Computer-generated Holograms and Diffractive Optical Elements

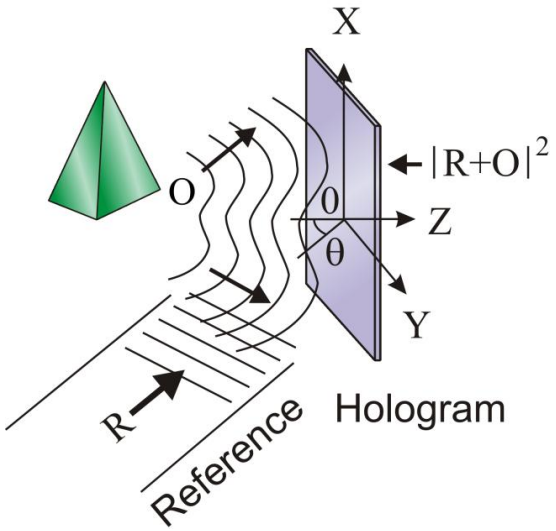
MICRO-373
Project Lecture 3

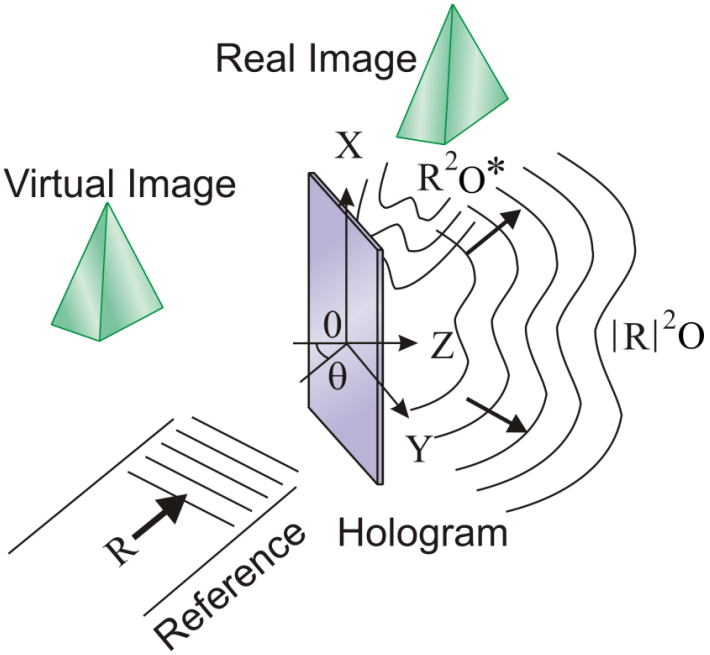
Ye Pu
27.02.2025

What is Holography?

- **Holography: recording** and **reconstruction** of **3D** images using interference and diffraction of light
- Essentially recording and reconstruction of **wave front**
- Holography vs photography
- Applications: data storage, security, anti-counterfeit, microscopy, metrology, medical imaging, augmented reality, …

Principle of Holography



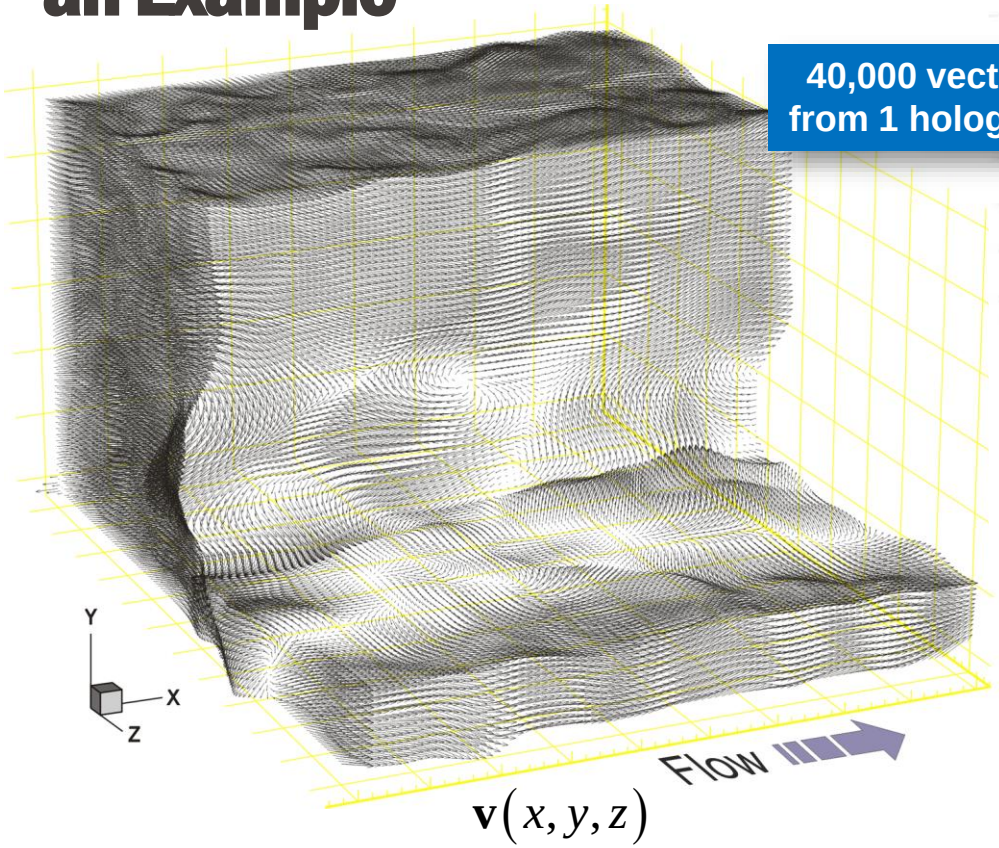


Recording Step $H = |R+O| = (R+O)(R+O)^* = |R|^2 + RO^* + R^*O + |O|^2$

Reconstruction Step $RH = R|R|^2 + R^2O^* + |R|^2 O + R|O|^2$

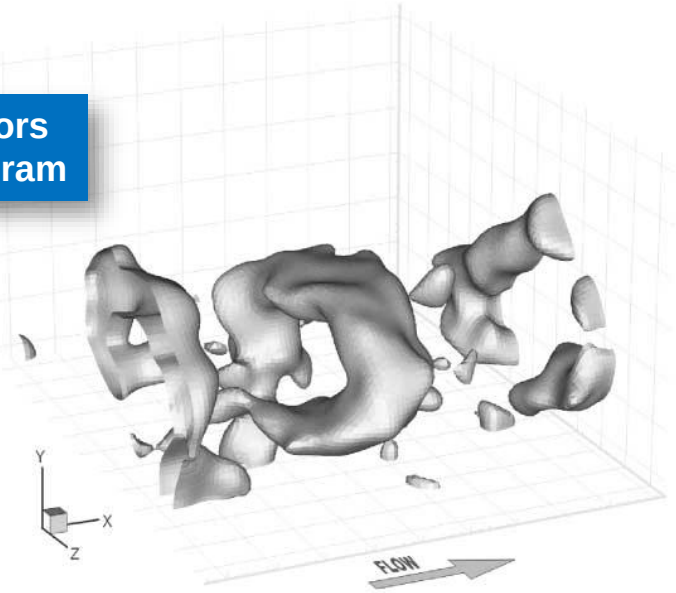
Alternatively $R^*H = R^*|R|^2 + |R|^2 O^* + (R^*)^2 O + R|O|^2$

Power of Holography: an Example



$\mathbf{v}(x, y, z)$

40,000 vectors from 1 hologram



$\nabla \times \mathbf{v}(x, y, z)$

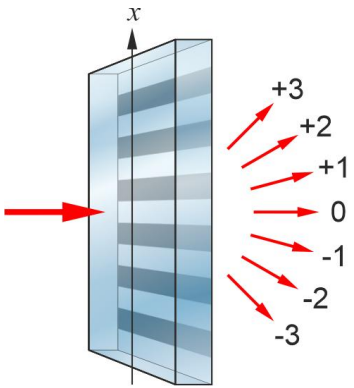
Isosurface

Computer-generated Holograms

- Algorithmic generation of holograms
  - Direct simulation of holographic process
  - Gerchberg–Saxton method
- 3D visualizations
  - Static
  - Dynamic
- **Challenge:** no device available for simultaneous amplitude and phase modulation

Amplitude vs Phase

$$\tilde{t}(x) = t(x)e^{i\varphi(x)}$$



$$t(x) = t_0 + \Delta t\,\mathrm{sgn}(\sin 2\pi x/d)$$

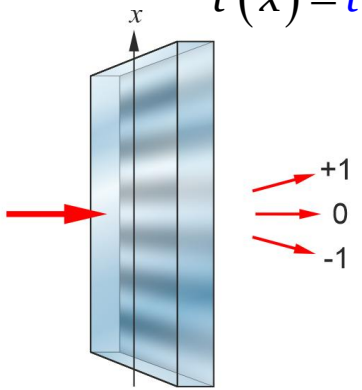
$$\Delta t \le t_0/2 \le 1$$

$$\eta_0 = t_0^2$$

$$\eta_{\pm 1} = \left(\frac{2\Delta t}{\pi}\right)^2 = 10.1\%_{\max}$$

$$\eta_m = \begin{cases} 0 & m \text{ even} \\ \dfrac{1}{m^2} & m \text{ odd} \end{cases}$$

$$\eta_{total} = \sum_{m}^{m\neq 0} \eta_m = \Delta t^2 = 24\%_{\max}$$



$$t(x) = t_0 + \Delta t \sin 2\pi x/d$$

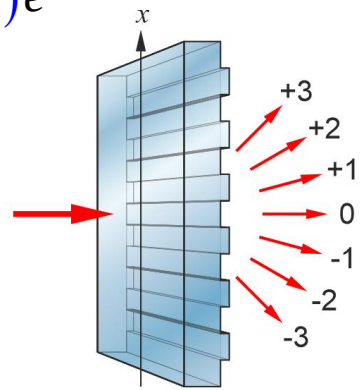
$$\Delta t \le t_0/2 \le 1$$

$$\eta_0 = t_0^2$$

$$\eta_{\pm 1} = \left(\frac{\Delta t}{2}\right)^2 = 6.25\%_{\max}$$

$$\eta_m = 0 \quad |m| > 1$$

$$\eta_{total} = \Delta t^2 = 12.5\%_{\max}$$



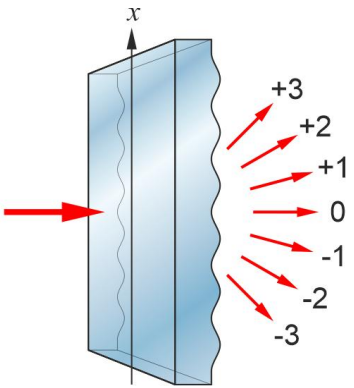
$$\varphi(x) = \varphi_0 + \Delta\varphi\,\mathrm{sgn}(\sin 2\pi\, x/d)$$

$$\eta_0 = \cos^2 \Delta\varphi$$

$$\eta_{\pm 1} = \left(\frac{2}{\pi}\sin \Delta\varphi\right)^2 = 40.5\%_{\max}$$

$$\eta_m = \begin{cases} 0 & m \text{ even} \\ \dfrac{1}{m^2}\eta_{+1} & m \text{ odd} \end{cases}$$

$$\eta_{total} = \sin^2 \Delta\varphi = 100\%_{\max}$$



$$\varphi(x) = \varphi_0 + \Delta\varphi \sin 2\pi\, x/d$$

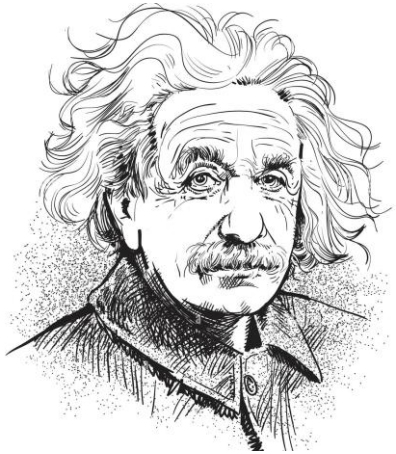
$$\eta_0 = J_0^2 \Delta\varphi$$

$$\eta_{\pm 1} = J_1^2 \Delta\varphi = 33.8\%_{\max}$$

$$\eta_m = J_m^2 \Delta\varphi$$

$$\eta_{total} = 1 - J_0^2 \Delta\varphi = 100\%_{\max}$$

Amplitude vs Phase

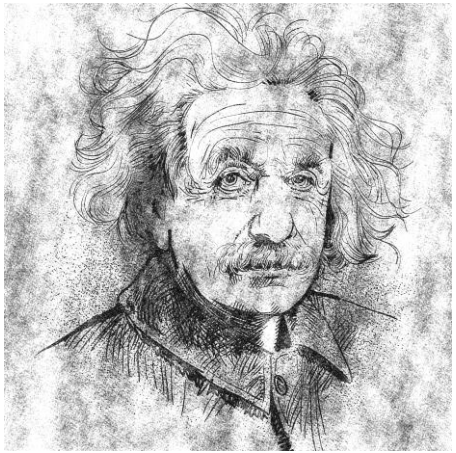


FT Amplitude

FT Phase

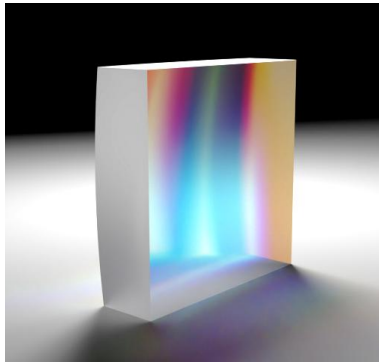
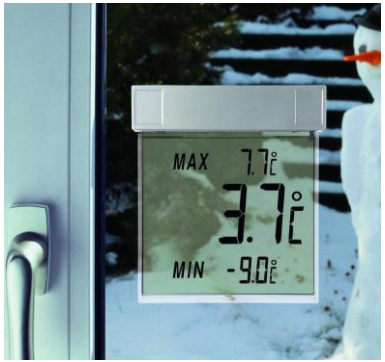
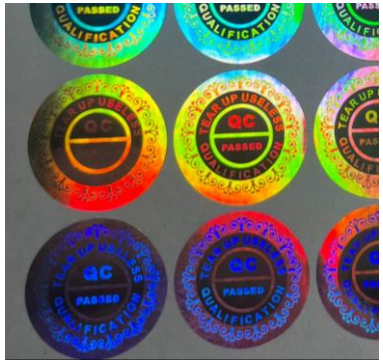
FT Phase

FT Amplitude



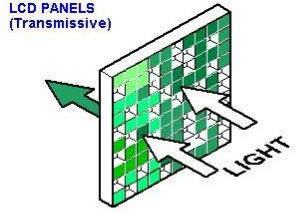
The Fourier phase is more important than Fourier amplitude in determining intensity spatial distribution

Spatial Modulation of Light

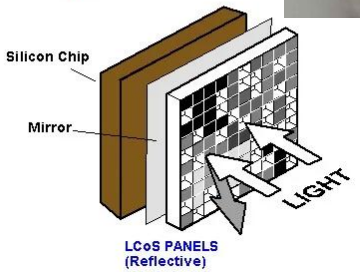
	Static (Amplitude/Phase Masks)		Dynamic (SLMs)	
	Amplitude	Phase	Amplitude	Phase
Transmission				
Reflection				

Spatial Light Modulators

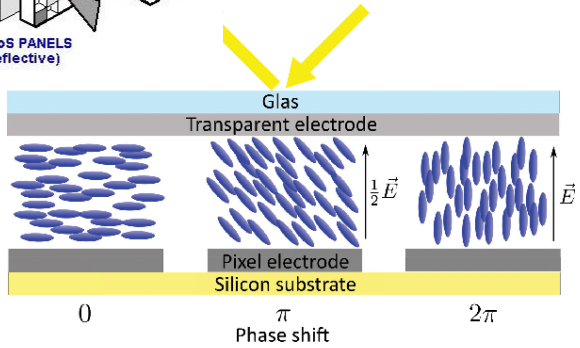
LCD



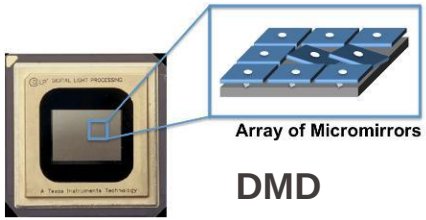
LCD TV



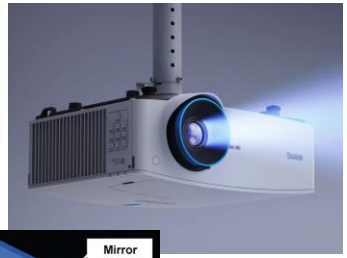
Continuous Amplitude or Phase



MEMS

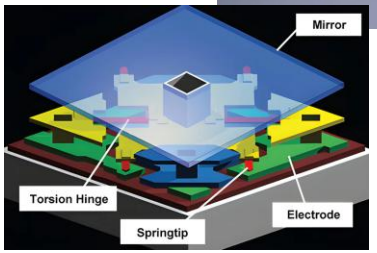


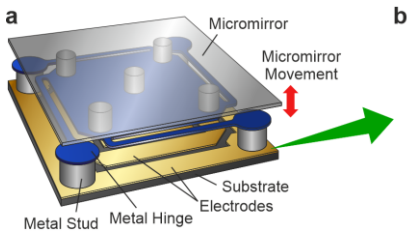
DMD

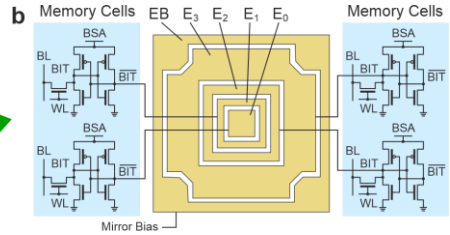


Projector

Binary Amplitude Only



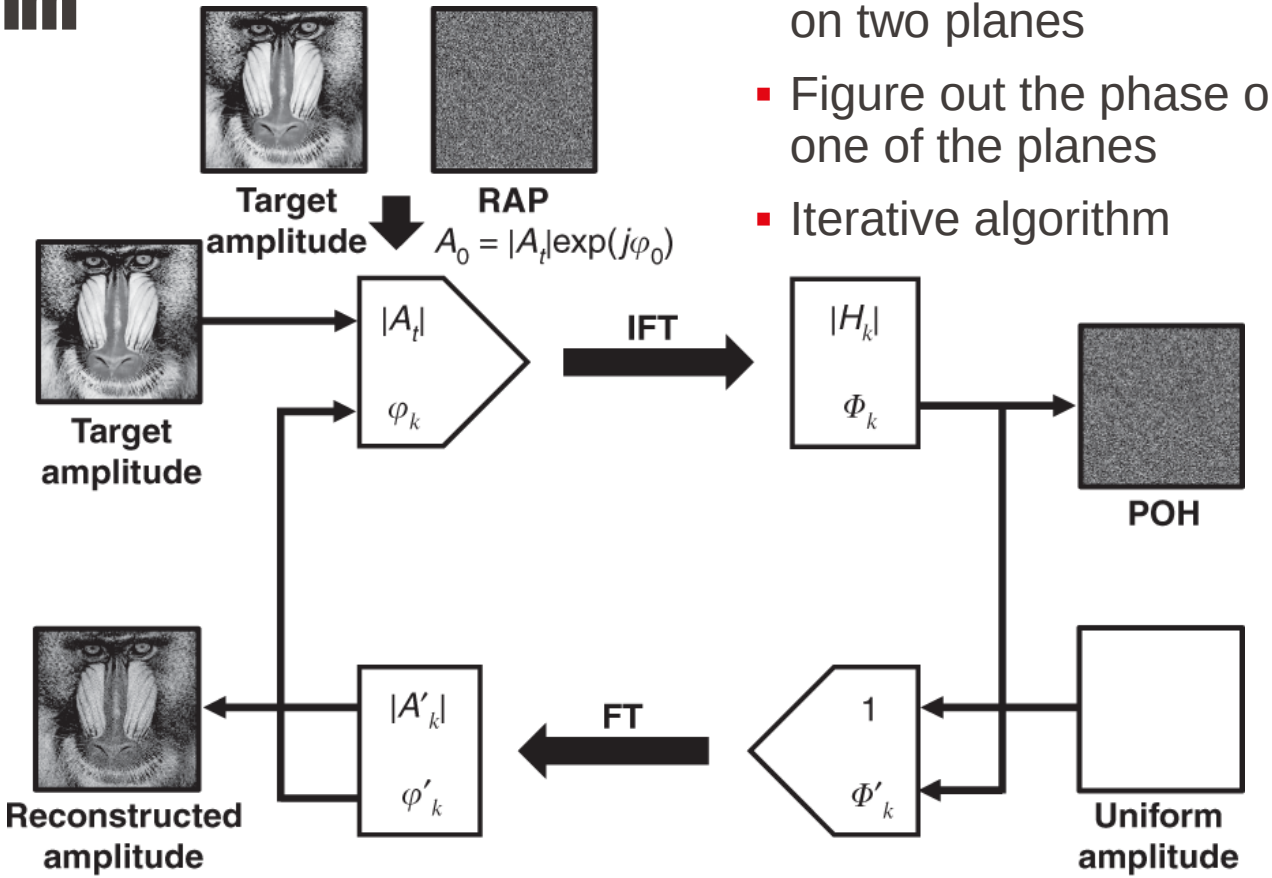




Phase Light Modulator

The Gerchberg–Saxton Algorithm

- Knowing Intensity patterns on two planes
- Figure out the phase on one of the planes
- Iterative algorithm




Thank You!
EPFL
#epflcampus