Holographic capturing and rendering systems, suitable holographic data representations

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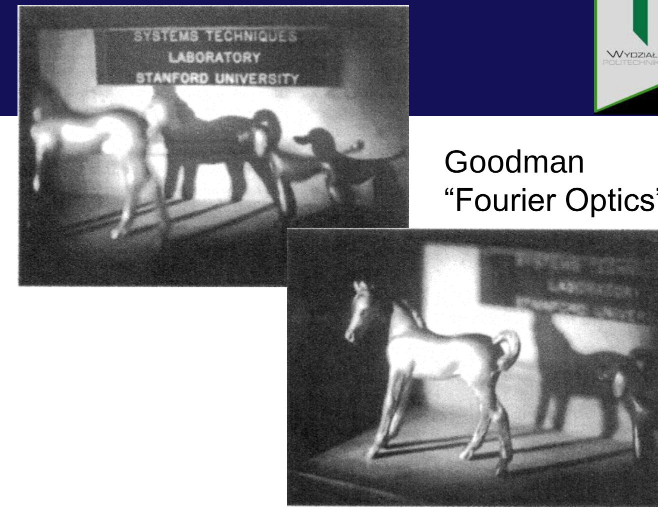
Introduction: Holography



Goodman
“Fourier Optics”

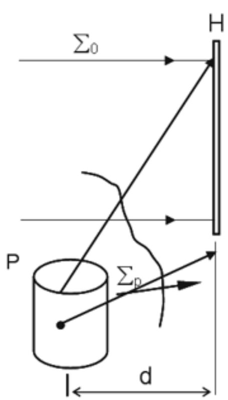
The two step method for lensless recording of 3D information about an object in the form of a complex amplitude

Object amplitude *Object phase*

$$A(x,y)= A_o(x,y)\exp(\Phi(x,y))$$

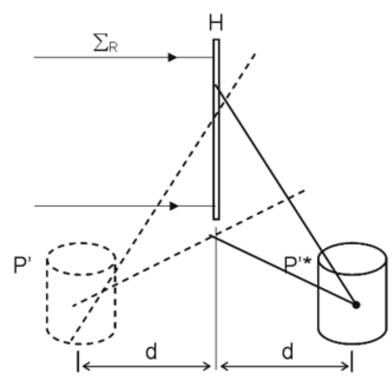
greek holos – whole (entire)
grapho – write (record)

Registration	Reconstruction



Interference

Hologram processing



Diffraction

Holography = True-3D: physical duplication of light distribution in a volume of interest

Optical versus digital holography

Optical holography (analogue proces) requires:
coherent (laser) light, high resolution recording material, chemical processing
in practise: 3000lines/mm, aperture of holograms - yycm x yycm

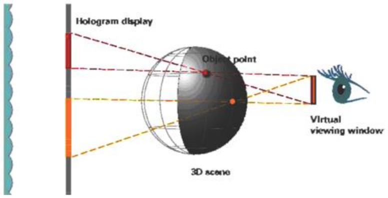
Digital holography requires:
Coherent light, high resolution and big aperture cameras and SLMs, numerical proc.
in practise: 100-200lines/mm, CCD matrix – 1/3”, 1/2”,

In consequence:
Digital holograms allows NOW to capture object/scenes with small angular size (2-4deg) i.e. small objects or objects situated far away.

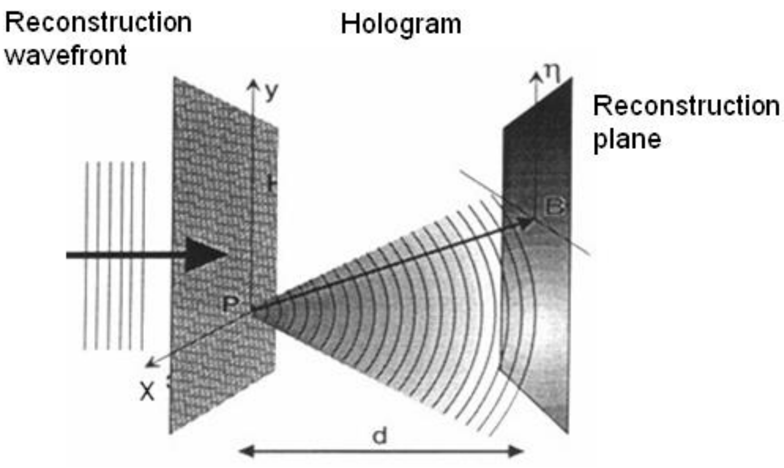
Applications:

Metrology of small objects:
Digital holographic microscopy
Holocameras/endoscopes

3D holographic displays:
Viewing window
Synthetic aperture



Numerical reconstruction of digital hologram



Example numerical reconstruction model:

- Diffraction of a plane wave on DH is given by Fresnel-Kirchoff integral.
- For small size of camera matrix versus the distance camera – object the complex wavefield atis given by Fresnel approximation :

$$U(m,n;d) = \exp\left[-i\frac{\pi}{\lambda d}\left(m^2\Delta\xi^2 + n^2\Delta\eta^2\right)\right]\sum_{k=0}^{M-1}\sum_{l=0}^{N-1} h(k,l) \times \exp\left[-i\frac{\pi}{\lambda d}\left(k^2\Delta x^2 + l^2\Delta y^2\right)\right]\exp\left[i2\pi\left(\frac{km}{M} + \frac{ln}{N}\right)\right]$$

h(k,l) – digital hologram (3D image)

Here we can also insert complex amplitude at hologram plane !!!!

Intensity at distance d:

$$I(\xi,n;d) = \mathrm{Re}^2\left[U(m,n;d)\right] + \mathrm{Im}^2\left[U(m,n;d)\right]$$

Phase at distance d:

$$\phi(\xi,\eta;d) = \arctan\frac{\mathrm{Im}\left[U(m,n;d)\right]}{\mathrm{Re}\left[U(m,n;d)\right]}$$

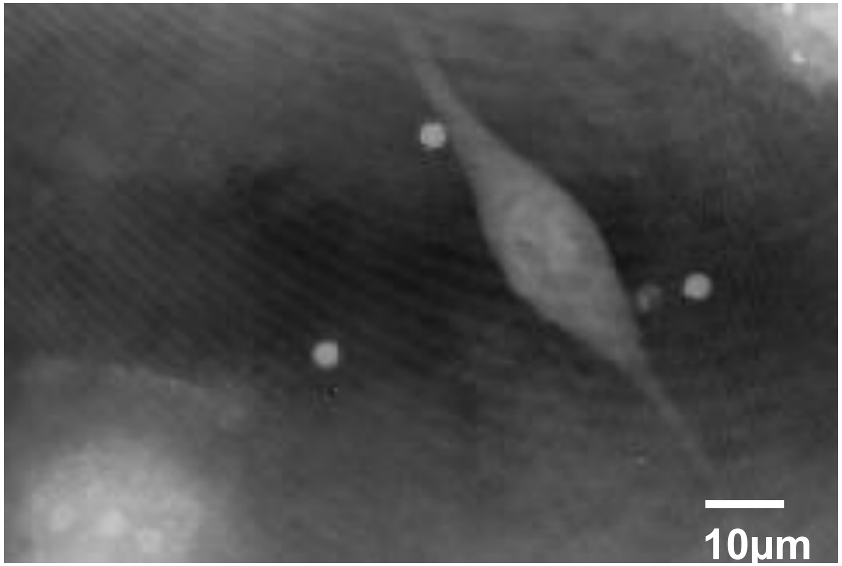
Input data (for single reconstruction) depending on the further processing:

- off-axis holograms (FTM):

a single hologram + intensity in object beam (no ref. beam) – 2 images

- on-axis hologram (phase shifting method):

a set of min 3 phase shifted holograms + intensity in object beam – min 4 images



Vizualization of phase changes (transparent cell)

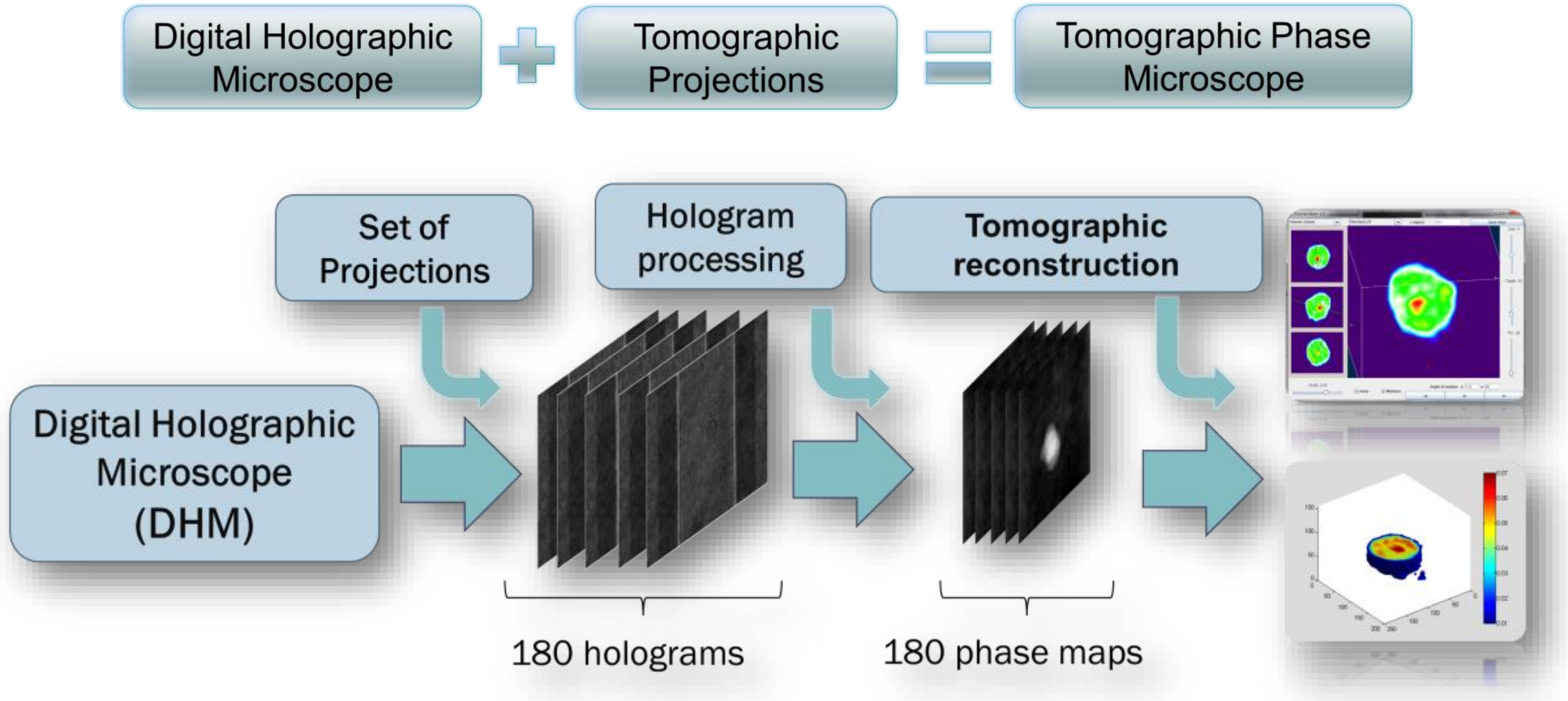
t_{max} = 17 h Δt = 3 min

Example: DHM phase contrast video of Chinese Hamster Ovary (CHO) cells during internalization of SiO_2 micro particles (∅ 3.44 µm)
B. Kemper (Munster Univ.)

Numerical reconstruction incl. defocusing and other manipulations:
1 step – calculation of complex amplitude at hologram plane
2 step – propagation to selected object plane, visualization of phase or intensity

Applications:

- Imaging 3D phase-amplitude objects with numerical focusing (DHM)
- Integrated phase measurement of the biological microobjects (DHM)
- 3D refractive index distribution measurement in biological microobjects (TPM)



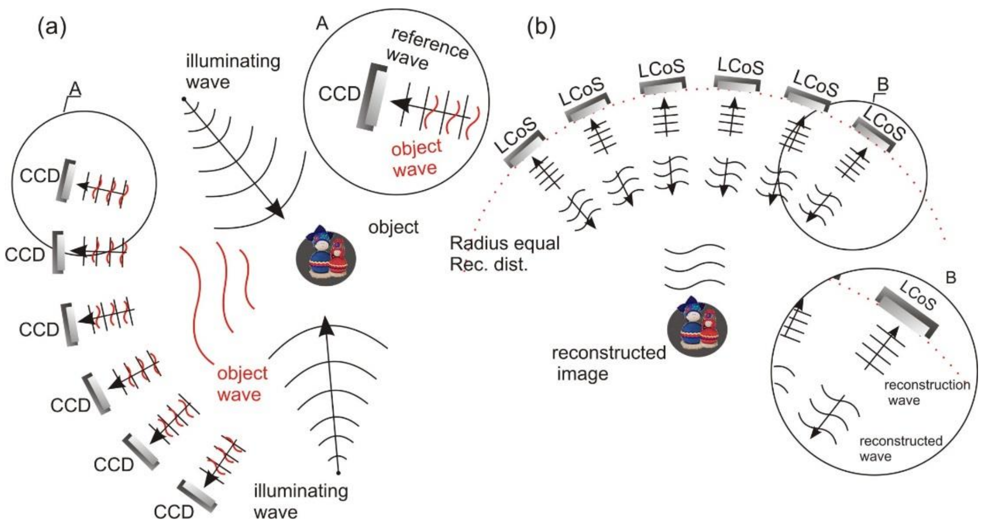
Fundamental challenge in holographic video

Goal:

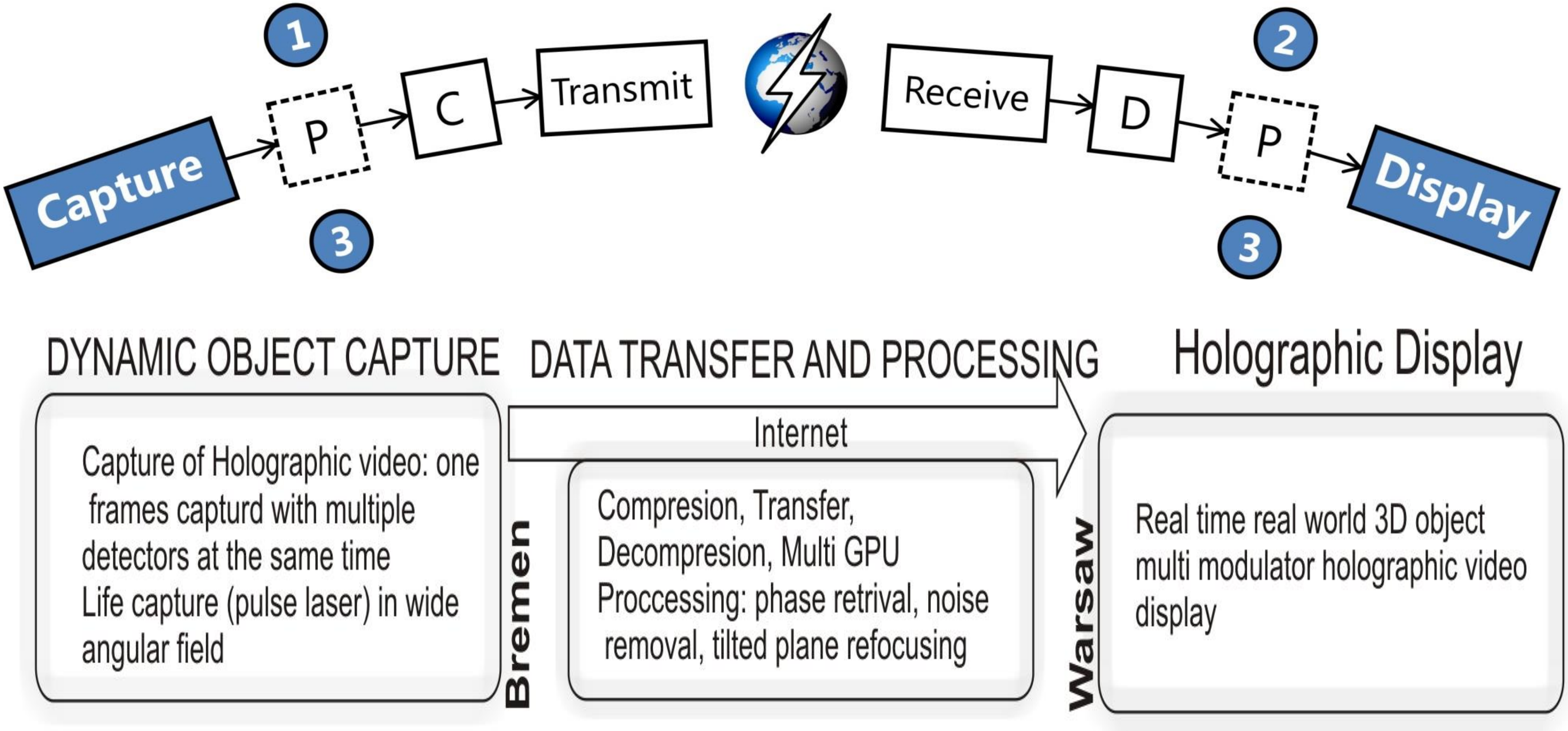
achieving a high enough space-bandwidth product of capture and display systems to meet the image size and view angle requirements for the viewer.

- a large view angle is possible only with very high frequency interference fringes (and thus small pixels),
- a large image translates to a large aperture of CCD and light modulator

Therefore what’s necessary is a massive number of very small pixels at both capture and display side.

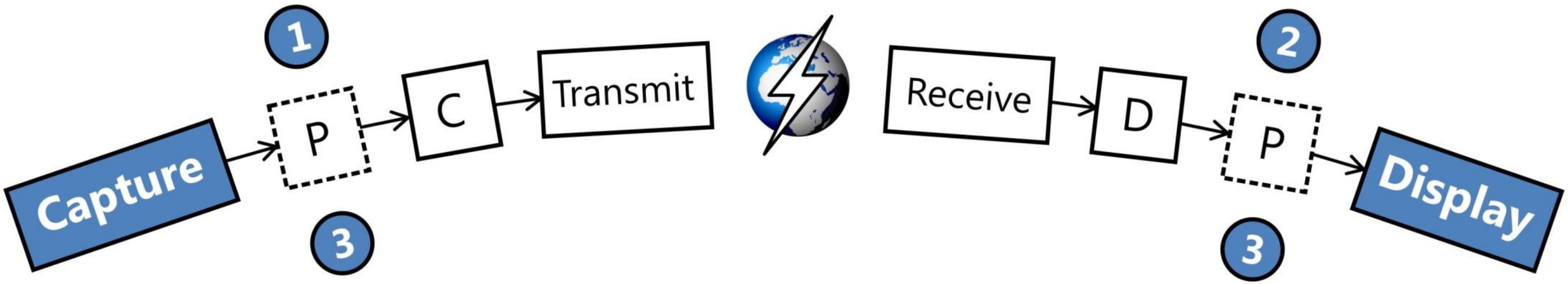


Concept of DH video technology chain



M. Kujawinska et al. "Multiwavefront digital holographic television," Opt. Express 22, 2324-2336 (2014)

Location of processing module versus compression method

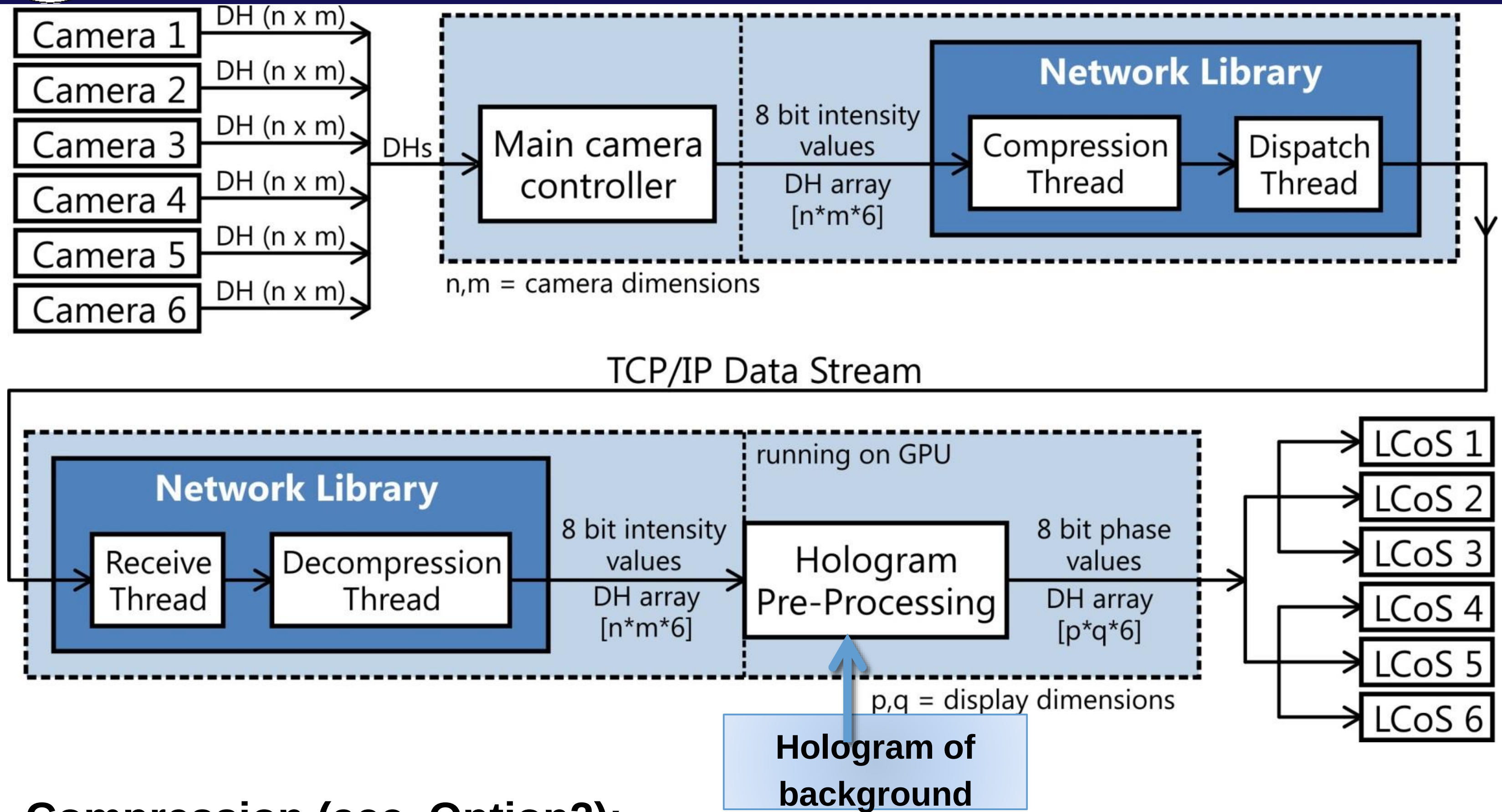


(1) allows a simpler display side architecture, facilitates the efficiency that only the real-valued phase data will be transmitted rather than the larger corpus of raw hologram data. The full details of the display architecture needs to be known *a priori*.

(2) allows **decoupling of the capture and display**, so that several different display technologies could use the same capture side. Additionally conventional coding/ compression algorithms can be applied for intensity data.

(3) finds a compromise, e.g. performing twin removal and noise reduction on the capture side and display-specific processing on the display side, but may require the overhead of transmitting complex valued wavefront data.

General concept of 4D video technology chain based on holographic capture

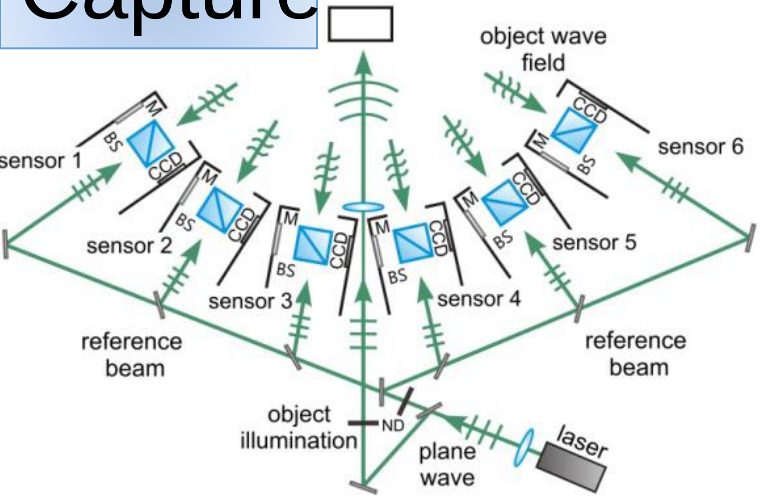


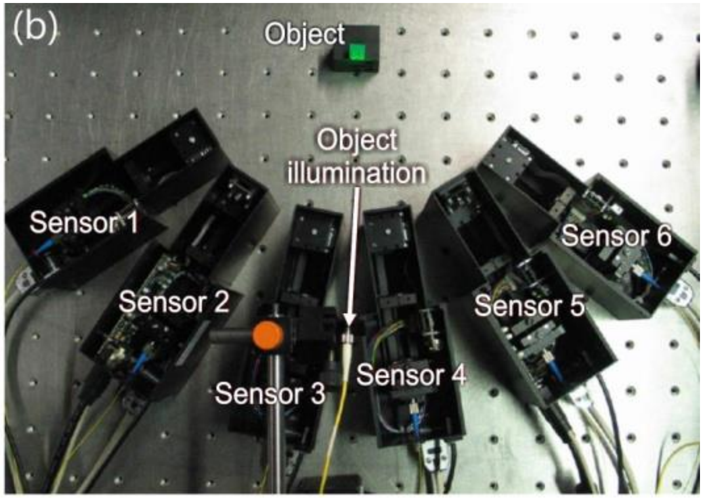
Compression (acc. Option2):

- effected by a QoS (quality of service) algorithm incl. removing blocks of pixels at the edges of the holograms, uniformly quantizing the remaining pixels from 8-bits to lower value
- applying JPEG-LS lossless standard for continuous-tone images (take advantage of two-dimensional spatial redundancy).

Capture and display systems architecture

Capture

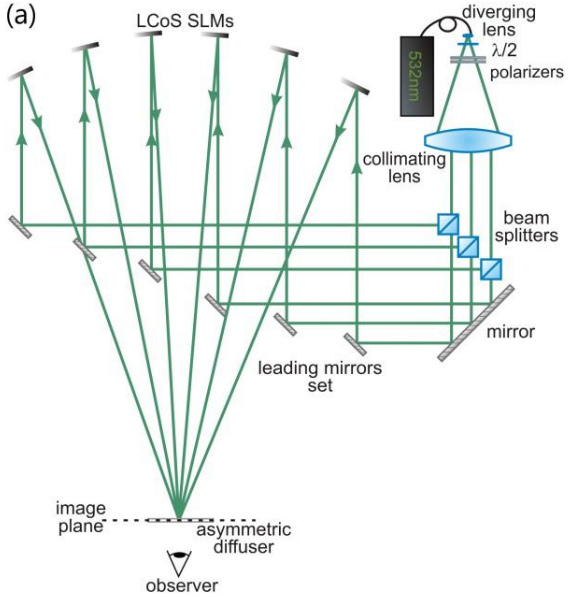


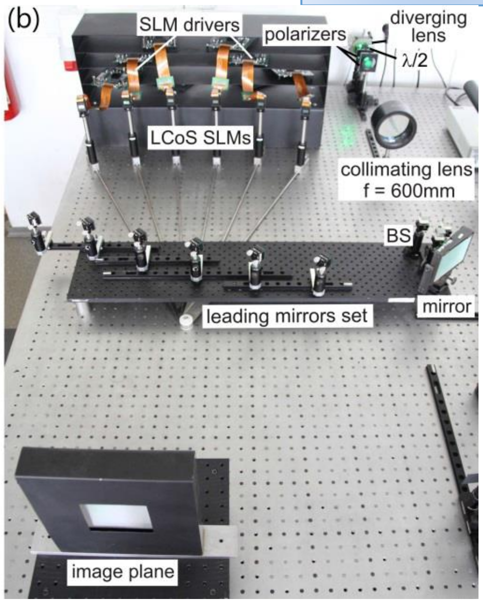


Display

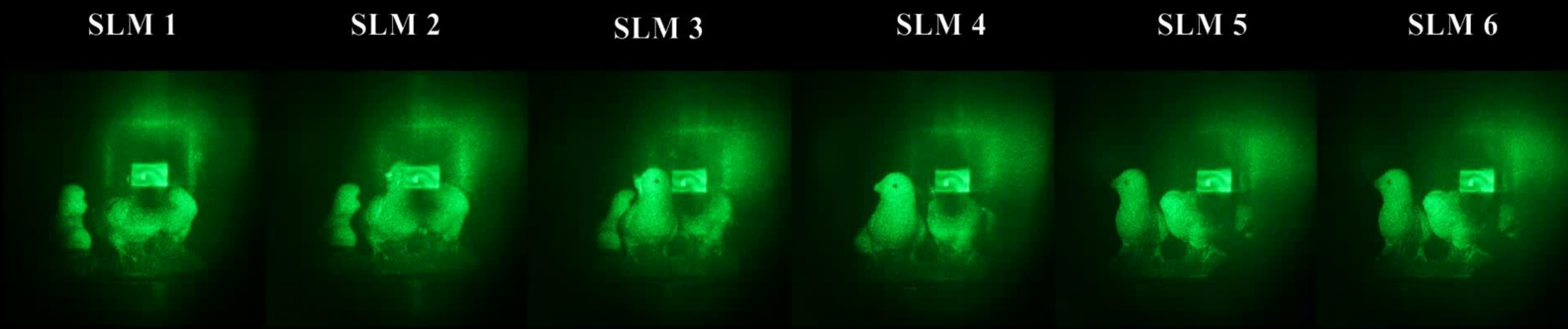
Source : impulse laser 6ns
Small fill factor of captured field

Adding spatio-temporal multiplexing for capture and display required



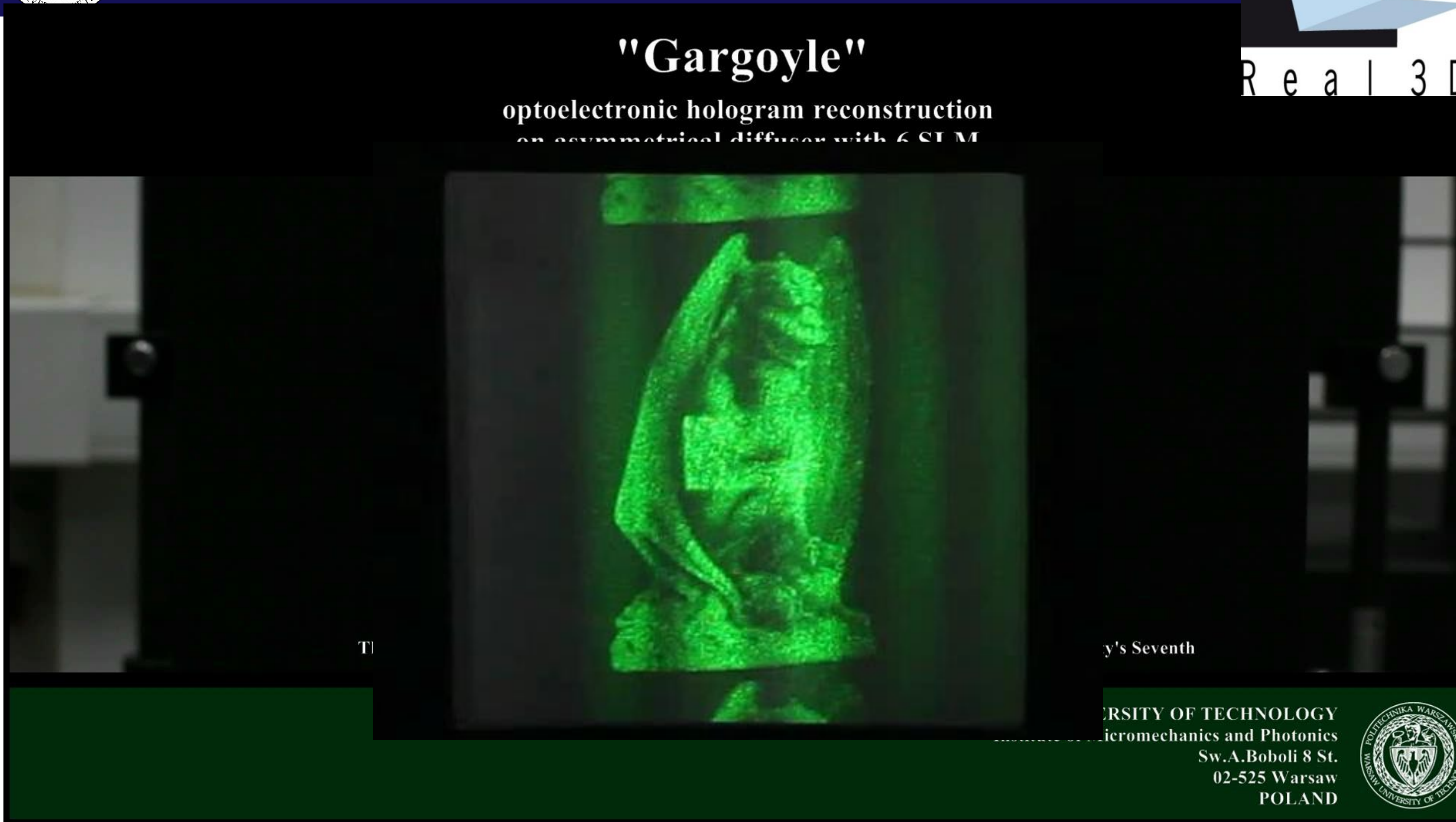


Video reconstruction



Hologram capture: BIAS, Germany
Optoelectronic reconstruction: WUT, Poland

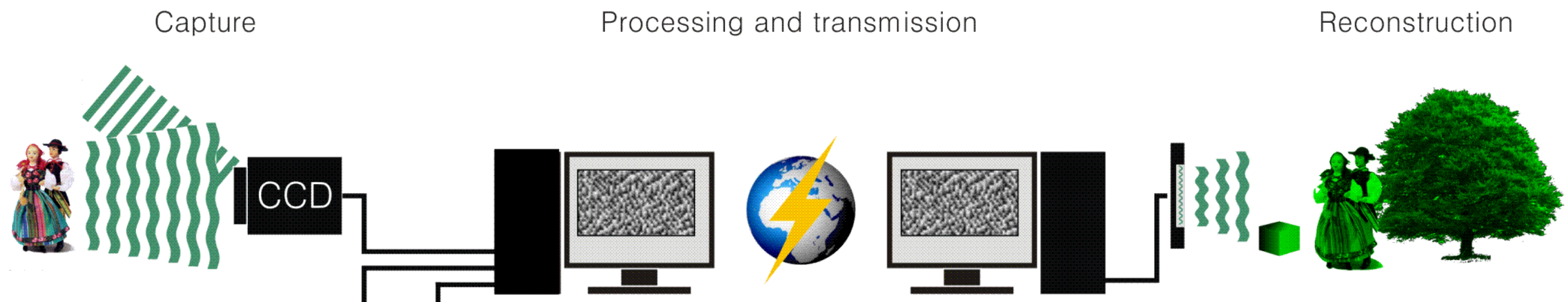
Multiplexing methods for wide angle holographic display



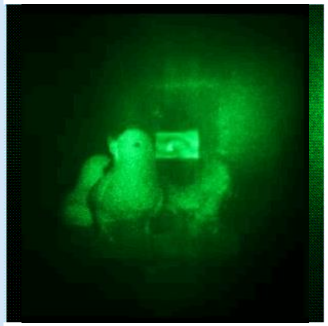
Need: Viewing angle increase

Remove gaps in reconstructed image

Holographic video technology chain



As part of 7FP EU project **Real3D** (2008-2011) the first holographic video transmission in real time between Bremen (capture) and Warsaw (display) was performed. **HoloTrue3D** significantly extends these works.

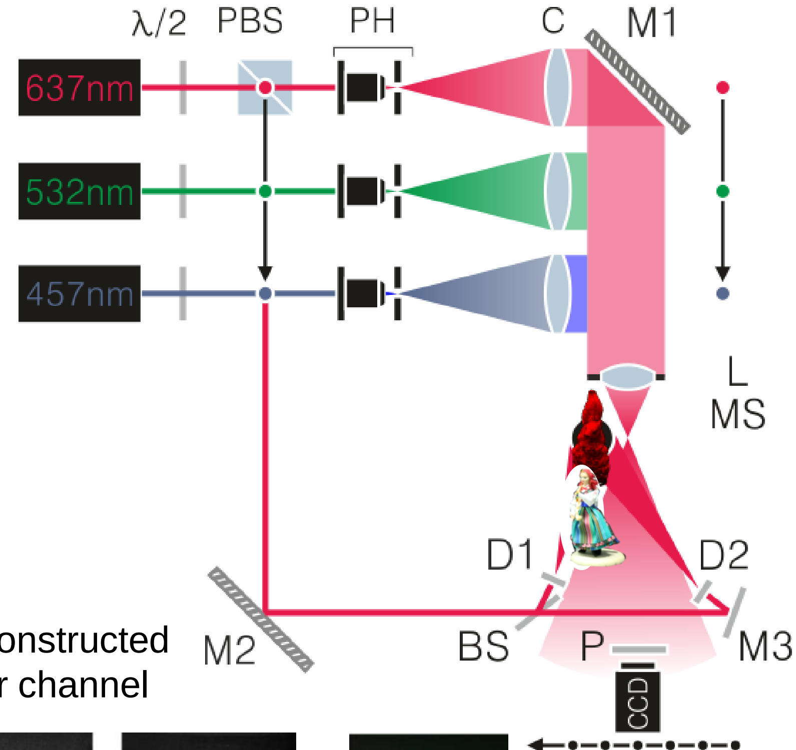


- Photorealistic color holographic content capture
- Other sources of holographic content
- Full decoupling between capture and display through creating a general holographic format

Holographic photorealistic content capture

Holographic data acquisition of high resolution (73 Mpx) color, **synthetic aperture** Fourier holograms

- Bigger size of an object (up to 140mm)
- Higher resolution, color
- Wide viewing angle (20deg)



However:

- 3 RGB holograms large size holograms
- Different capture and display configuration ↓

Proc. Fourier into Fresnel hologram

- Corrections of magnifications and aberration due to RGB

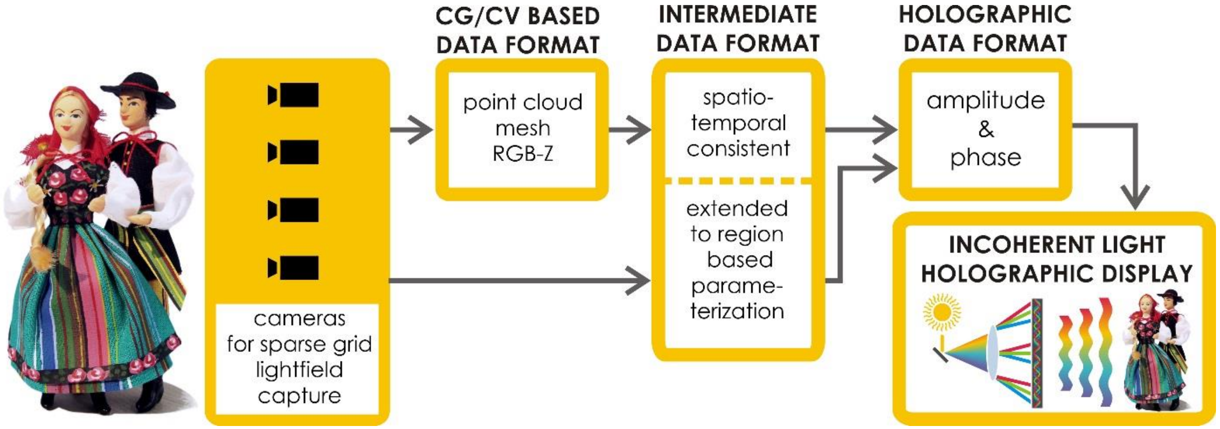
Holograms reconstructed for each color channel

Combined reconstructions

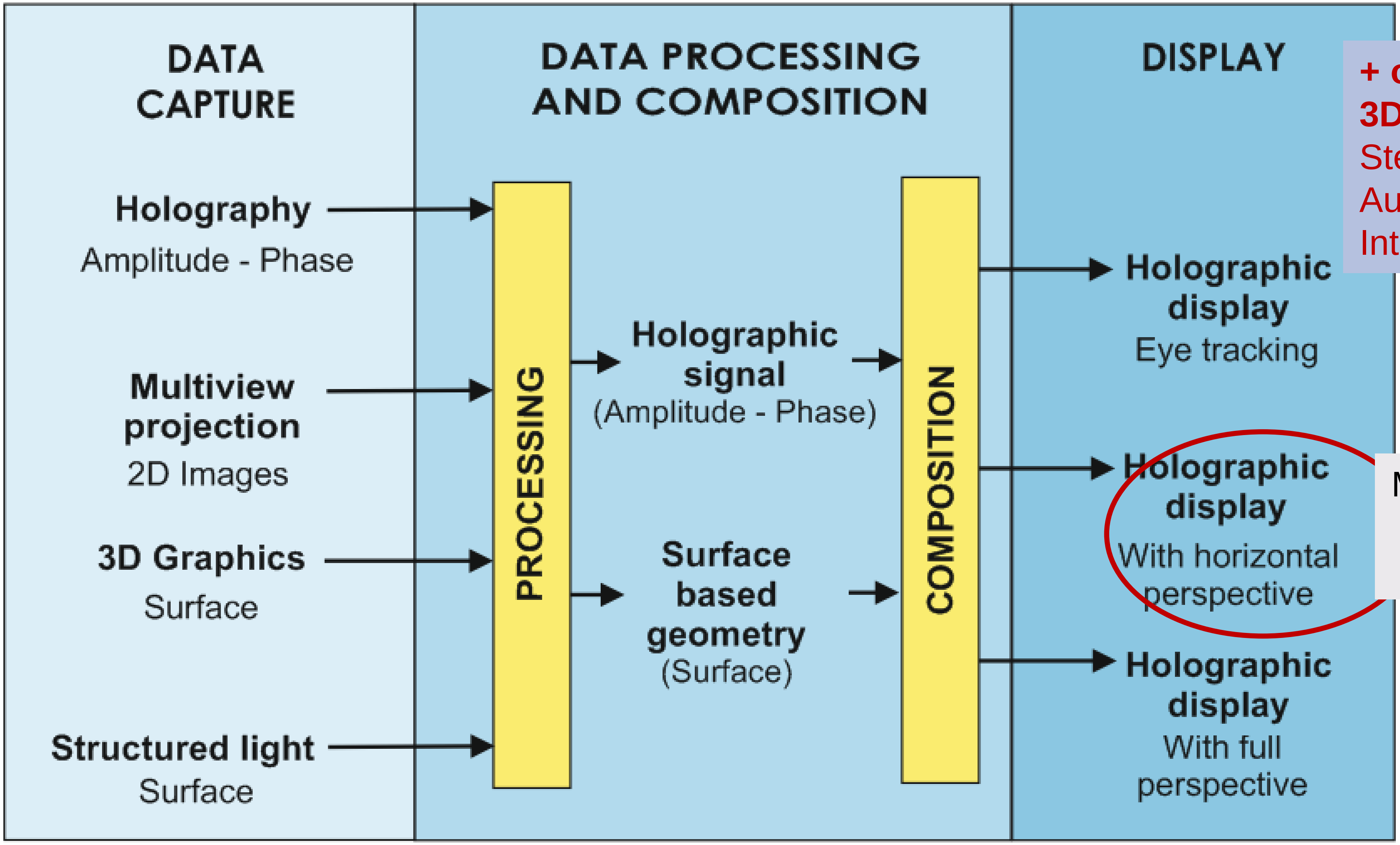
Holographic content capture from real world scens

Problems with holographic content capture of real big scenes:

- Digital sensors have not sufficiently high resolution
- Difficulties with registration of large objects
- Not fully safe due to use of laser source
- Impossible to register hologram of far background



Holographic display based on integrated content



+ other 3D displays
Stereo 2v.
Autost. 6-8v.
Int. Phot yxy

Monochrome

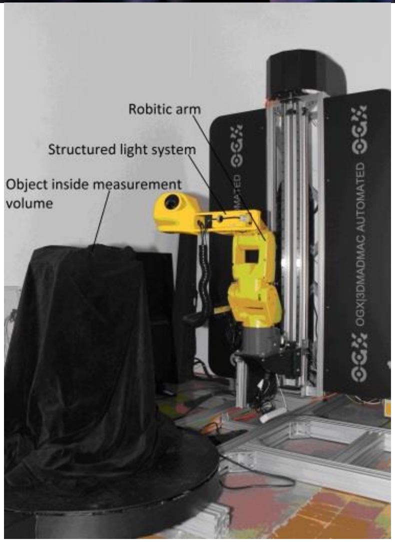
Colour

M. Kujawinska, R. Sitnik, T. Kozacki, "New concept of technology chain for 3D/4D content generation and display," Proc. SPIE, 9013 (2014) ,

Multi-source 3D data capture

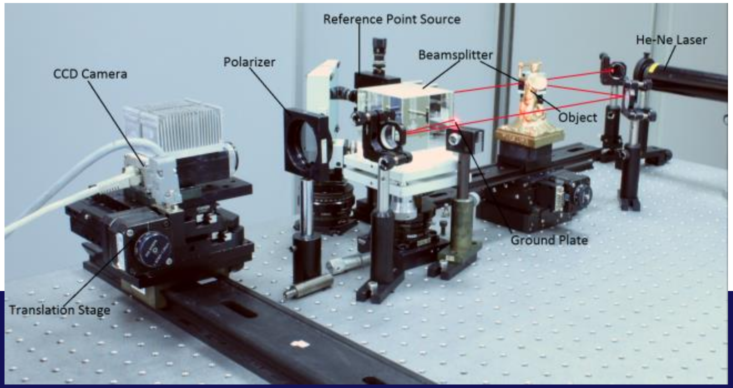
3 different types of data:

- high resolution <u>2D image </u>– background (multi-view)

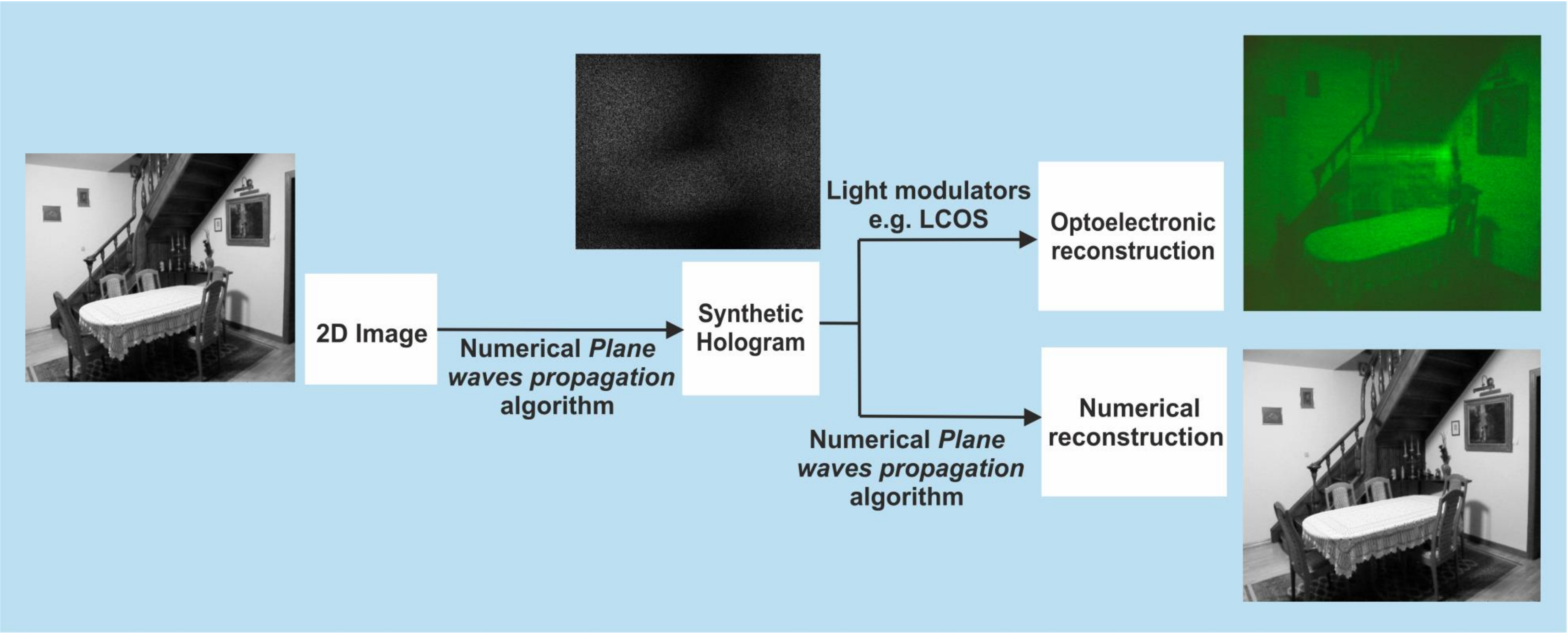


- high quality <u>cloud of points </u>of 3D object: generated and measurements of real objects

- high resolution <u>digital hologram </u>of a real object



Hologram of background



Conversion into stereohologram:
a single colour component image converted by the Gerchberg–Saxton iterative phase retrieval algorithm into 2D phase hologram.

Cloud of points (x, y, z, RGB) of 3D object

Automatic structured light system

Structure from Motion

Computer graphics

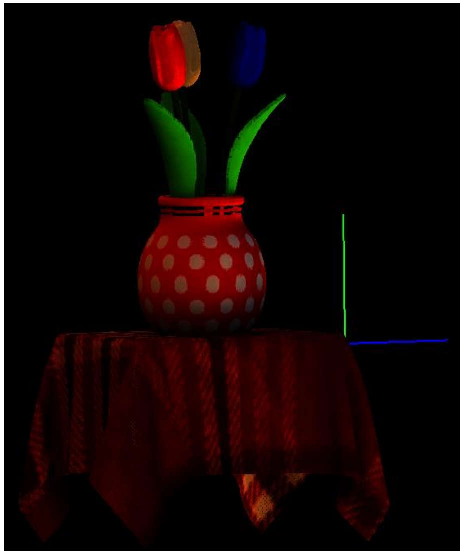
350mm (H) x 180mm (W) x 180mm (D), material: terracotta,

200mm (H) x 440mm (W) x 300 mm (D), material: metal

520mm (H) x 400mm (W) x 400 mm (D)
Numerical model

Exemplary clouds of points

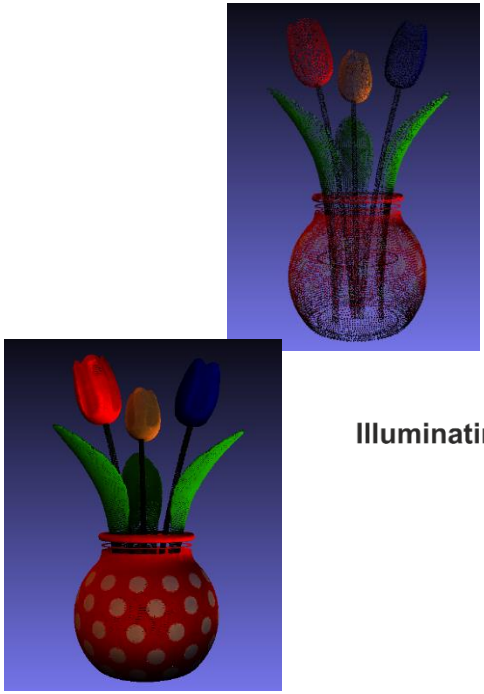
Antique oil lamp: no of points: 2 308 167, no of triangles: 769 389, quality of geometry representation 0,05mm

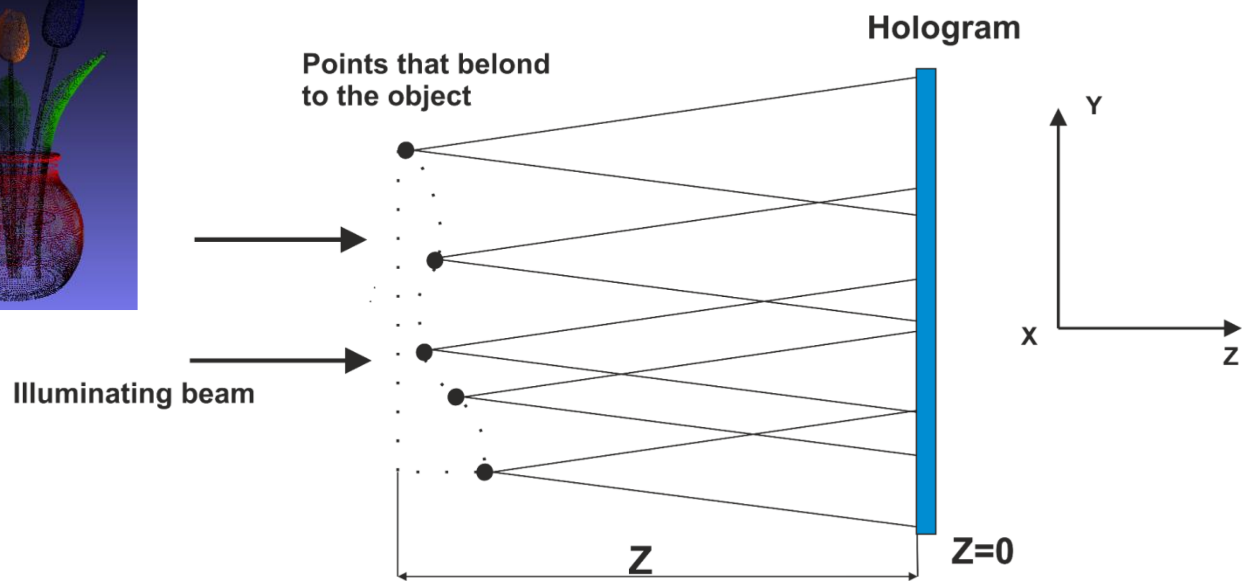


Kybele godess: no of points: 5 175 408 (quality of geometry representation 0,05mm), no of triangles: 431 284).

Tulips: no points:2 132 172 (quality of geometry representation 0,05mm), no of triangles: 710 724

Hologram based on Cloud of points





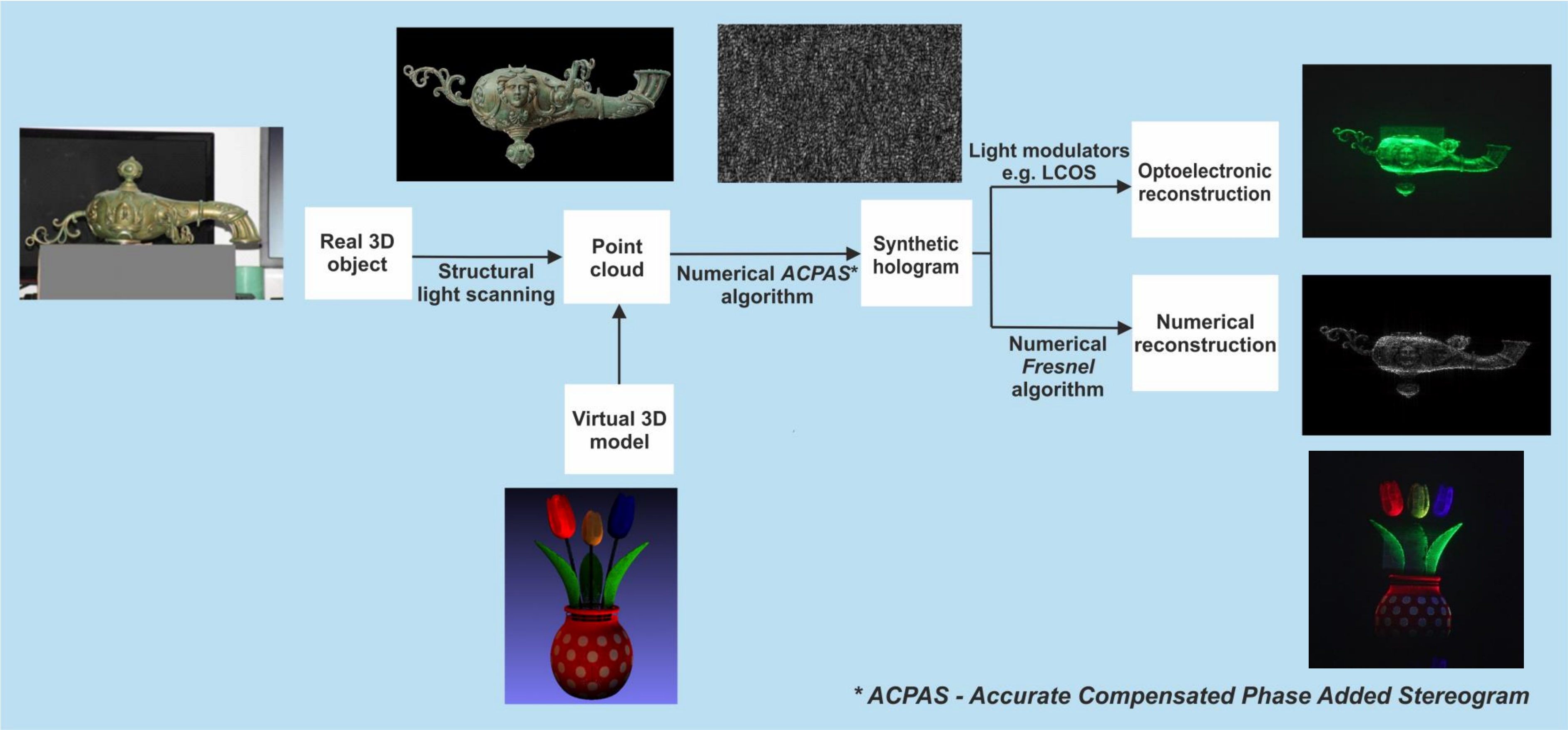
Implemented algorithms

Algorytm **CPAS** (*Compensated Phase Added Stereogram)*

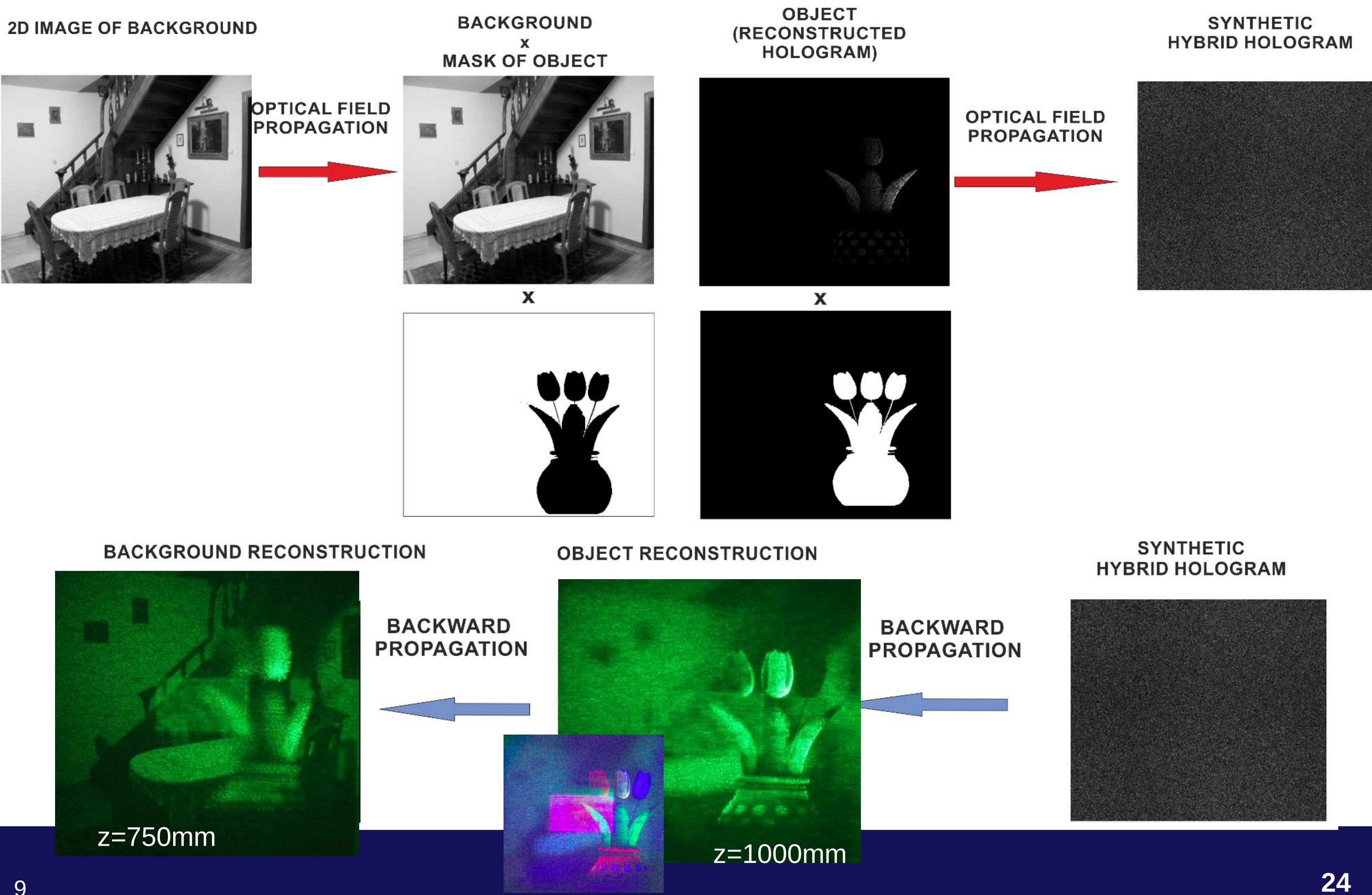
Algorytm ACPAS (*Accurate Compensated Phase Added Stereogram)*

Algorytm **FPAS** (*Fast Phase Added Stereogram)*

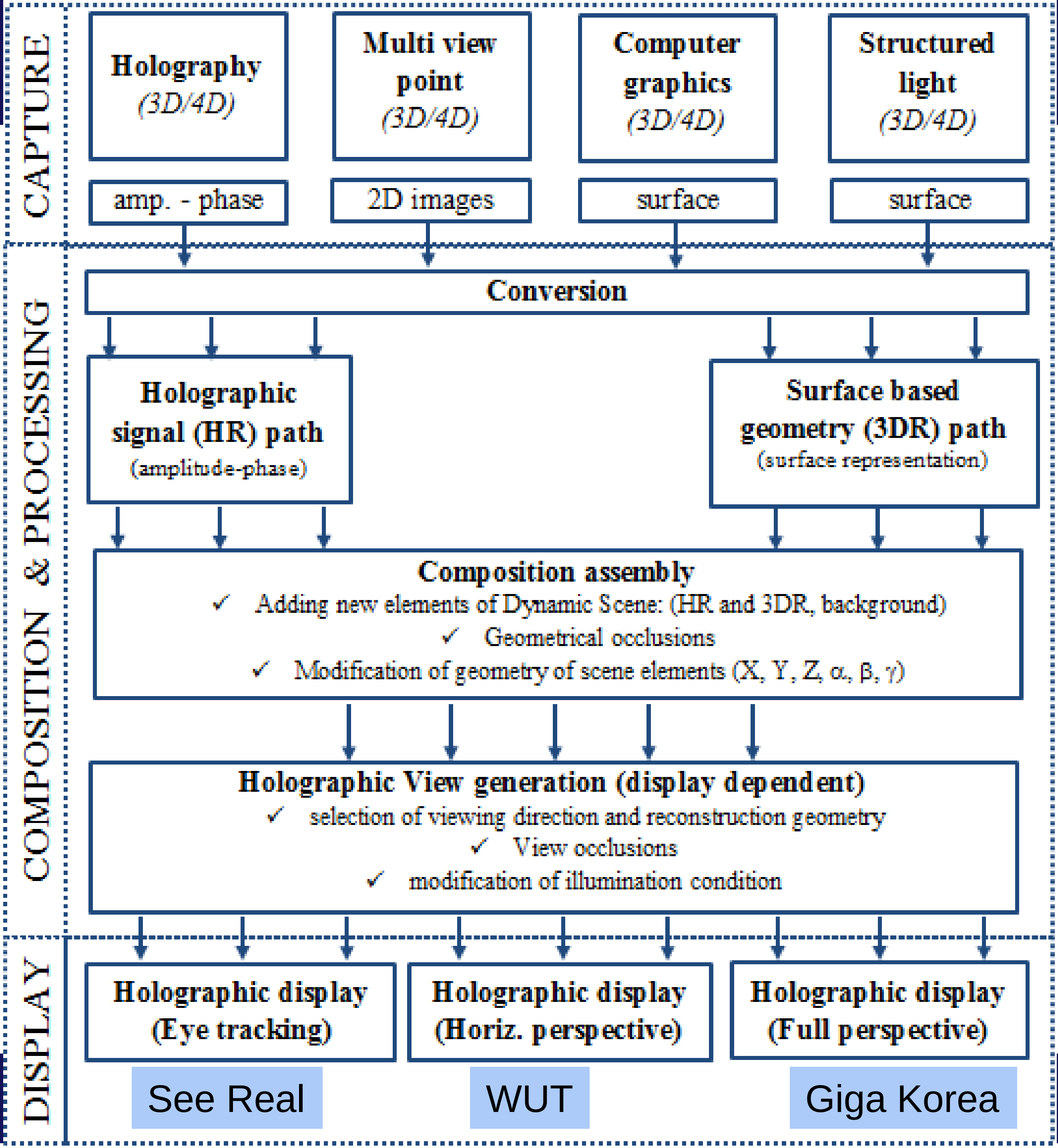
Processing path of CoP hologram



Generation of hybrid content hologram (HCH) -1



General concept of 4D video processing based on multimodal capture



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