

Computational Photography

- * Study the basics of computation and its impact on the entire workflow of photography, from capturing, manipulating and collaborating on, and sharing photographs.

Light Fields

- * Introducing the Concepts of a Light Field and the PLENOPTIC Function
- * How can we capture a Light Field?



Lesson Objectives

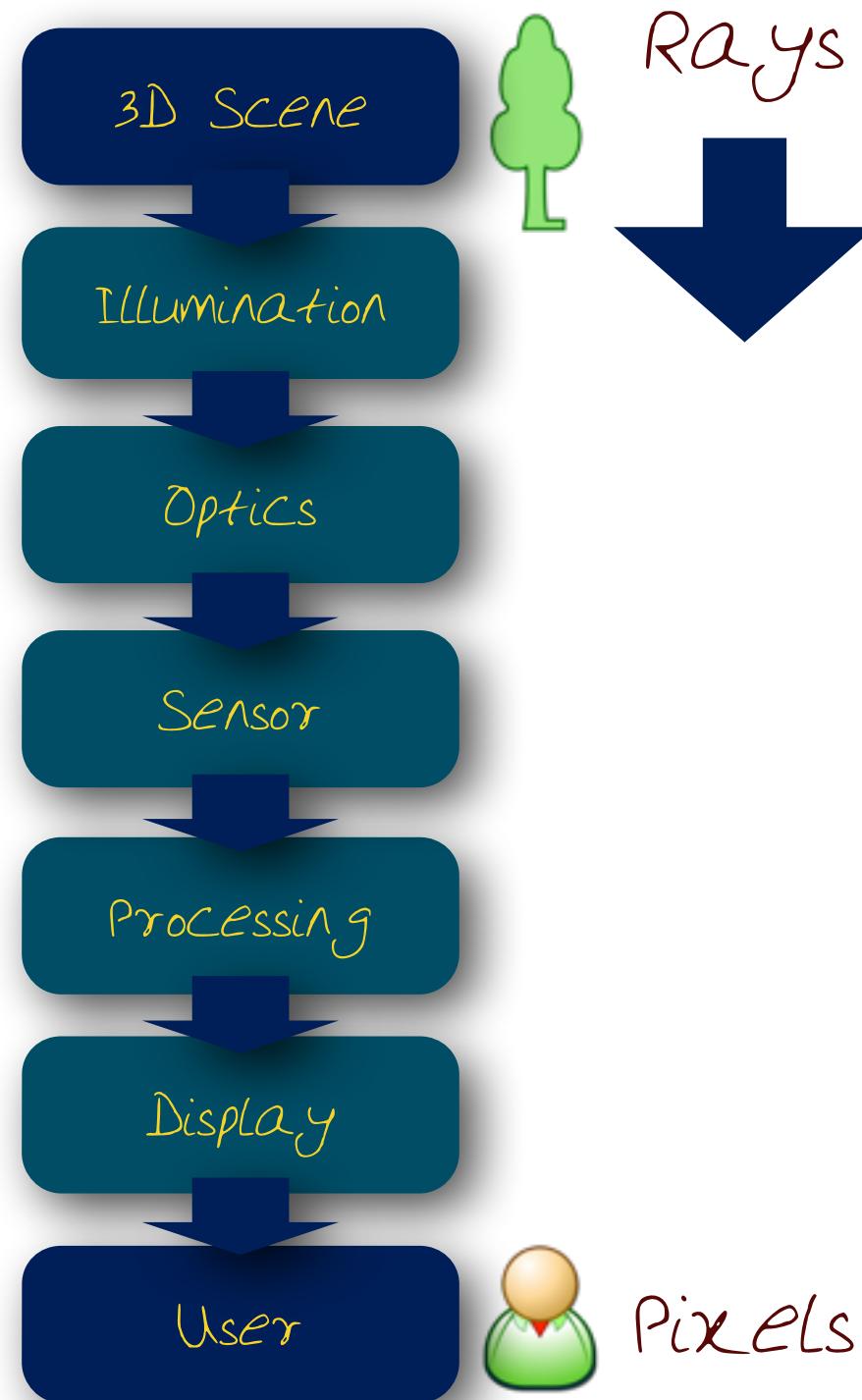
1. Concept of a Light Field
2. Seven parameters of the Plenoptic Function
3. Different types of Light Fields



Lesson Objectives

4. Scene viewed from a pinhole and a lens system
5. Use of an eccentric aperture on a simple lens system
6. An array of pinhole cameras
7. A 4D Light Field camera

Recall: Photography (Light Rays)

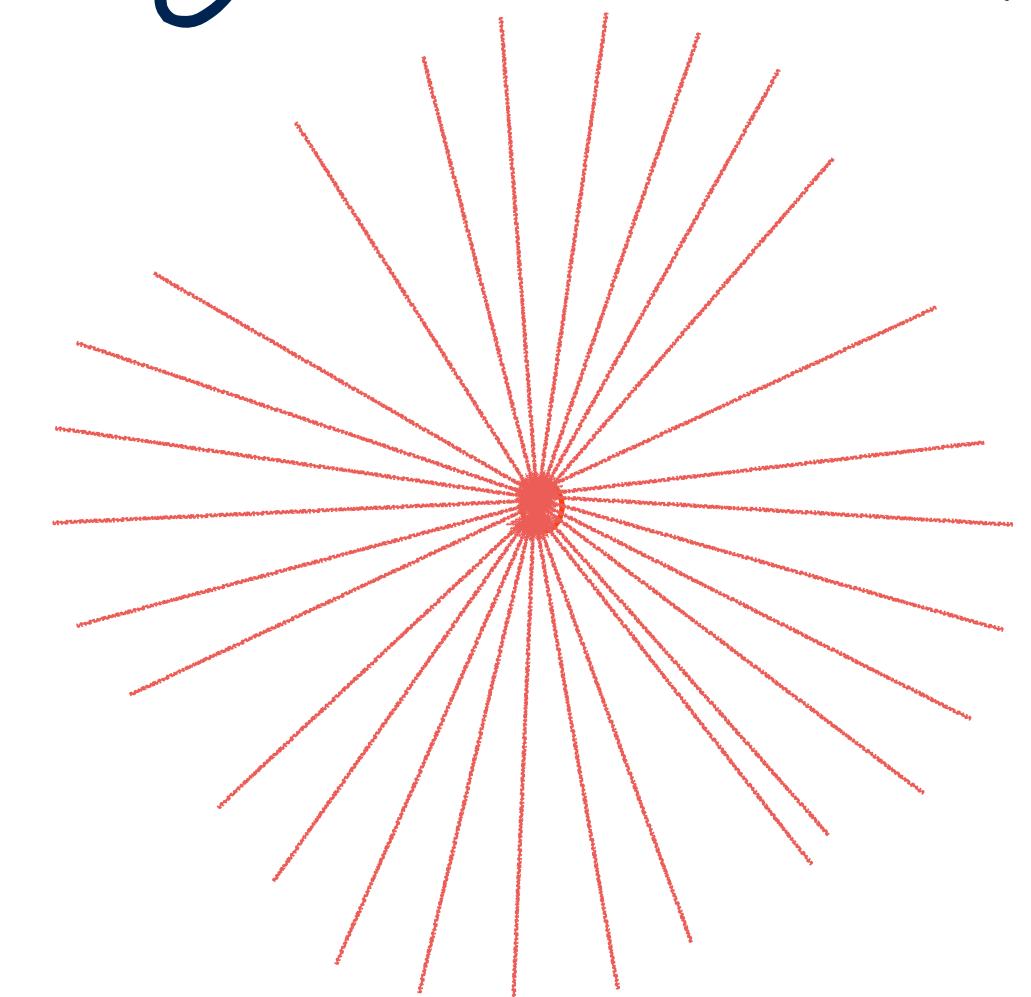
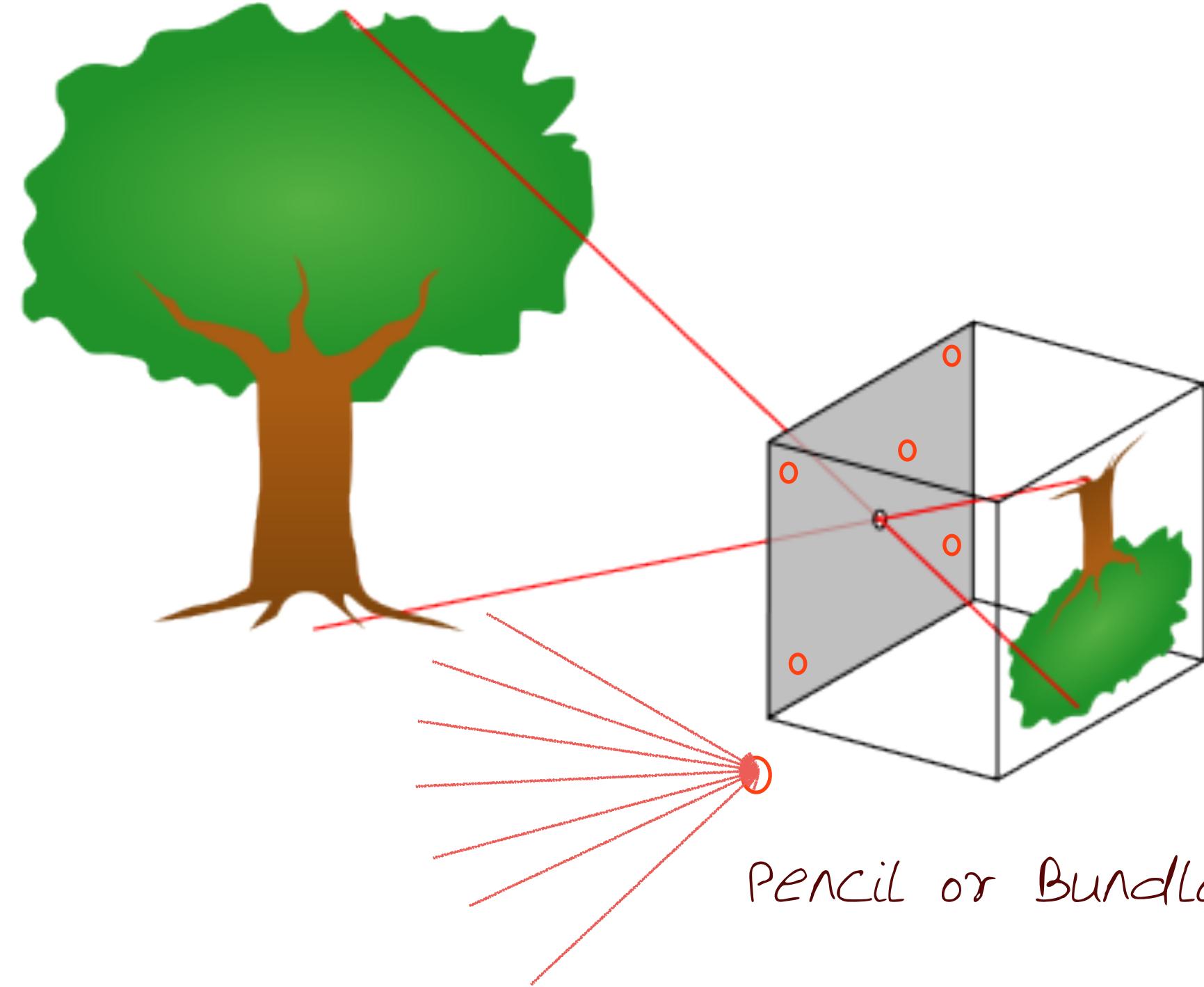


- * Image of a scene using 2D array of pixels
- * Rays of Light are the fundamental primitives
- * Illumination (Light Rays) follows a path from the scene to the sensor
- * Computation adaptively controls the parameters of the optics, sensor and illumination

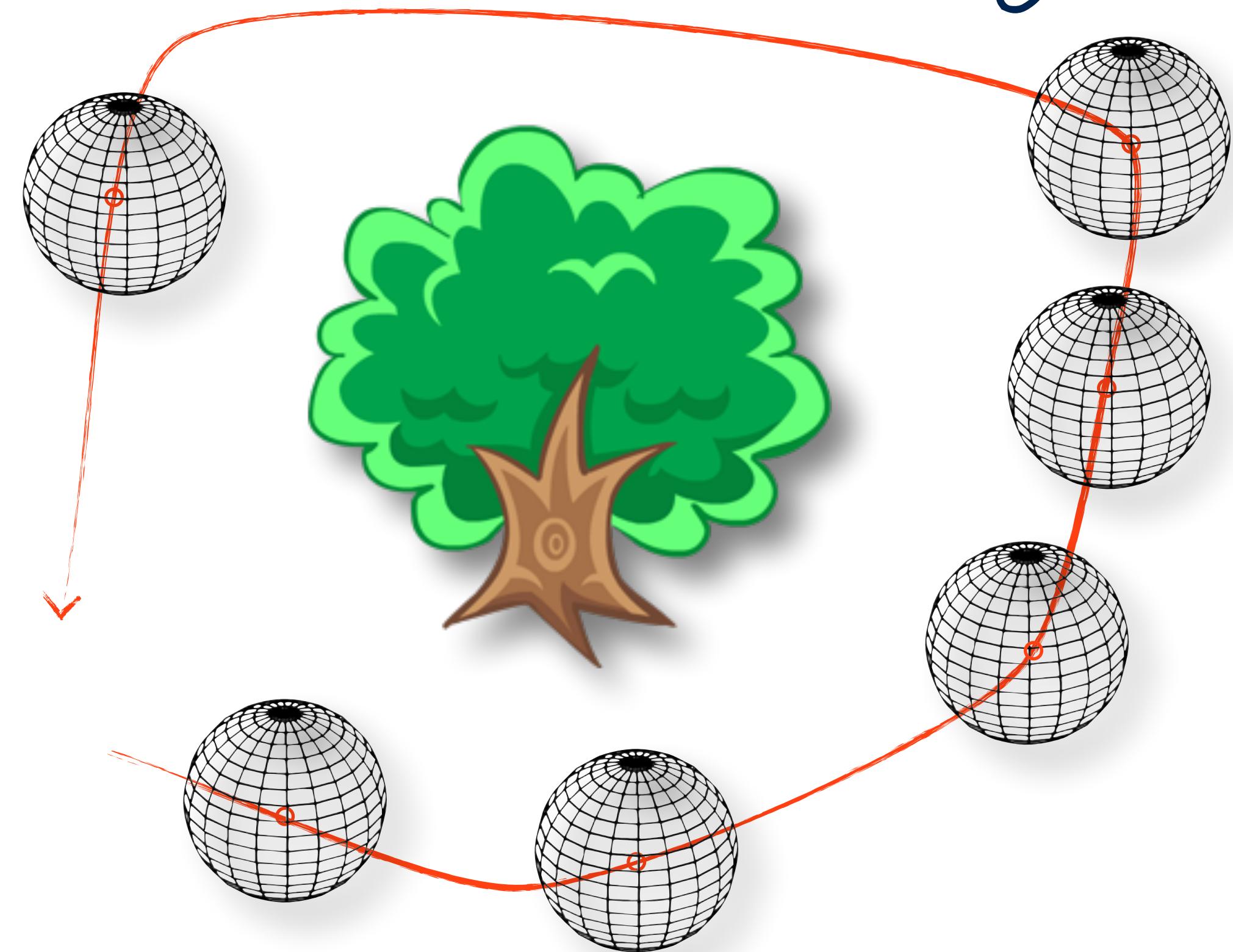
Is this limiting?

Can we not be just stuck with pixels at the end?

Pinhole Camera and a Light Field

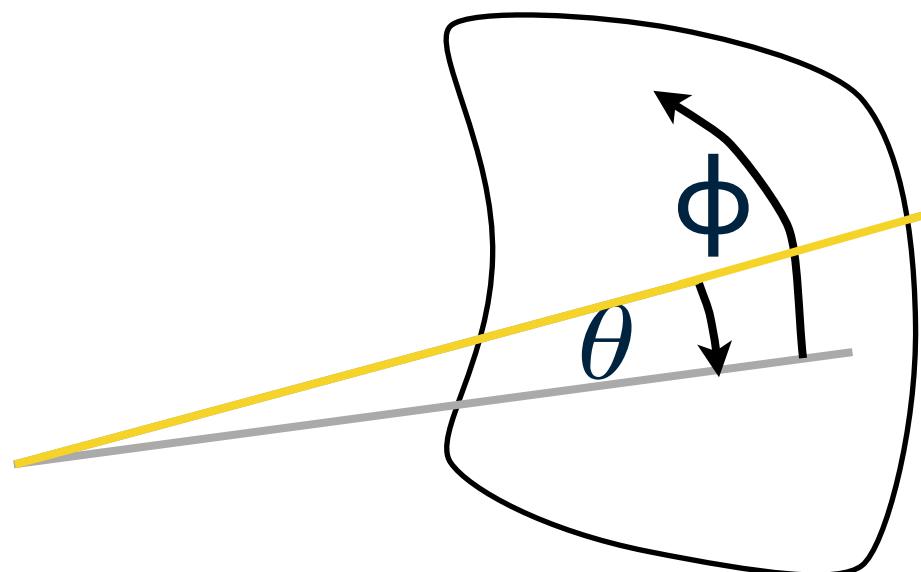


Pinhole Camera and a Light Field

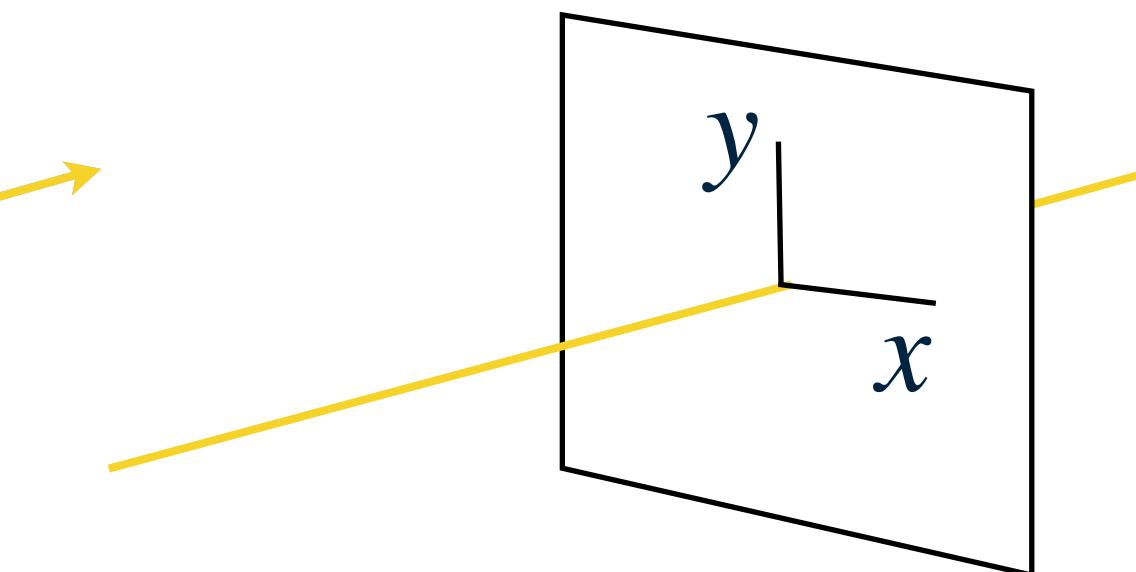


Parameterizing the Light Field

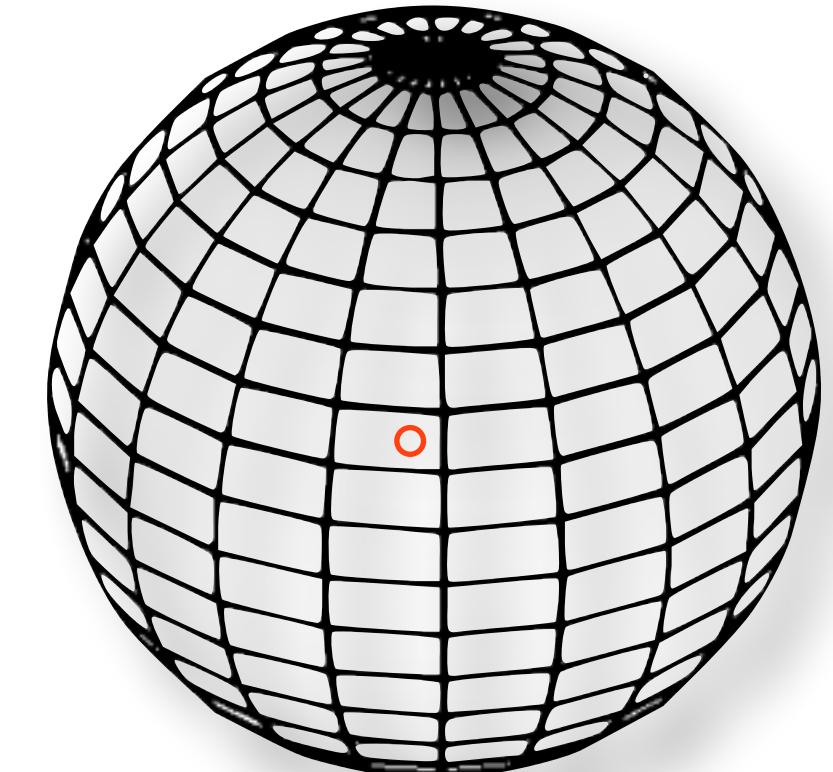
Say P is the intensity distribution at that point



$$P(\theta, \phi)$$



$$P(x, y)$$



Light has color (wavelength), so need λ

And, scenes change over time, so need t

$$P(\theta, \phi, \lambda, t)$$

$$P(x, y, \lambda, t)$$

Parameterizing the Light Field

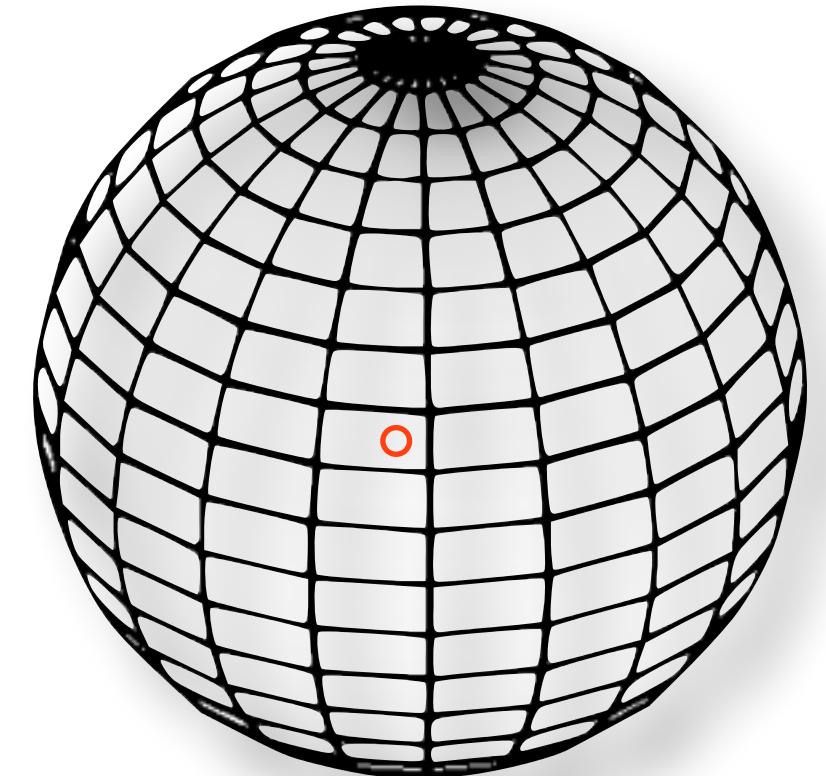
Say V_x, V_y, V_z is the position of the viewing point

$$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$$

$$P(x, y, \lambda, t, V_x, V_y, V_z)$$

$$P(\theta, \phi, \lambda, t)$$

$$P(x, y, \lambda, t)$$

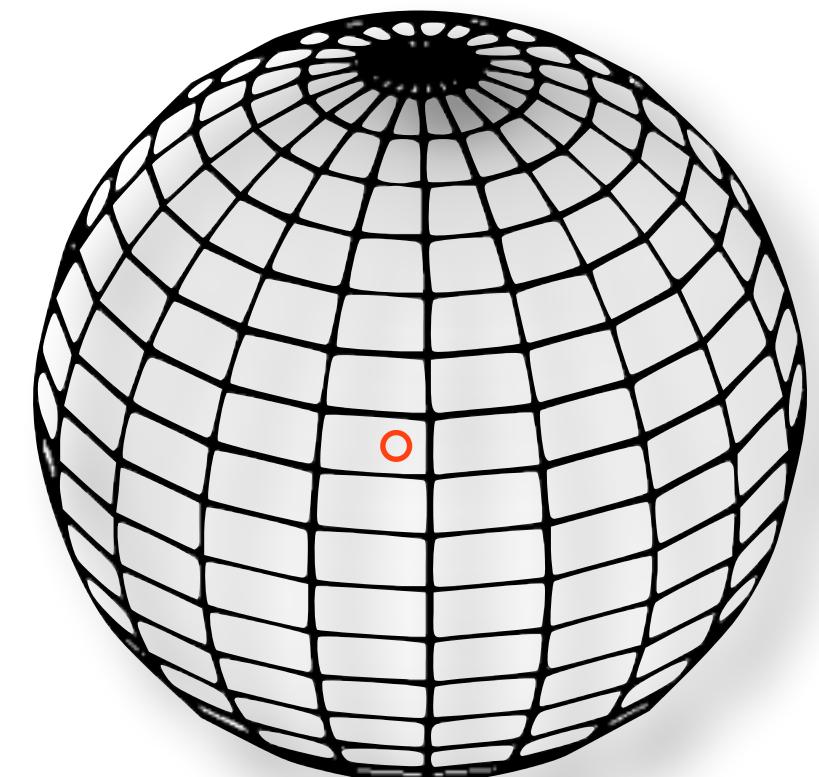


The Plenoptic Function

Introducing the Plenoptic Function, P_f

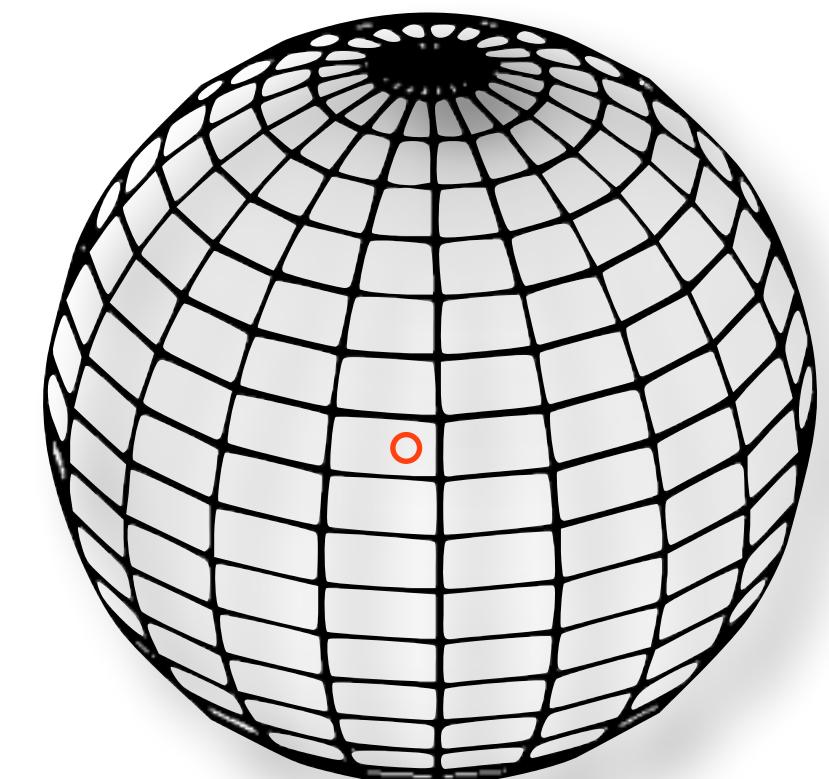
$$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$$

$$P(x, y, \lambda, t, V_x, V_y, V_z)$$



The Plenoptic Function, P_f , is measured in an idealized manner by placing an eye at every possible location in the scene (V_x, V_y, V_z) and recording intensity of light rays, wavelength λ , at time t , at every possible angles (θ, ϕ) (around V_z) or in terms of (x, y)

The Plenoptic Function



$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$ (Latin) plenus (full) + optic
"Of or relating to all the light, traveling in every direction in a given space."

Plenoptic OR Light-field Camera

A camera that can capture a Light-Field, and render to Pixels as needed

Adelson and Bergen (1991)

Light Fields (7-D)

$$P(\theta, \phi, \lambda, t, V_x, V_y, V_z)$$

- * 7 Dimensions
- * Complete scene;
holographic video



Star Wars (1977)

Light Fields (5-D)

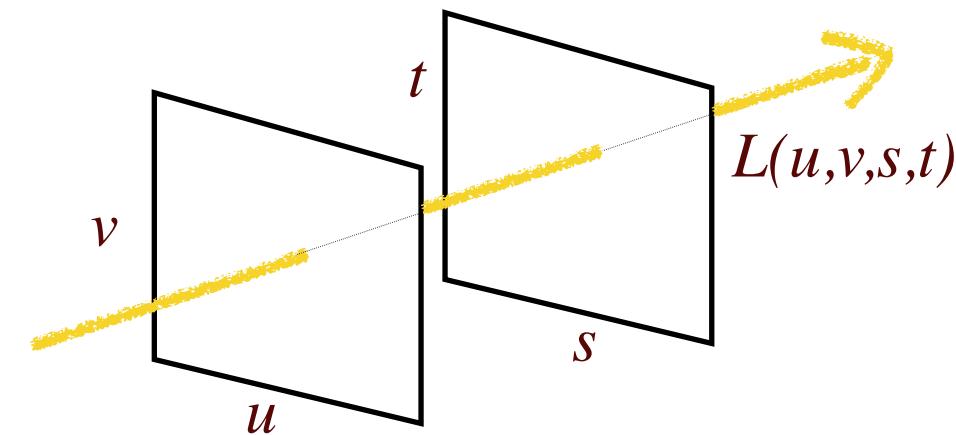
$$P(\theta, \phi, V_x, V_y, V_z)$$

- * 5 Dimensions
- * Ignore time and wavelength
- * Capture only viewpoint and direction



Light Fields (4-D)

$$P(\theta, \phi, V_x, V_y, V_z)$$

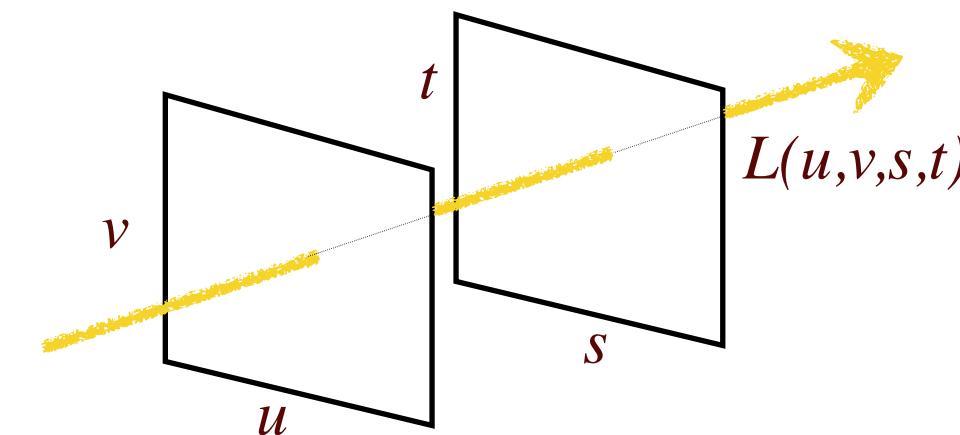


- * 4 Dimensions
- * Within a bounding box. (Space of all lines in 2D space is 4D)
- * No occluding objects, with viewpoint and direction

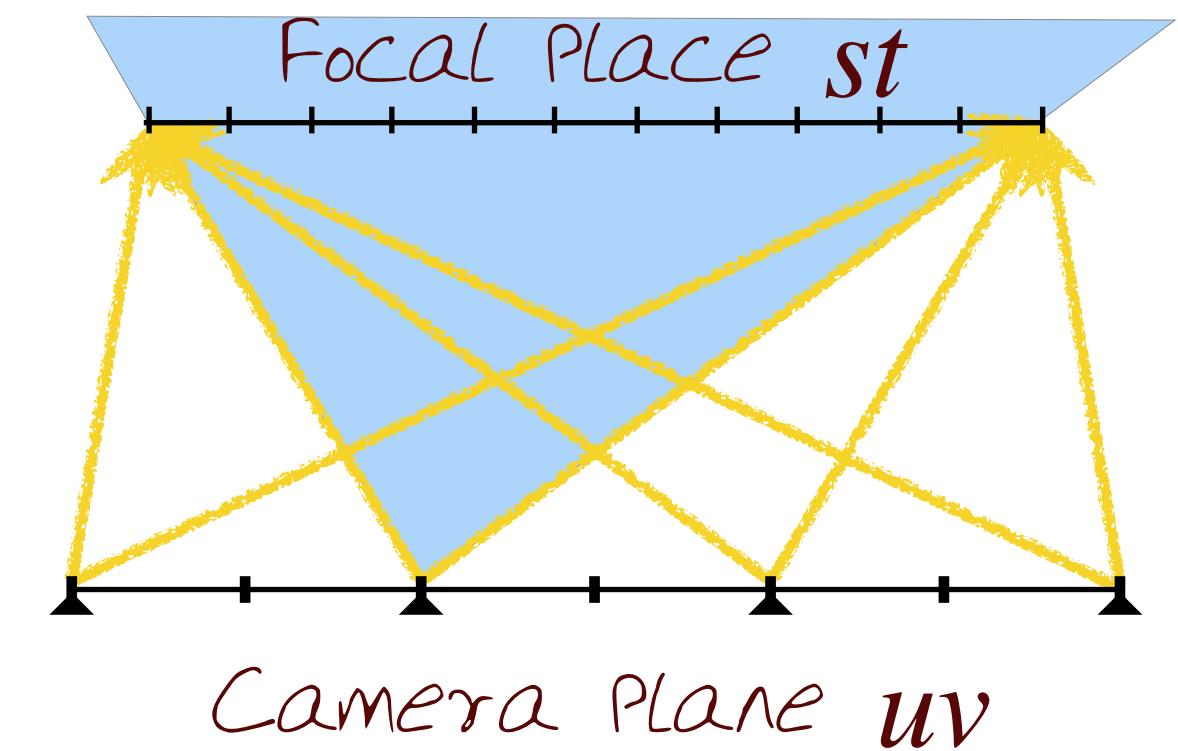
Any point within a scene is represented by a 5D plenoptic function. Outside of a scene (outside of the sphere of a snow globe) light from the scene does not get occluded by objects, and is represented, as a 4D light field.

Light Fields (4-D)

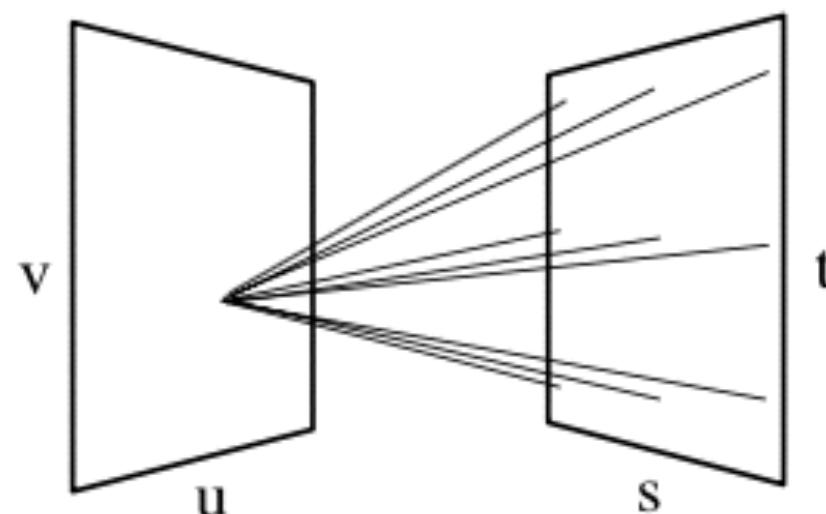
$$P(\theta, \phi, V_x, V_y, V_z)$$



- * Two plane Parameterization for Light Slab/Beam
- * Light flows from uv to st plane
- * Parameters uv and st between 0 and 1



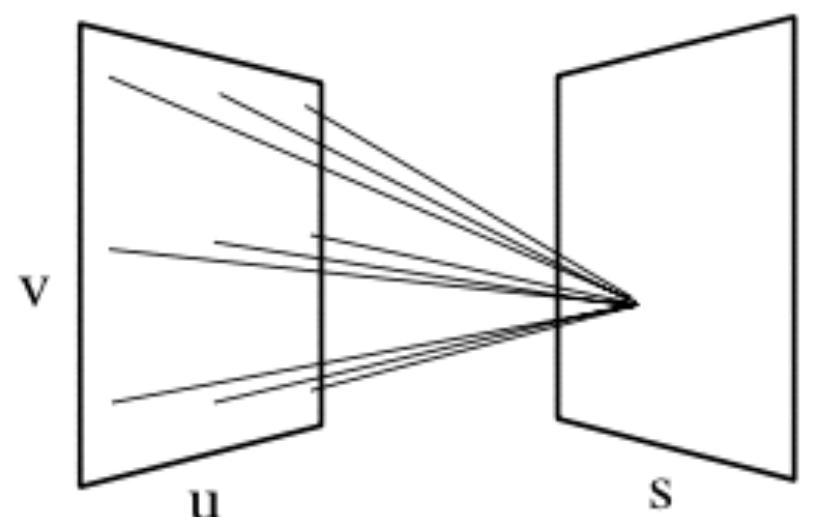
Visualization of a Light-Field (a)



Rays arriving at one point on the uv plane from all points on the st plane

Levoy & Hanrahan (1996)

Visualization of a Light-Field (b)



Rays leaving at one point on the st plane bound for all points on the uv plane

Levoy & Hanrahan (1996)

Capture a Light-field, Store and Render

$$P(\theta, \phi)$$

- * 2 Dimensions
- * At the same viewpoint
- * Panorama



Examples

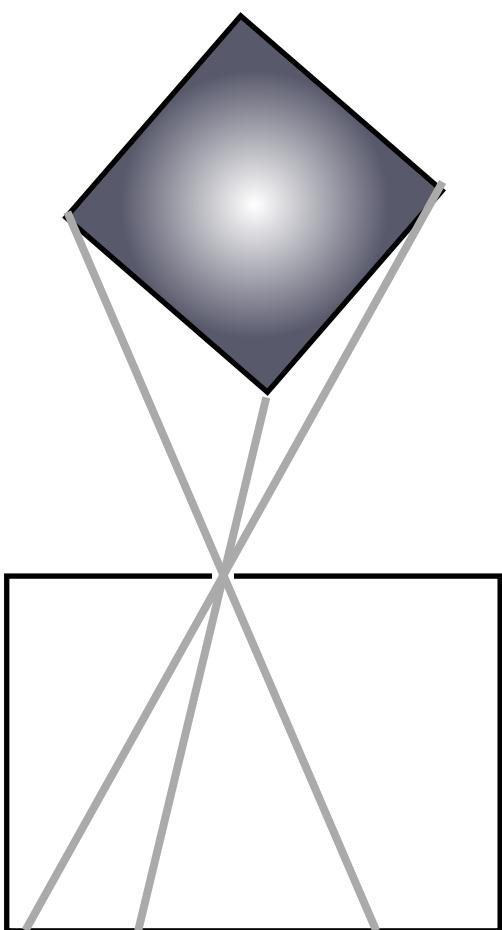


Google Street Views

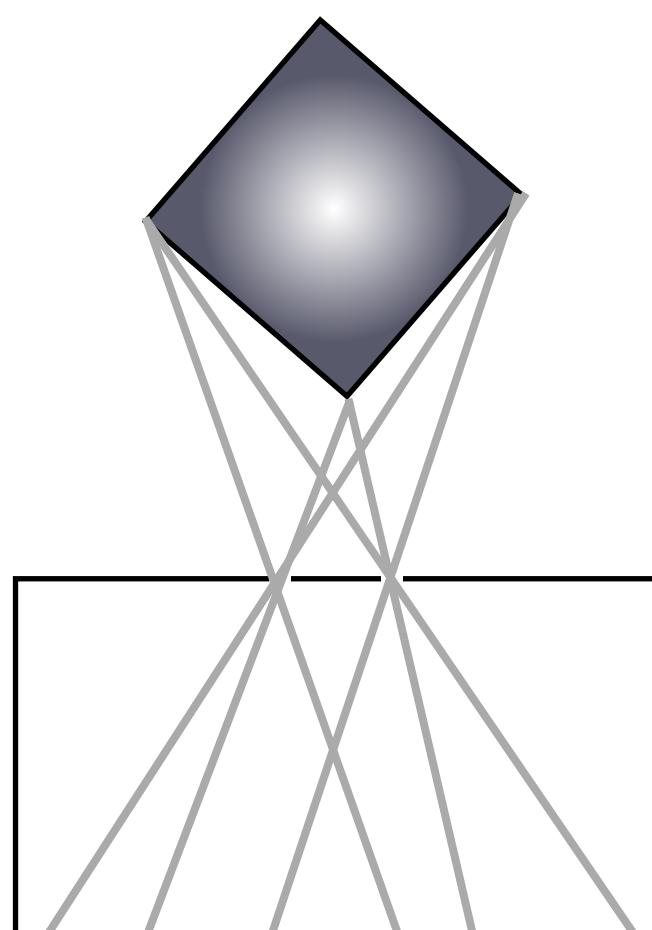
But not just images, they use Geometry too.

Can you think of others?

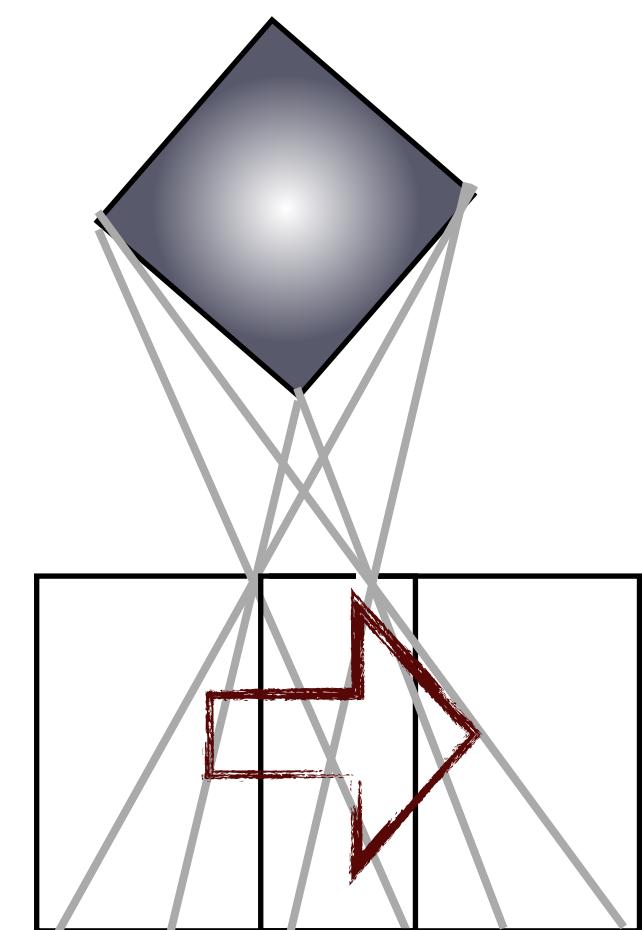
Light field via a PinHole Camera



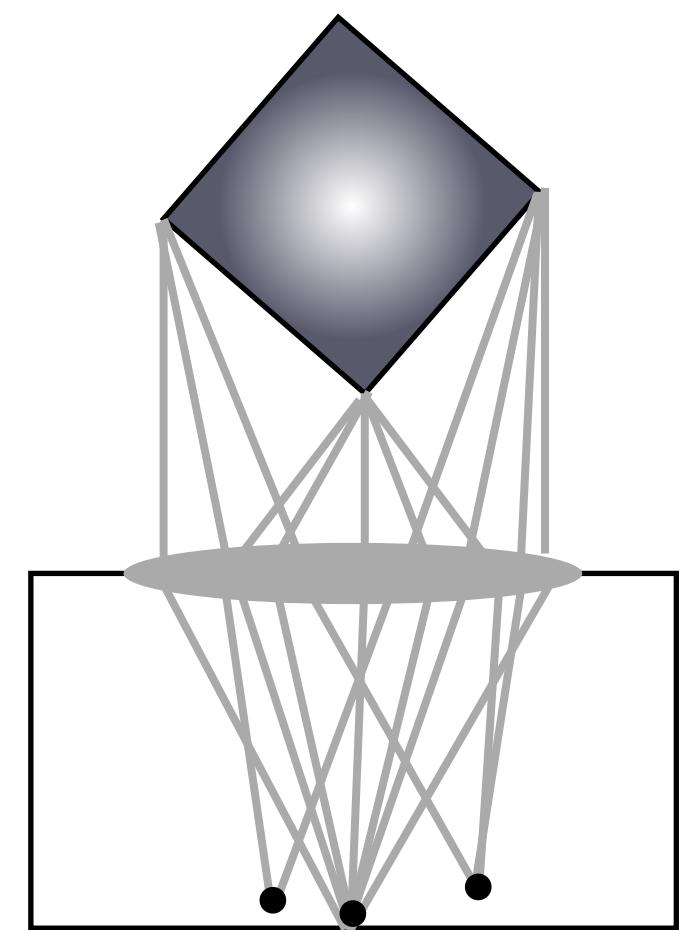
Single Pinhole



Double Pinholes



Motion Parallax

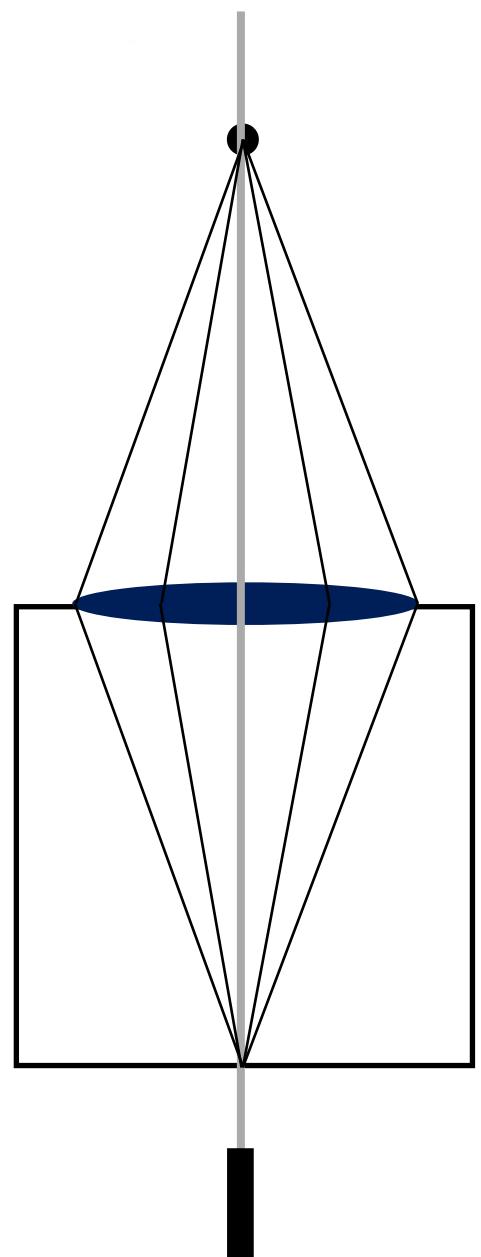


With Lens

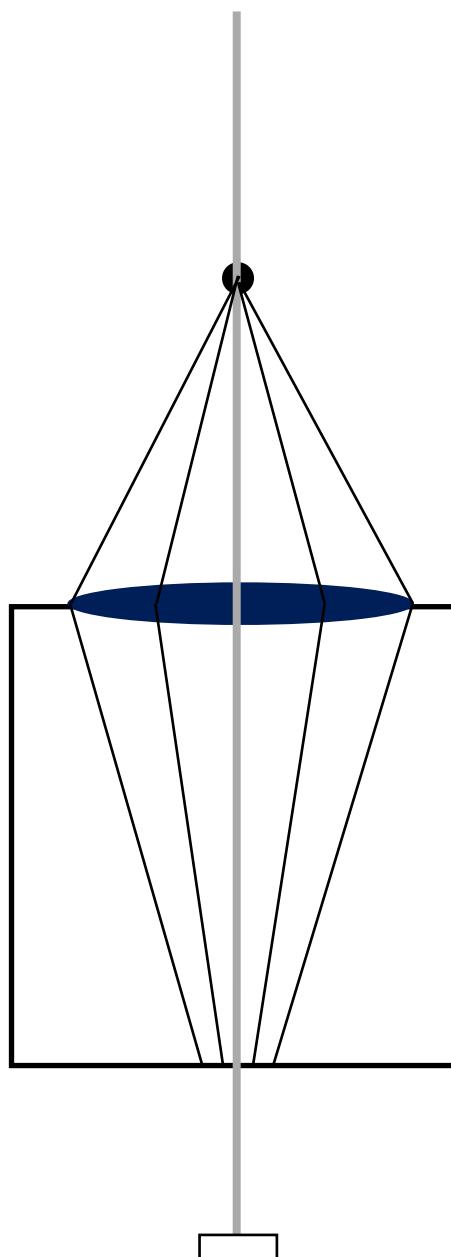
Adelson and Wang (1991)



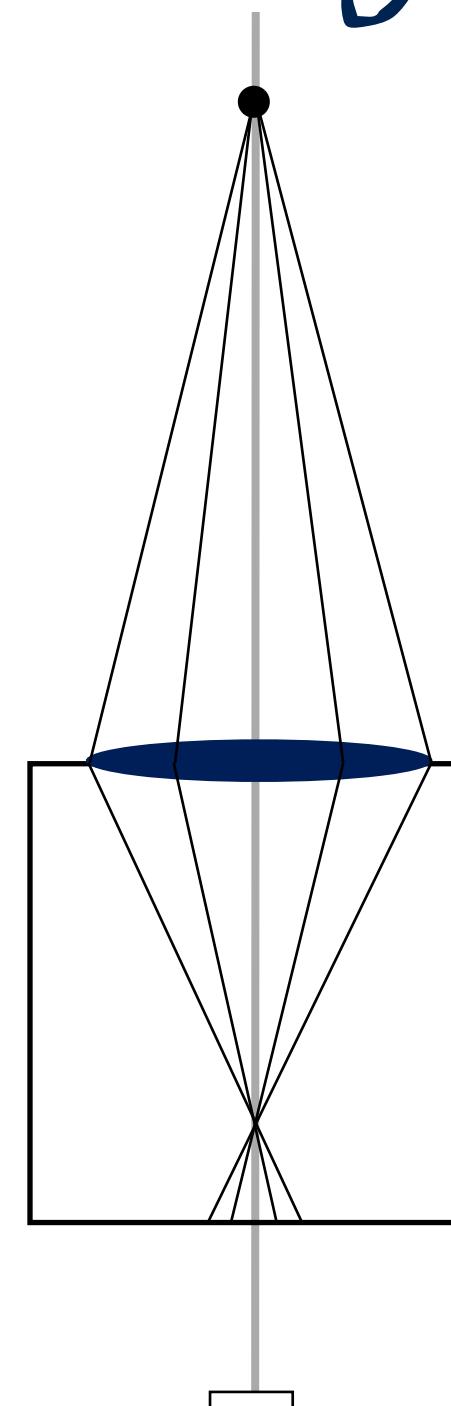
Single Lens System (I)



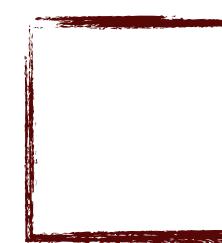
(1)



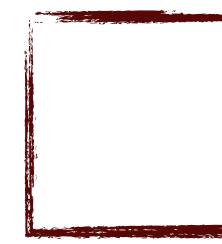
(2)



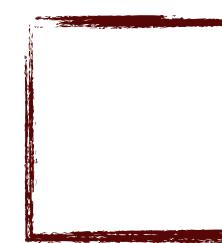
(3)



Near object;
blurred

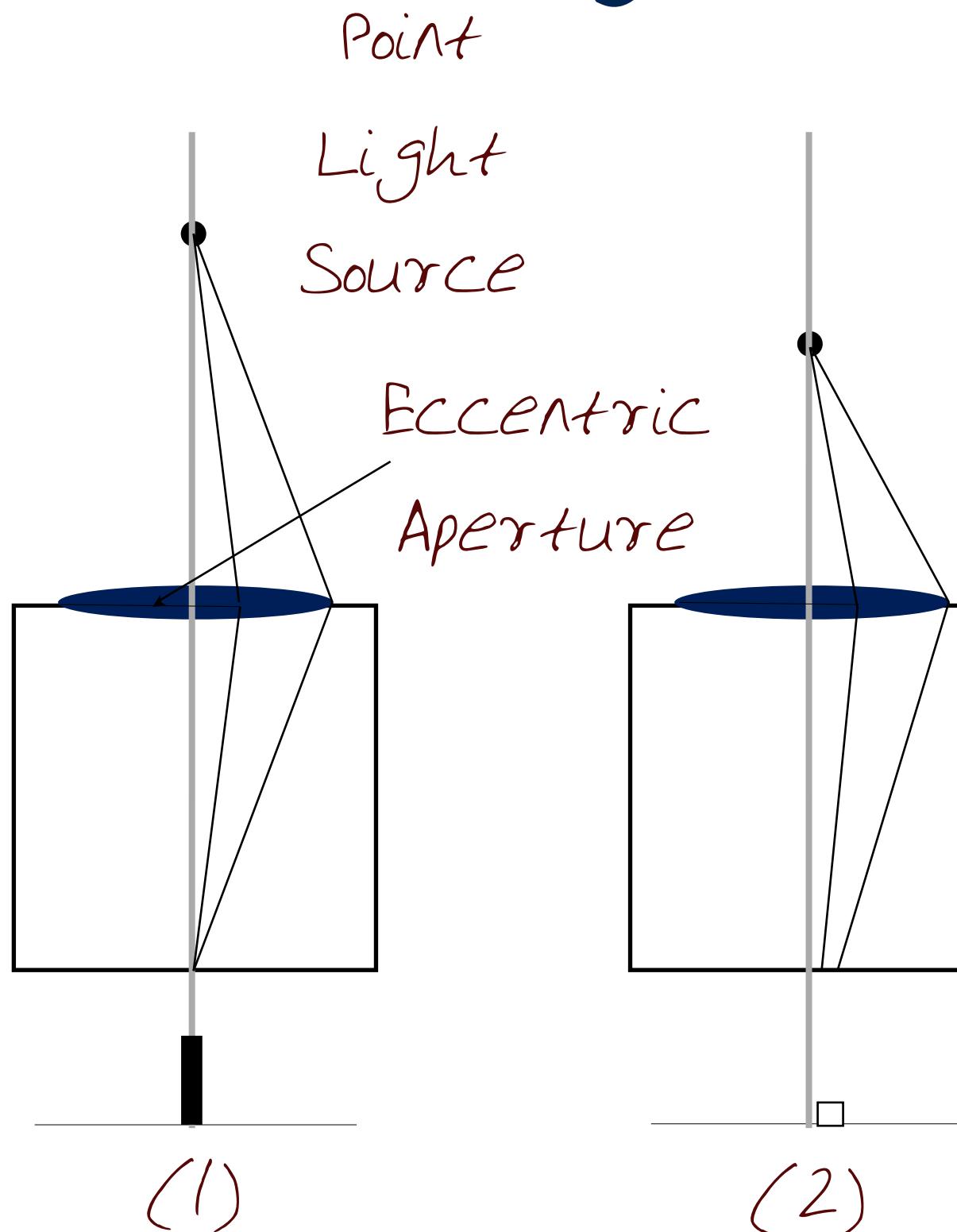


Far object;
blurred



In-focus object;
point image

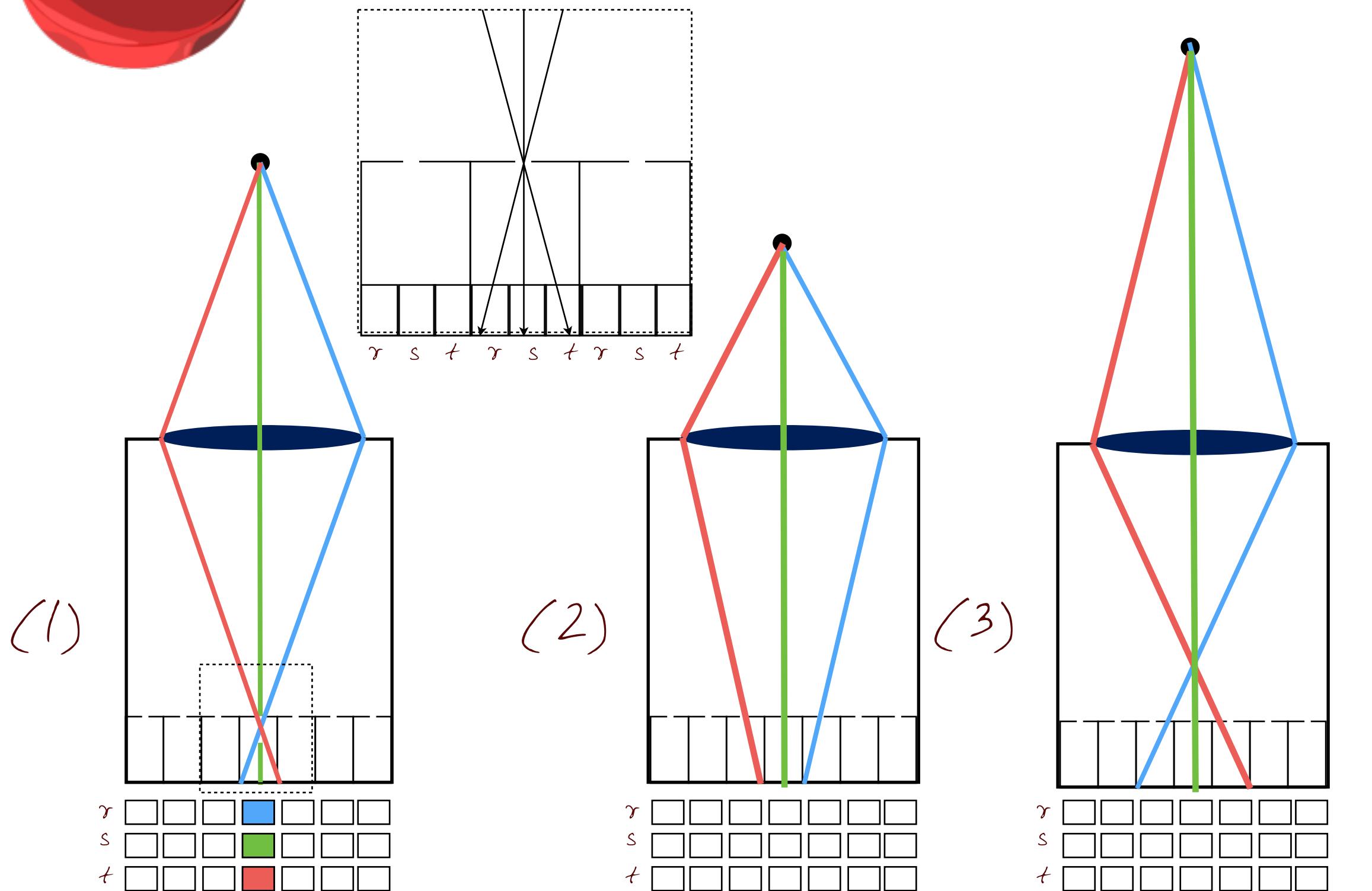
Single Lens System (2)



1. In-focus object;
forms a Point Image
2. Near object;
blurred, to the right
3. Far object;
blurred, to the left

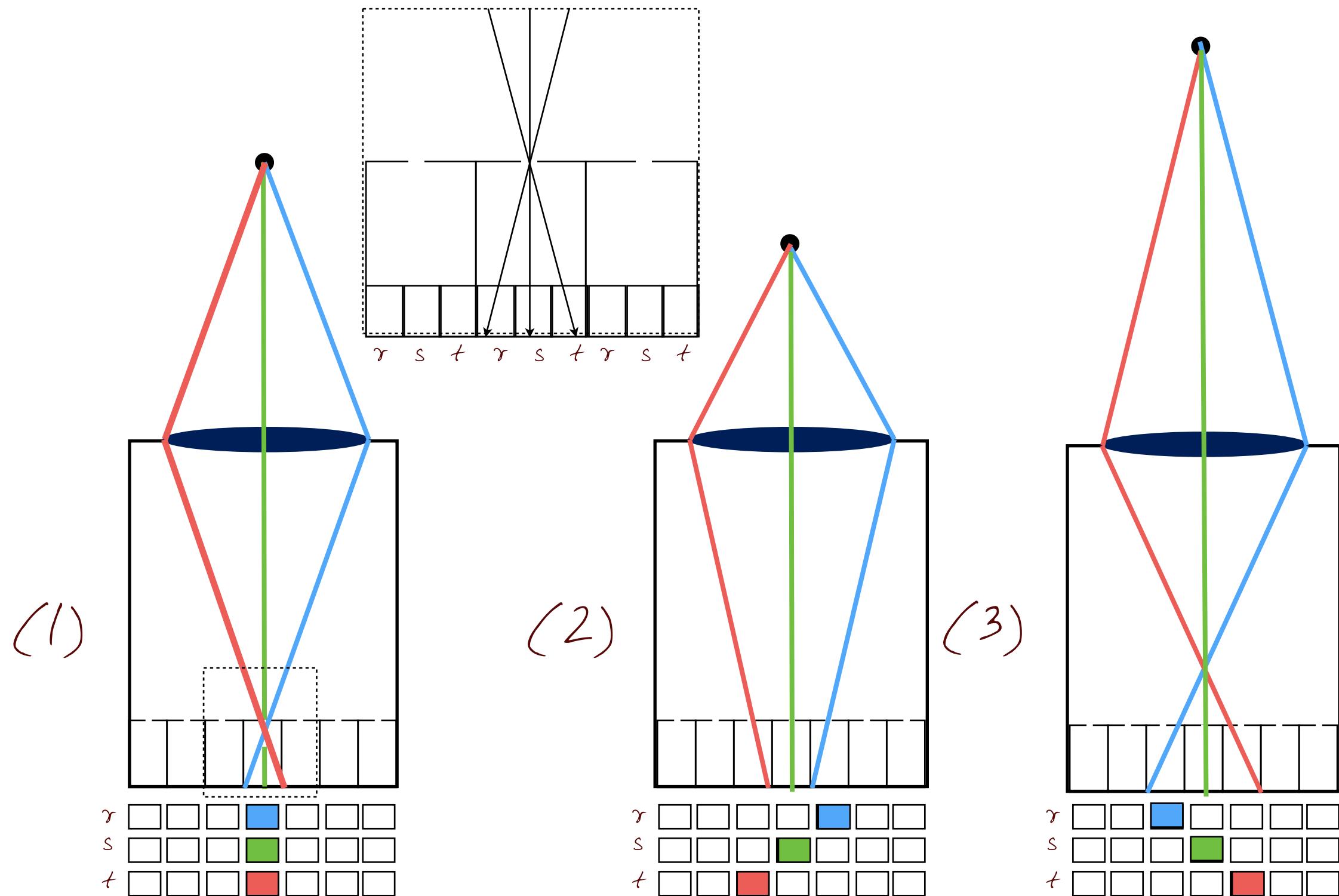


Encode Direction and Intensity



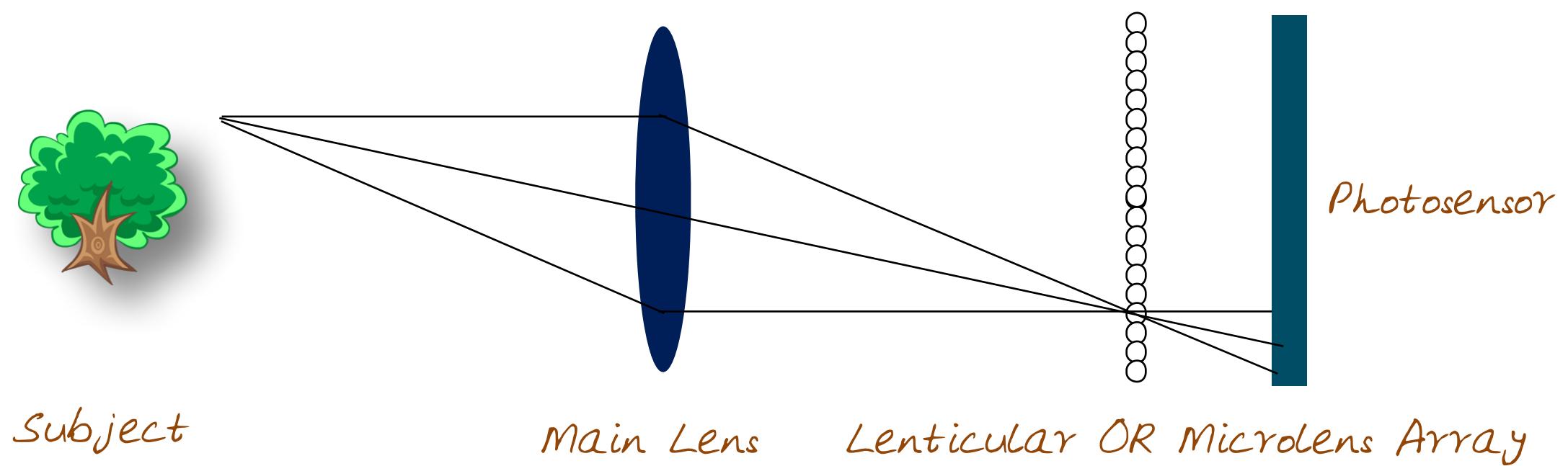
Select which
rst will be
highlighted
for (2) and
(3)?

Encode Direction and Intensity



- * We add a miniature pinhole at the image plane
- * Analyzes the structure of light at each macro-pixel.

Lens and Microlens

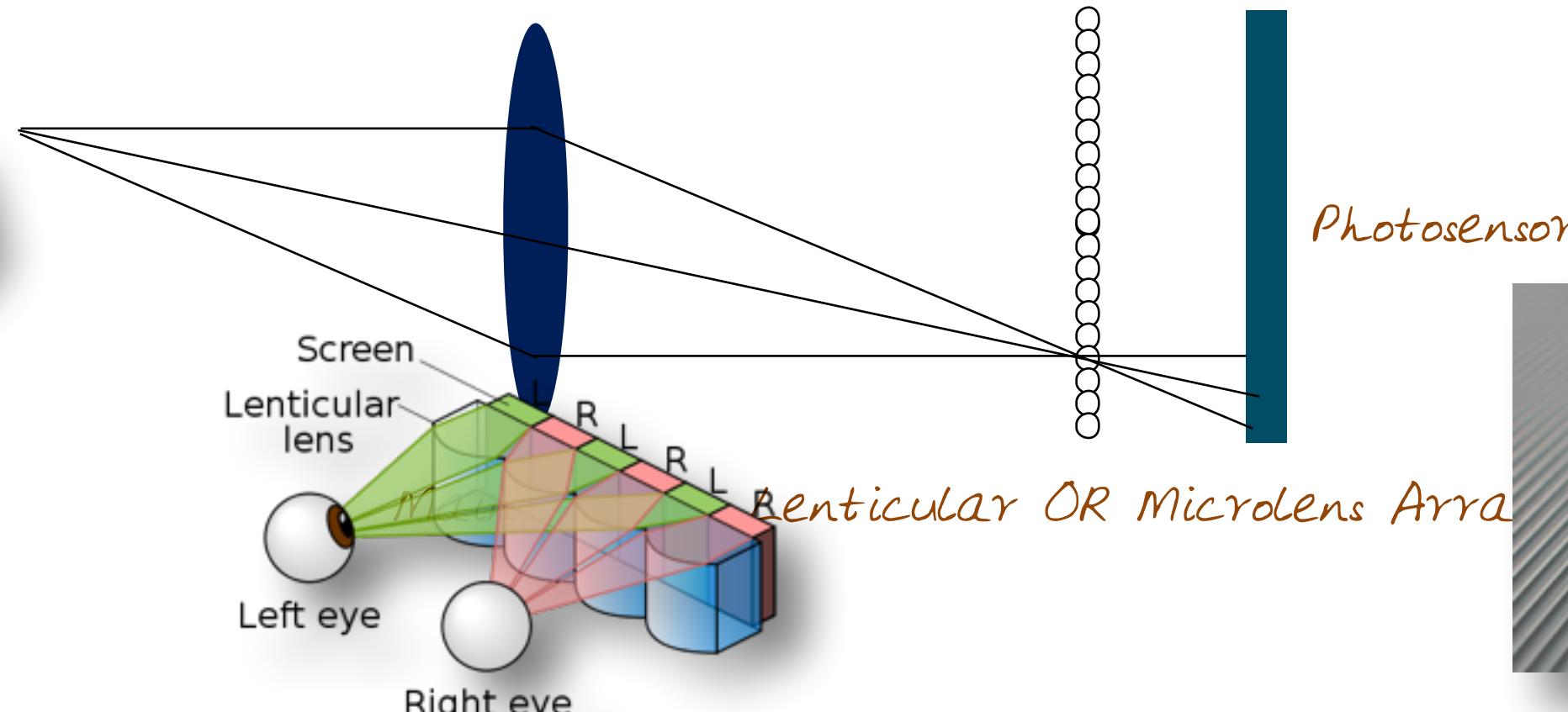


A Light-field /
PLENOPTIC Camera
(Ng et al. 2005)

Lens and Microlens

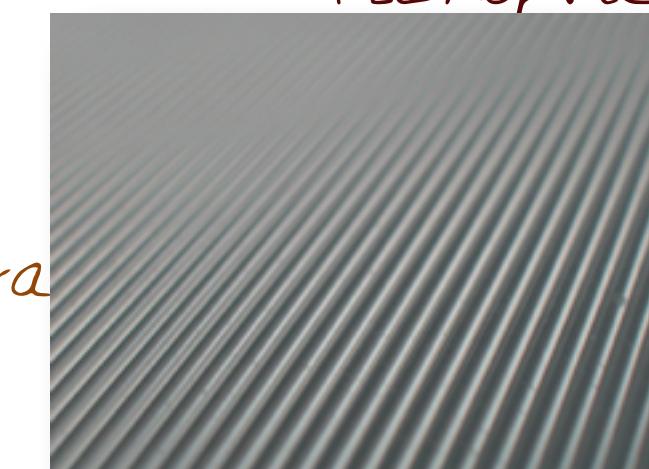


Subject



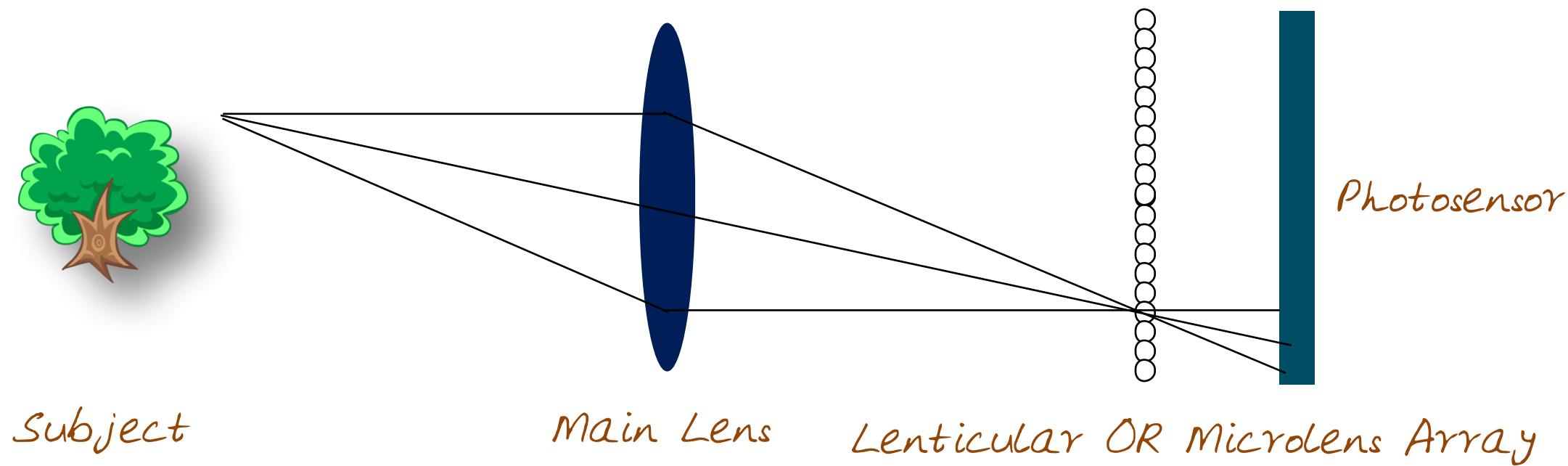
Lenticular Array
used in lenticular printed cards

A Light-field /
PLENOPTIC Camera
(al. 2005)

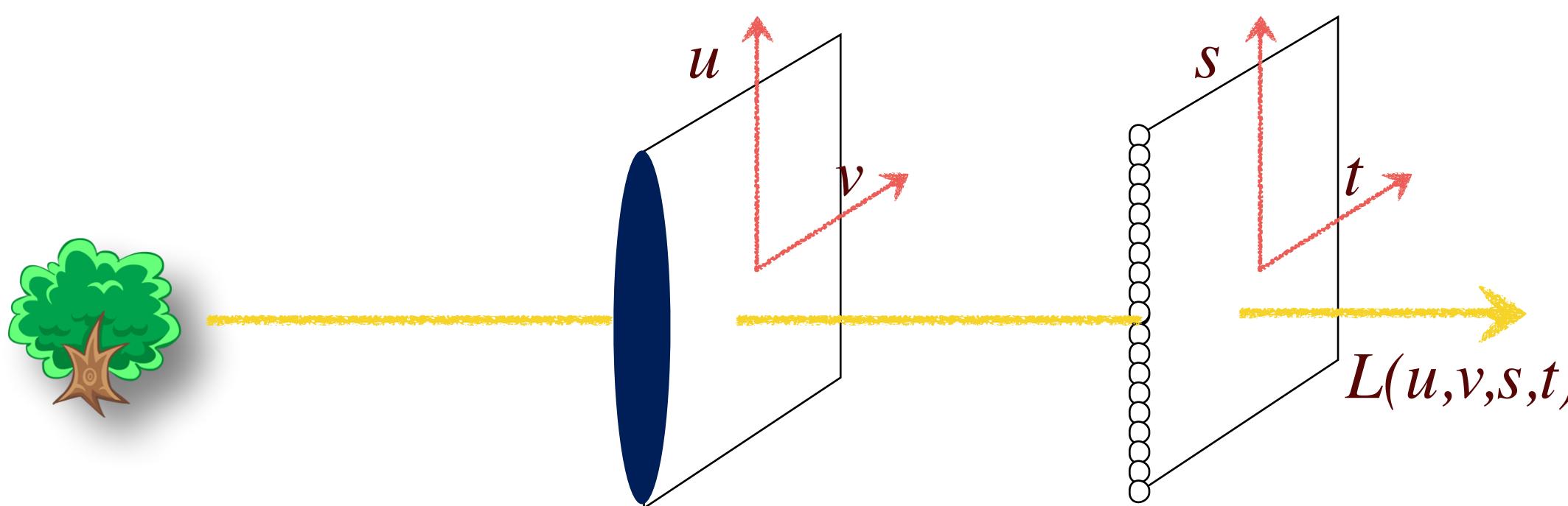


Cylindrical lenses to form a
Lenticular Array

Lens and Microlens



A Light-field /
PLENOPTIC Camera
(Ng et al. 2005)



History of Light Field Camera

- * 1908: Lippmann proposed one that used integral photography
 - * A Nobel Laureate in physics for a method to reproduce colors photographically based on interference
- * 1930: Ives constructed Parallax Panorama grams
- * 1992: Adelson and Wang proposed a plenoptic camera and used it to generate stereo from a single lens
- * 1990s (mid): Graphics researchers explored Light fields for Image-based Rendering
- * 2005: Ng et al. proposed a hand-held plenoptic Camera
- * 2012: Lytro available (Lytro.com)



http://en.wikipedia.org/wiki/Light-field_camera

4D Light Field
(Lytro)



Summary (I)



- * Concept a Light Field
- * Plenoptic function and its seven (7) parameters
- * Different types of Light Fields in terms of the Dimensions captured

Summary (2)



- * Uses of a pinhole and a lens system to analyze the scene
- * Eccentric aperture on a simple lens system
- * A lens with an array of pinhole camera to encode direction and intensity of the rays of light
- * 4D Light Field camera

Further Reading



- * Adelson and Bergen (1991), "The Plenoptic Function and the Elements of Early Vision" » Computational models of visual processing [[PDF](#)]
- * Adelson and Wang (1992) "Single lens stereo with a plenoptic camera" , IEEE PAMI 14(2) [[PDF](#)]
- * Levoy and Hanrahan (1996) "Light field Rendering" , ACM SIGGRAPH 1996 [[PDF](#)]
- * Gorler, Grzeszczuk, Szeliski, Cohen (1996) "The Lumigraph" » ACM SIGGRAPH 1996 [[PDF](#)]
- * Ng, Levoy, et al. (2005), "Light field photography with a hand-held plenoptic camera" » Stanford Tech Report CTSR 2005-02, 2005 [[PDF](#)]

Credits



- * For more information, see
- * Richard Szeliski
(2010) Computer Vision:
Algorithms and Applications,
Springer
- * Lytro.com

Computational Photography

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