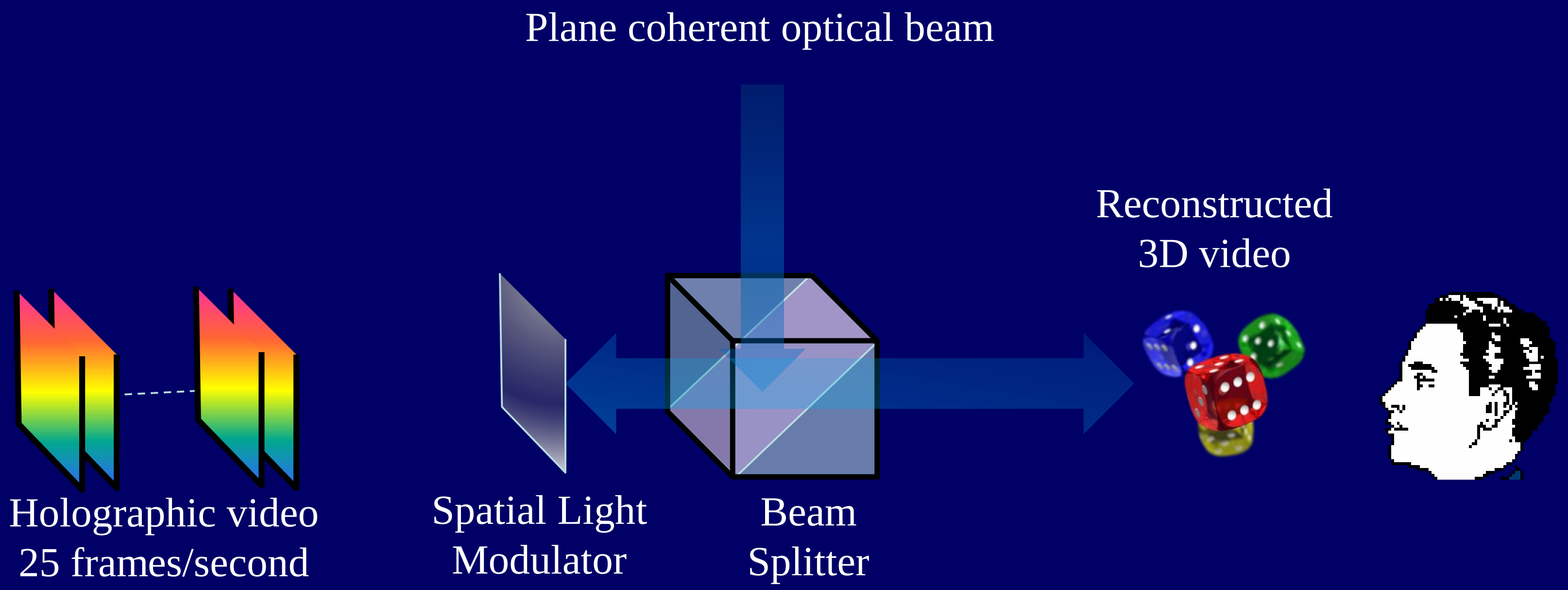
Holographic video system: require very high speed in generating the hologram

Holographic video system: the future of three dimensional television (3DTV)

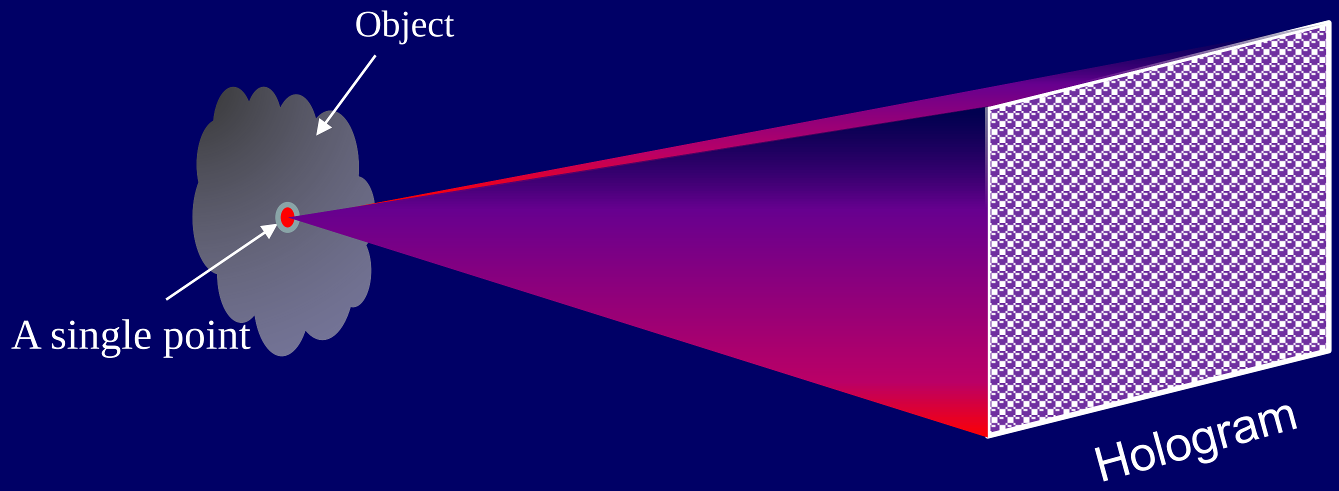


Computation time is proportional to the size of the hologram.

LUT speed up CGH in software implementation, but not the hologram formation process

Hologram Generation

The problem is, each object point will contribute to the entire hologram.



For multiple points, their individual wavefront is summed up in the hologram leading to large amount of calculations.

Computer Generated Holography

Computer Generated Hologram (CGH): Computes the sum of the wavefront contributed by all the object points in a three dimensional (3D) scene.

$$H(m,n) = \sum_{k=0}^{K} O_k(m,n)$$

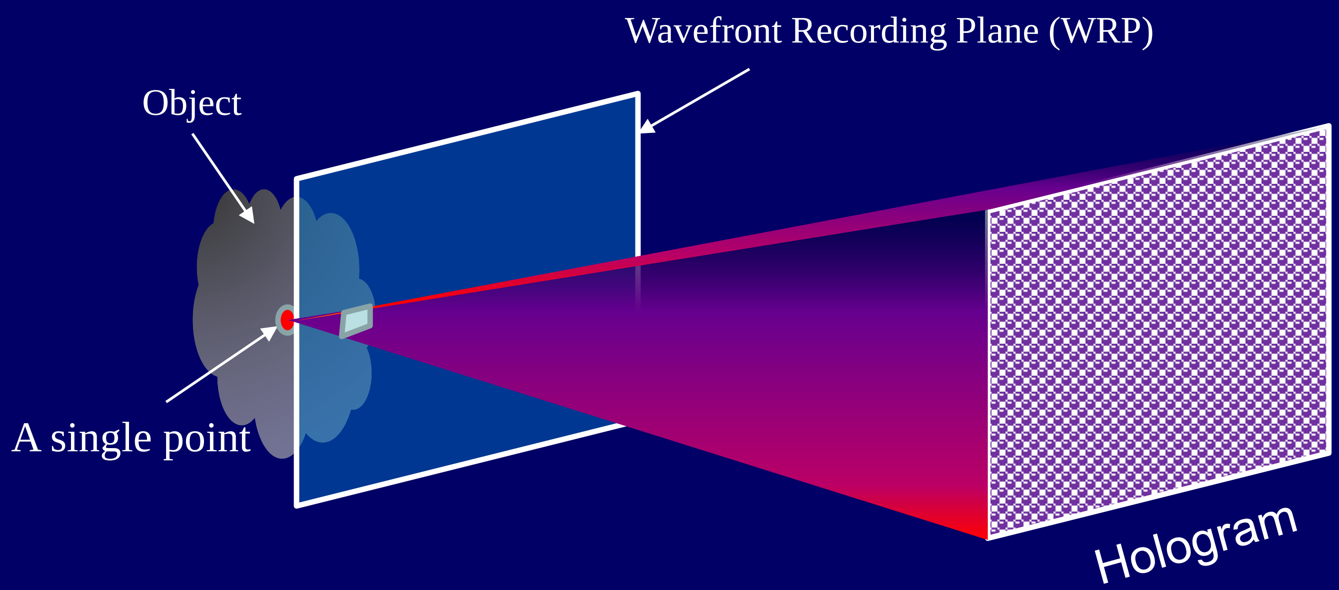
$O_k(m,n)$ is the optical beam contributed by the k^{th} object point.

The more pixels in a hologram, the heavier will be the computation. As mentioned before, LUT methods do not improve the hologram formation process.

Fast hologram generation: A WRP approach

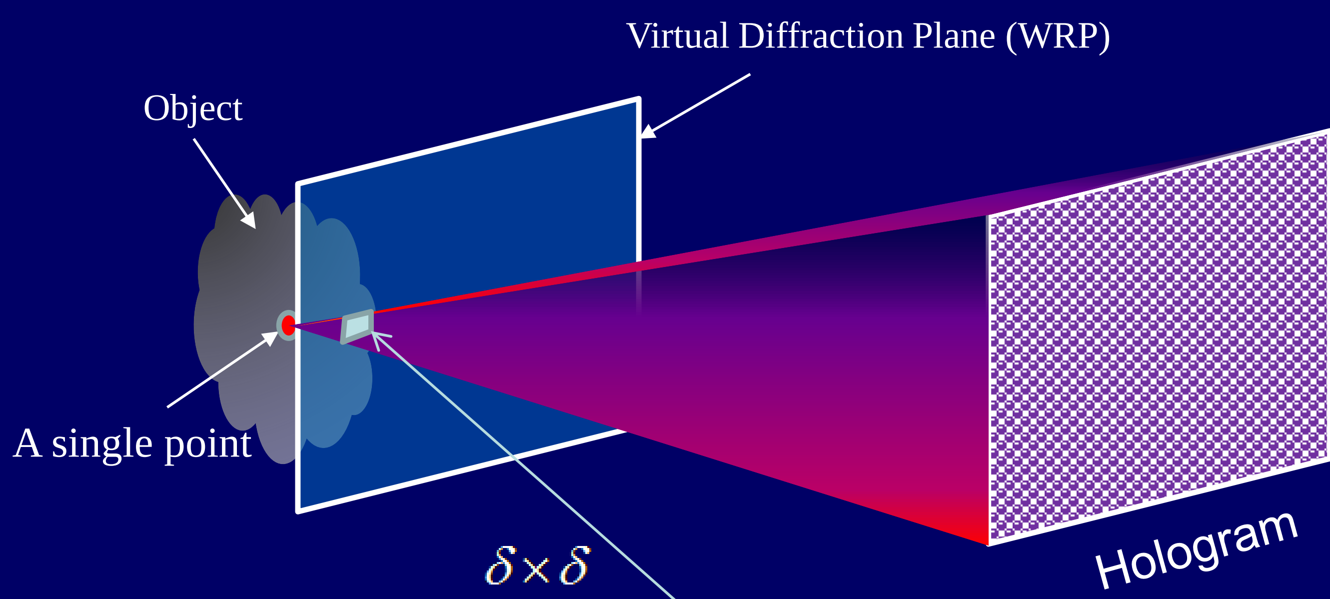
WRP is a hypothetical plane that is close to the object space. Within a short distance, each point contributes to a small region on the WRP

For example, contribution of a single point



T. Shimobaba, N. Masuda, and T. Ito, "Simple and fast calculation algorithm for computer-generated hologram with wavefront recording plane," Opt. Lett. 34, 3133-3135 (2009).

Fast hologram generation: A WRP approach



Generation of entire hologram directly from the object points

Generation of WRP

Support is much smaller than the size of the hologram

$$H(m,n) = \sum_{k=0}^{K} O_k(m,n)$$

$$V(m,n) = \sum_{k=0}^{K} wrp_k(m,n)$$

$wrp_k(m,n)$ is the wavefront of the support for the kth point.

Fast hologram generation: A WRP approach

Step 1: Load the point cloud of a 3D object from a CG model

Step 2: Generate the WRP by summing the wavefront of each point at $(u,v;z_k)$

$$wrp_k(m,n) = FZP(m-u, n-v; z_k)$$

$$where\ u-\frac{\delta}{2} < m < u+\frac{\delta}{2}, \qquad u-\delta/2 < m < u+\delta/2$$

$$V(m,n) = \sum_{k=0}^{K} wrp_k(m,n)$$

Step 3: Convert the WRP image to the hologram

$$H(m,n) = V(m,n) * FZP\left(m,n;z_{vdp}\right)$$

Where z_{wrp} is the distance between the WRP and the hologram

Fast hologram generation: A WRP approach

Fast algorithm employing FFT,

$$[FZP(\omega_m, \omega_n)] = \mathcal{F}[FZP(m, n)],$$

$$[V(\omega_m, \omega_n)] = \mathcal{F}[V(m, n)],$$

$$H(\omega_m, \omega_n) = V(\omega_m, \omega_n) \times FZP\left(\boldsymbol{\omega_m}, \boldsymbol{\omega_n}; \boldsymbol{z_{wrp}}\right),$$ and

$$H(m, n) = \mathcal{F}^{-1}[H(\omega_m, \omega_n)]$$

The forward and backward of the Fourier Transform can be conducted in less than 10ms based on a commodity PC that is equipped with a graphic processing unit (GPU).

Trading off computation time with image quality

Computation is heavy if there are lots of object points, i.e. large value for *K*.

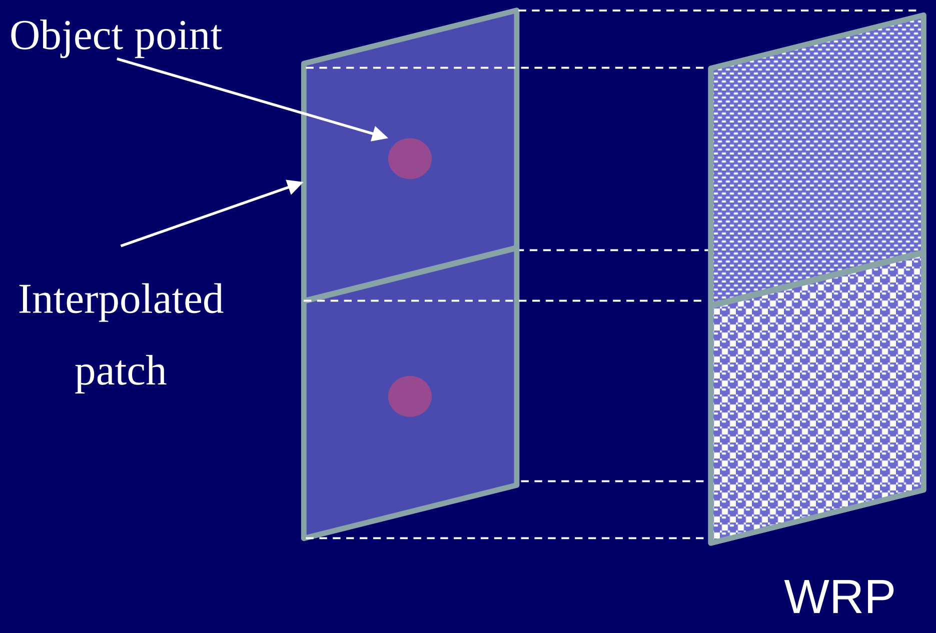
$$V(m,n) = \sum_{k=0}^{K} wrp_k(m,n)$$

To decrease the computation time, the object image is down-sampled. However this leads to a sparse image that is dim in appearance.

Down-sampled by 2 along horizontal and vertical directions. Object points reduced by 4 times.

Trading off computation time with enhanced image quality: Interpolative WRP (IWRP)

1. Interpolate each object point image to its support area.
2. Compute the optical wave to the corresponding support on the WRP.
3. Supports are non-overlapping with each other.
4. Expand the WRP to the hologram.



Trading off computation time with enhanced image quality: Interpolative WRP (IWRP)

Computation is reduced through down-sampling the object image, i.e. less object points.

$$V(m,n) = \bigcup_k iwrp_k(m,n)$$

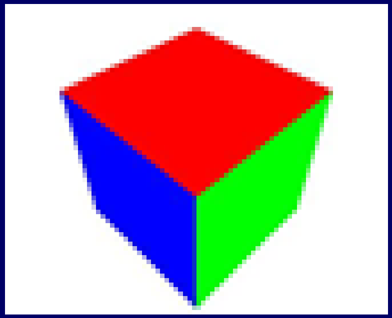
A union operator is used as the interpolative wrps (*iwrp*) are non-overlapping.

Image quality is enhance with interpolation.

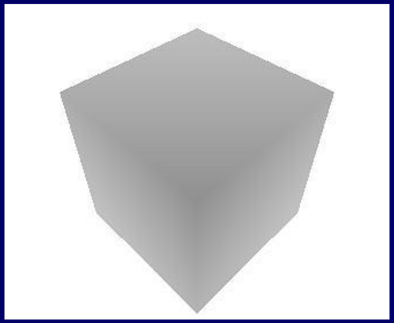
Down-sampled by 2 along horizontal and vertical directions, following by interpolation. Object points reduced by 4 times, but quality is good apart from slight blurring.

Example on a color hologram generated with the 2D+depth and IWRP method

Color and depth map of the point cloud image of a cube, derived from the CG model below



Color map



Depth map

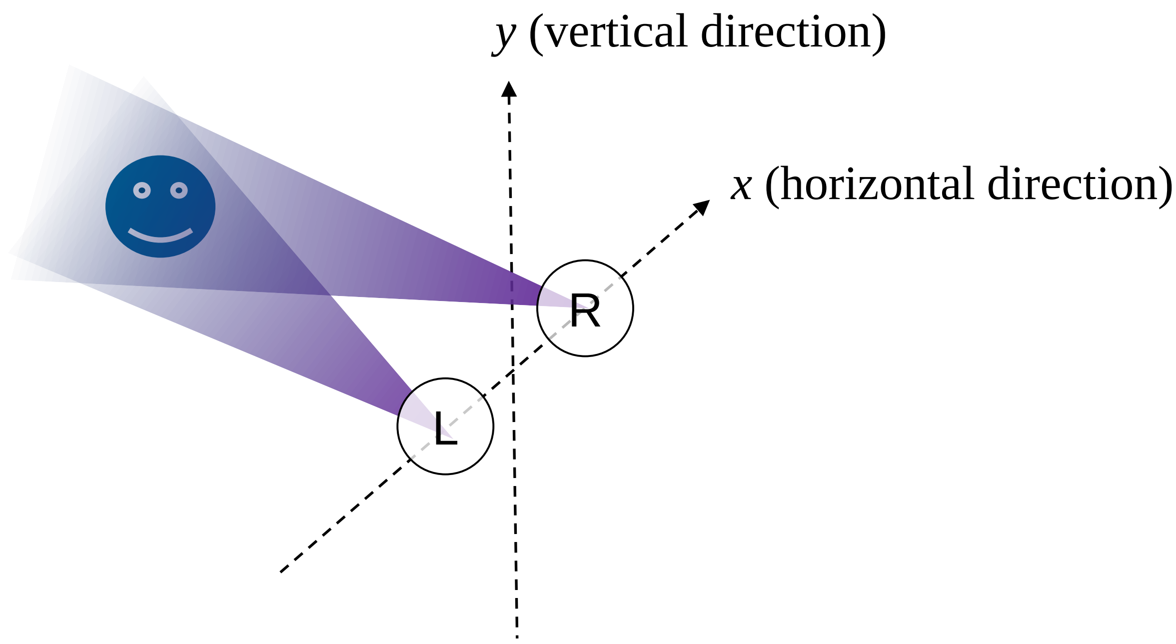
Color hologram generated with the WRP method, and display with a high resolution LCoS device

Example on a color hologram generated with the IWRP method

Color holograms of different views of an earth model, generated with the WRP method, and display with a high resolution LCoS device

Sub-line method

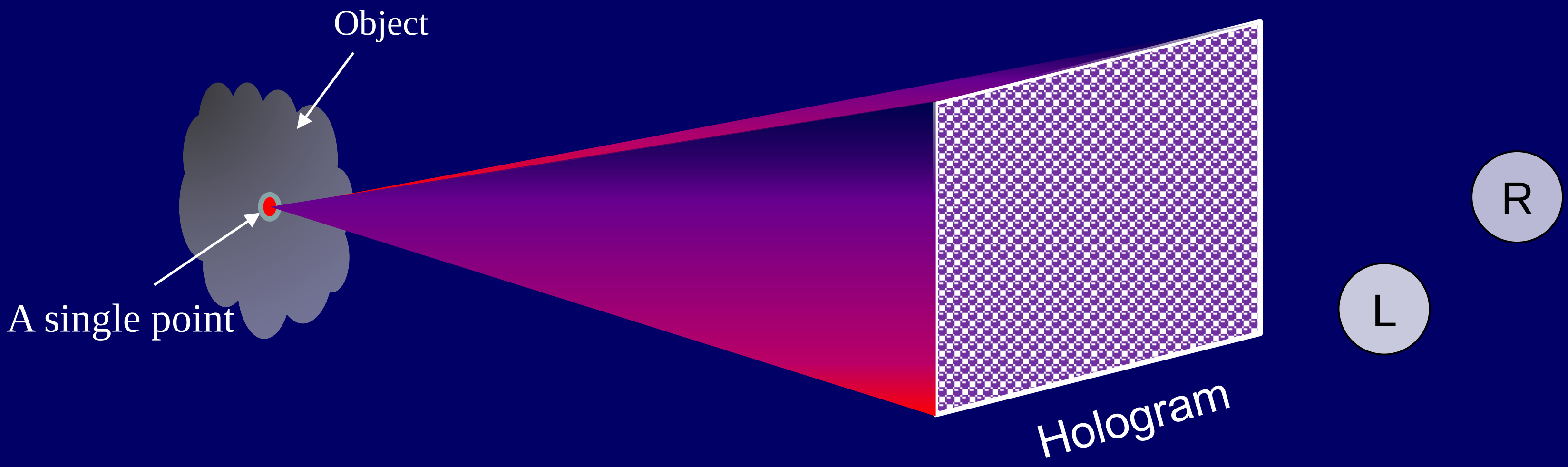
- For most of the time, we maintain horizontal eye level in viewing.
- Panning horizontally to observe different views of a 3D scene along the horizontal direction.
- Occasionally, move up and down to observe different views of a 3D scene along the vertical direction.



A hologram preserve optical waves of a 3D object from all directions, but we are interested in only the change in view horizontally for most of the time.

Hologram Generation

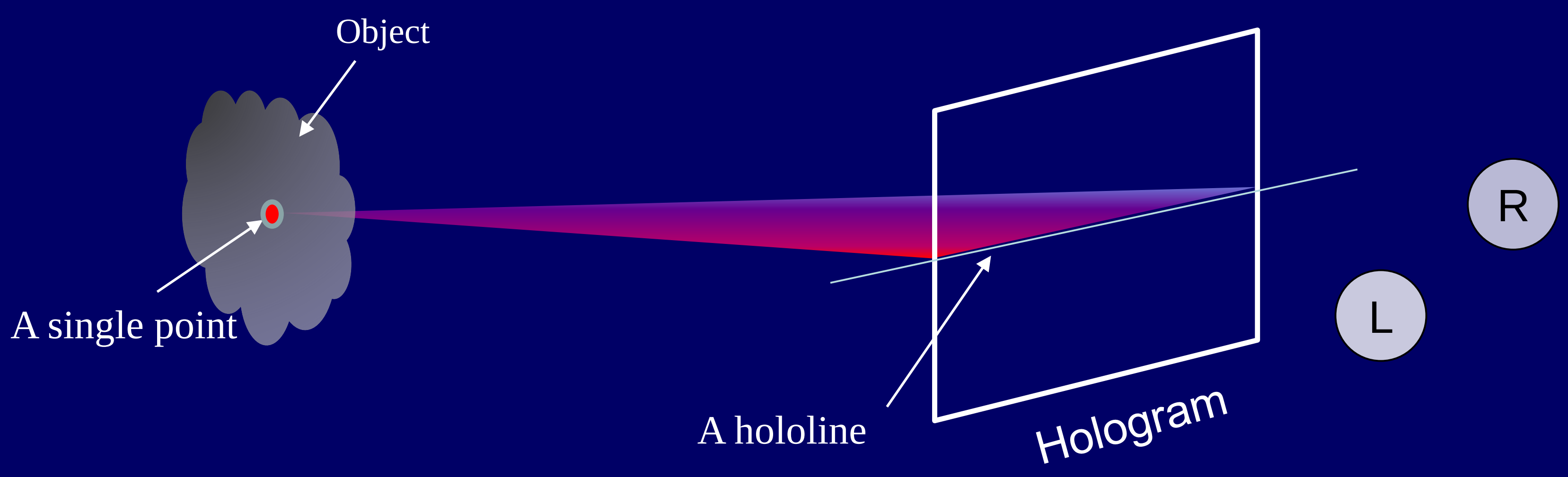
To compute the optical wavefront for the entire hologram is large, even for a single point.



But are all the calculations necessary if we are not interested in the change in view vertically?

Hologram Generation

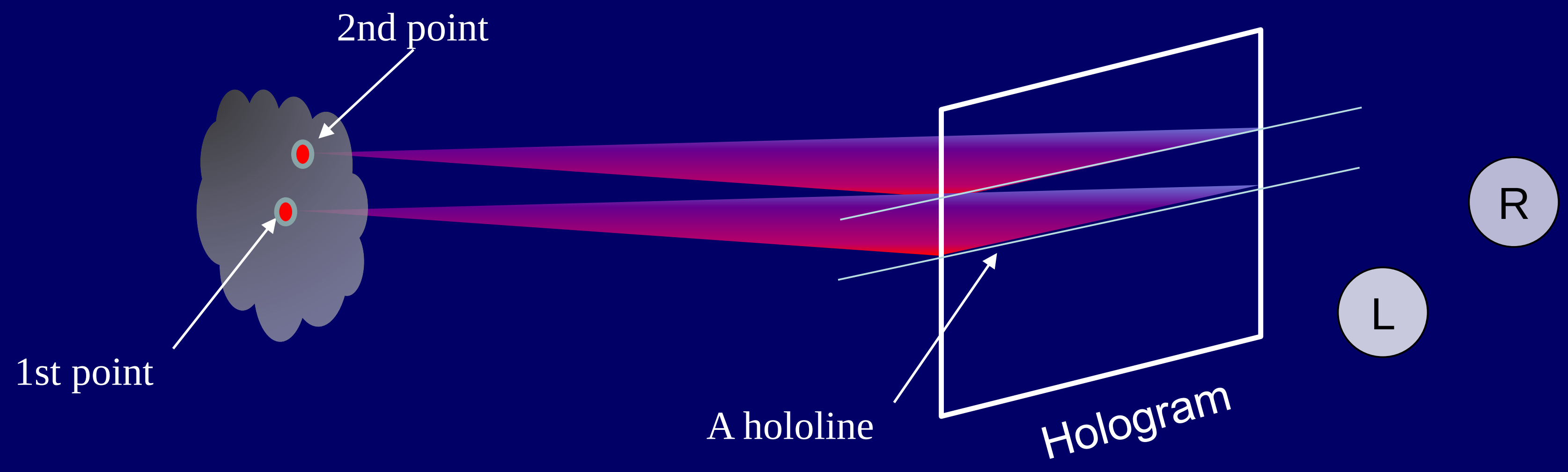
To compute the optical wavefront for the entire hologram is large, even for a single point.



A single hologram line can represent different views of the object point along the horizontal direction. However, there is no change in view as the eye level moves vertically. Computing a single hologram line involves much less operations.

Hologram Generation

If there is another point at a different vertical direction, simply add another hololine.

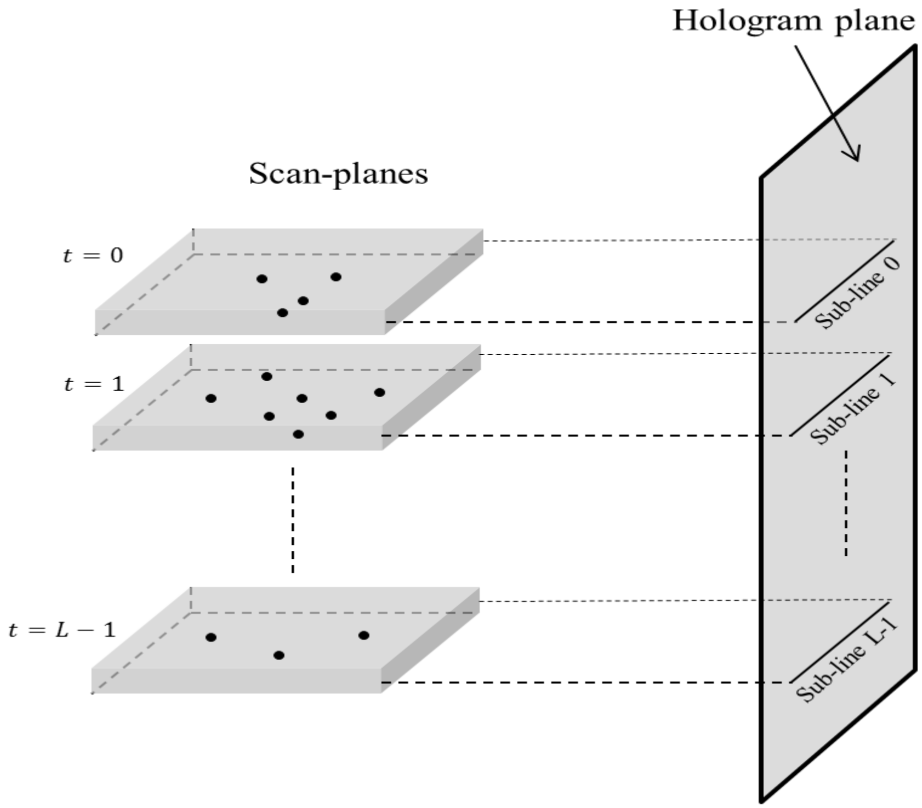


If there are more than one points on the same horizontal level, accumulate their optical waves on the corresponding hololine.

Sub-line method

- Partition the object space into a vertical stack of horizontal scan-planes.
- Generate a 1-D hologram sub-line for each scan-plane.
- The data-size of the hologram sub-lines is much smaller than that of a hologram, hence can be transmitted at lower data-rate.

- At the receiving end, a 2-D hologram is generated from the sub-lines.



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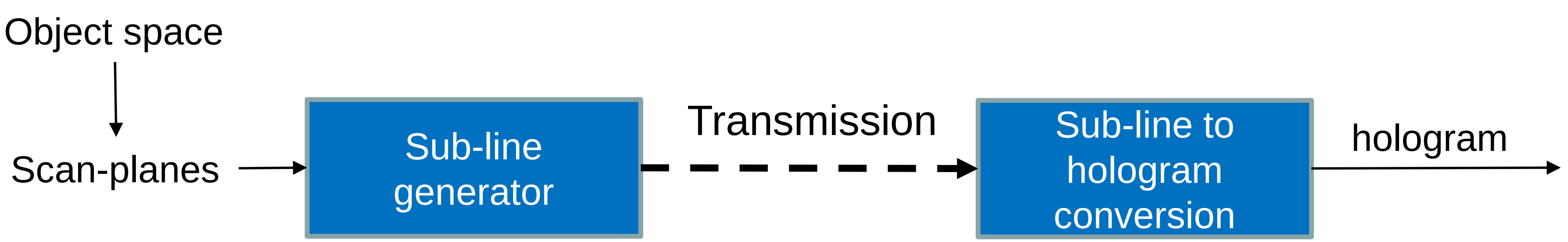

A video holography framework based on sub-lines

P.W.M. Tsang, J.-P. Liu, W. Cheung, and T.-C. Poon, "Fast generation of Fresnel holograms based on multirate filtering," Appl. Opt. 48, H23-H30 (2009).

P.W.M. Tsang, J.P. Liu, K.W.K. Cheung, and T.-C. Poon, "An enhanced method for fast generation of hologram sub-lines", Chinese Opt. Lett. 7, pp. 1092-1096 (2009).