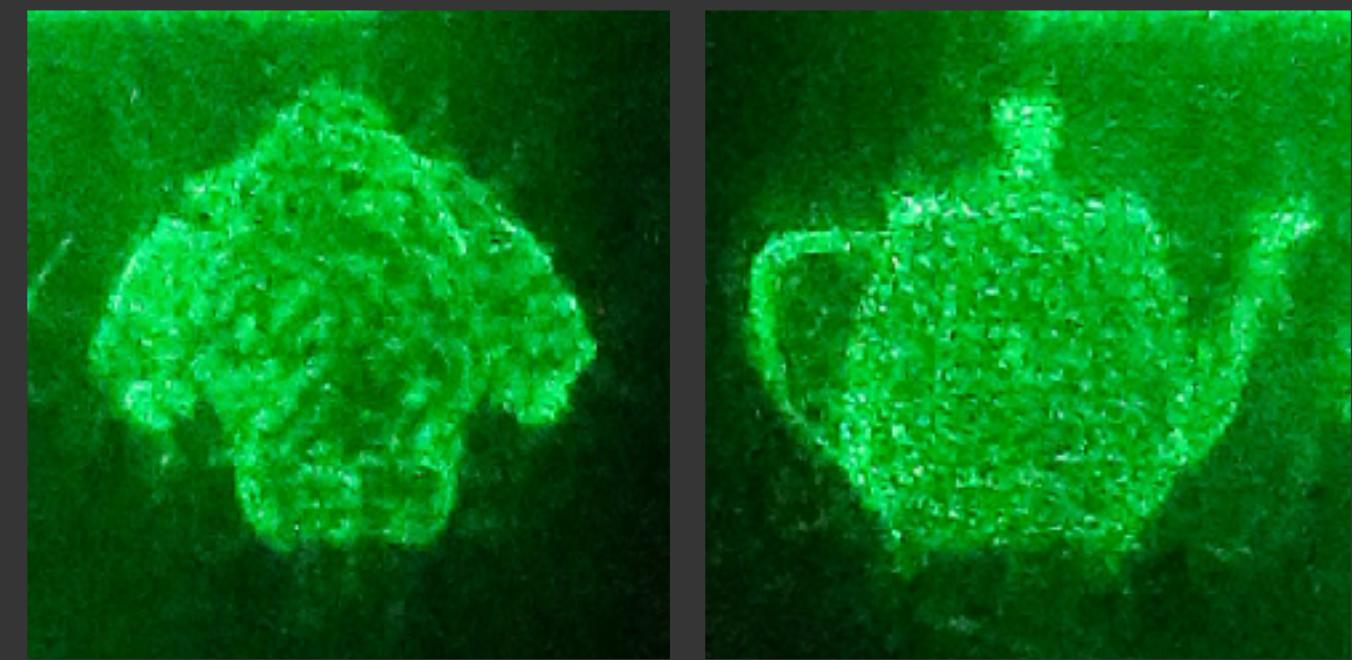
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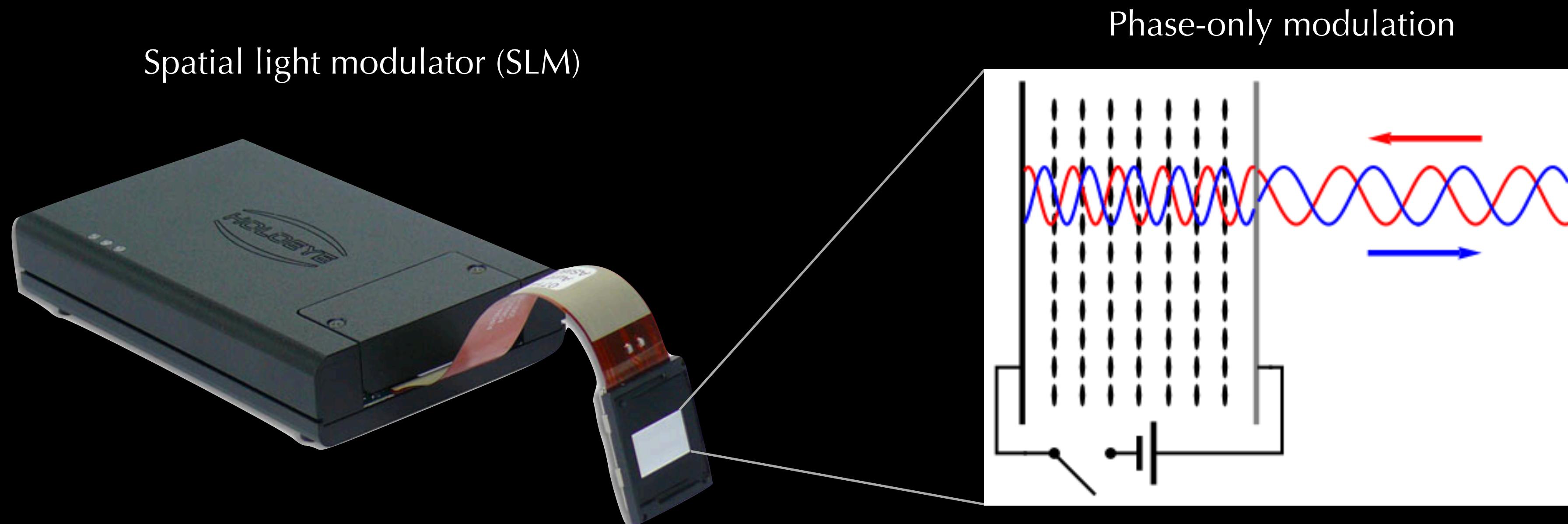
Polygonal Tile Approximation



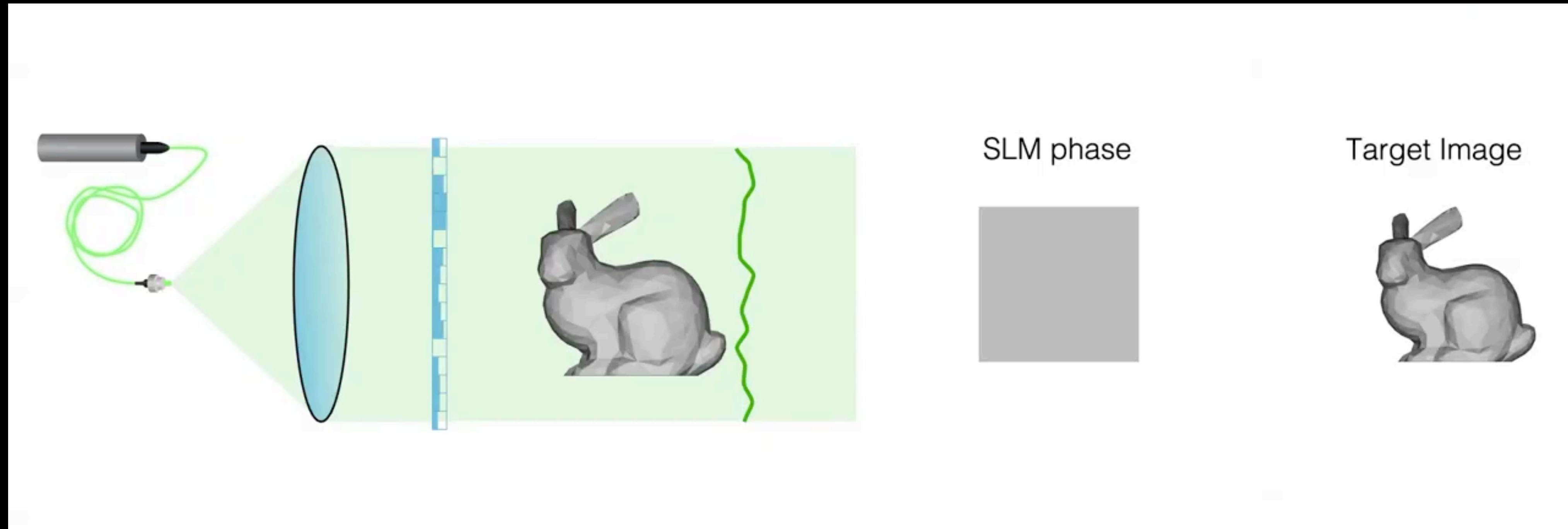
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Conversion to Phase-only Representation



Conversion to Phase-only Representation



Iterative Methods

[Peng et al. 2020, Chakravarthula et al. 2019, 2020, Choi et al. 2021]

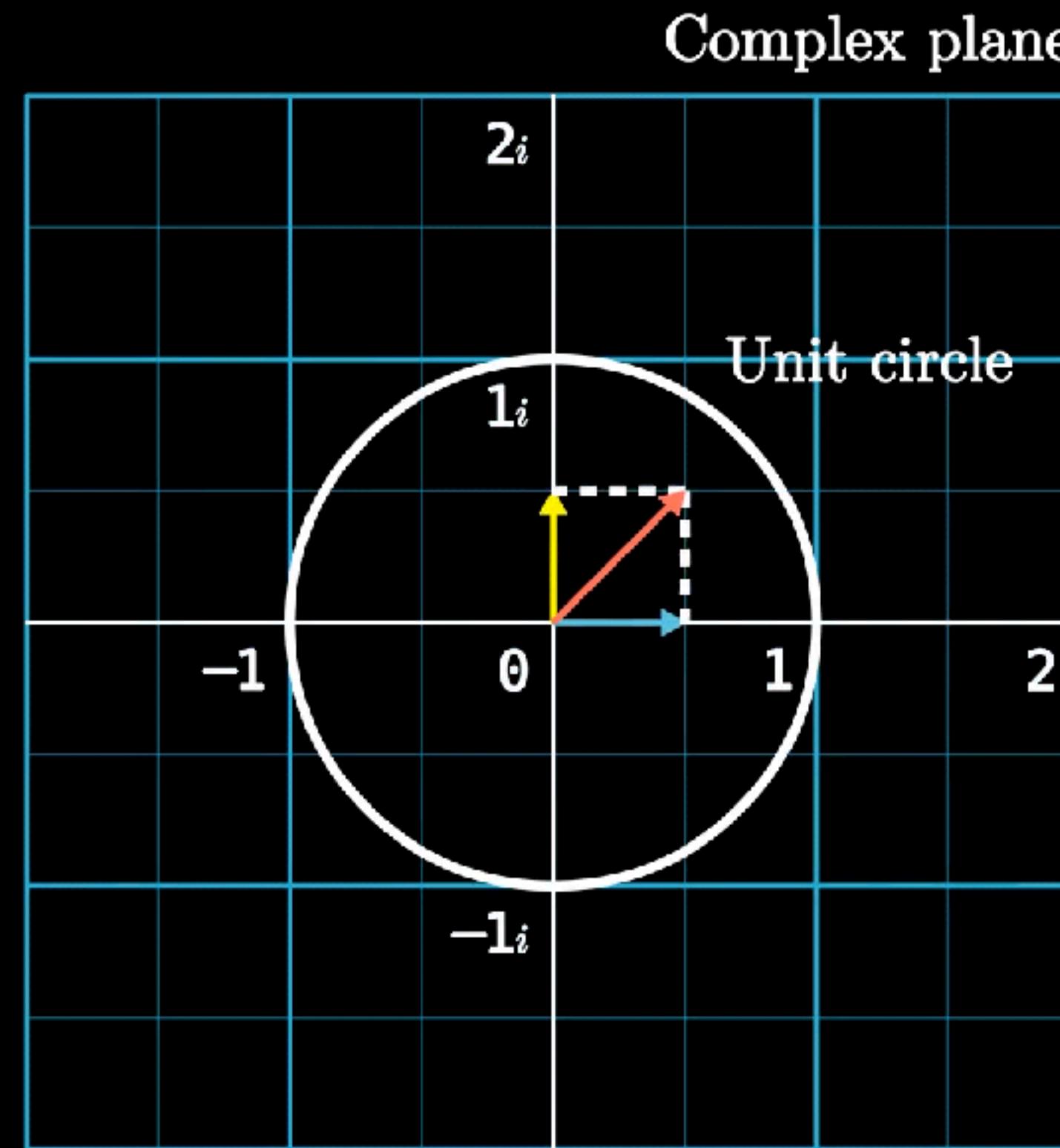
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Conversion to Phase-only Representation



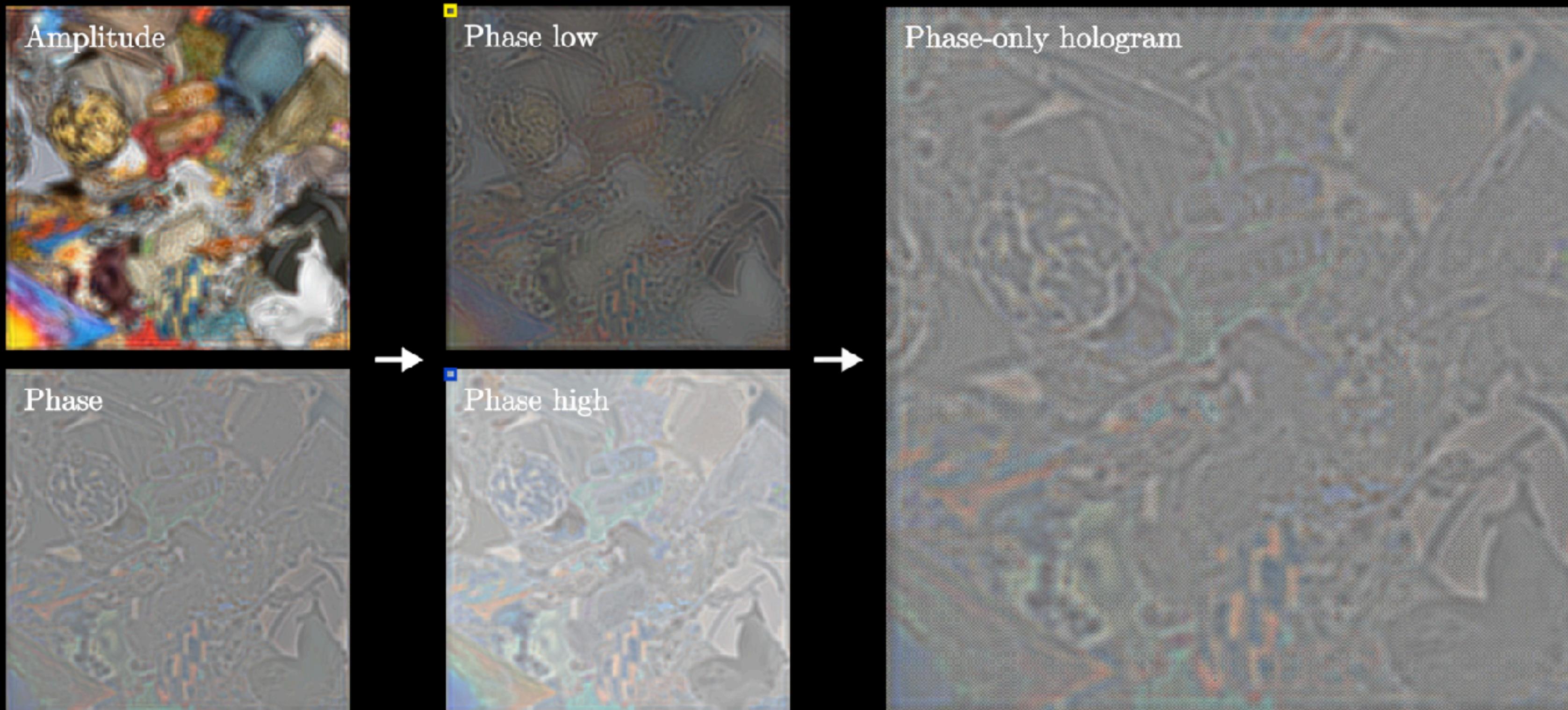
$$ae^{ip} = 0.5e^{i(p-\cos^{-1} a)} + 0.5e^{i(p+\cos^{-1} a)}$$

- Target complex value
- Decomposed phase-only value (low)
- Decomposed phase-only value (high)

Double Phase Method

[Maimone et al. 2017, Mendoza-Yero 2014, Hsueh 1978]

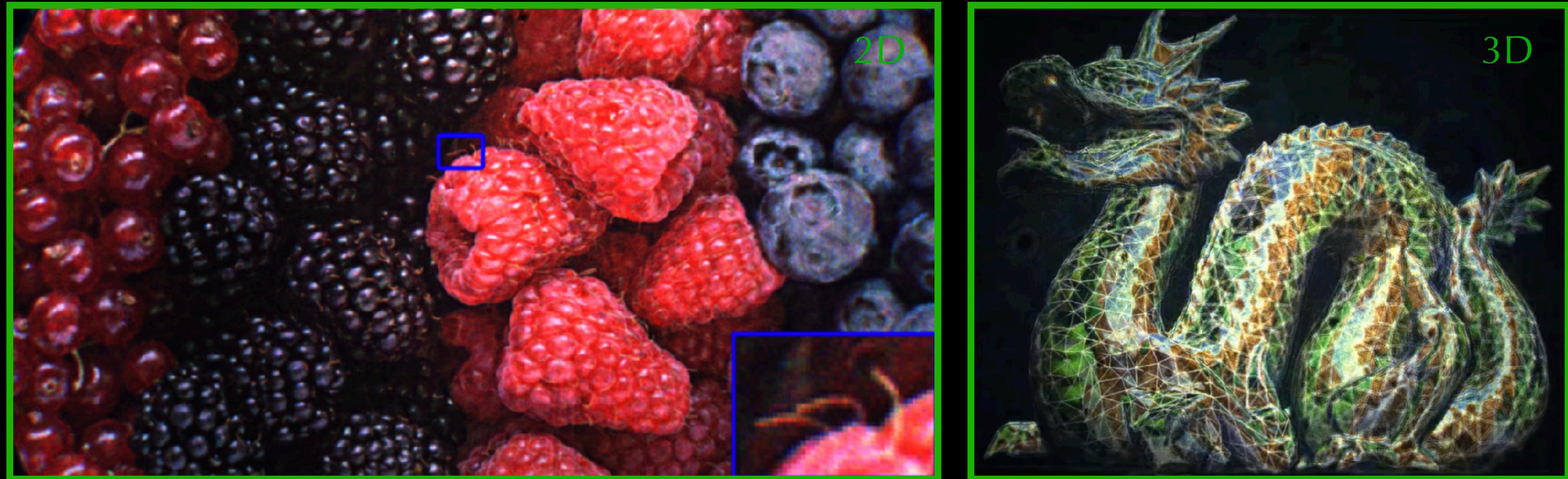
Conversion to Phase-only Representation



Double Phase Method

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Conversion to Phase-only Representation



Double Phase Method

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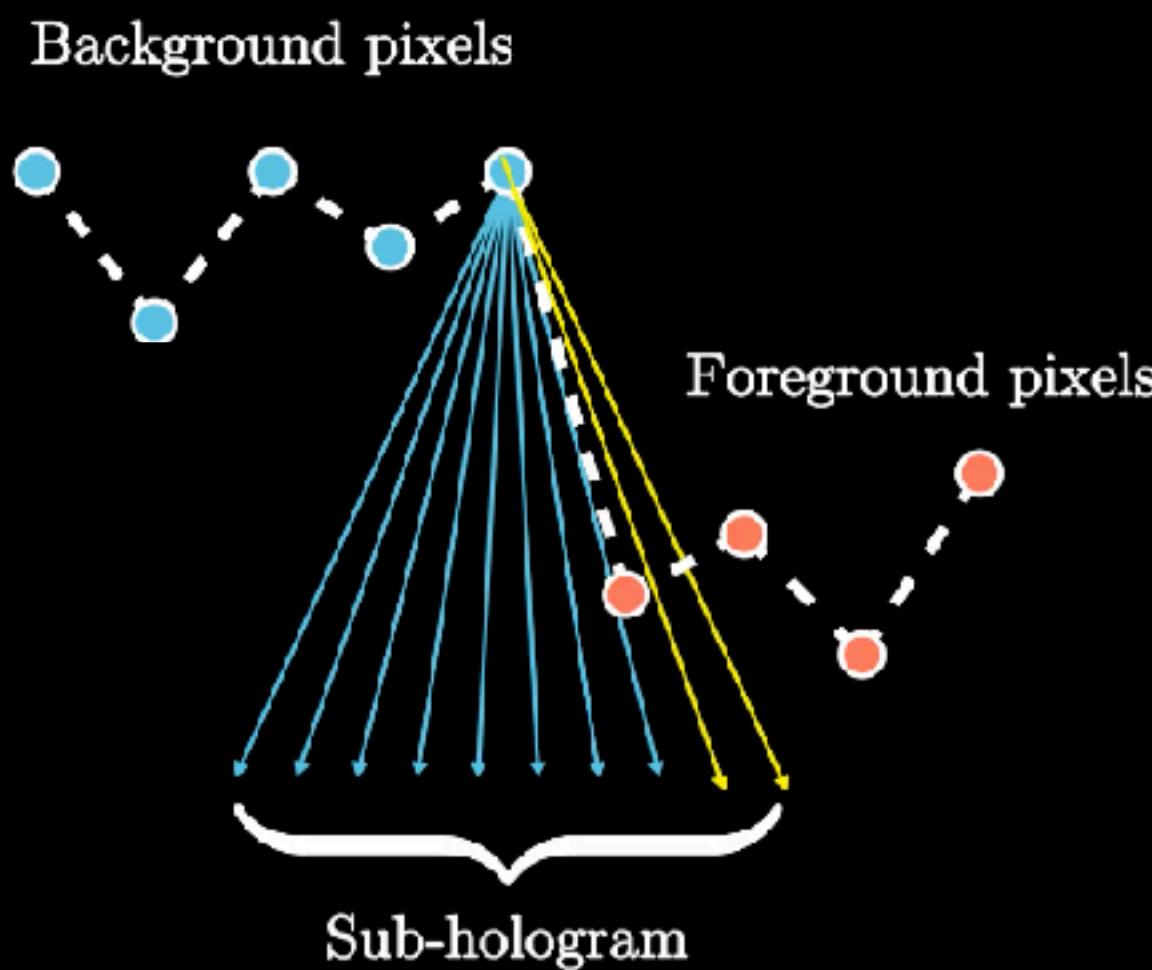
Conversion to Phase-only Representation



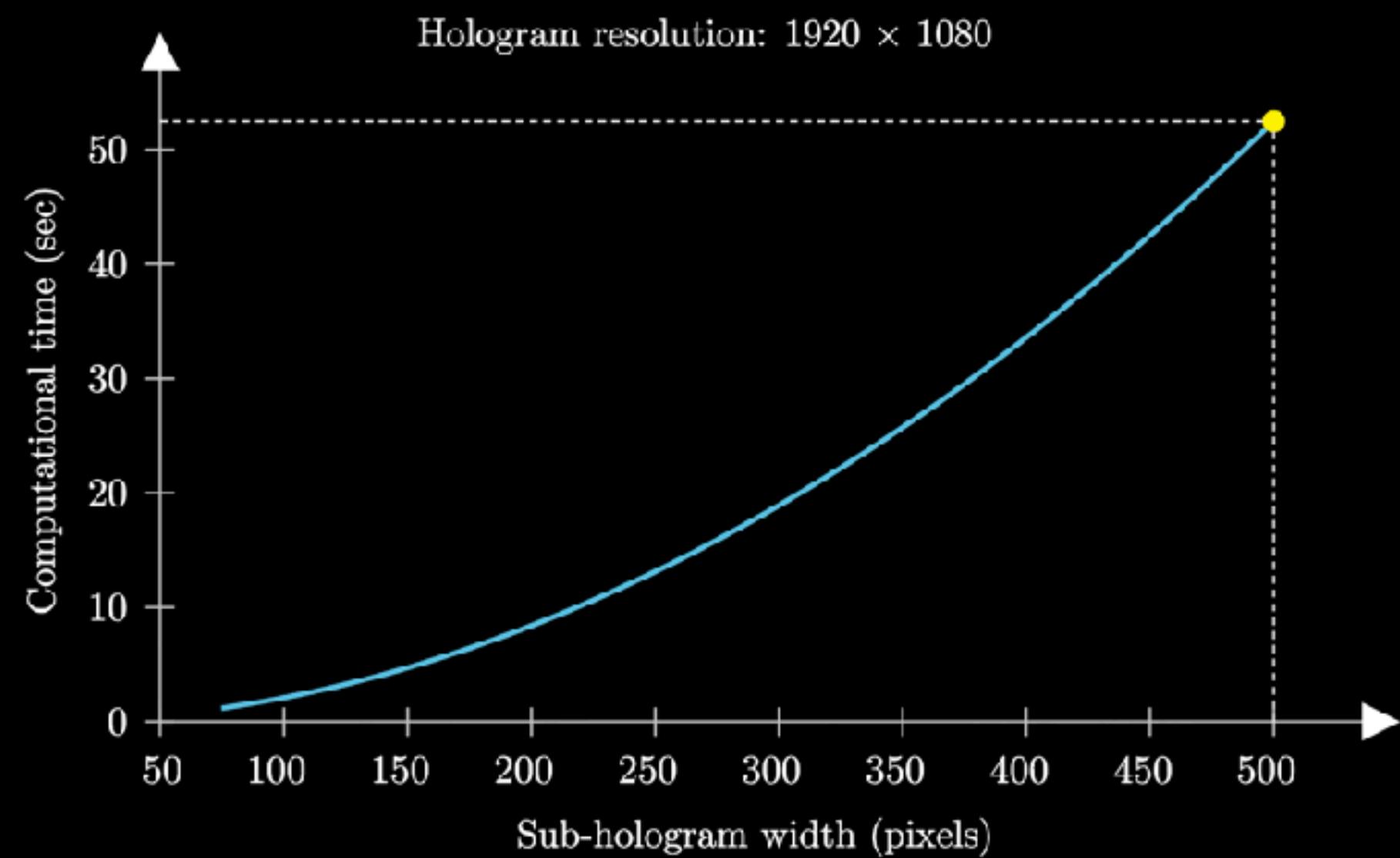
Double Phase Method

[Maimone et al. 2017, Mendoza-Yero 2014, Hsueh 1978]

Computational Challenges for 3D Hologram



Lack of occlusion modeling

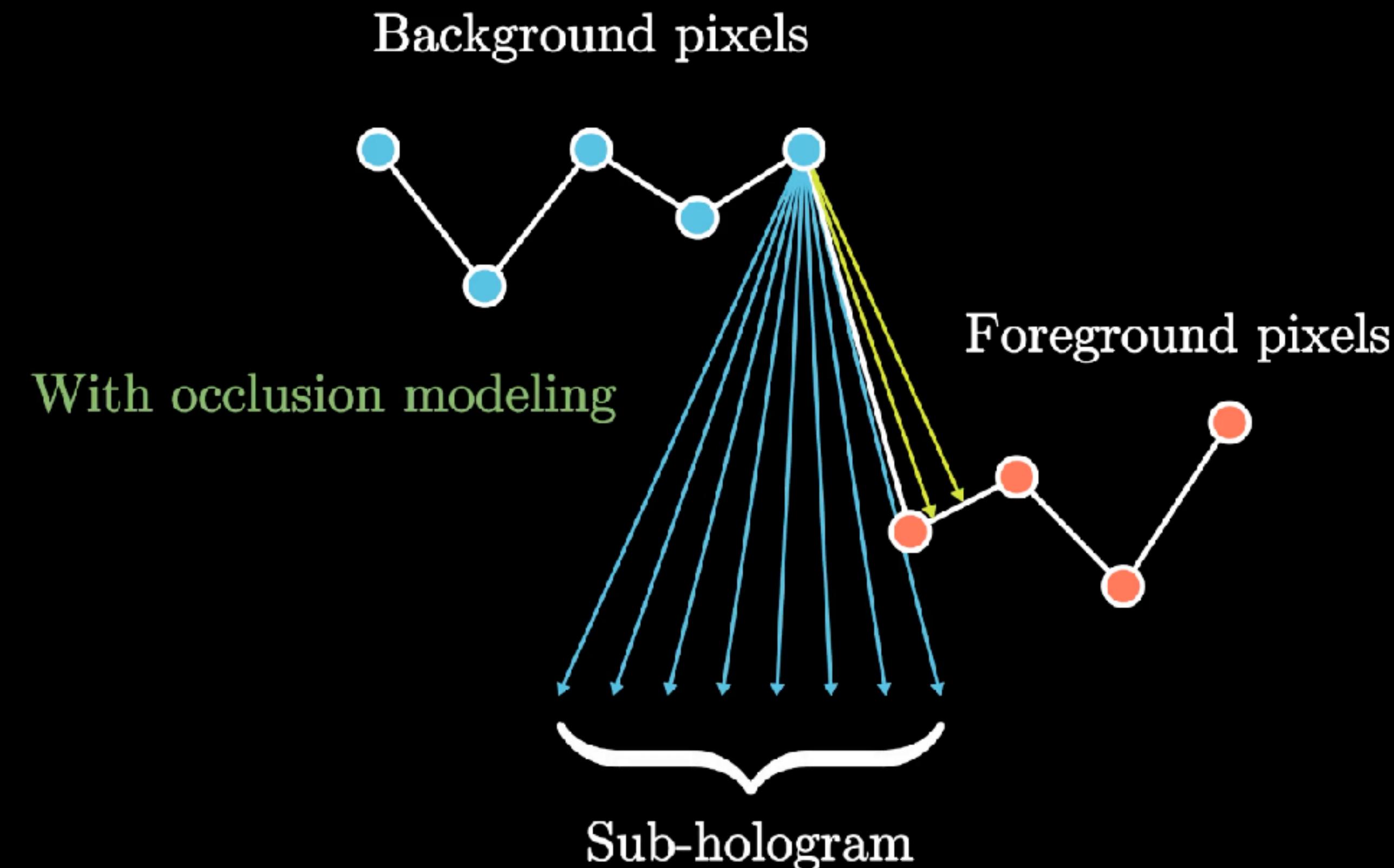


High computation cost

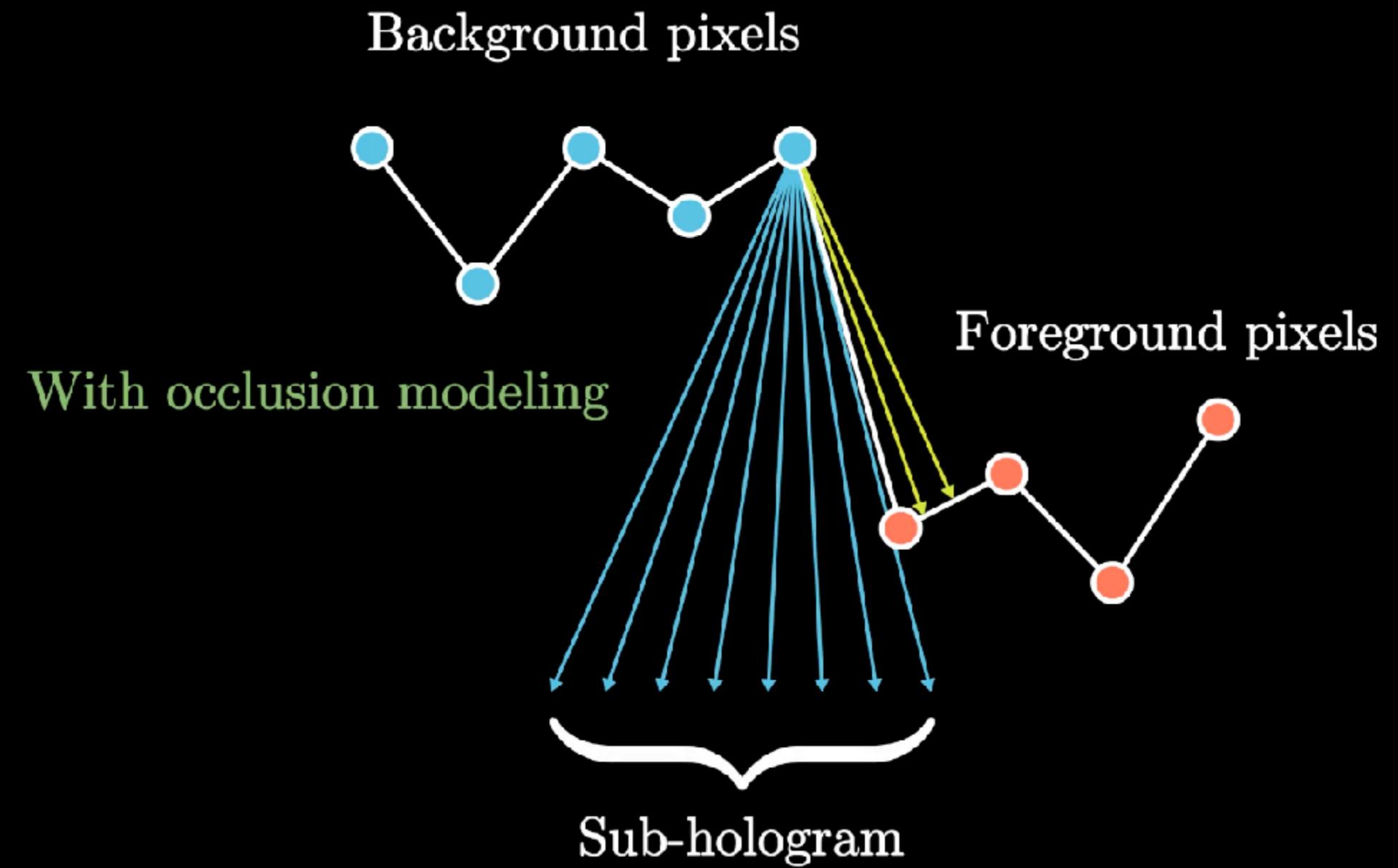


Non-robust phase-only encoding

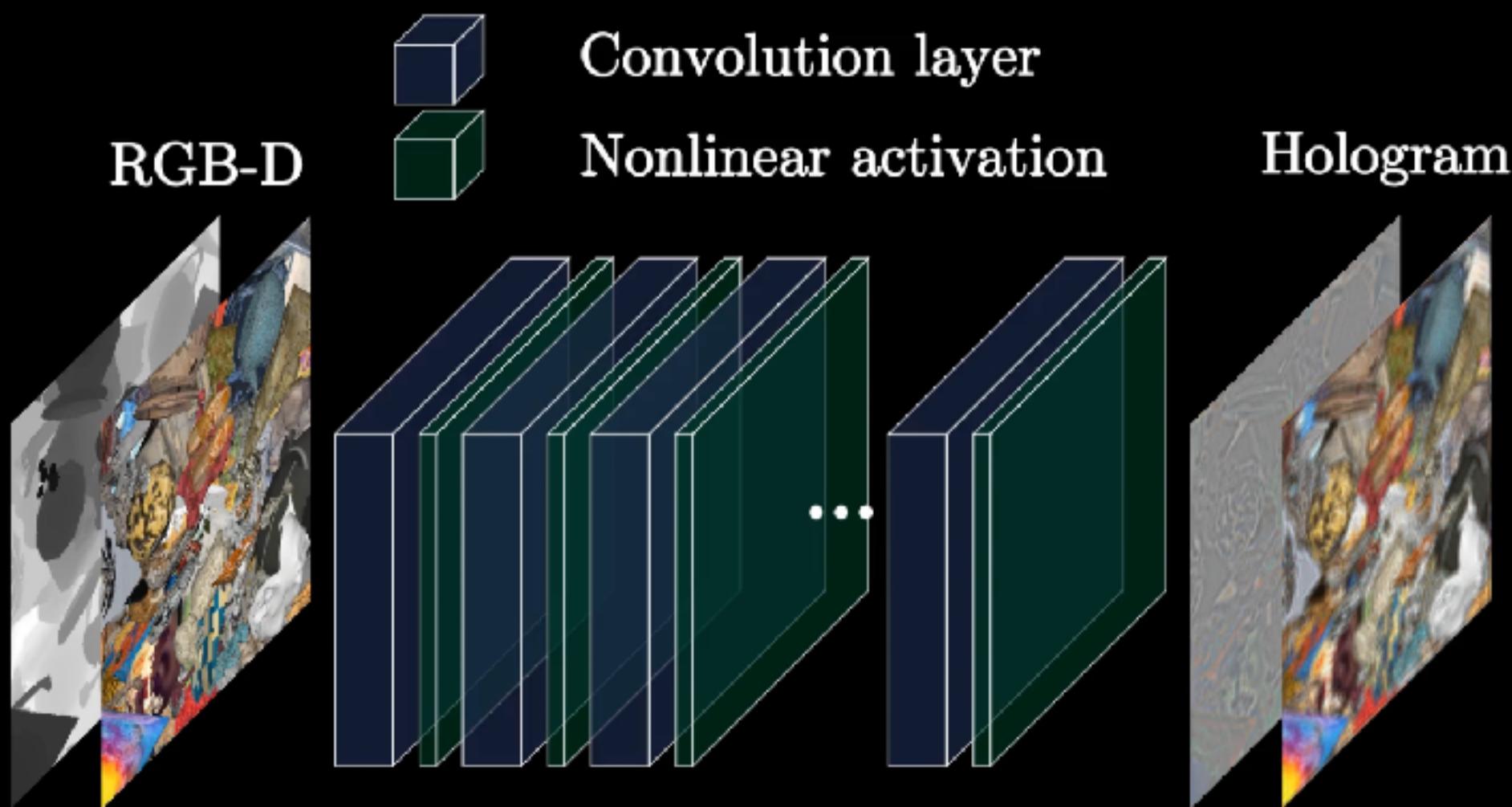
Occlusion-aware Point-based Method (OA-PBM)



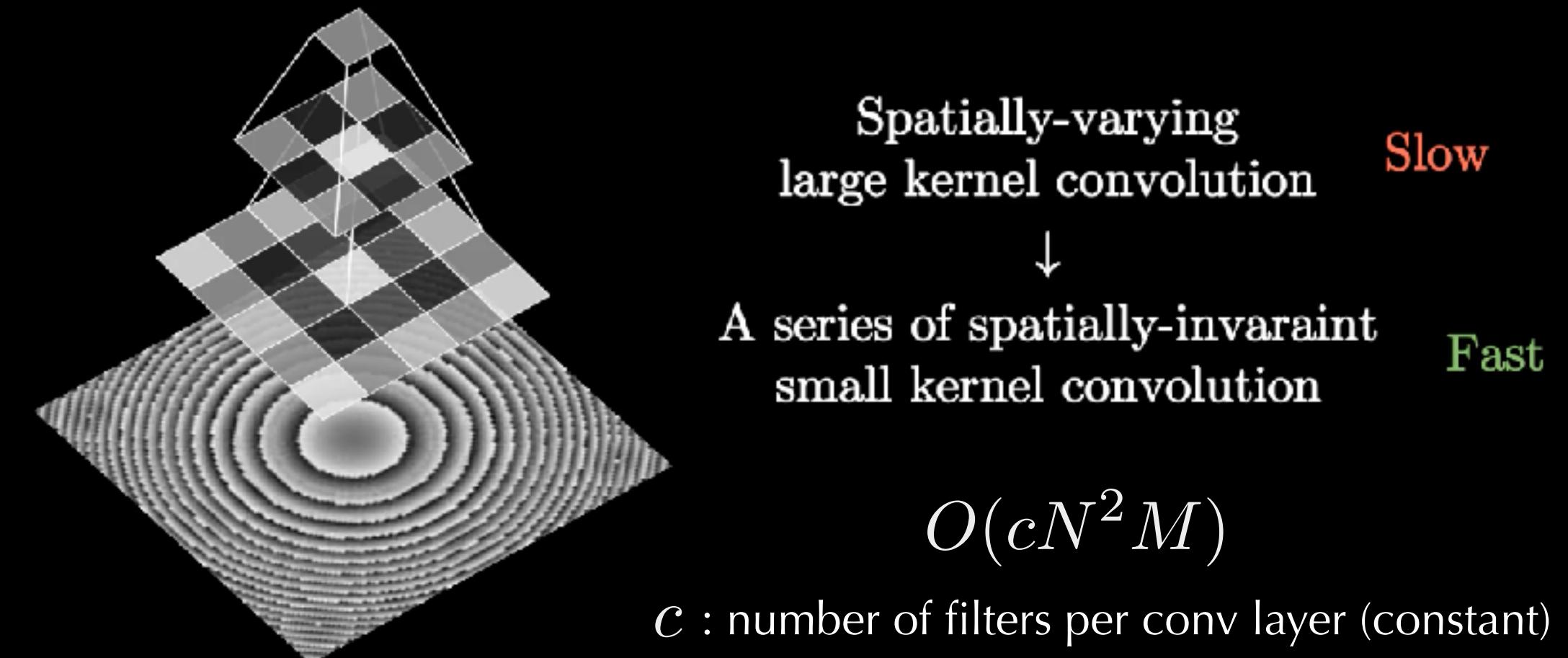
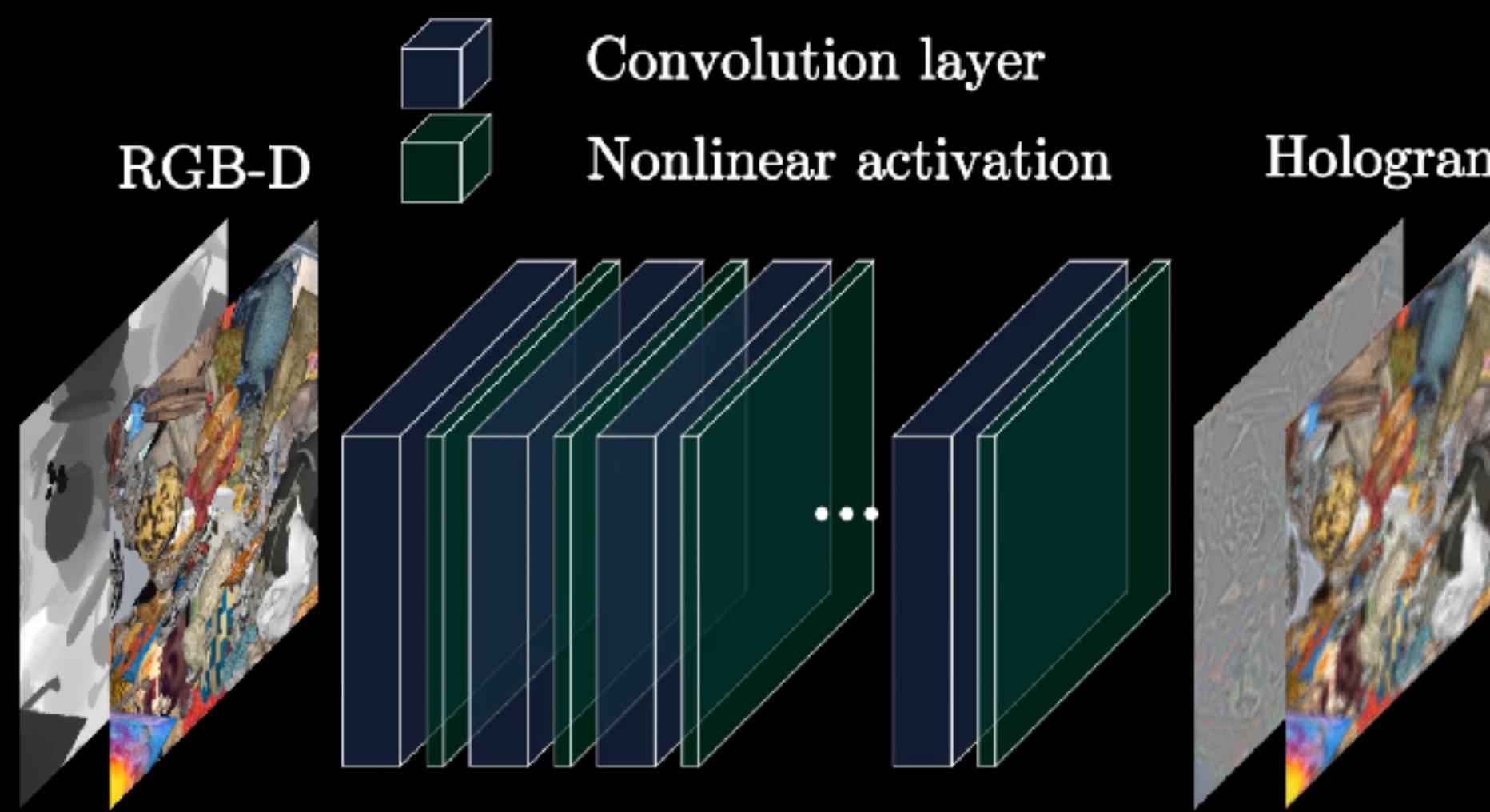
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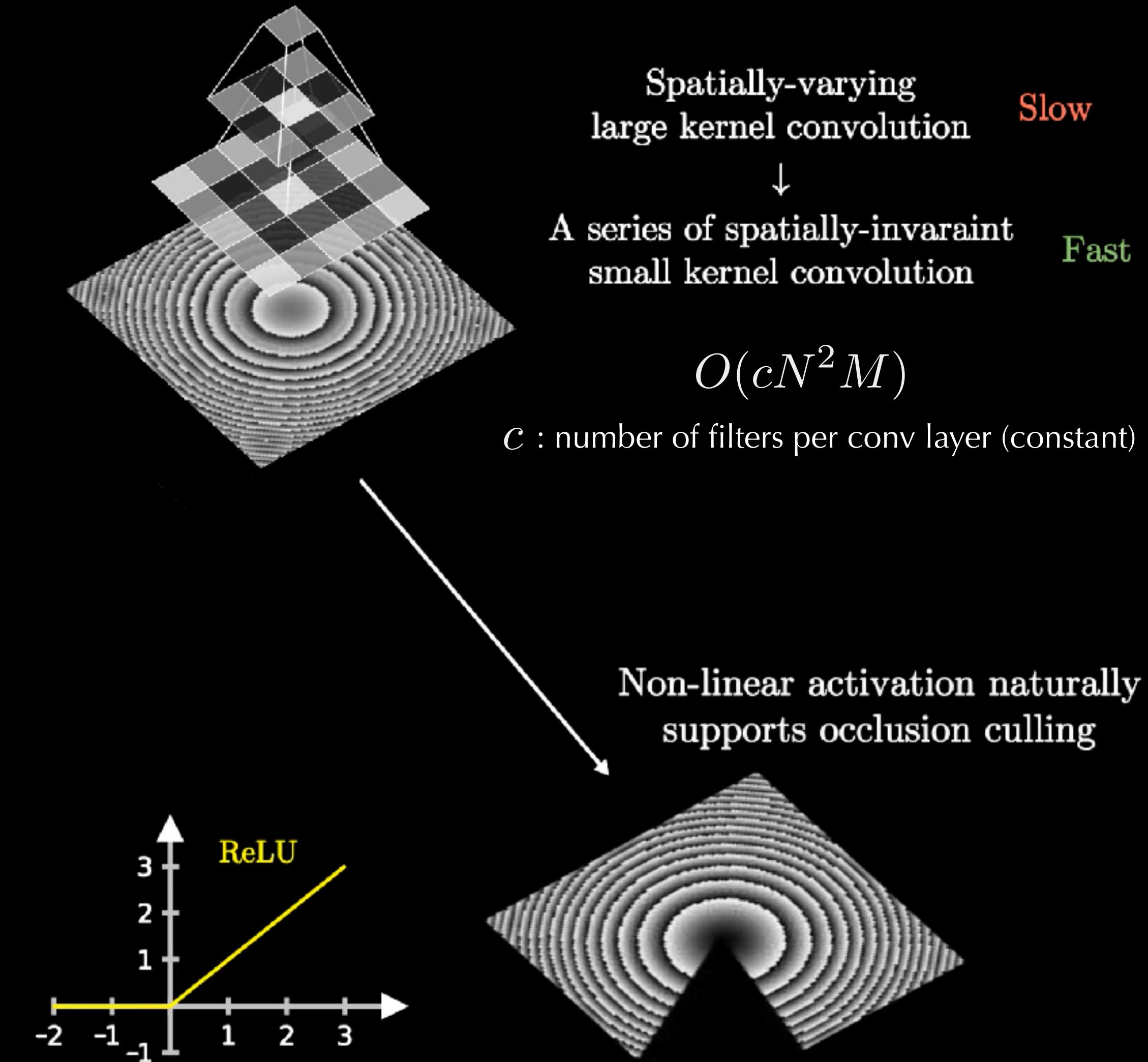
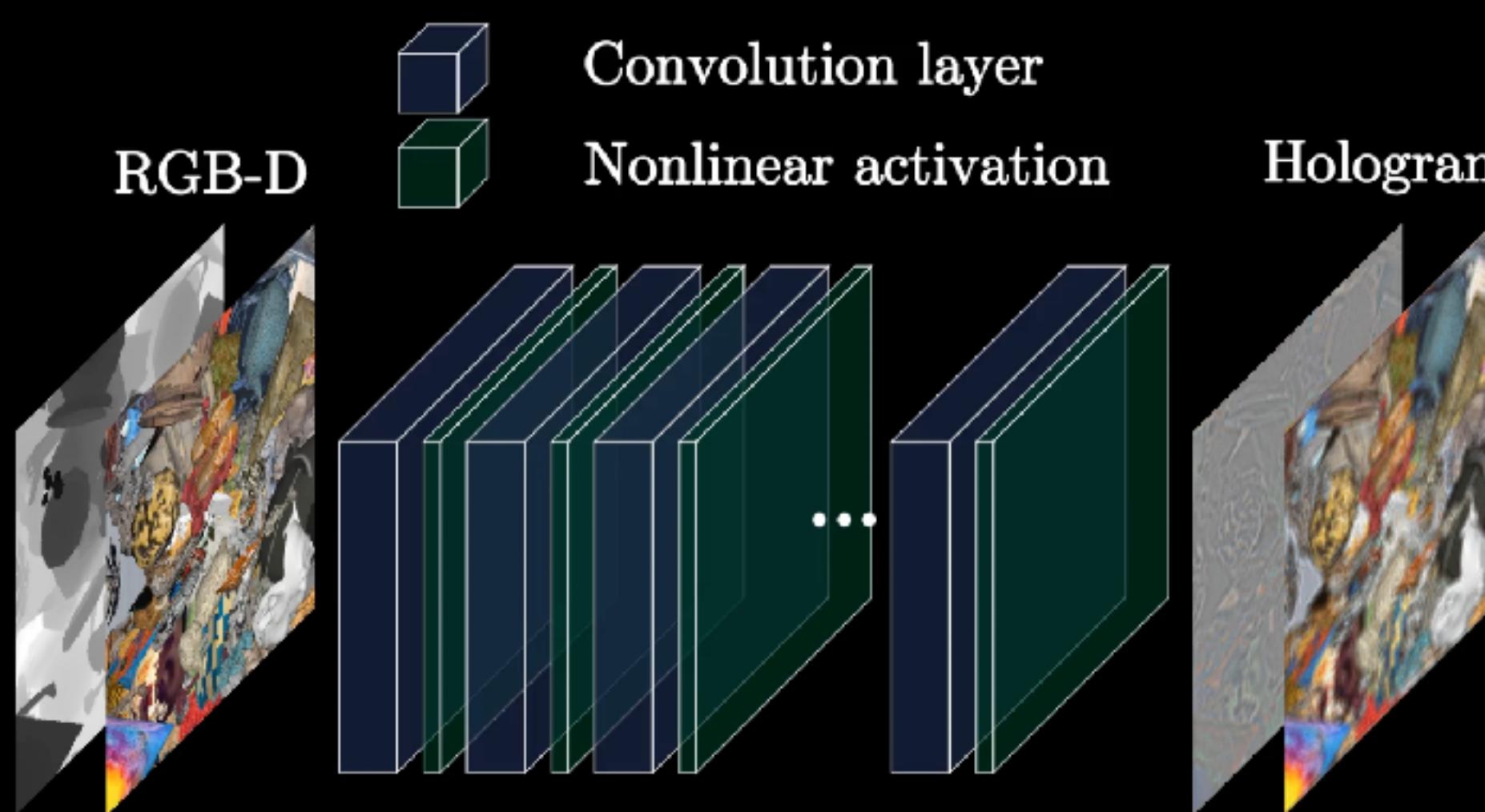
CNN for 3D Hologram Synthesis



CNN for 3D Hologram Synthesis



CNN for 3D Hologram Synthesis

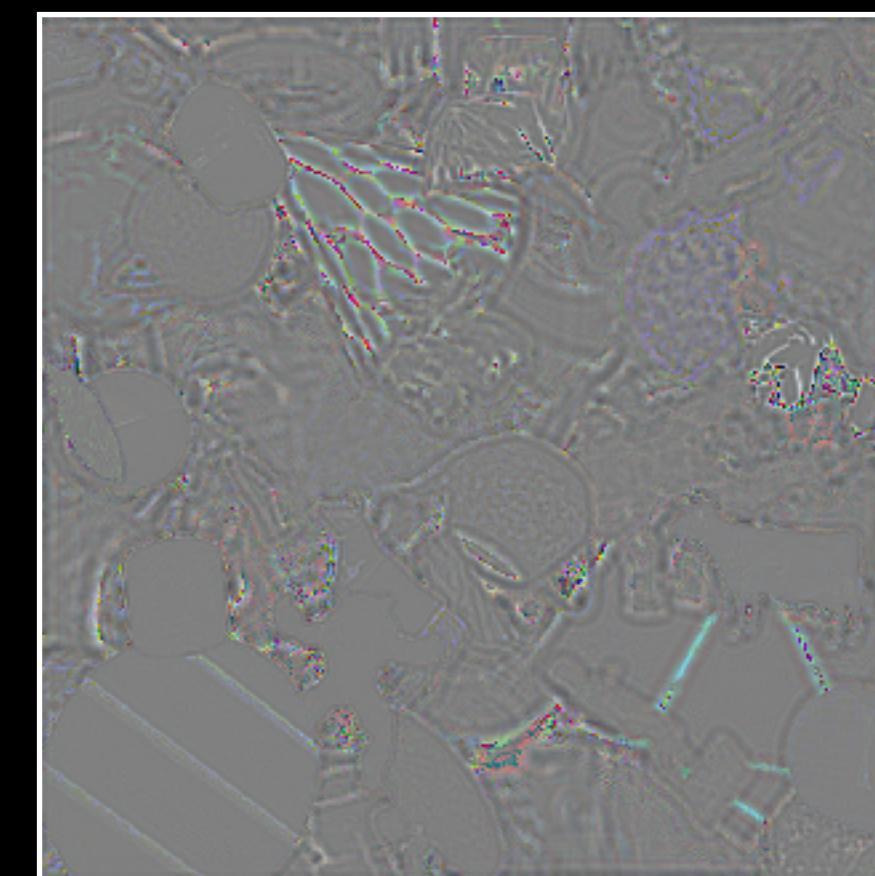


Dataset for 3D Hologram Synthesis

Input:



Output:



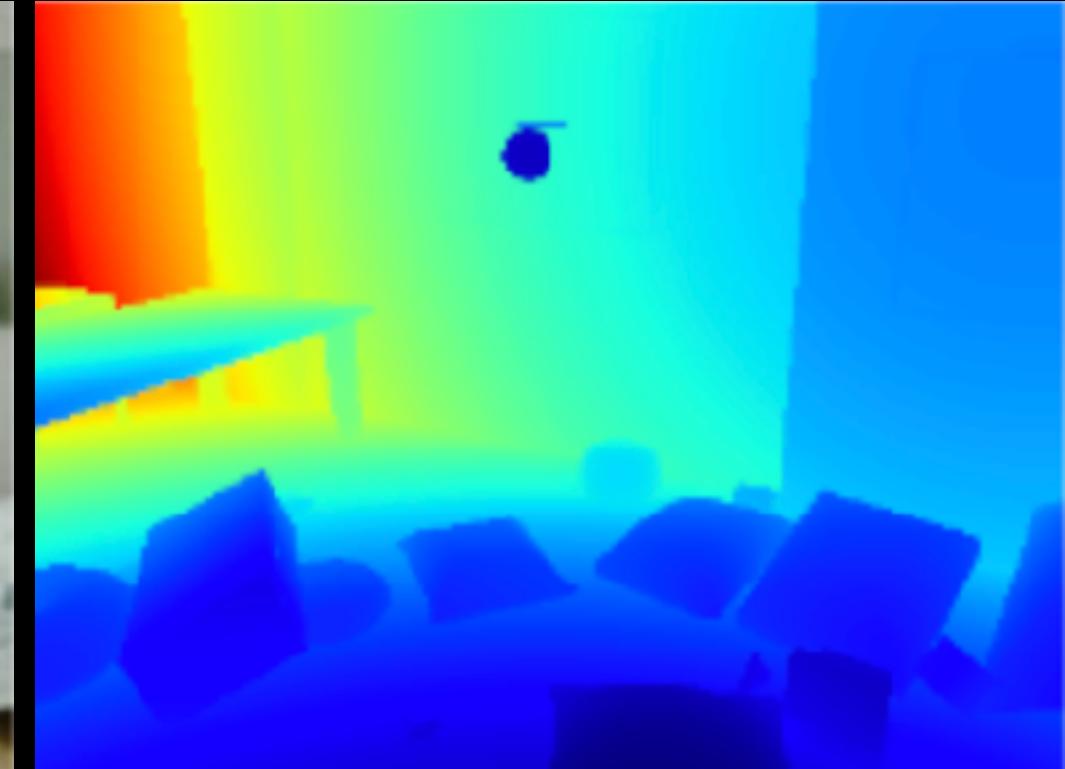
1. Uniform pixel depth distribution
2. Enough scene complexity
3. No undefined depth or depth misalignment

Dataset for 3D Hologram Synthesis

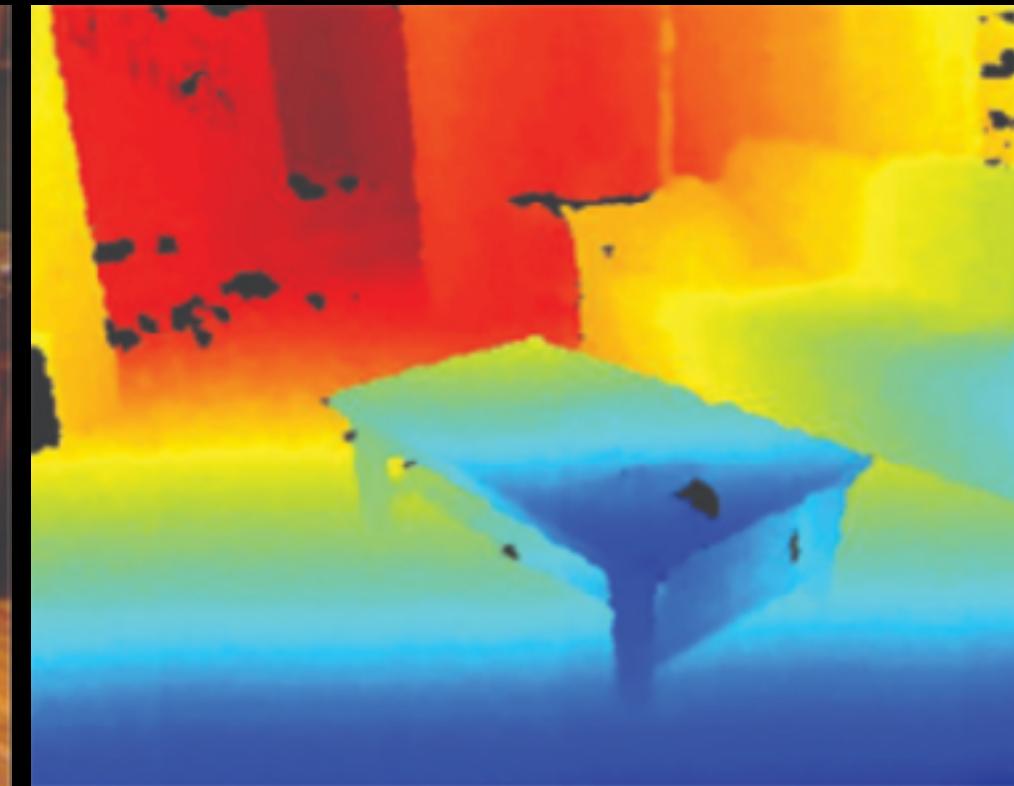
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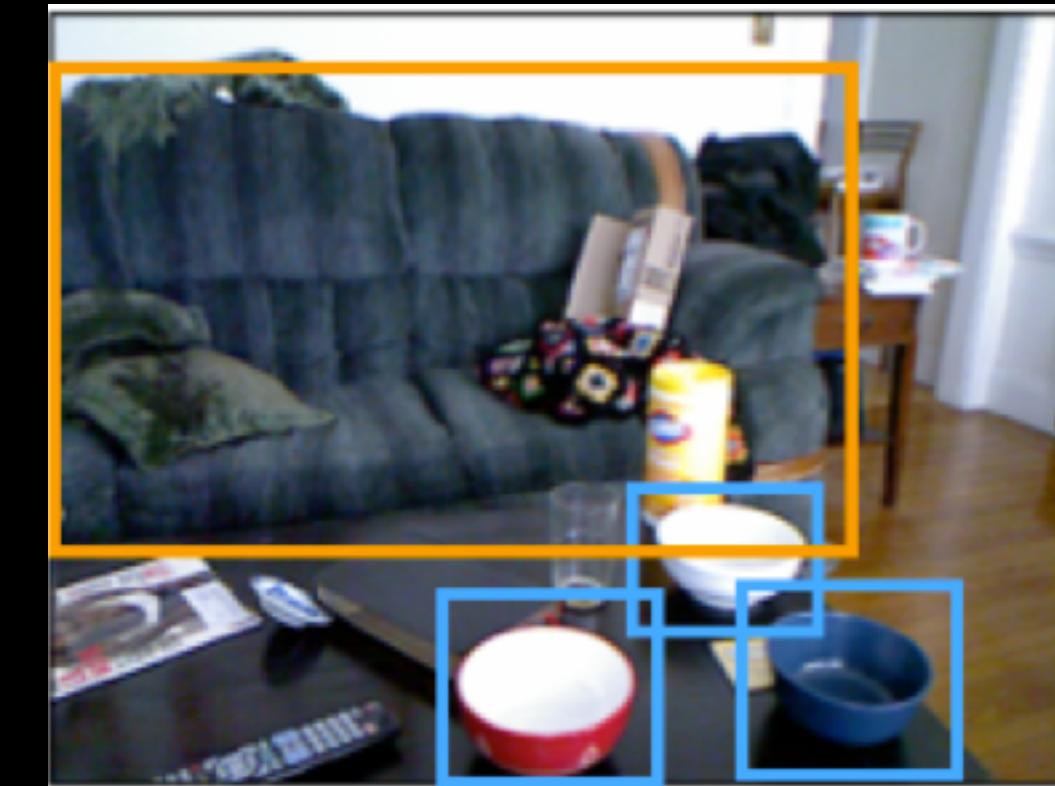
DeepFocus Dataset [Xiao et al. 2018] [\(1\)](#) [\(2\)](#) [\(3\)](#)



Berkeley 3-D Object Dataset [Janoch et al. 2011] [\(1\)](#) [\(2\)](#) [\(3\)](#)

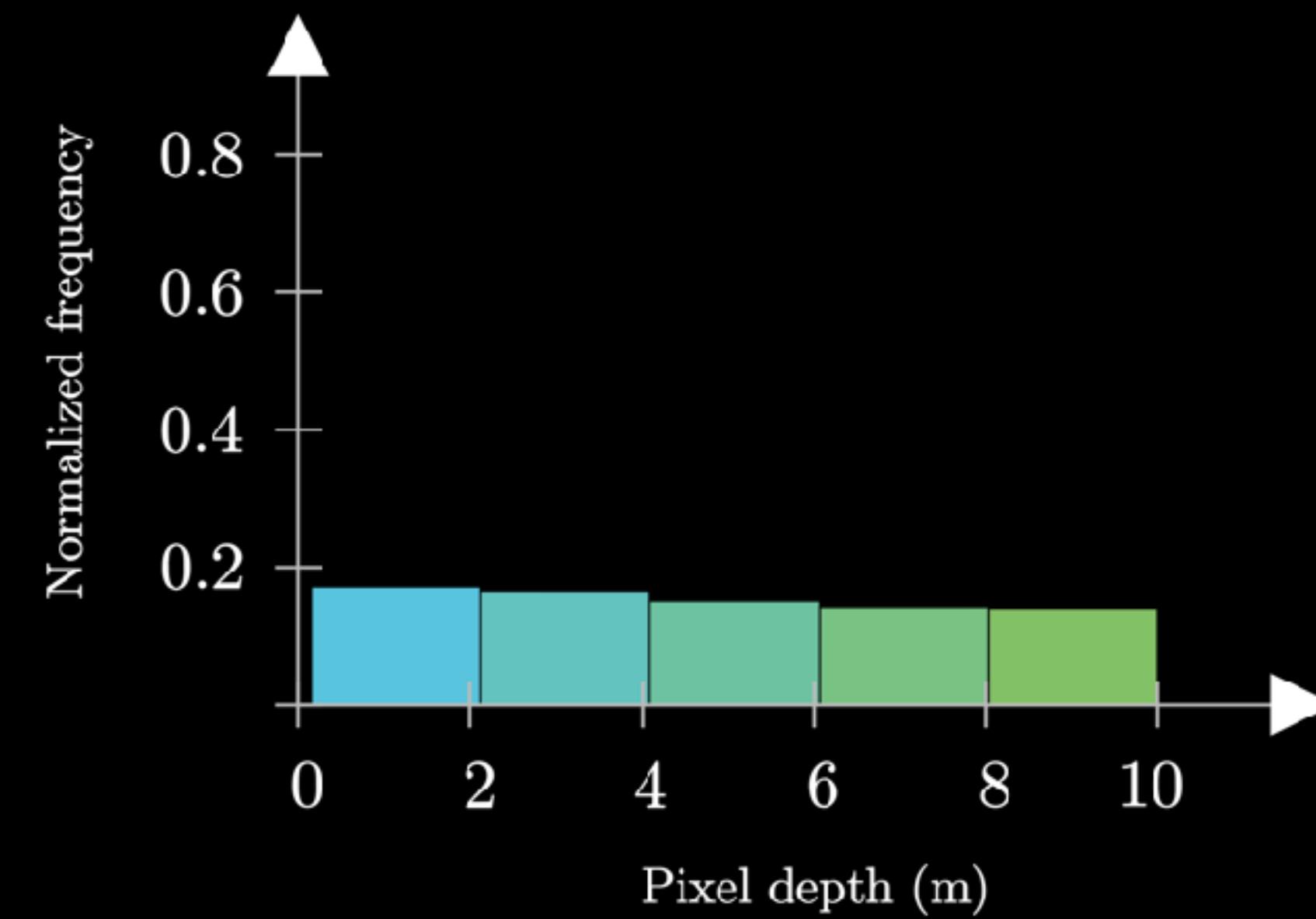
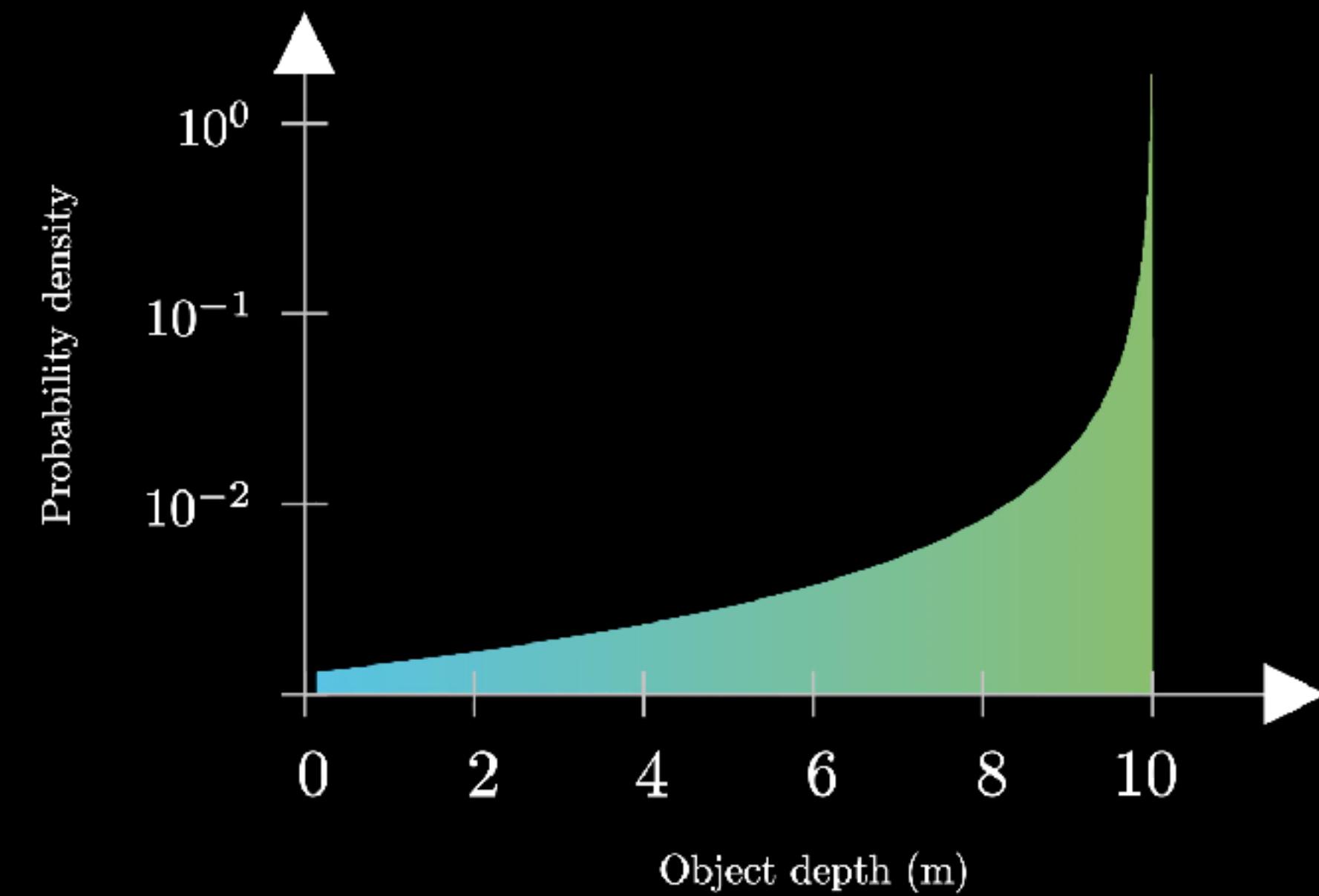


NYU Depth Dataset V2 [Silberman et al. 2012] [\(1\)](#) [\(2\)](#) [\(3\)](#)



Berkeley 3-D Object Dataset [Janoch et al. 2011] [\(1\)](#) [\(2\)](#) [\(3\)](#)

Dataset for 3D Hologram Synthesis

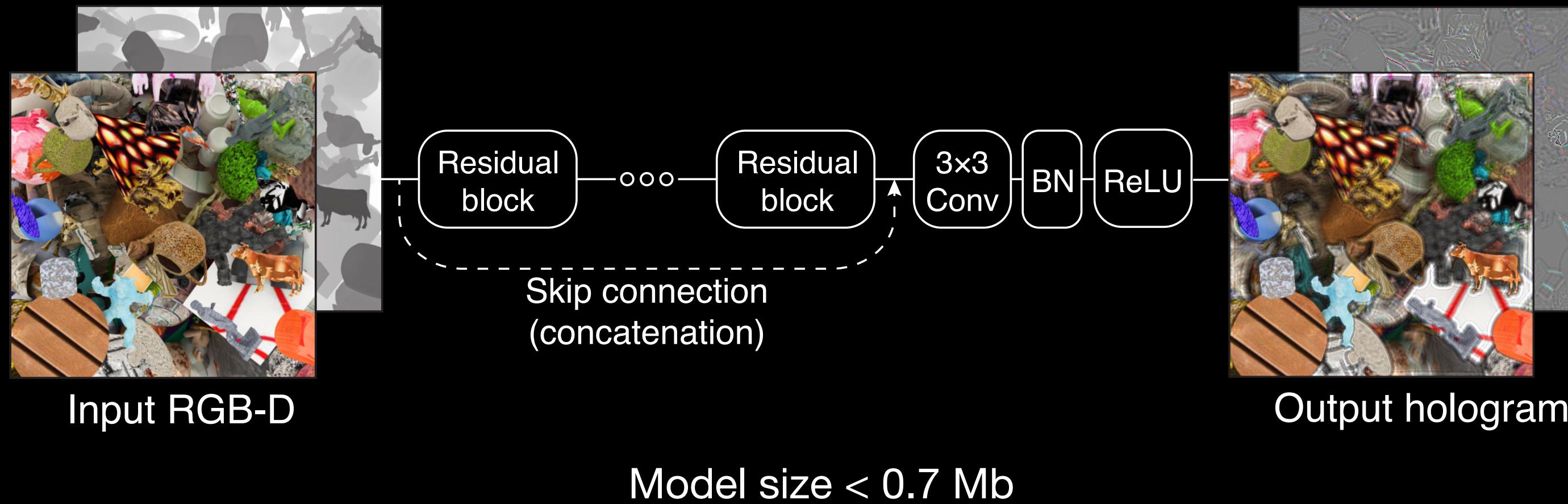




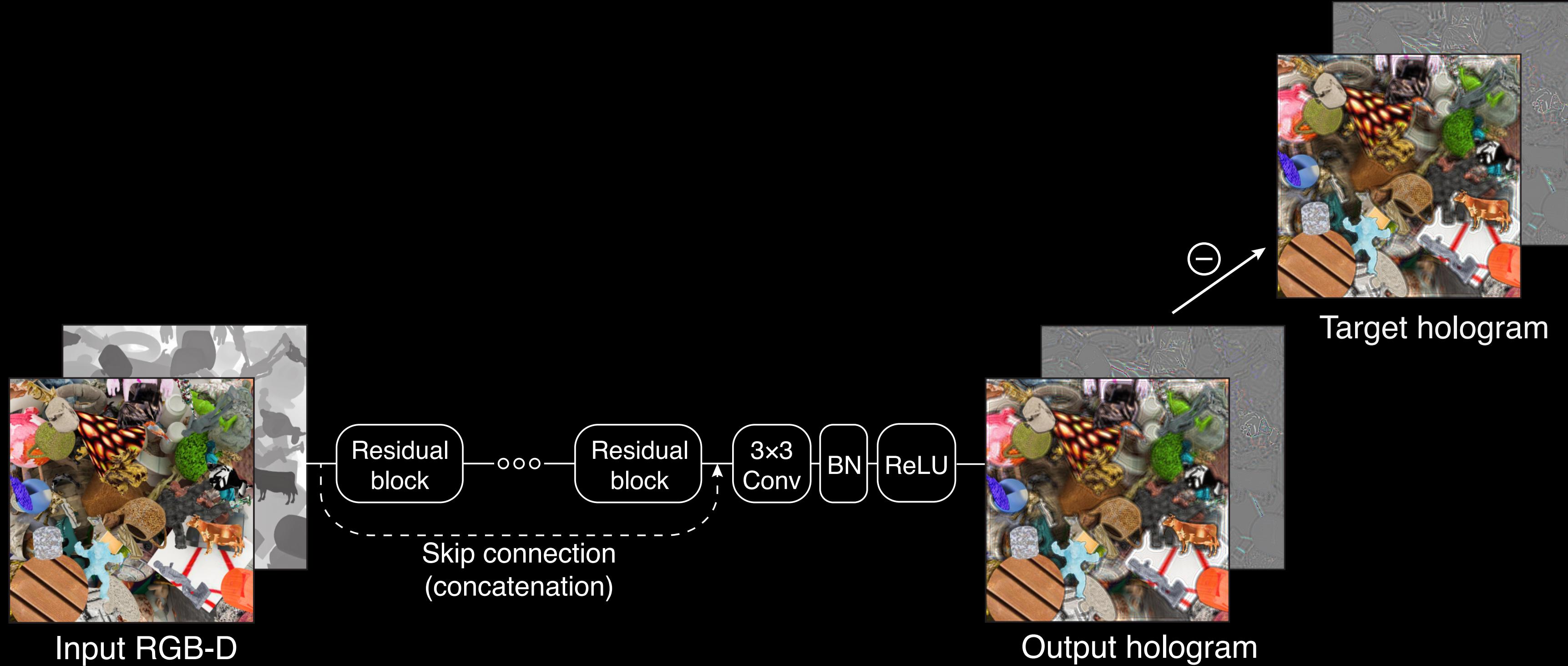
MIT-CGH-4K

The first large-scale 3D hologram dataset

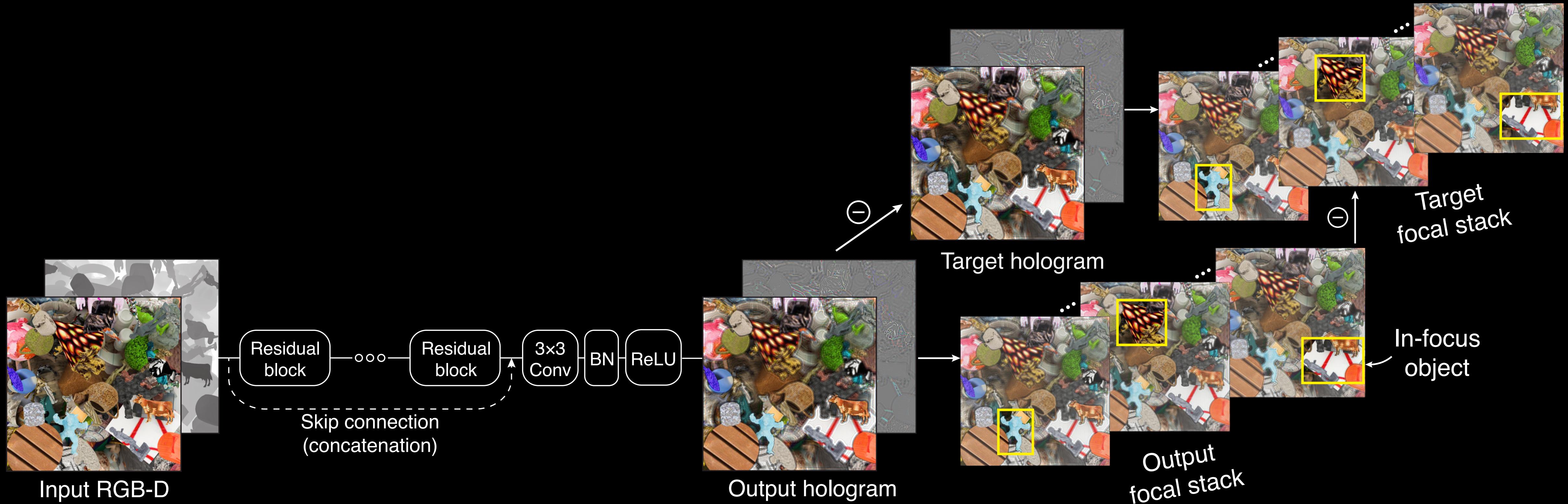
Training CNN for 3D Hologram Synthesis



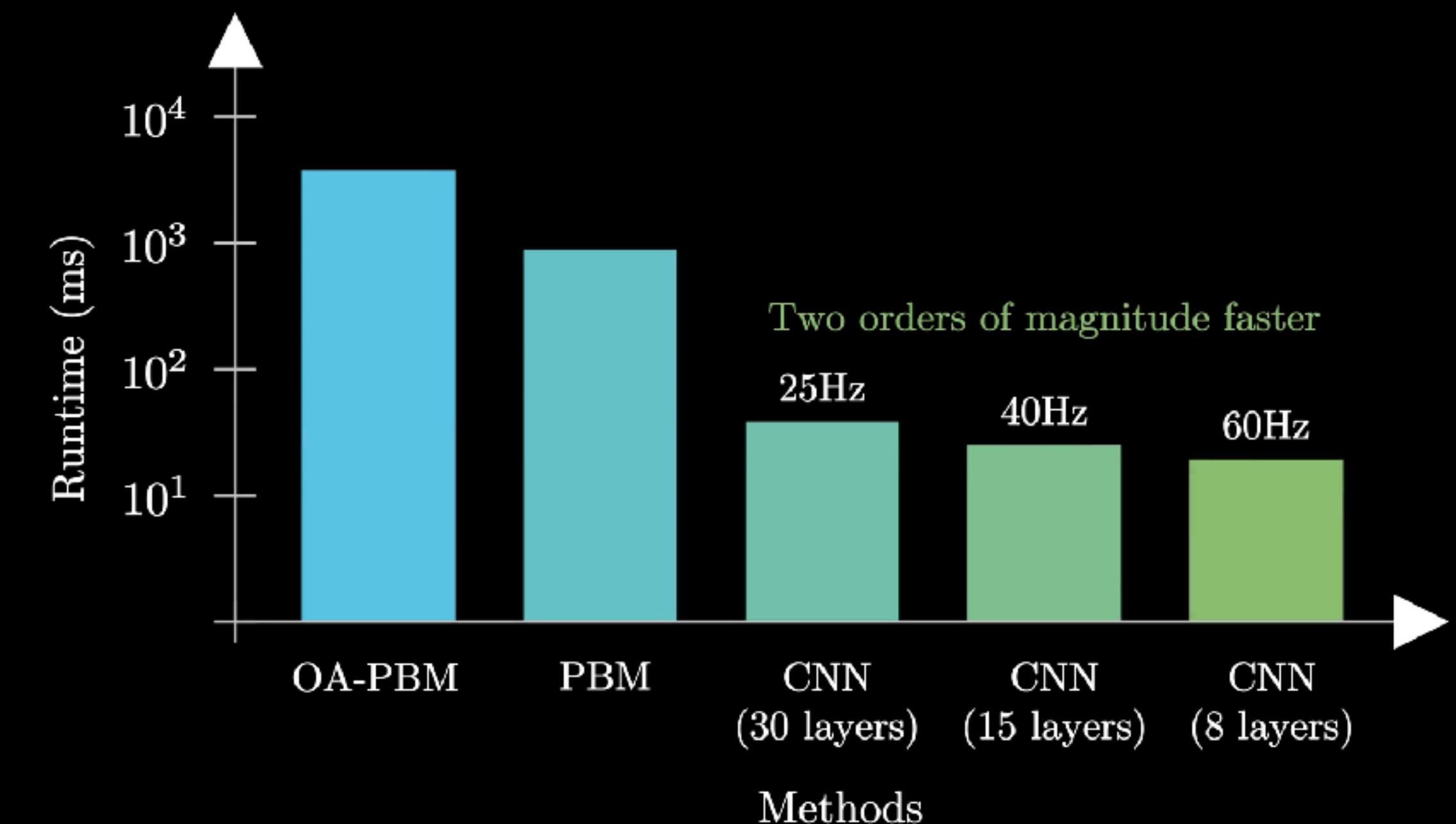
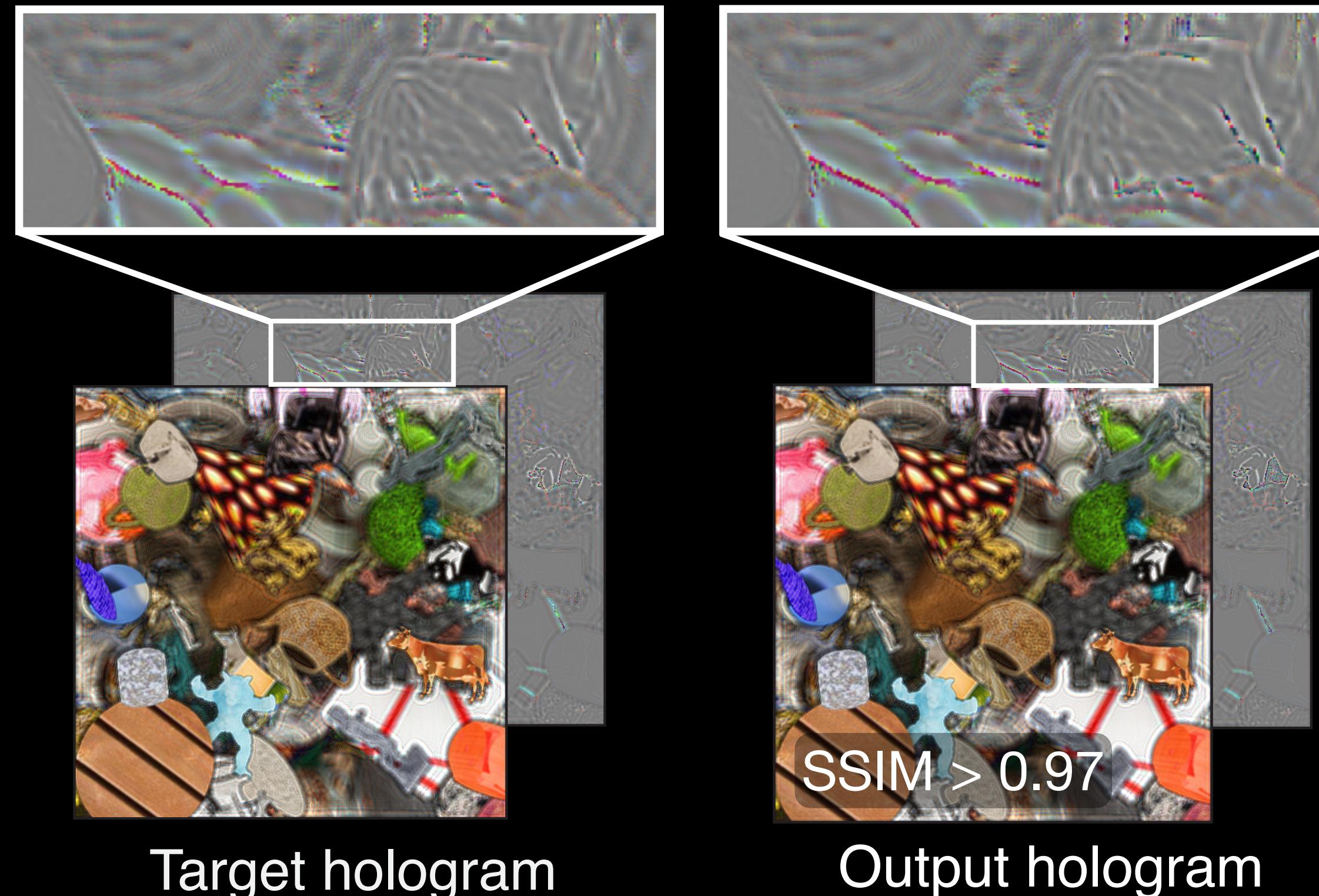
Training CNN for 3D Hologram Synthesis



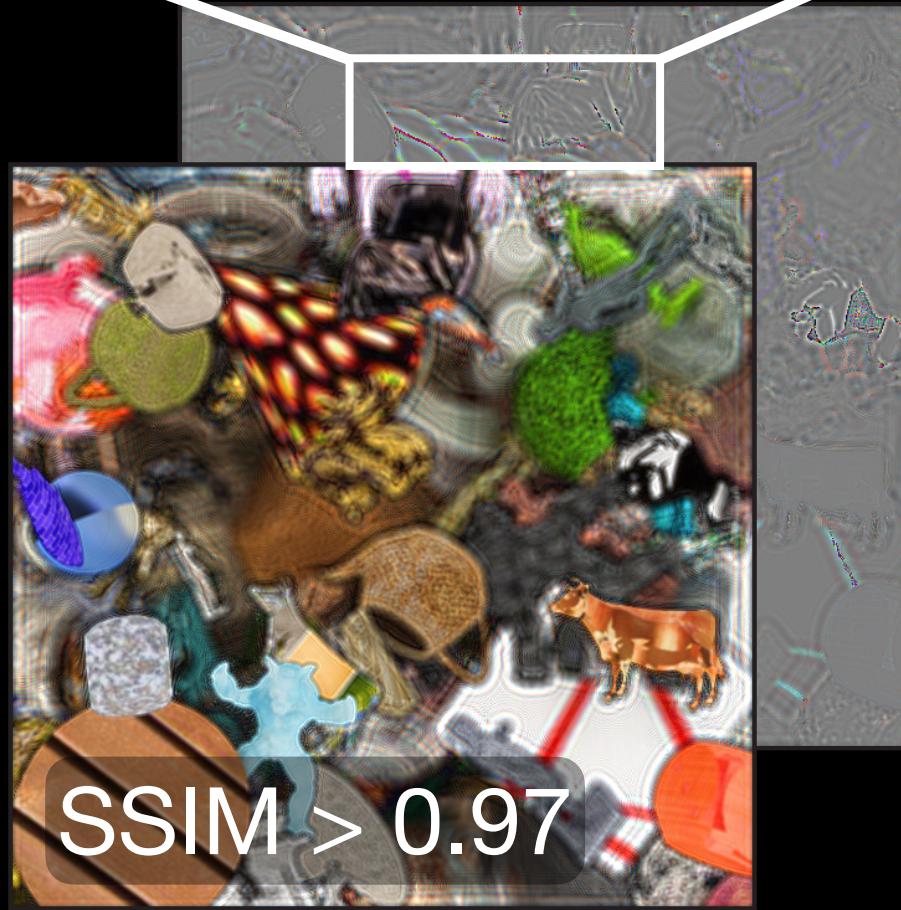
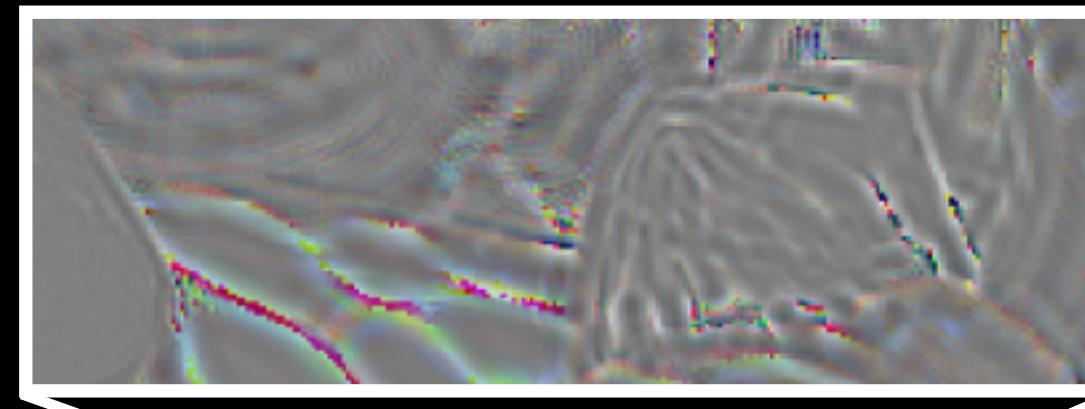
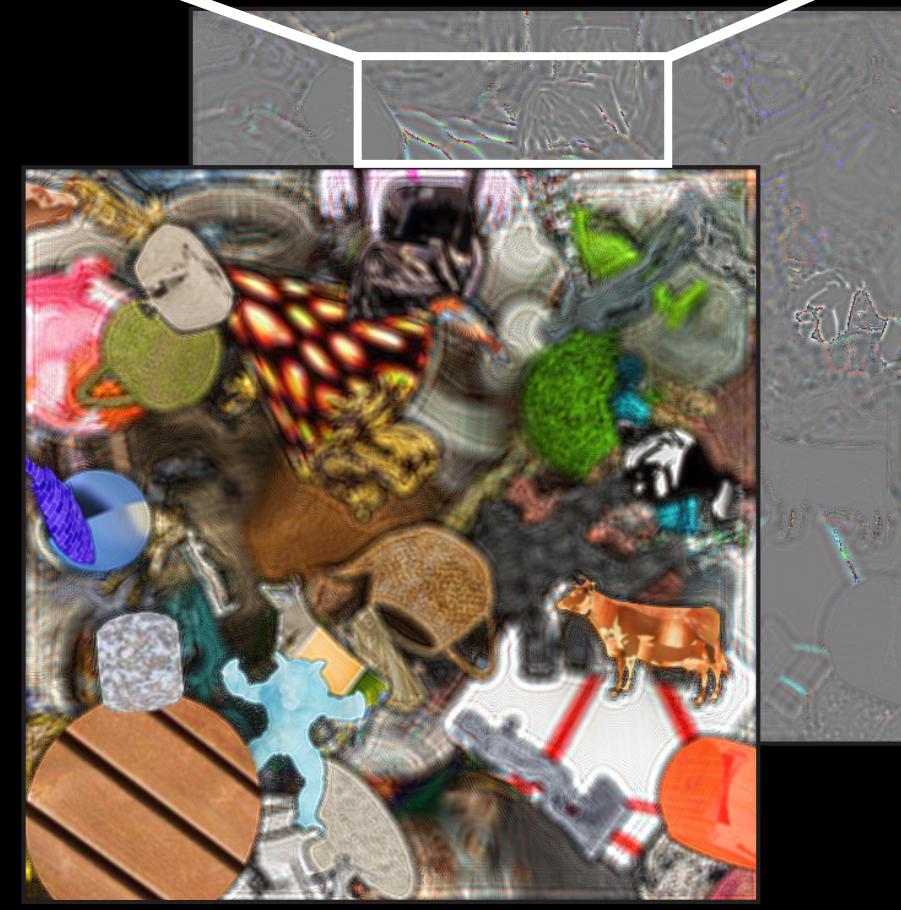
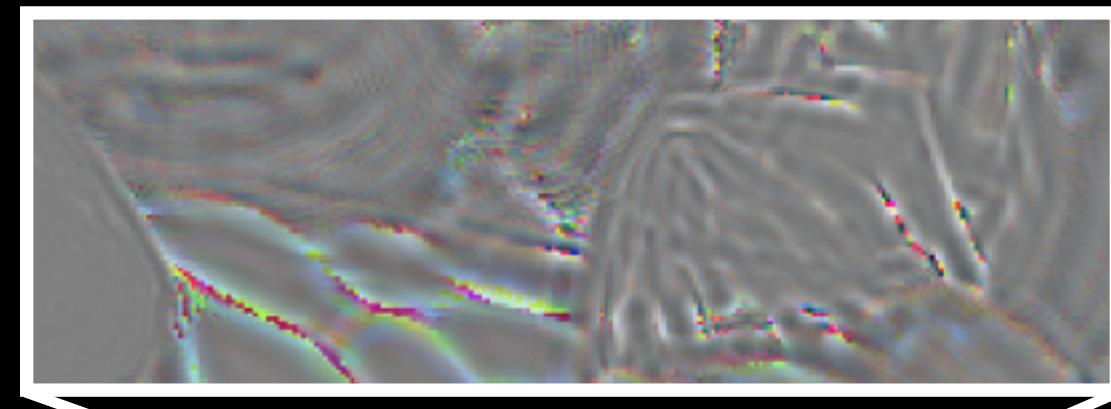
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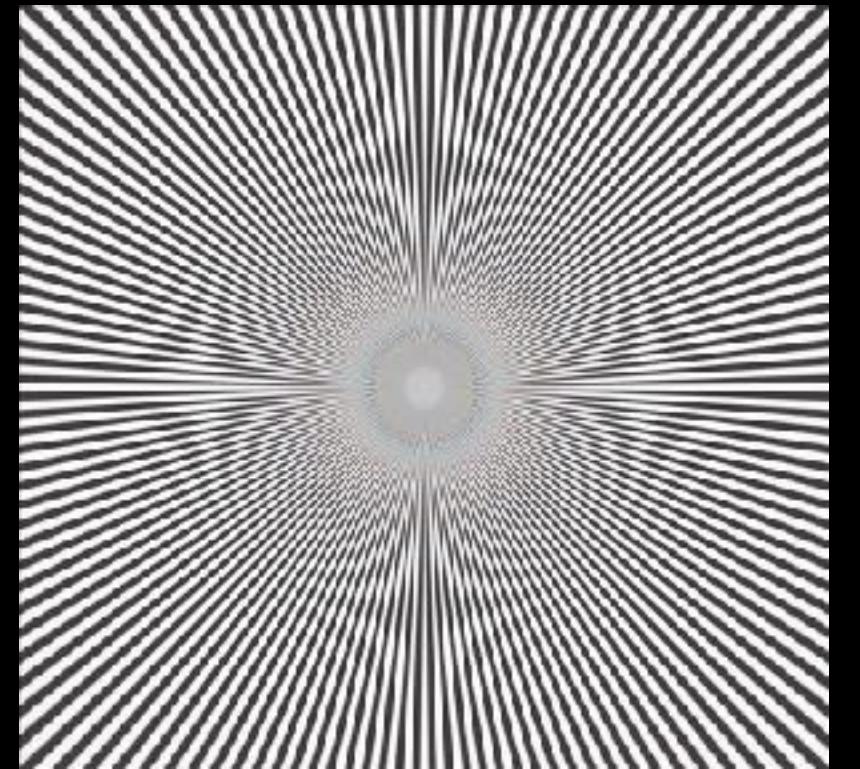


Training CNN for 3D Hologram Synthesis

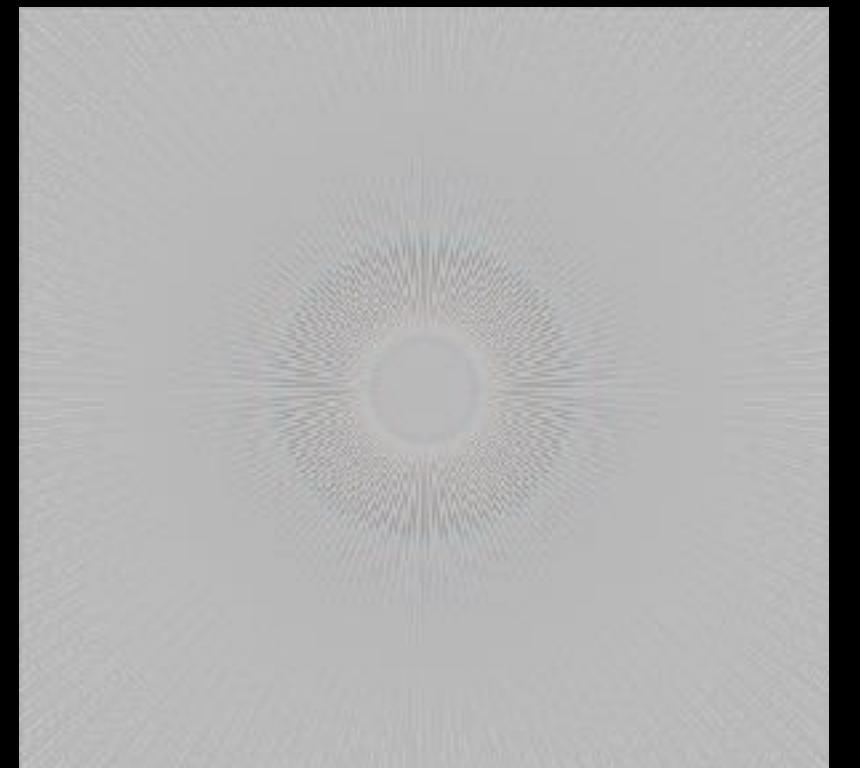




RGB-D image from the light fields dataset by Kim et al. [2013]



Amplitude



Phase



RGB

Depth

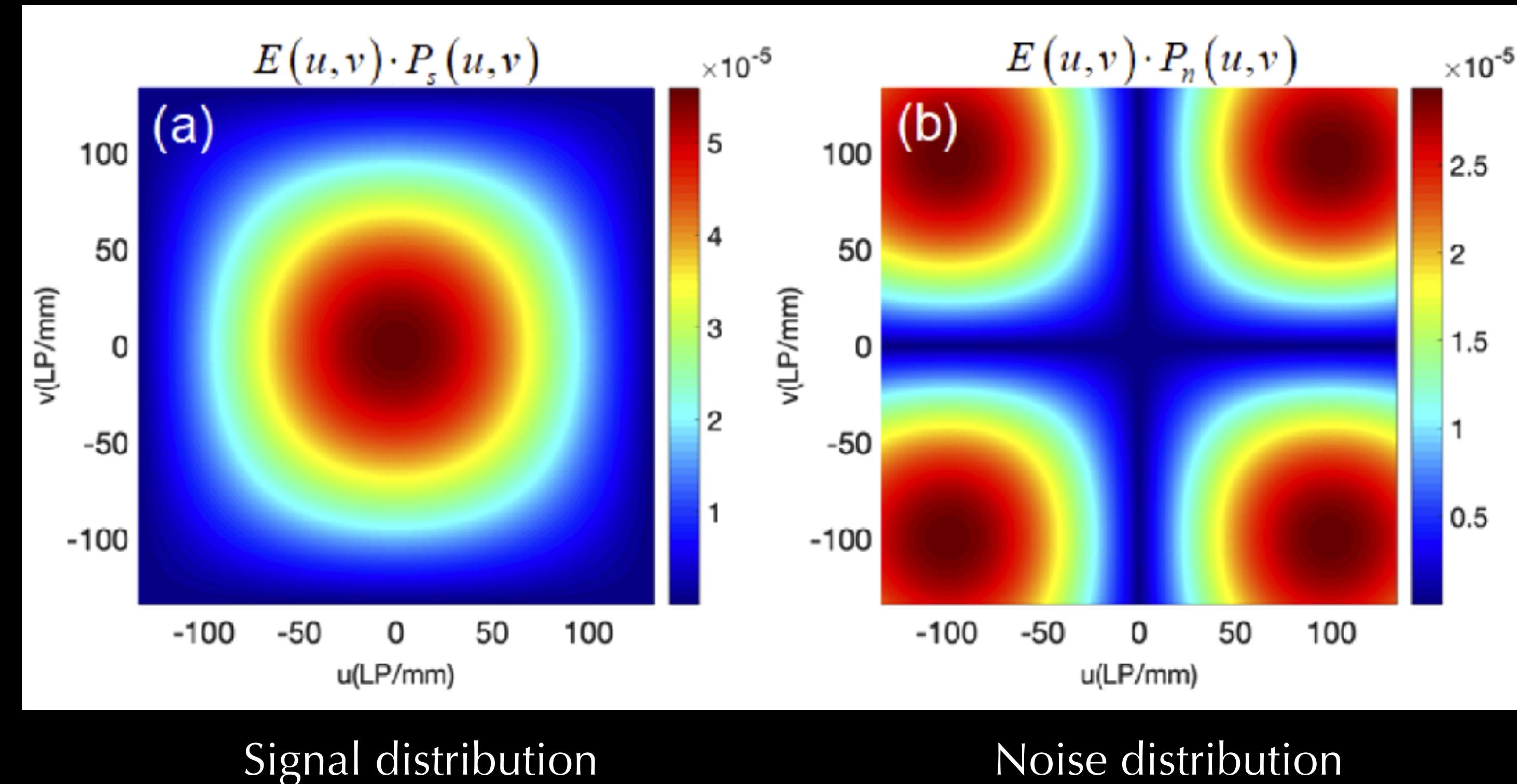


Non-robust phase-only encoding

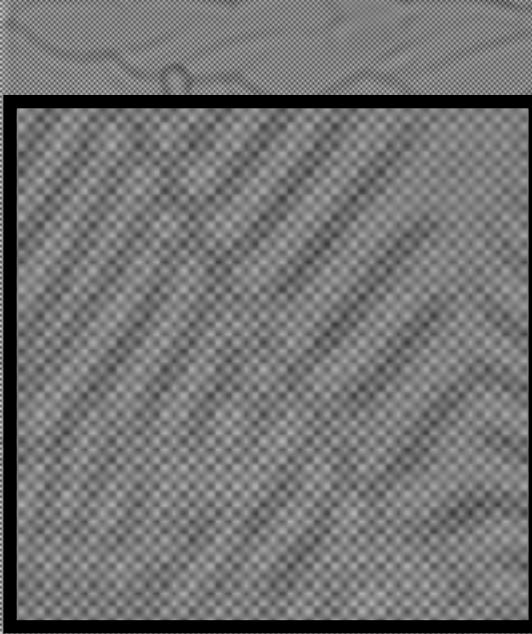
Double phase hologram



Theoretical Analysis of Double Phase Method

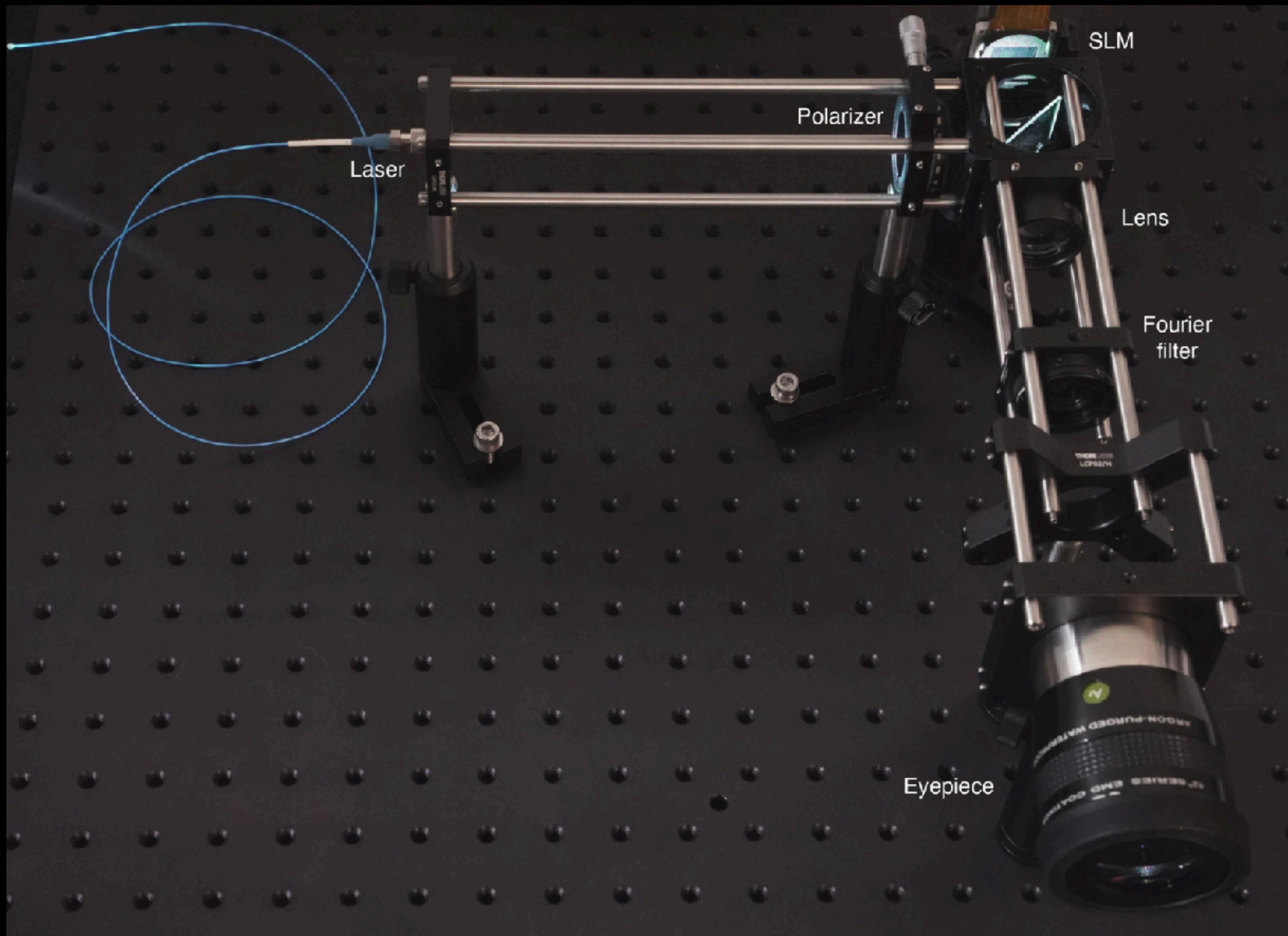


Anti-aliased double phase hologram

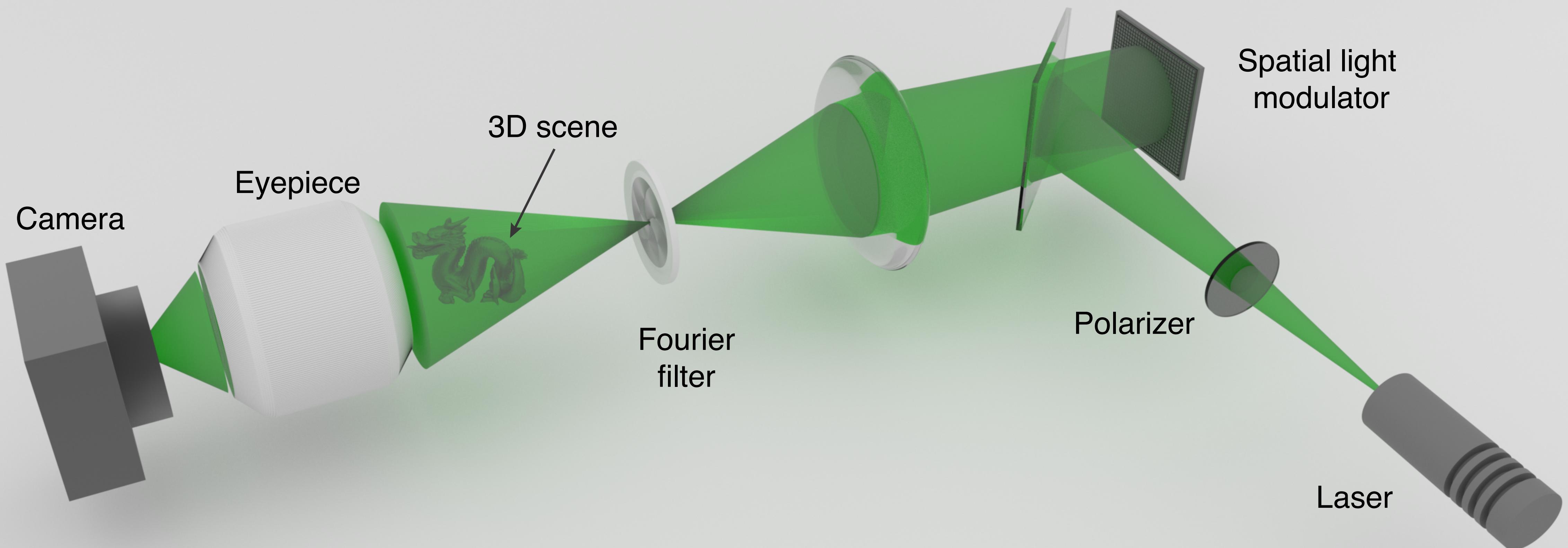


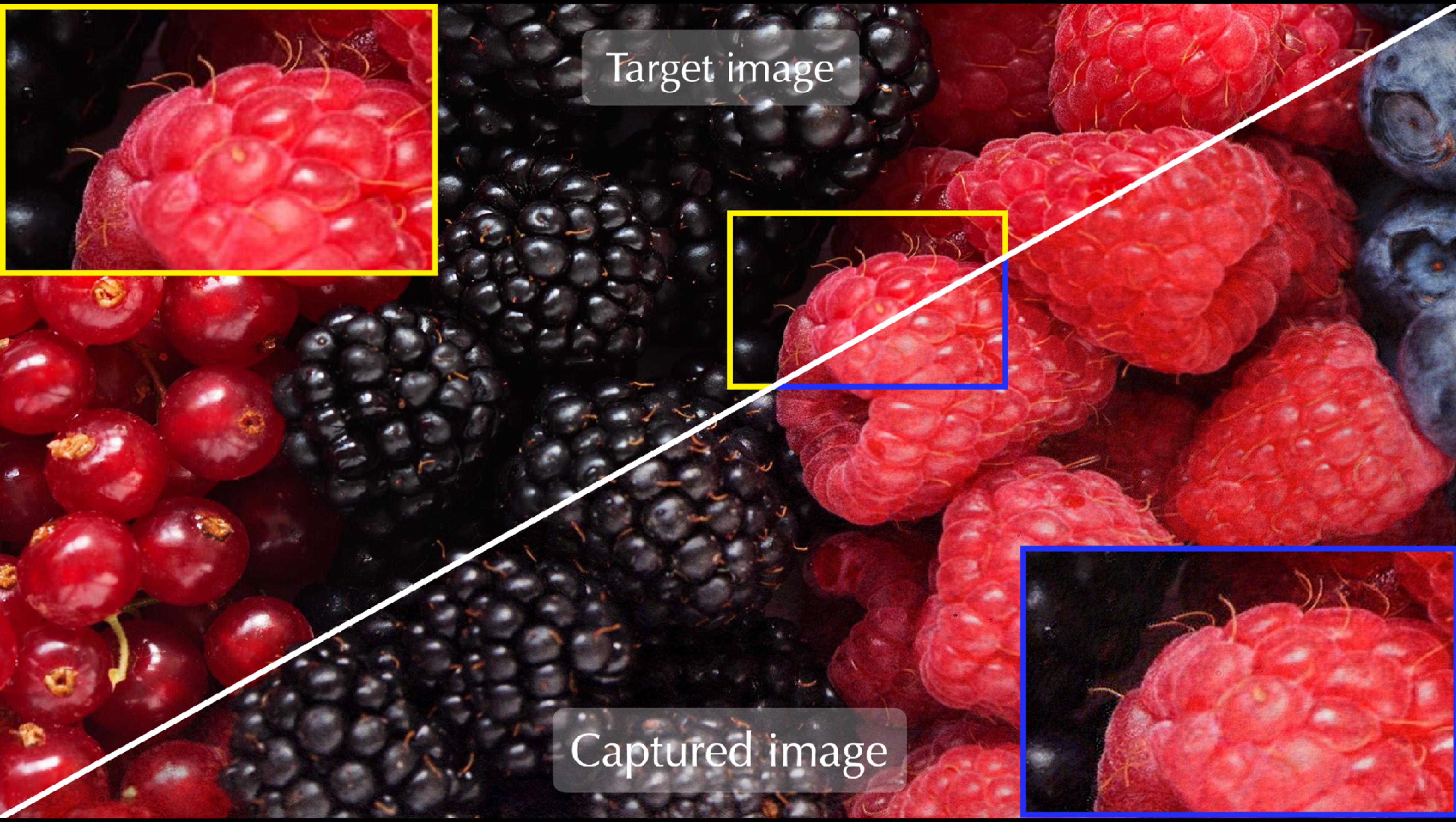


Hardware Prototype



Hardware Prototype



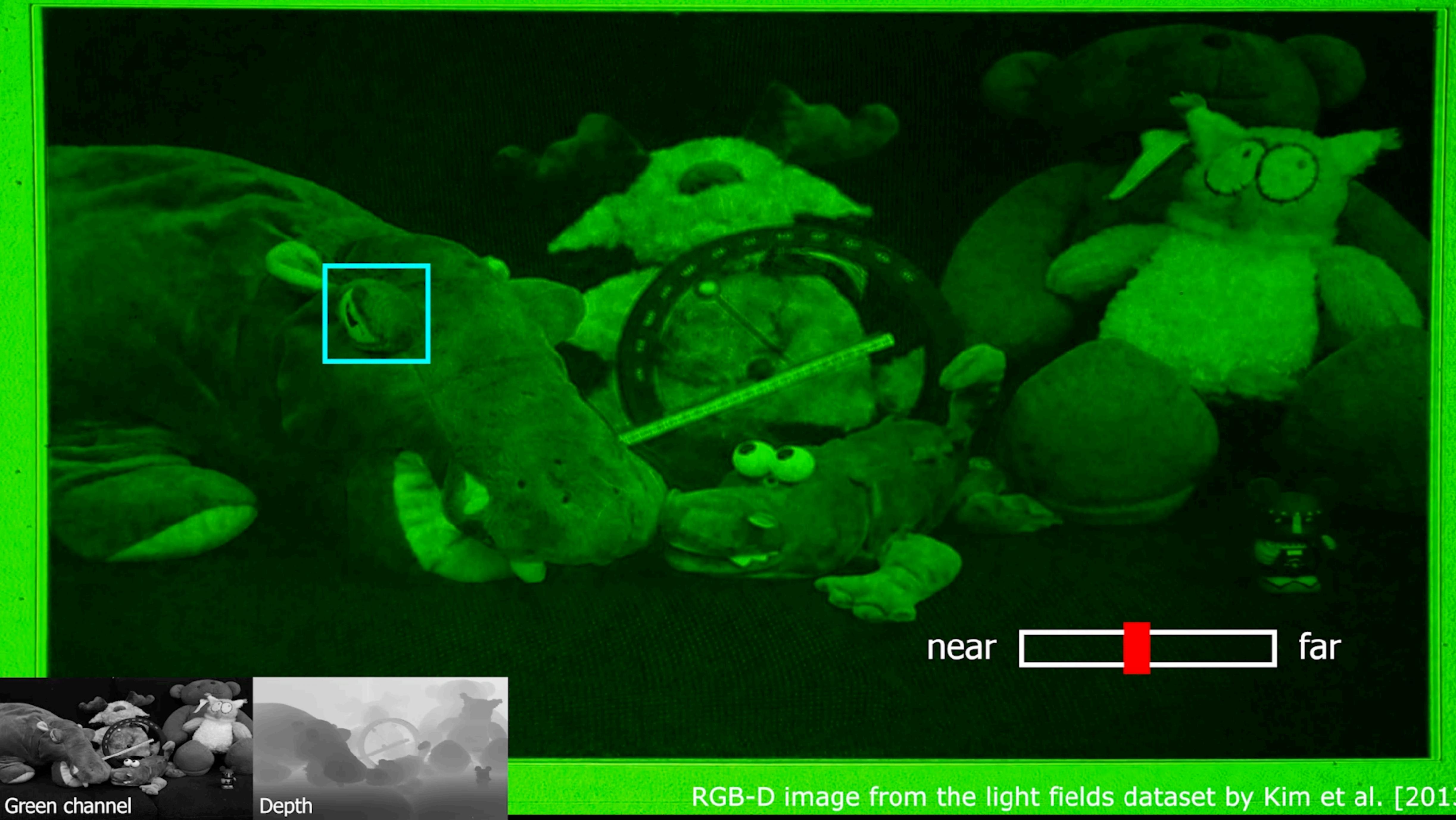


Target image

Captured image



Rear focus





Out-of-focus background



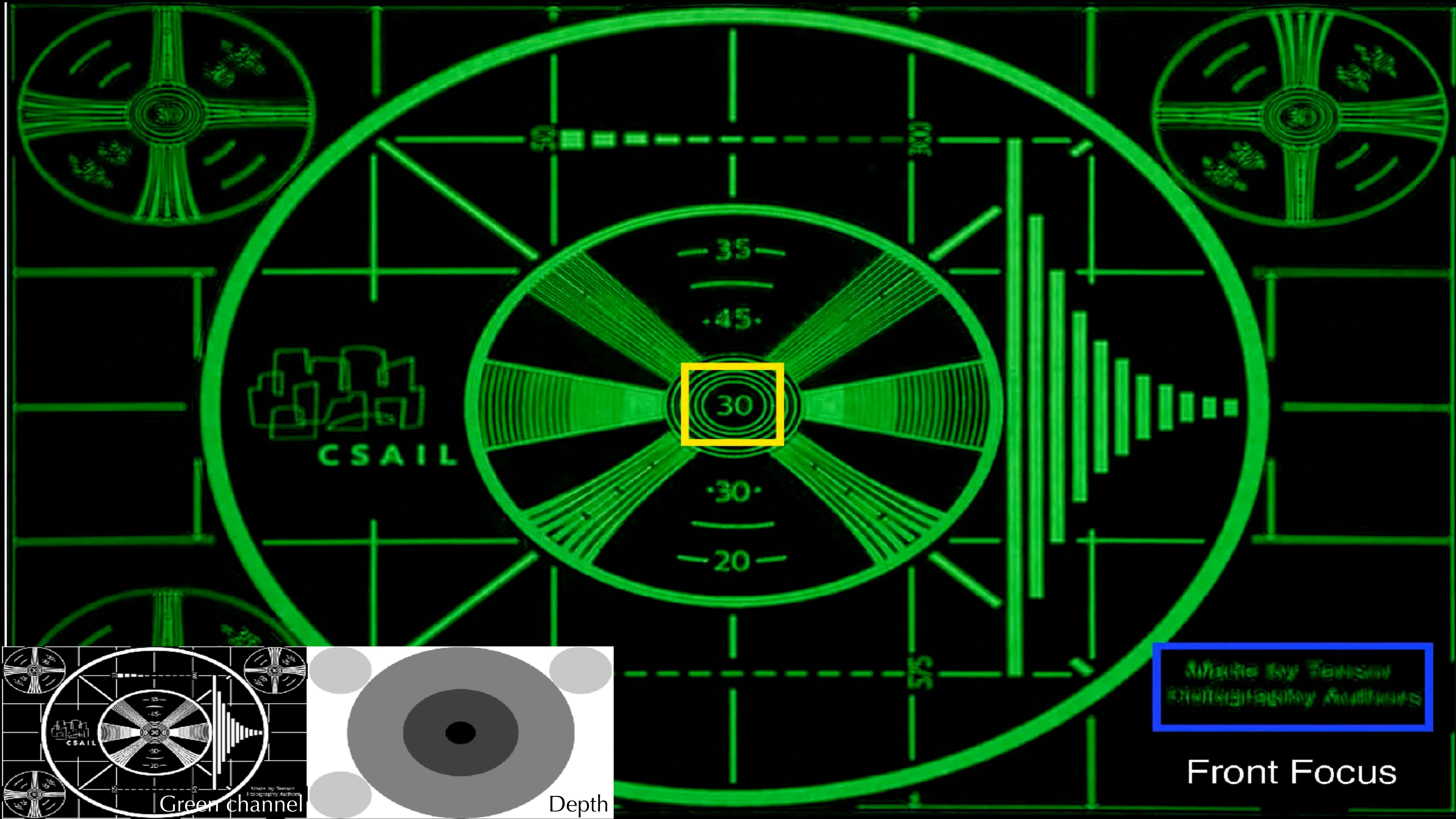
In-focus foreground



Depth

RGB

Video source from Big Buck Bunny © by Blender Fundation



Towards real-time photorealistic 3D holography with deep neural networks



Project website: cgh.csail.mit.edu

Liang Shi
Beichen Li
Changil Kim
Petr Kellnhofer
Wojciech Matusik

