SeeReal Technologies

GPU Technology Conference 2012 - San Jose

Content generation and real-time hologram computation for holographic 3D-displays

Enrico Zschau
SeeReal Technologies GmbH - Germany

Outline

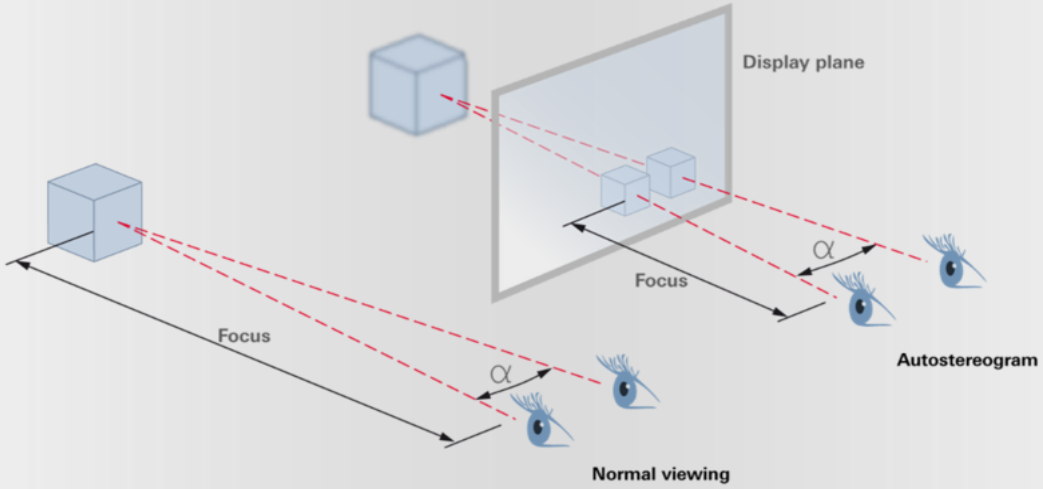
SeeReal Technologies

- Introduction to holography
- Sub-Hologram – technology
- Holographic Processing Pipeline on the GPU
  - Content generation
  - Hologram computation
  - Advanced content generation
- Holographic 3D-display

Introduction to holography

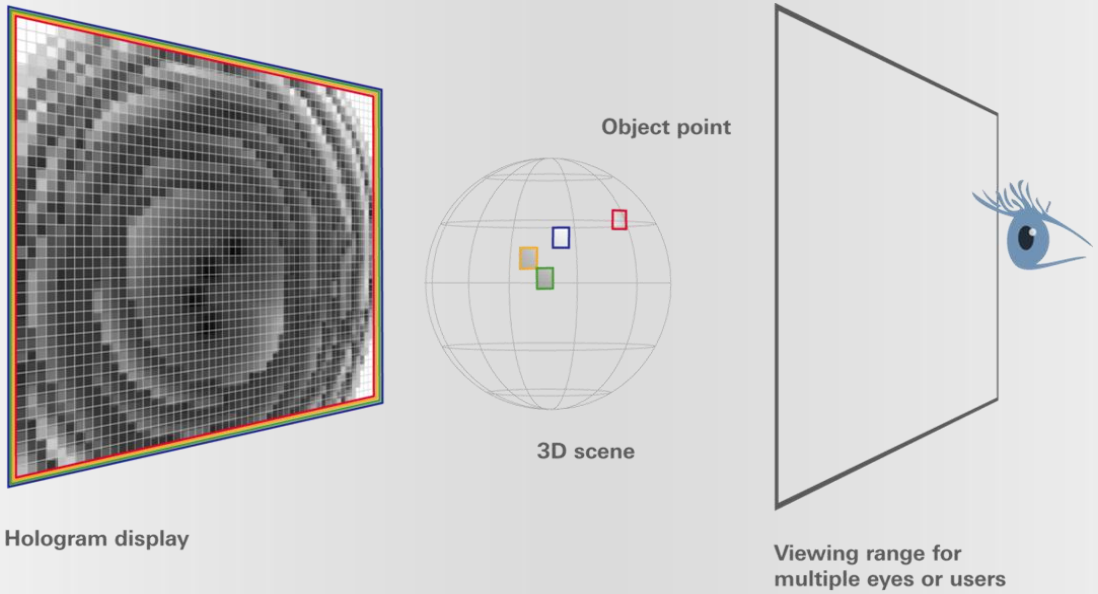
3D-Stereo vs. Holography

- 3D-Stereo
  - Mismatch between focus (display) and convergence (object)
  - Possible effects: headache, fatigue, short loss of orientation after longer use
- Holography
  - like natural viewing – focus and convergence match



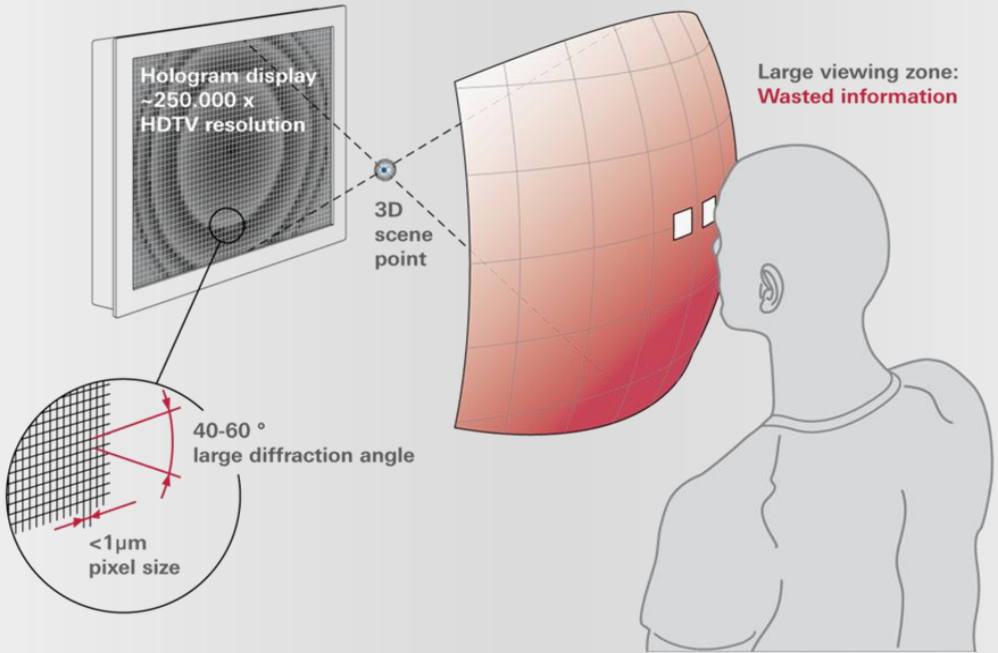
Conventional Holography

- A hologram is a large diffraction pattern
- 3D-scene is reconstructed when illuminated by coherent light – visible in the viewing zone – allows the eye to focus on different depths
- each hologram-pixel contributes to each scene-point



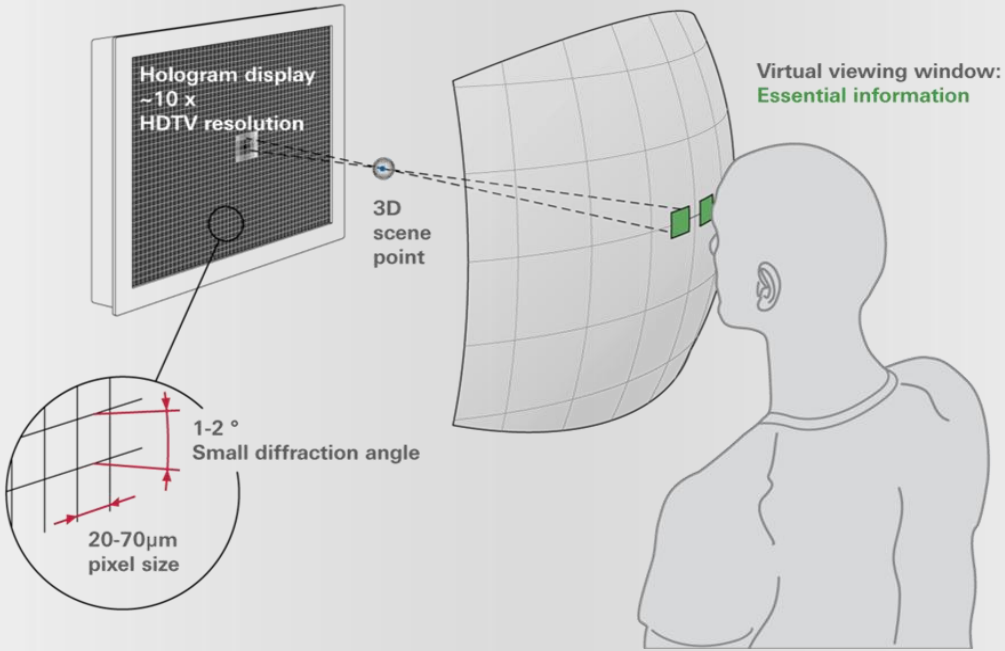
Conventional Holography

- Large viewing zone results from the very small pitch ➔ But most information calculated is wasted
- extreme resolution ➔ computation, memory, bandwidth
- Not in a foreseeable future esp. for real-time



Sub-Hologram - technology

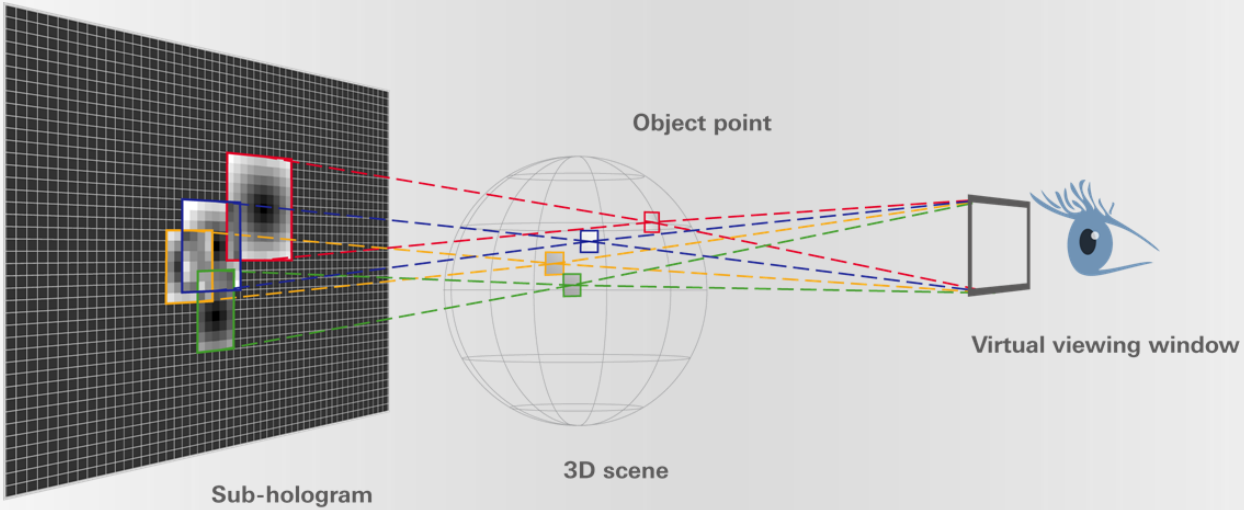
- SeeReal's Solution: Viewing Windows and Sub-Holograms
  - only the information the eyes can see is required ➔ small viewing zone – the "Viewing Window"
  - Viewing Window is shifted according to eye-positions using Eye-Tracking
  - larger pitch ➔ allows application of current LCD-technology



Sub-Holograms

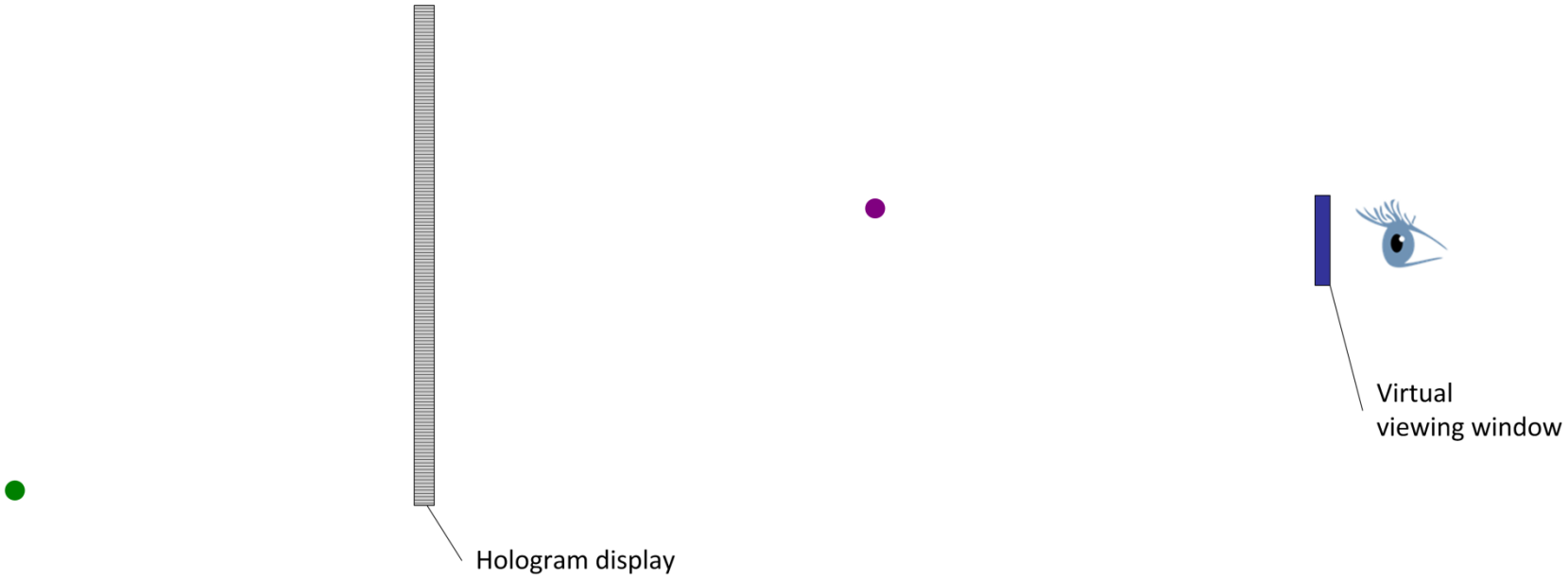
- only a small area of a hologram which is responsible to reconstruct a scene-point needs to be calculated – a “Sub-Hologram”
- Direct computing of Sub-Holograms (Phases + Amplitudes) – no FFTs required
- Super-positioning of multiple Sub-Holograms
- Results in enormous savings regarding computation power

  ➔ Enables real-time computation using off-the-shelf components



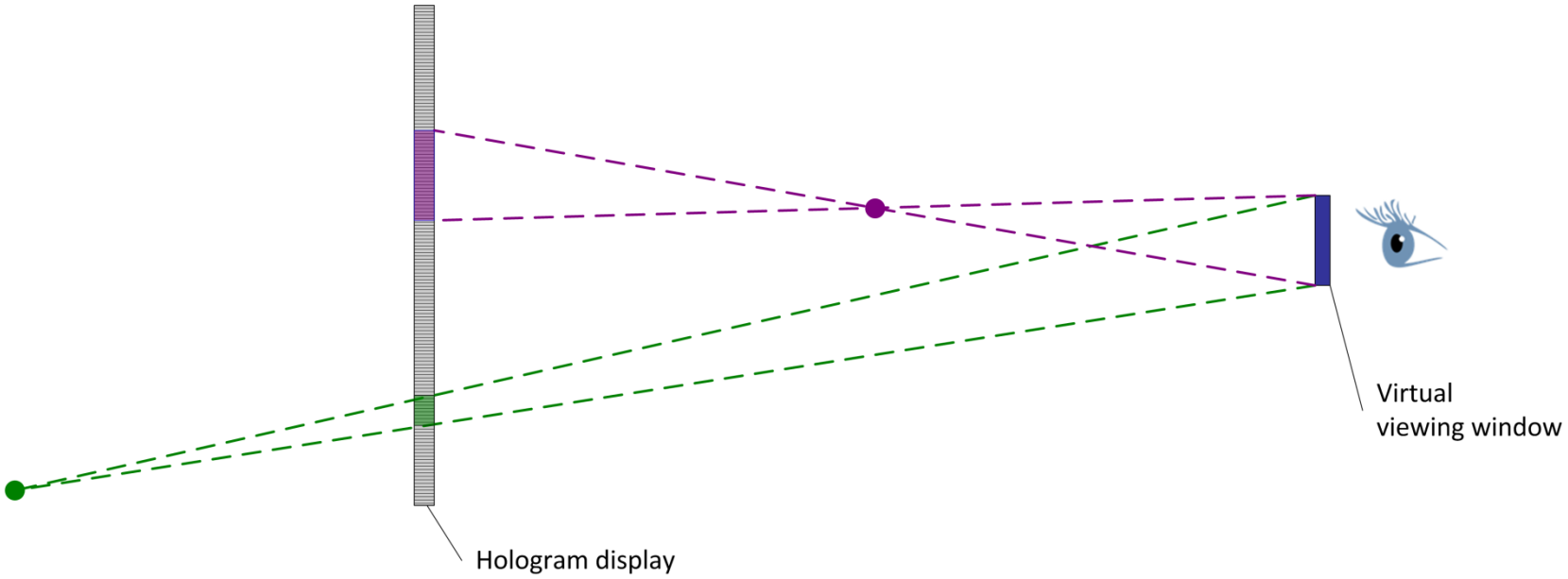
Sub-Holograms

For each scene-point to be reconstructed …



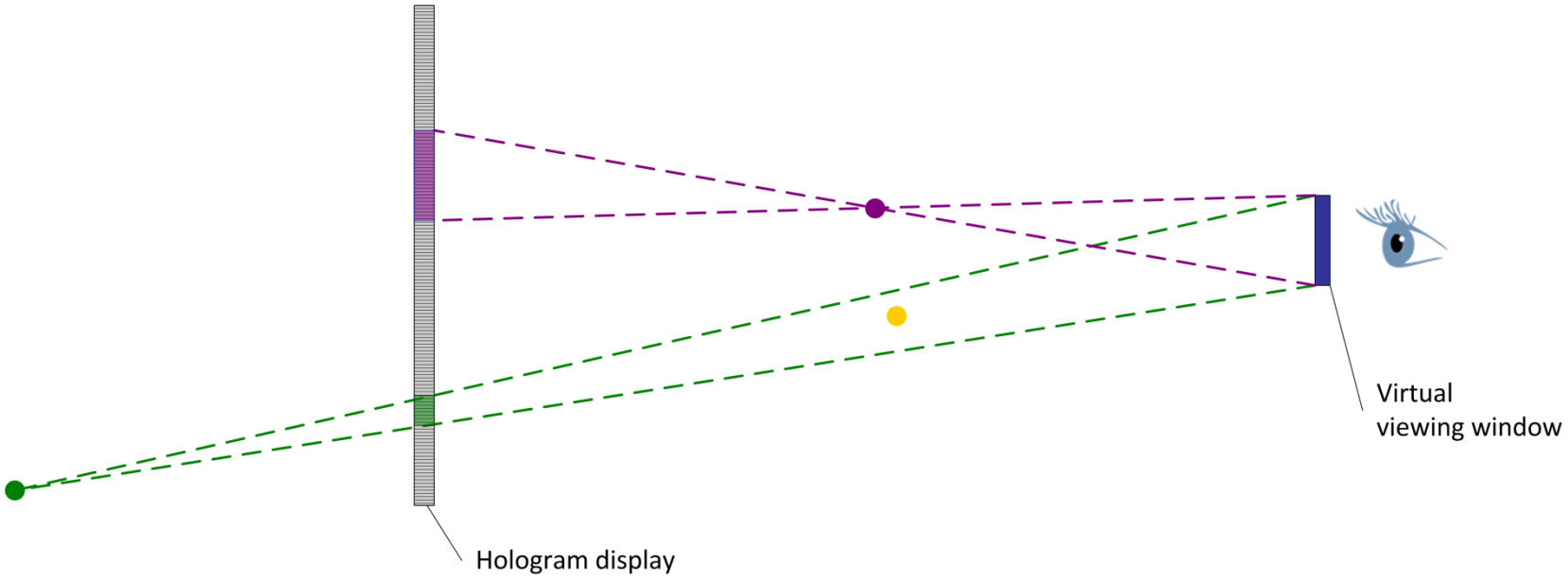
Sub-Holograms

Sub-Holograms are created and accumulated into the hologram.



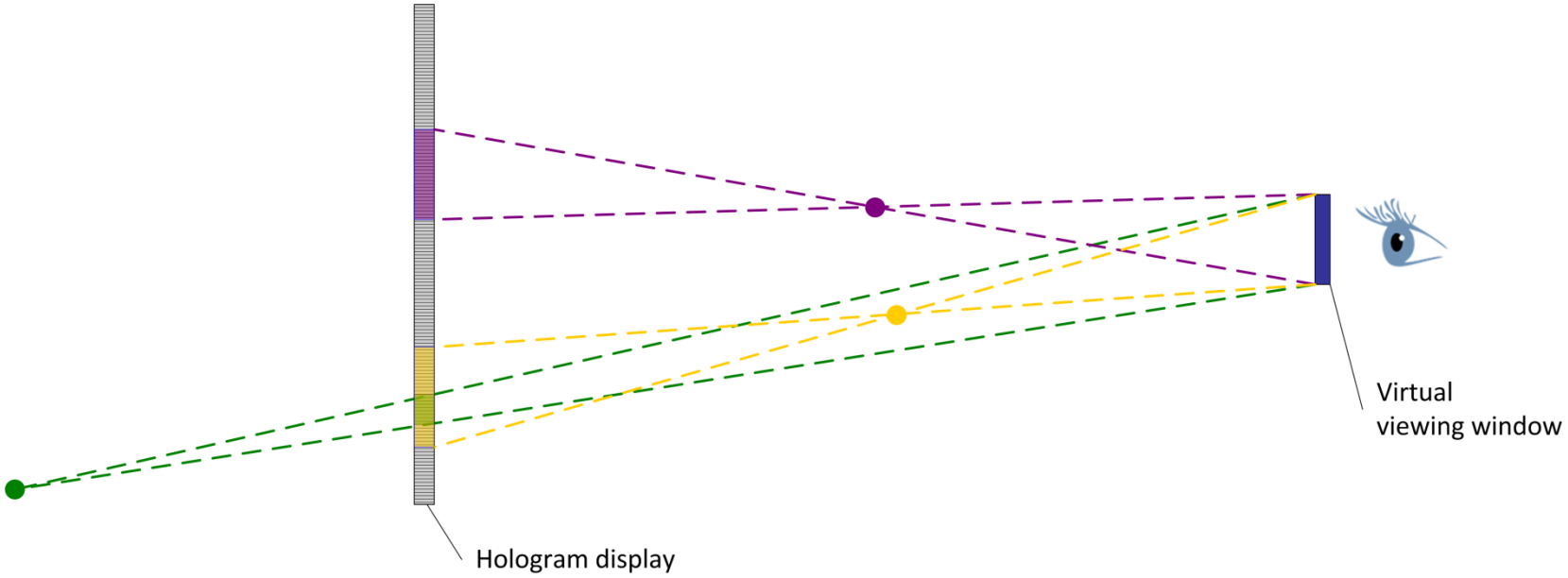
Sub-Holograms

The Sub-Holograms for different scene-points …



Sub-Holograms

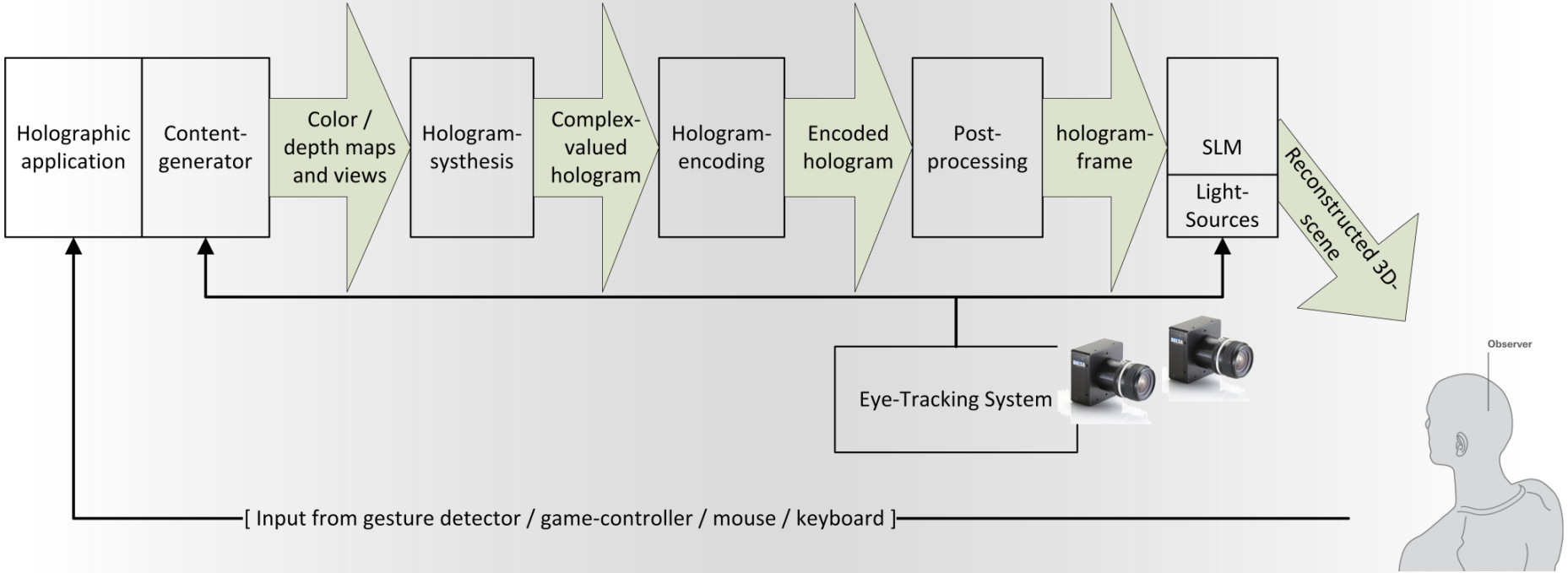
… are super-positioned to create the hologram, reconstructing the complete scene inside the Viewing-Window.



Holographic Processing Pipeline

Holographic Processing Pipeline

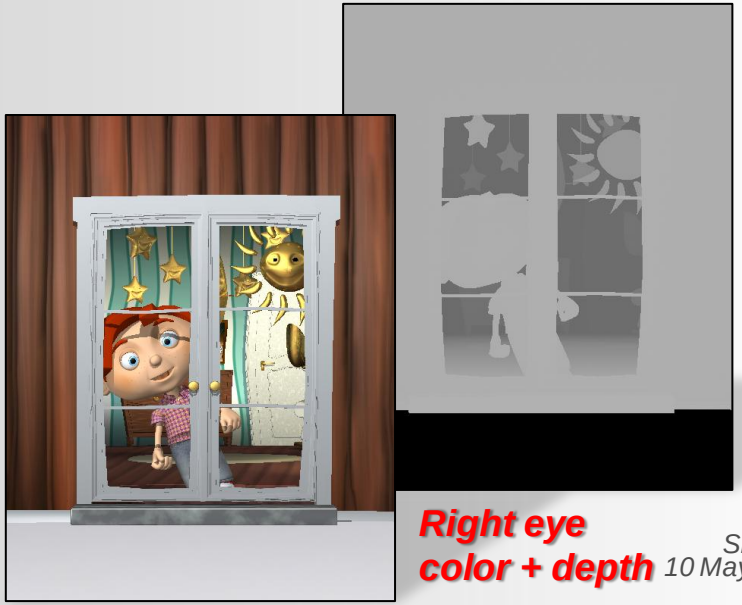
- Holographic-Software-System contains all steps to drive holographic displays



Content Generation

- For each observer and eye a color- and depth-map is required
- Color/depth-maps represent a dense distribution of 3D-scene-points
- Allows reconstruction of nice-looking holographic 3D-scenes
- Eye-Tracking enables the natural Look-around effect of conventional holograms

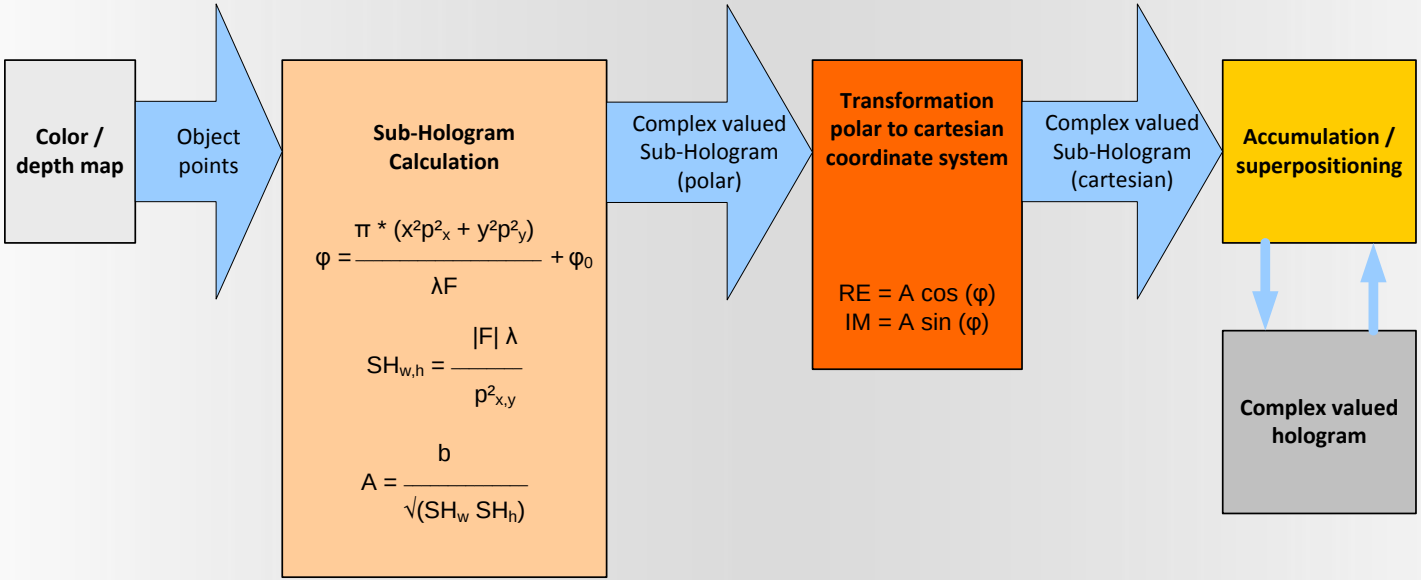
Left eye color + depth



Right eye color + depth

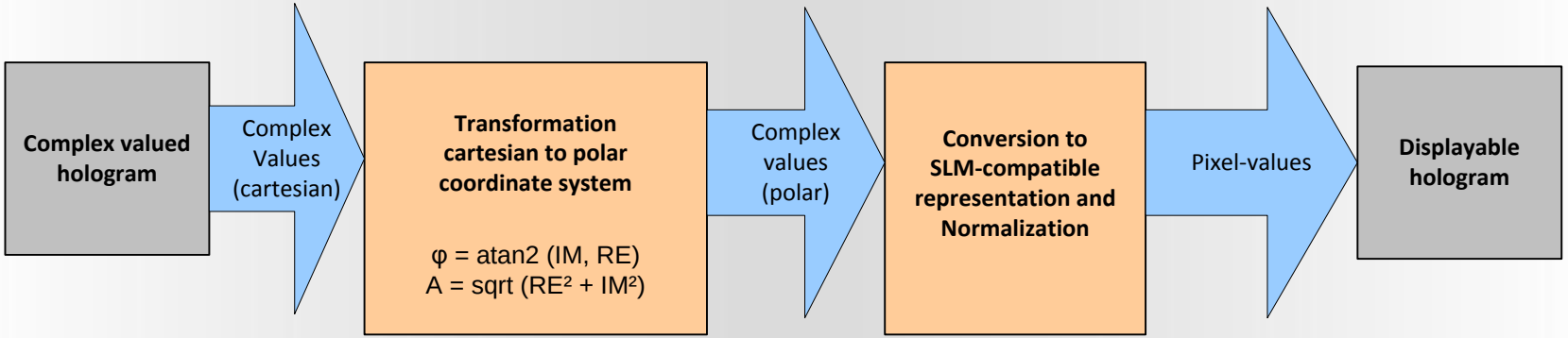
Hologram Synthesis

- Hologram Synthesis transforms object-points into complex valued Sub-Holograms
- Complex valued Hologram is created by superpositioning those Sub-Holograms
- Process is done separately for each view and color-component
- **Hologram Synthesis, esp. the transformation from polar to carthesian coordinate system is most time consuming part in hologram calculation process**



Hologram Encoding

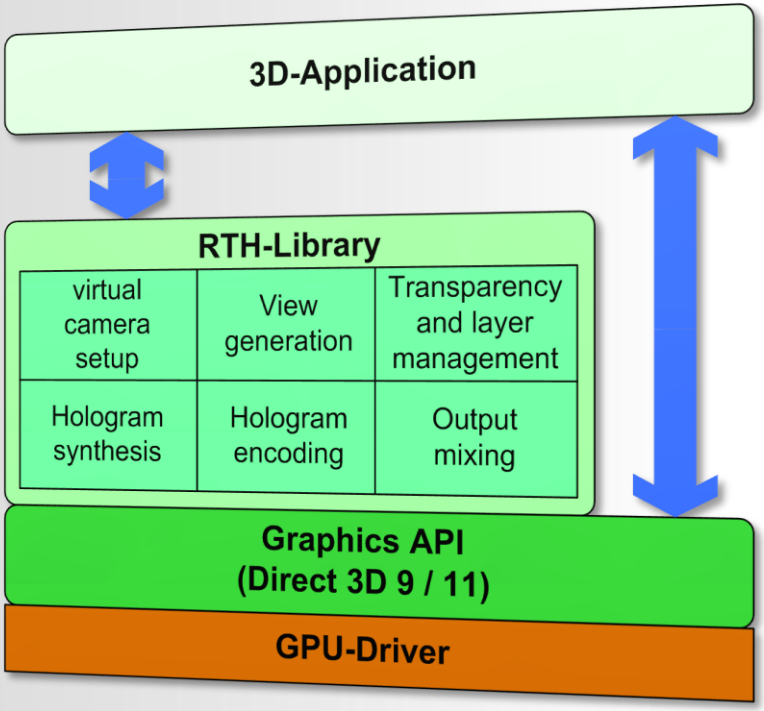
- Converts complex values to a representation compatible with spatial light modulator (SLM)
  - complex values cannot be written into a display ➔ change of representation necessary
  - i.e. 2 phases or 3 amplitudes (detour-phase / burckhardt encoding)
  - Requires normalization of amplitude
- Post processing step formats hologram data according to type of spatial light modulator
  - time-sequential / spatial presentation of color and views



Hologram calculation using the GPU

Hologram Calculation using the GPU

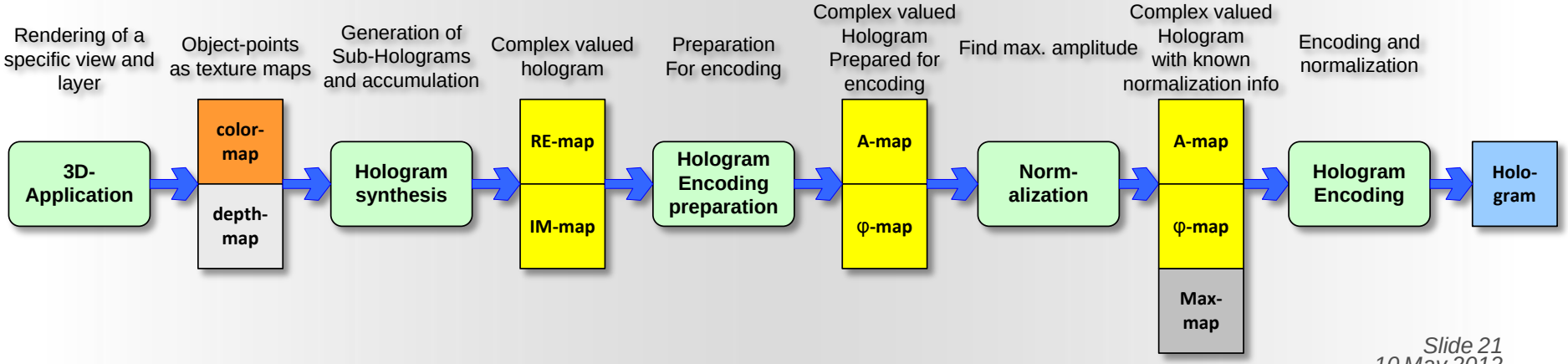
- Implementation for D3D 9 and D3D 11
- Hologram calculation implemented as a DLL, the **R**eal **T**ime **H**olography Library with very simple API
- An application is build on top of the RTH-Lib to enable holographic output on holographic 3D-displays
  - **no knowledge** about holography is necessary for the application designer – just draw your content
  - since all holographic processing is performed in the background **encapsulated** in the library
  - even correct setup of **virtual cameras** is handled automatically



- **It is desirable, that this system could be directly implemented in the graphics driver to enable holographic output out of the box similar to Nvidias 3D-Vision**

Hologram Calculation using the GPU

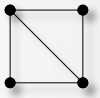
- Multiple calculation stages making use of various vertex and pixel shader
- Intermediate results are stored in FP-rendertargets and used as FP-textures in the following stages
- Content is directly taken from application's rendertarget (as color-texture + depth-texture)
  - Depth access: For DX9 Nvidia's "INTZ" depth buffer is used, for DX11 this is straightforward
- Encoded hologram can then directly be written into a holographic display



Hologram Synthesis using the GPU

SeeReal Technologies

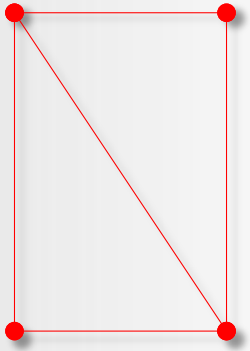
- For each object point a rectangle is drawn which represents a Sub-Hologram



- VS shifts vertices re Sub-Hologram size and position according to depth value
- Applies additional parameters to vertices for later use in PS using color/texture coordinate registers

Sub-Hologram VS

- Rectangle representing the formatted and parameterized Sub-hologram is handed over to rasterizer



$$SH_{w,h} = \frac{|F|\,\lambda}{p^2_{x,y}}$$

$$A = \frac{b}{\sqrt{(SH_w\, SH_h)}}$$

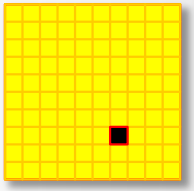
color-map | **depth-map** | **Params-map (look up table)** | **Random phase-map**

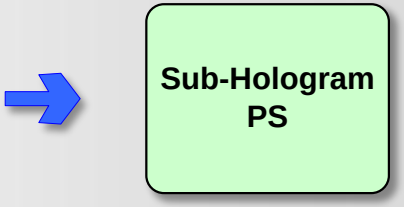
Hologram Synthesis using the GPU

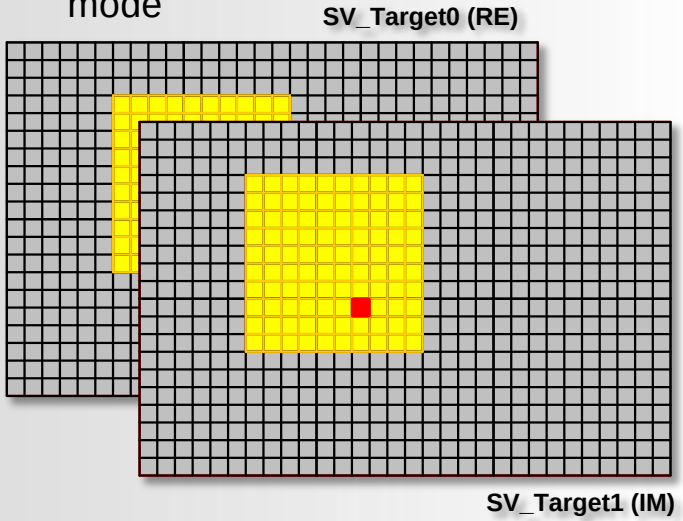
- Rasterizer generates fragments from Sub-Hologram rectangle

- PS calculates φ from inter-polated parameters issued by VS
- transforms to cartesian space
- MRT is used to separately store real and imaginary values

- generated values are added into the hologram (RE / IM rendertargets)
- Adding is realized at no additional cost by using a special alpha blending mode





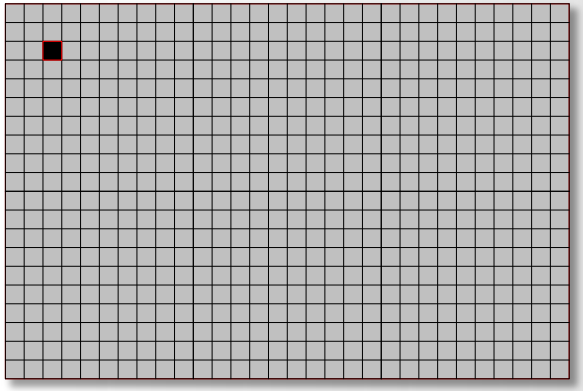


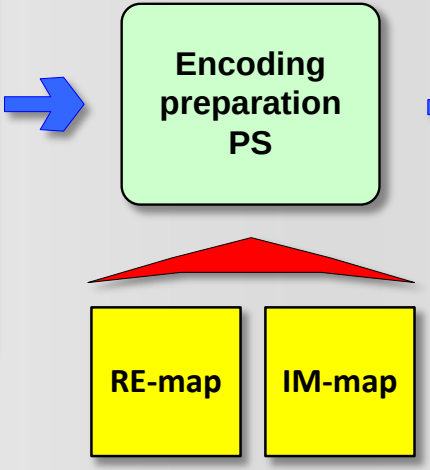
$$\varphi = \frac{\pi * (x^2p^2_x + y^2p^2_y)}{\lambda F} + \varphi_0$$

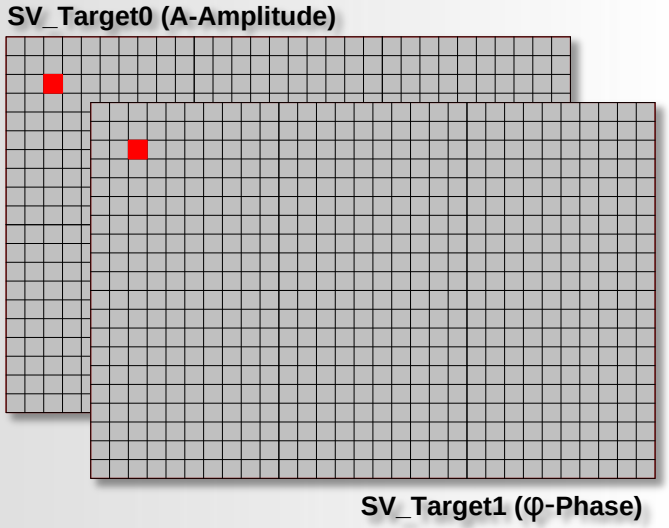
$$RE = A \cos(\varphi)$$
$$IM = A \sin(\varphi)$$

Hologram Encoding using the GPU - Preparation

- By drawing a fullscreen rectangle fragments for each hologram pixel are generated
- PS transforms hologram pixels from cartesian to polar space
- generated color-values are stored into the A/φ rendertargets



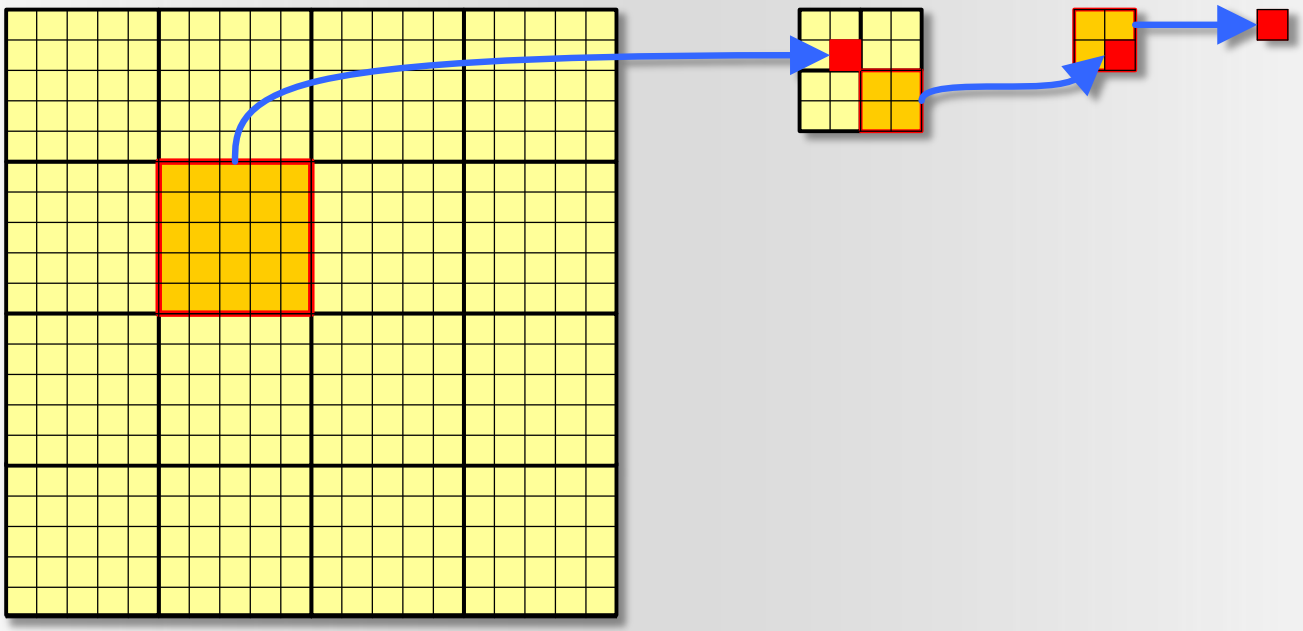




$$\varphi = \text{atan2}(IM, RE)$$
$$A = \text{sqrt}(RE^2 + IM^2)$$

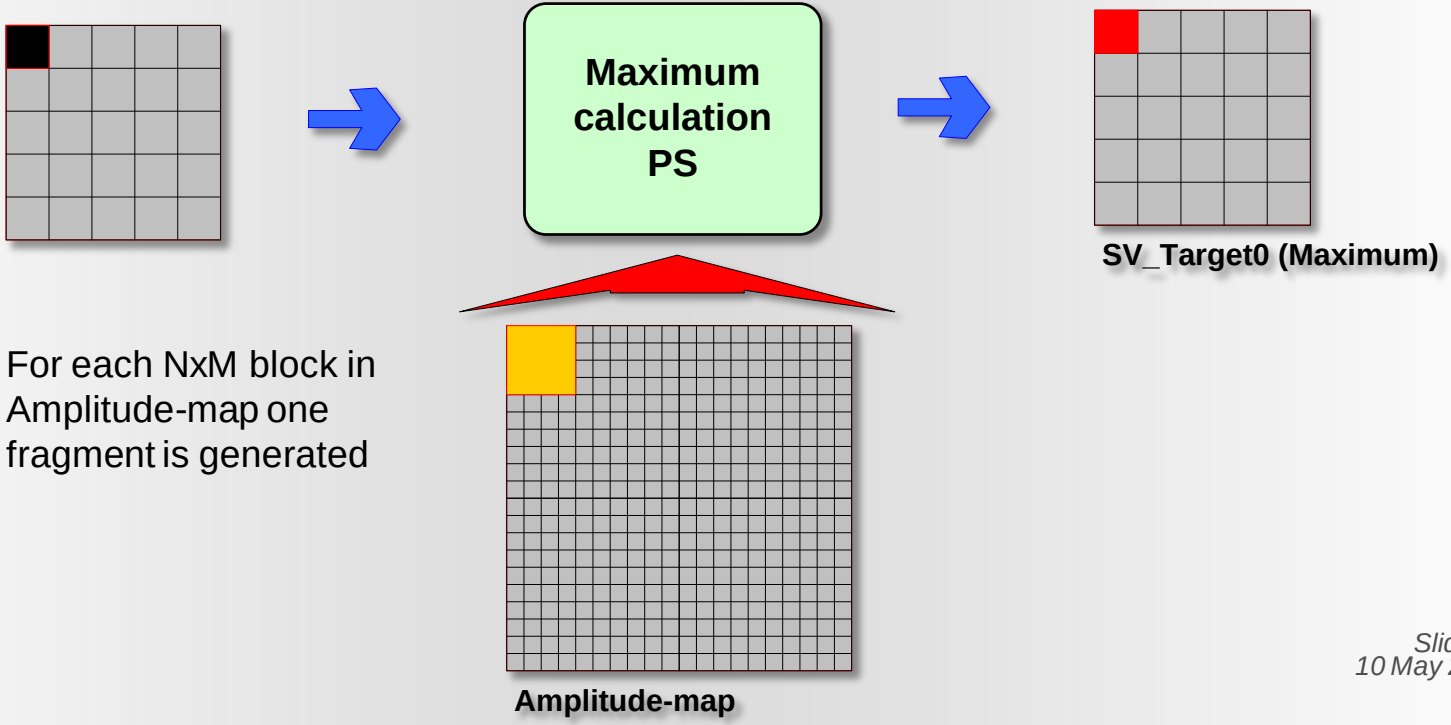
Hologram Encoding using the GPU - Normalization

- Using a tree based reduction technique, maximum of all pixels in the whole hologram is calculated using only few rendering passes (< 8) with good shader-core utilization in comparison to full sequential maximum calculation



Hologram Encoding using the GPU - Normalization

- By drawing a fullscreen rectangle fragments for each pixel are generated
- PS calculates maximum of all pixels inside a NxM block in bound Amplitude-map
- generated maximum is stored in the maximum rendertarget



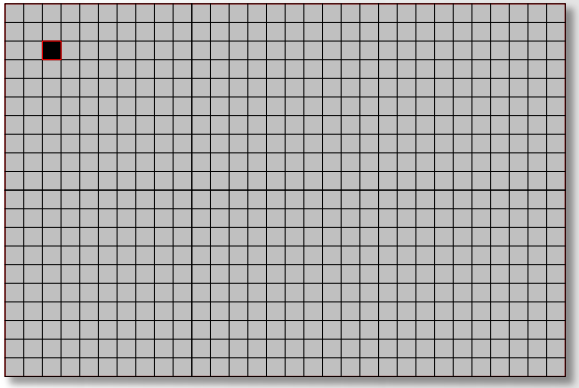
- For each NxM block in Amplitude-map one fragment is generated

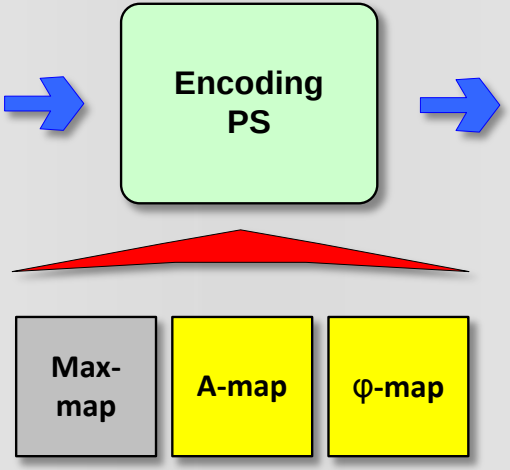
Hologram Encoding using the GPU – Final step

- By drawing a fullscreen rectangle fragments for each hologram pixel are generated

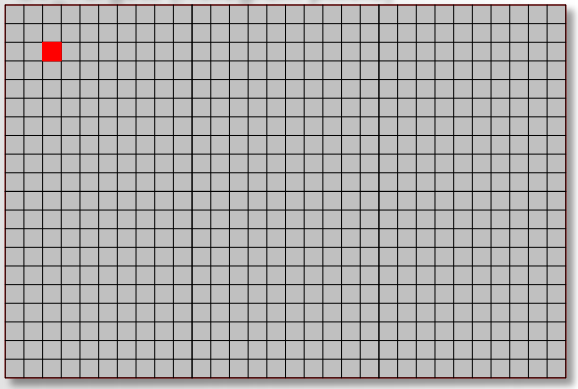
- PS transforms complex values to SLM-compatible pixel-values
- Performs normalization of amplitude using the maximum value

- generated color-values are stored in the hologram





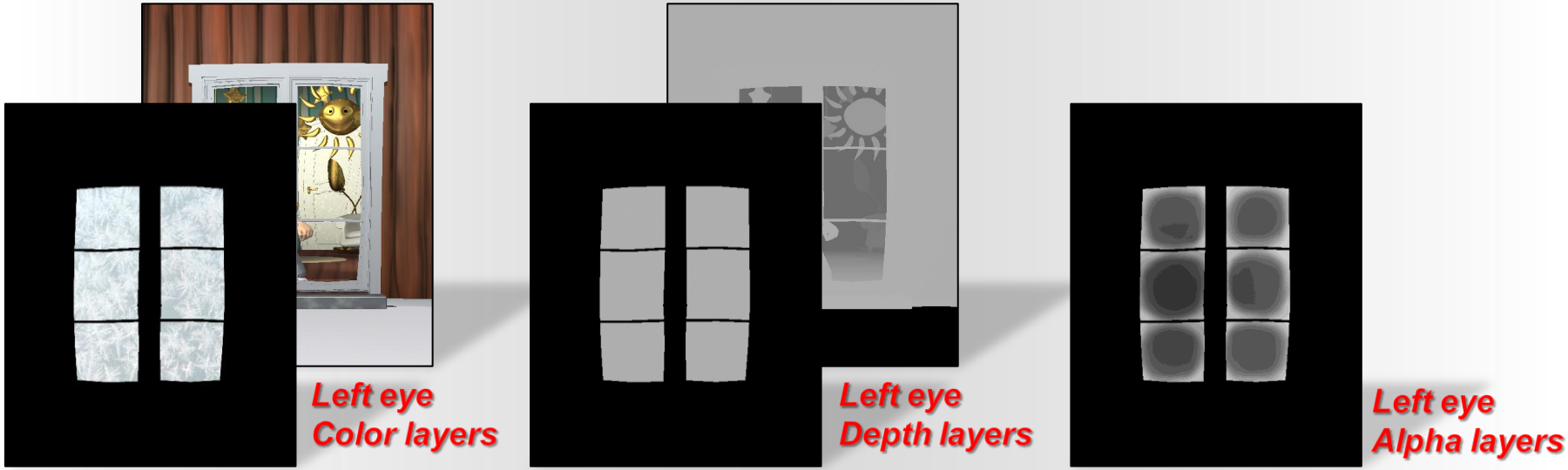
SV_Target0 (Hologram pixels)



Advanced content generation

Content Generation – Transparency

- Sub-Holograms enable realization of (semi-) transparent objects
  - multiple scene-points in different depths at the same lateral position
- (Semi-) transparent scene-points stored in additional content-layers
- Additional alpha-map per layer defines grade of transparency

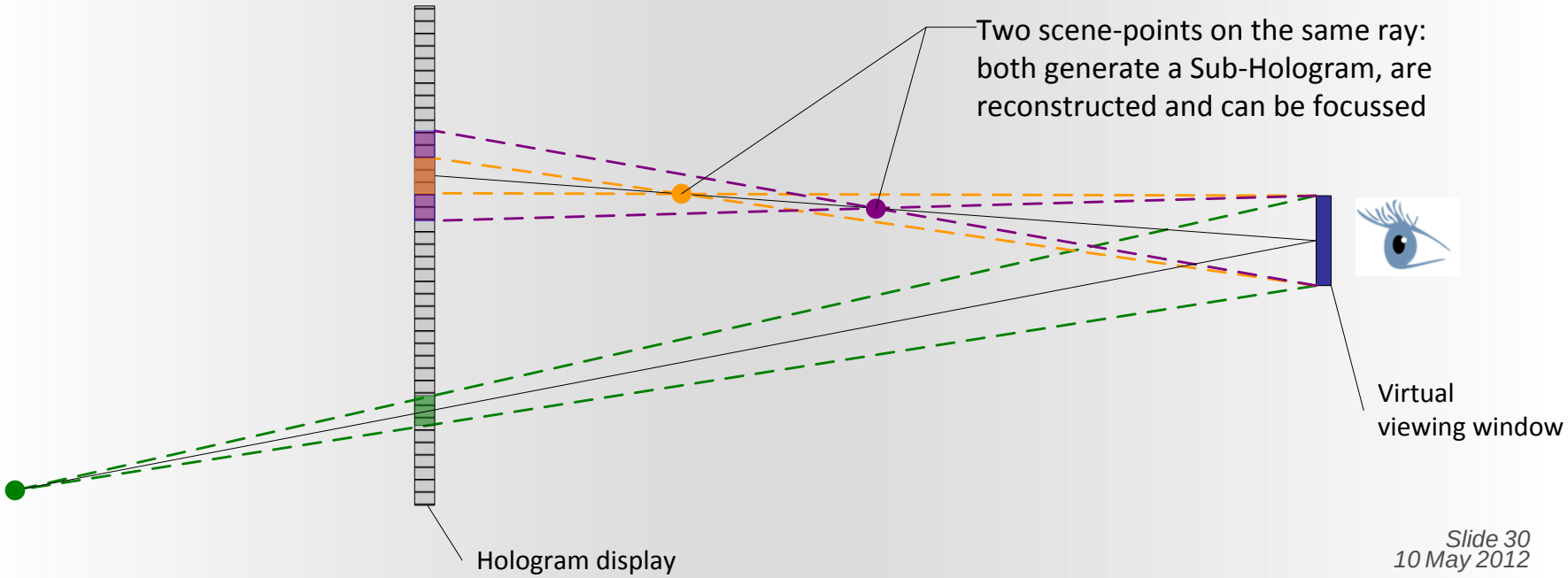


Content Generation – Transparency

(Semi-) transparent scene-points are realized …

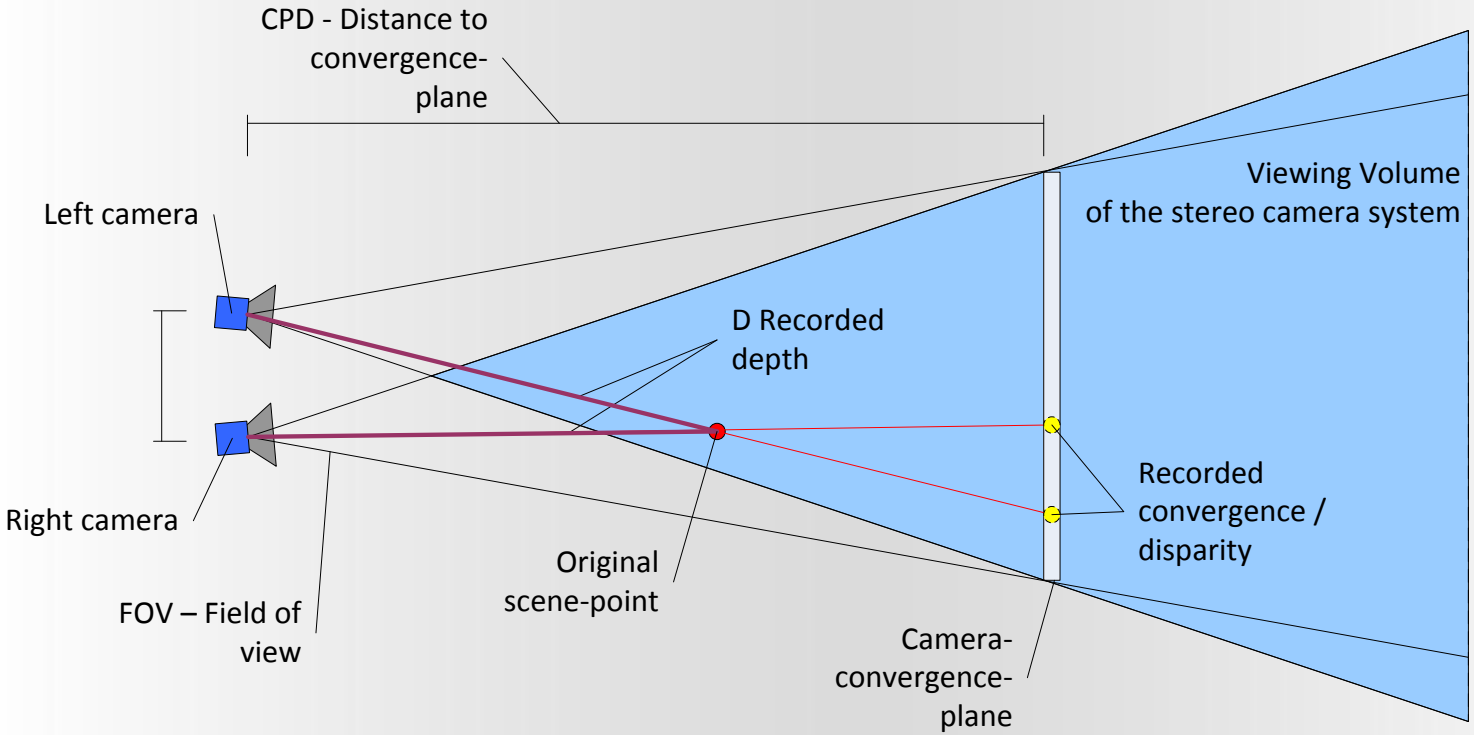
… by creating a new one at the lateral position of existing scene-points …

… and accumulation/super-positioning into the hologram.



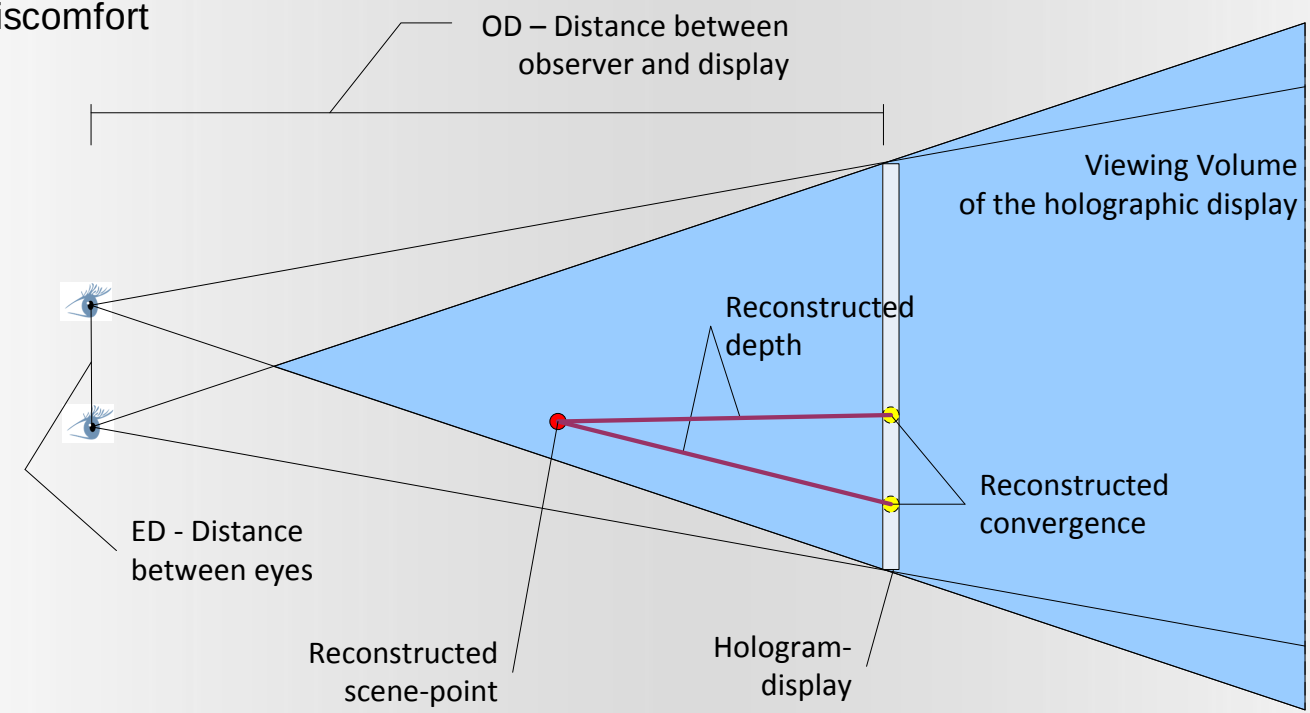
Content Generation – Camera setup

- Correct virtual camera setup when recording a scene is vital for a correct/natural reconstruction
- Recording a scene should be done using camera setup parameters …



Content Generation – Camera setup

- … mostly proportional to those parameters used for reconstructing the scene to enable 100% viewing comfort thus a natural representation
- **NO depth compression necessary** as used for 3D-Stereo, since unlimited depth range is possible at no discomfort



Holographic 3D-display Prototype

Current Holographic Prototype

20 inch direct view full color holographic 3D-display:

- **Off-the-shelf 20” / 60Hz** LCD with **7680x2048** amplitude modulating pixels
- Detour-phase / Burckhardt encoding
- Holographic encoding in vertical direction / **8mm Viewing-Window** at 2m distance
- Horizontal view multiplexing
- **Sequential color** presentation controlled by RGB-Backlight
- Thickness of housing comes from **large backlight and unoptimized optical components (low efficiency)** – final product designs will be much **thinner**

Current Holographic Prototype

- Currently **one observer** tracked by the **integrated** fast and precise **Eye-Tracking** (60 Hz, +/- 2.5 mm accuracy)

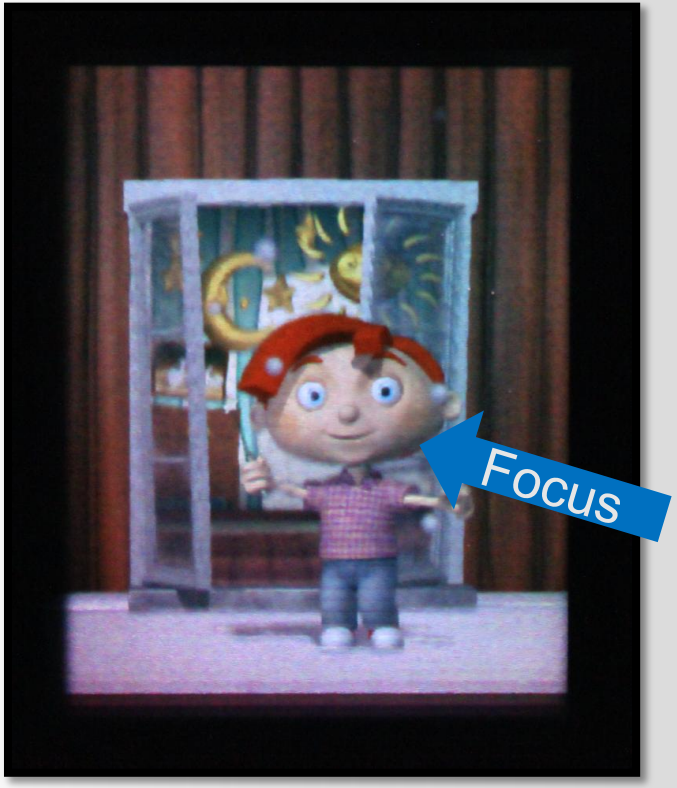
- PC using a single **NVIDIA GTX 285** performs **content generation and holograpic calculation** in **real-time** (60 Hz)

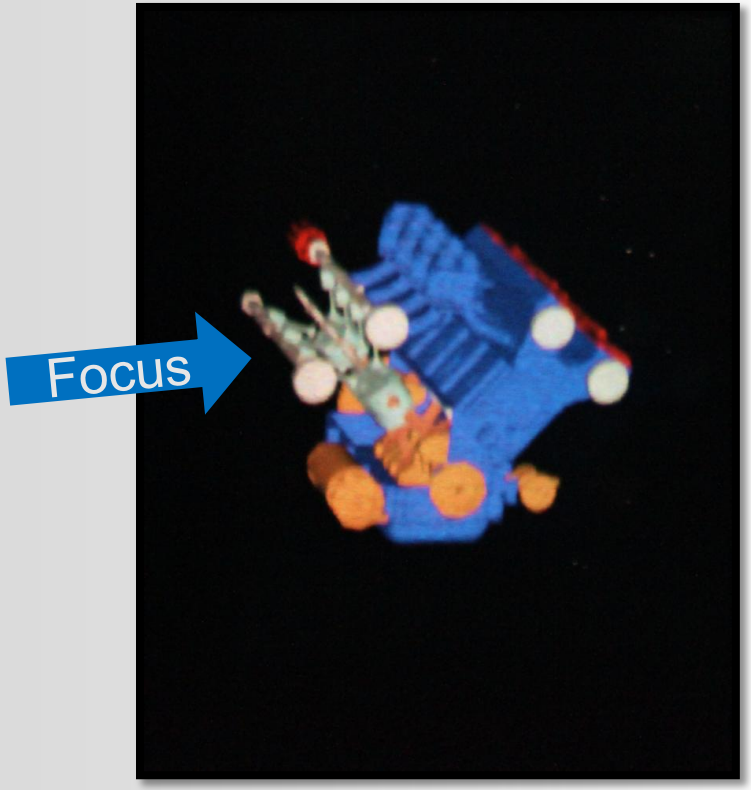
- Reconstruction of **640x512 scene-points** with **unlimited depth**
- Multiple **transparency depth cues** per scene-point

- Resolution is **not limited by the display**, but by the eye's capability to resolve more scene points at given display size and viewing distance
- **Full HD resolution** for large displays will be possible

Demo pictures taken with a camera

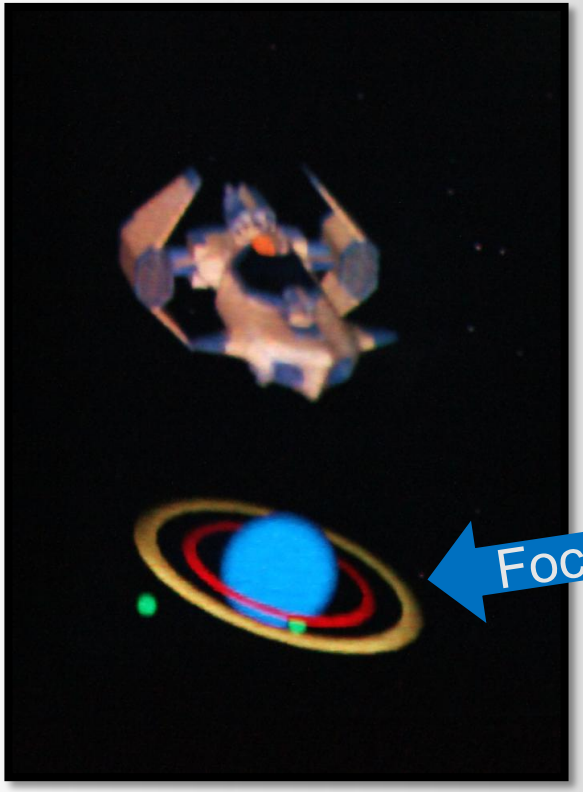
- Note: Pictures shown do not represent the same sharpness as perceived with human eye

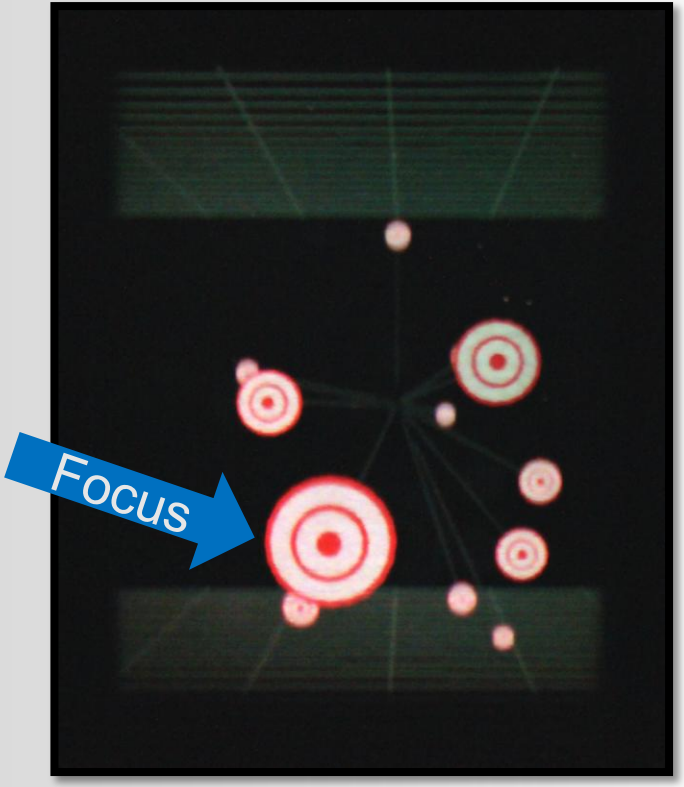




Demo pictures taken with a camera

- Note: Pictures shown do not represent the same sharpness as perceived with human eye





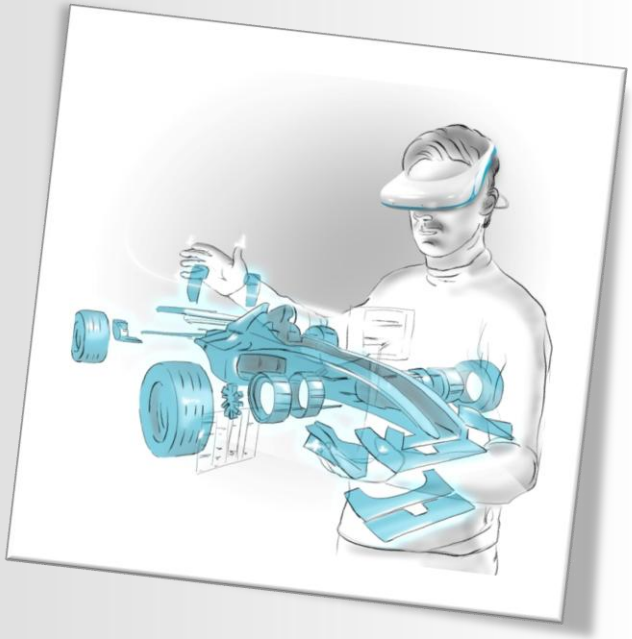
Summary

- Conventional holography and Sub-Holograms
- Holographic processing pipeline
- Holographic calculation using the GPU
- Advanced content generation
- Holographic display

Outlook

Currently: Development of technologies for different display classes together with asian display-partners

- Head mounted display
- Mobile
- Desktop
- TV



FPGA-Version to integrate hologram calculation into display

➔ later transition to ASIC

Further improvement and optimization of GPU-solution

➔ CUDA 4/5

➔ Compute Shader

End of Presentation