Georgia Institute of Technology

Computational Photography

Dr. Irfan Essa
Professor
School of Interactive Computing

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

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Light Fields:
Part 2 of 2
Really using the Rays of Light

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How can we capture a Light Field?

Lesson Objectives

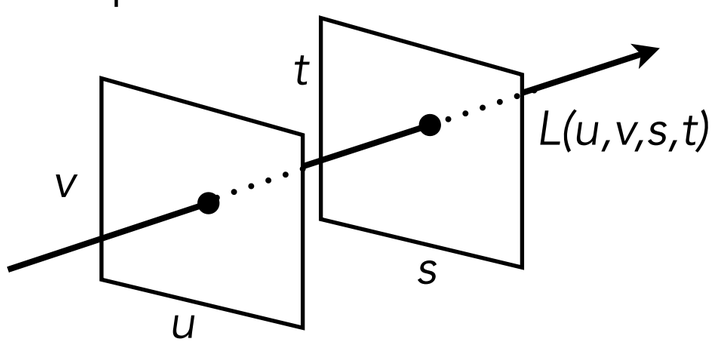
- ★ Explain in your own words how a different uses of a pinhole and a lens system can lead to observations about the scene.
- ★ Explain in your own words the impact of an eccentric aperture on a simple lens system.
- ★ Explain in your own words how a lens with an array of pinhole camera can encode direction and intensity of the rays of light.
- ★ Describe in your own words how a 4D Light Field camera works.

3

Review: Plenoptic Function and a Light Field

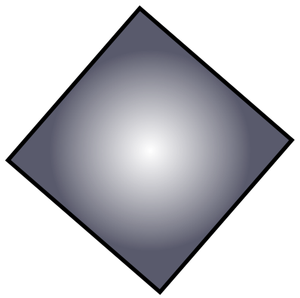
- ★ $P(\theta,\phi,\lambda,t,V_x,V_y,V_z)$ ➔ *7 Dimensions*
  - Complete scene; holographic video
- ★ $P(\theta,\phi,V_x,V_y,V_z)$ ➔ *5* Dimensions
  - Ignore time and wavelength
  - Capture only viewpoint and direction
- ★ $P(\theta,\phi,V_x,V_y,V_z)$ ➔ *4* Dimensions
  - Within a bounding box. (Space of all lines in 2D space is 4D)
  - No occluding objects, with viewpoint and direction
- ★ $P(\theta,\phi)$ ➔ *2* Dimensions
  - At the same viewpoint
  - Panorama

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.



http://en.wikipedia.org/wiki/Light_field
http://commons.wikimedia.org/wiki/File:Snow_Globe_icon.jpg

Light field via a PinHole Camera



Lens gathers light from all points. These are averaged at the sensor plane in a camera

Adelson and Wang (1991)

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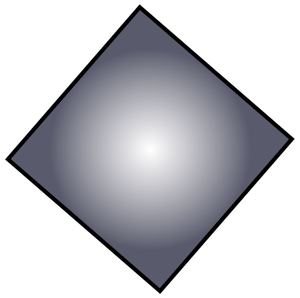

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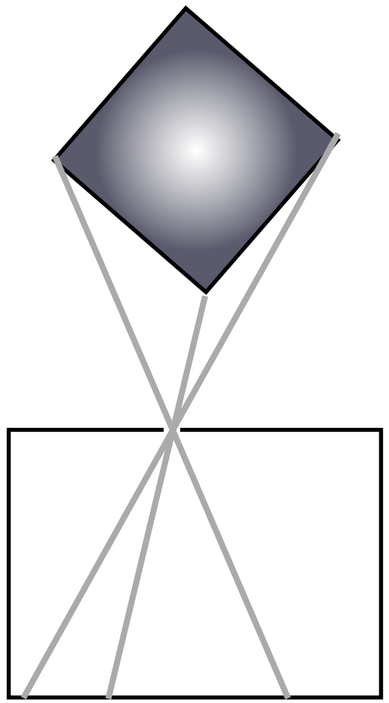

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5

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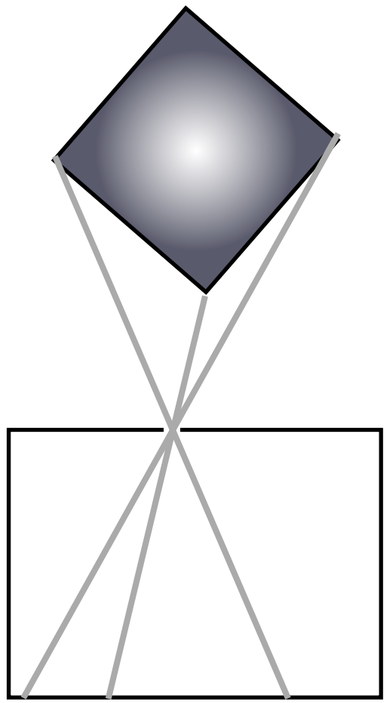

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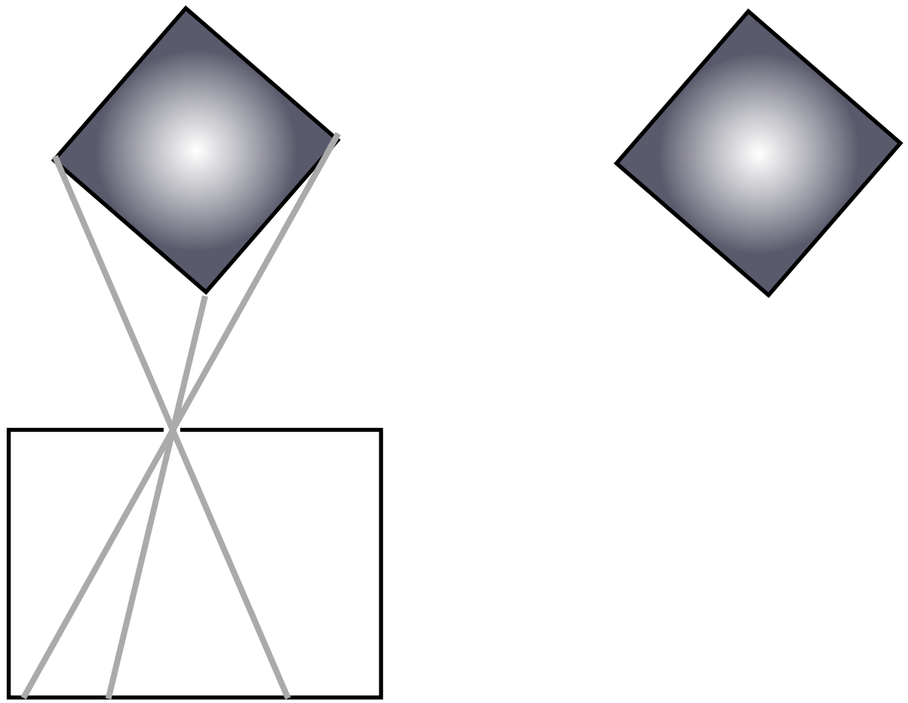

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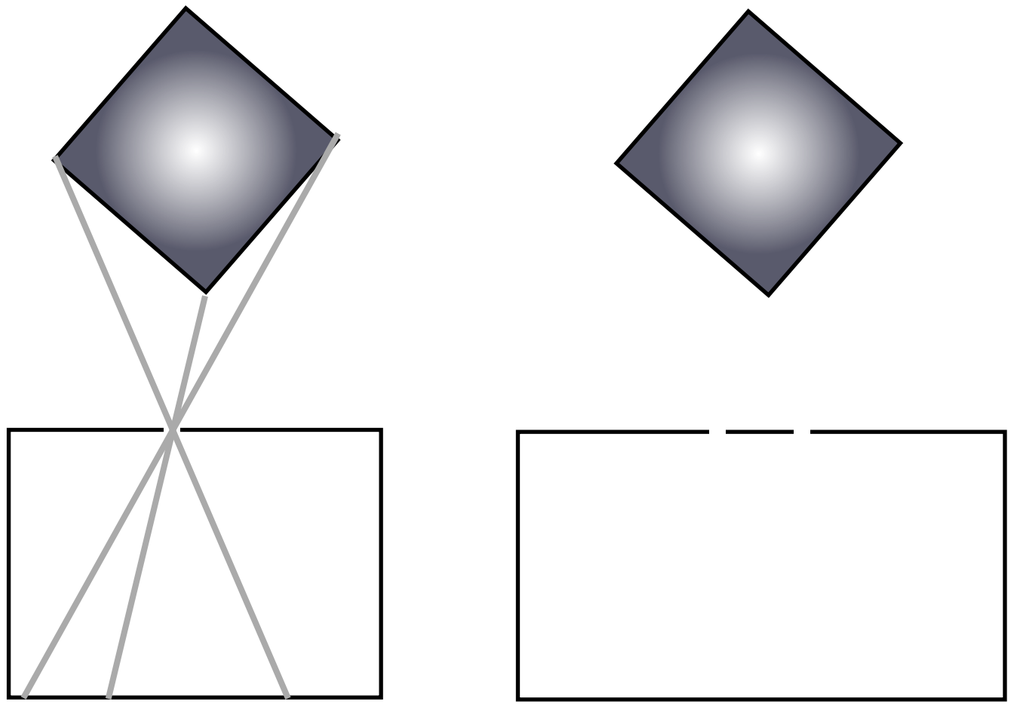

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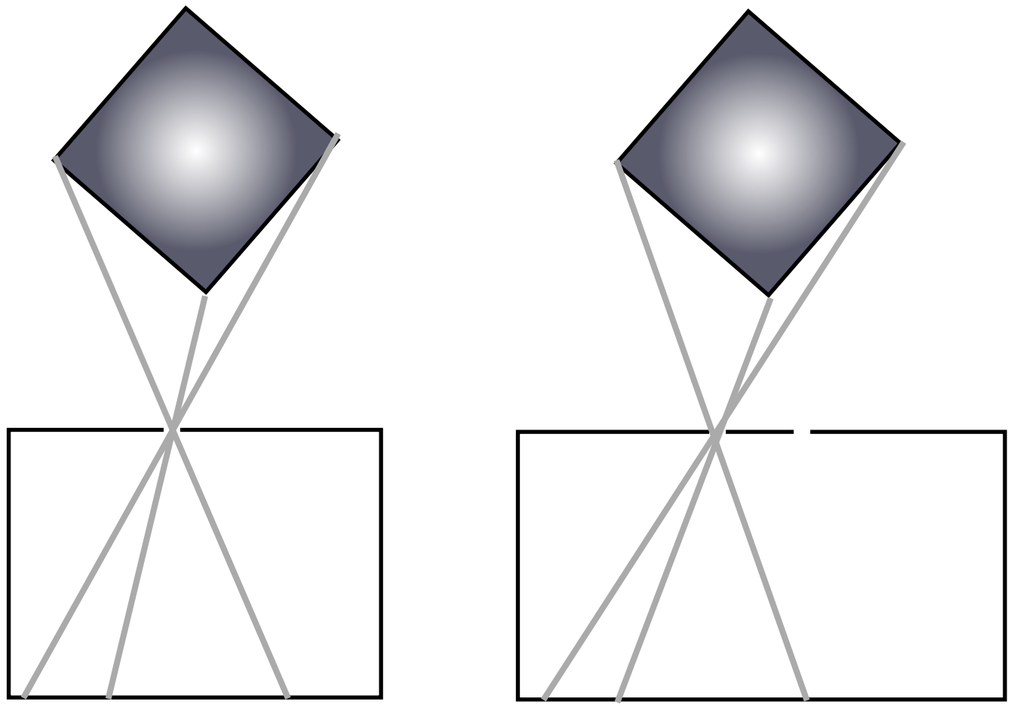

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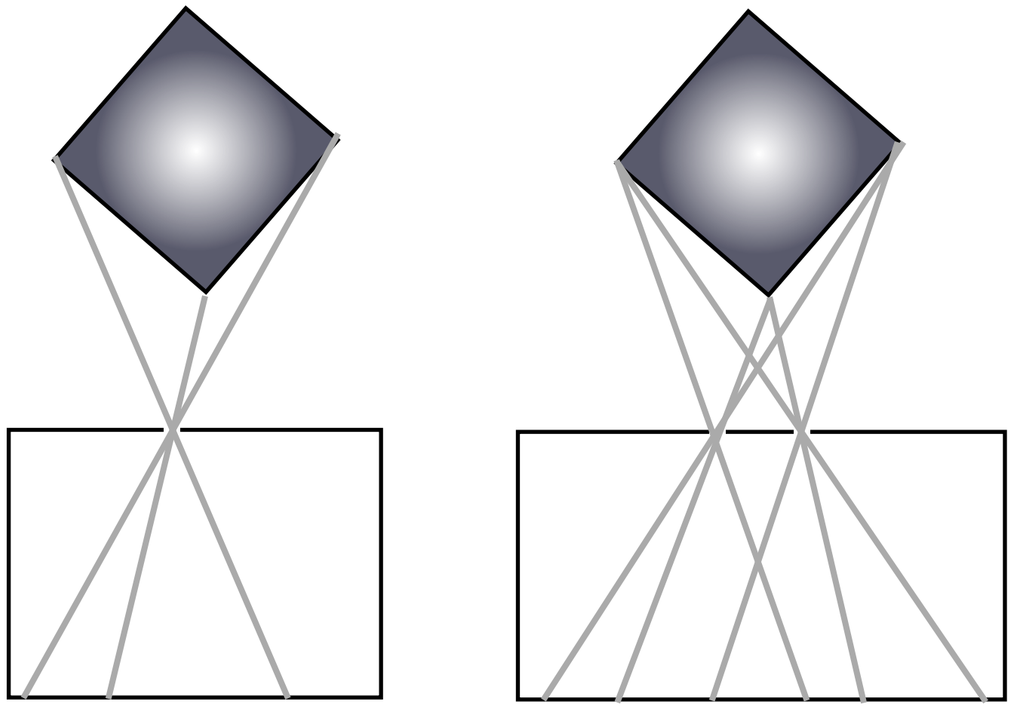

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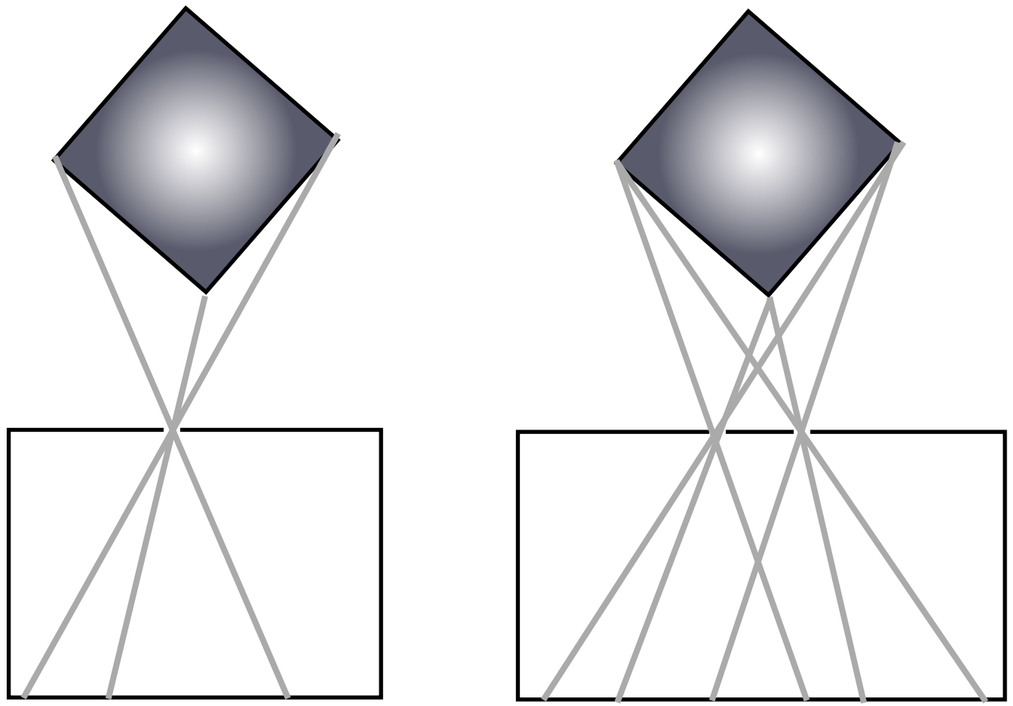

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Double Pinholes

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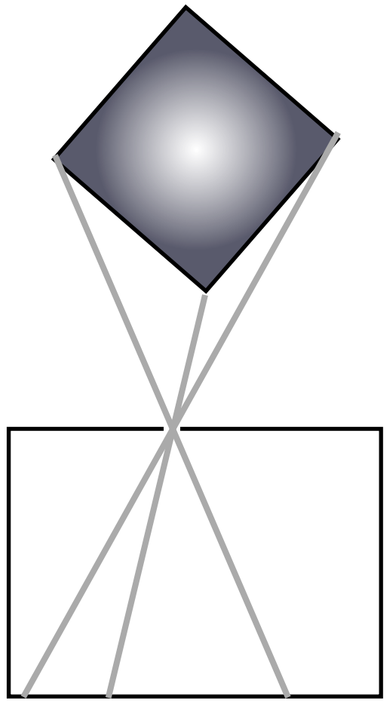

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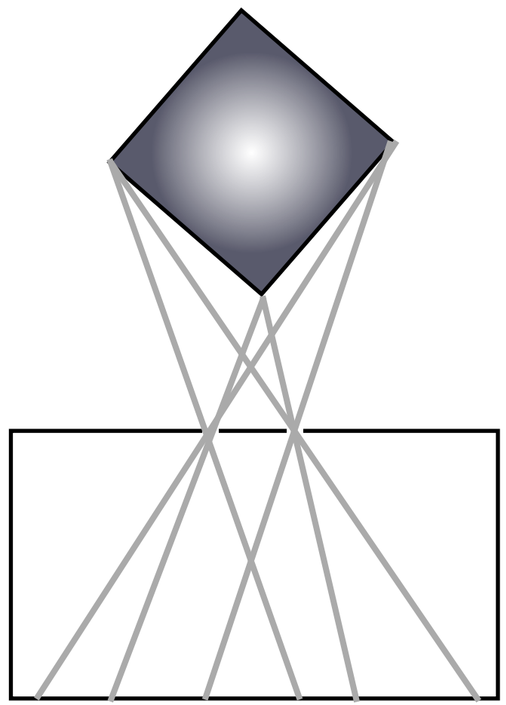

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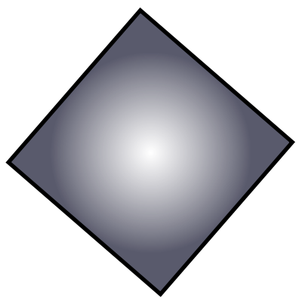

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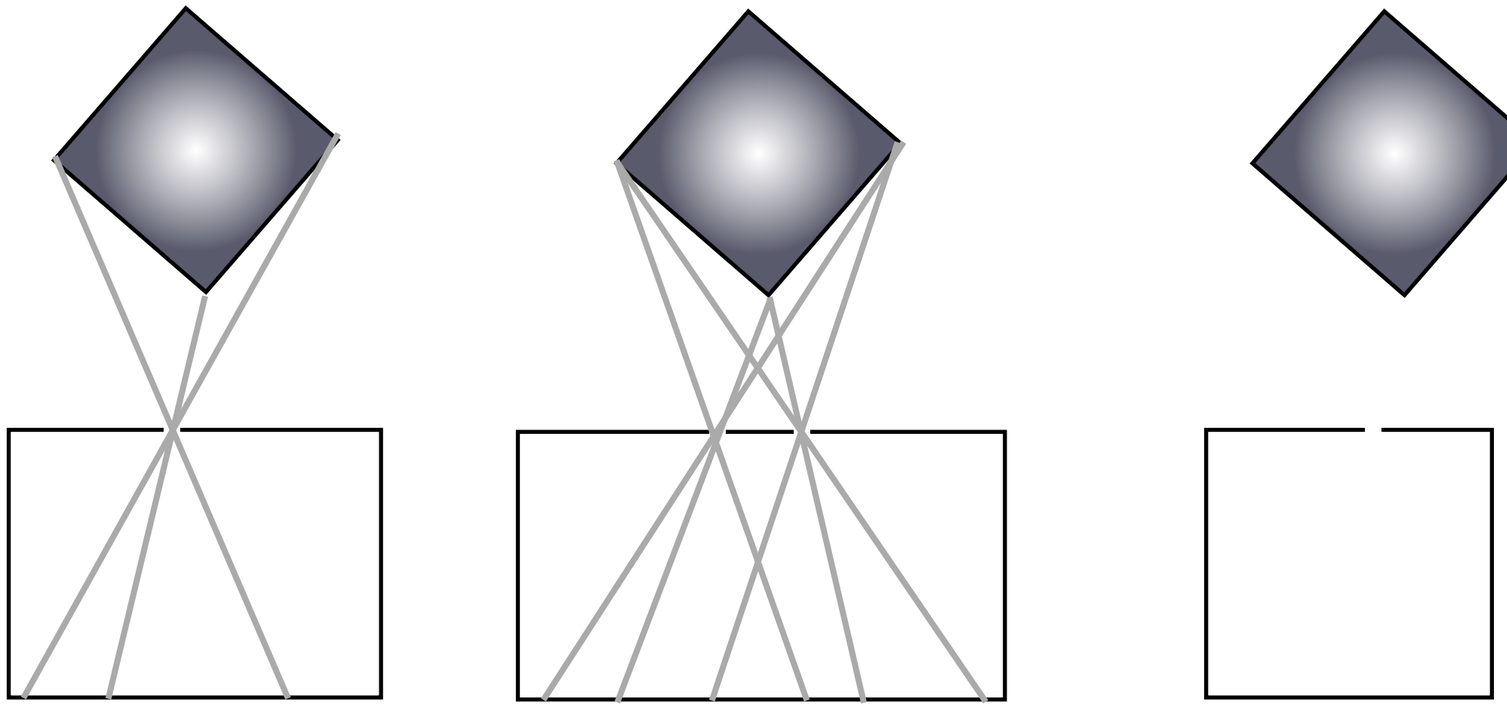

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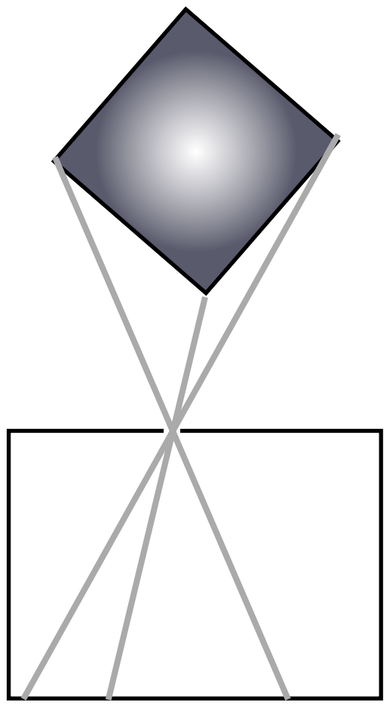

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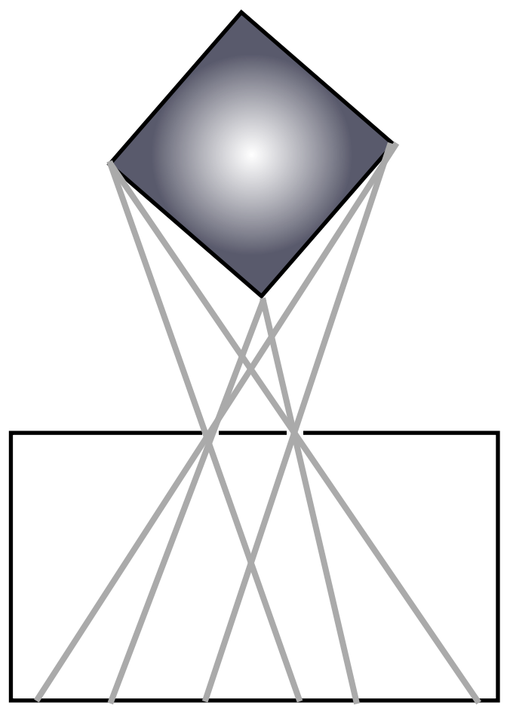

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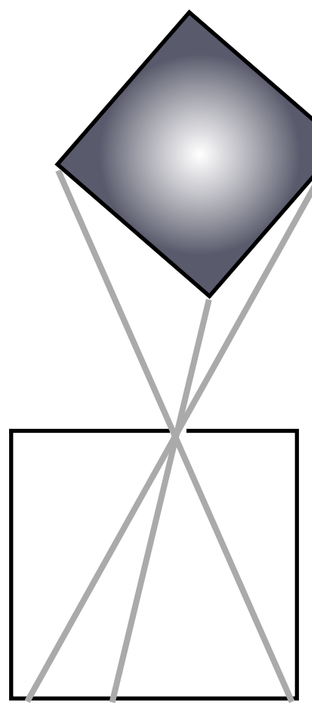

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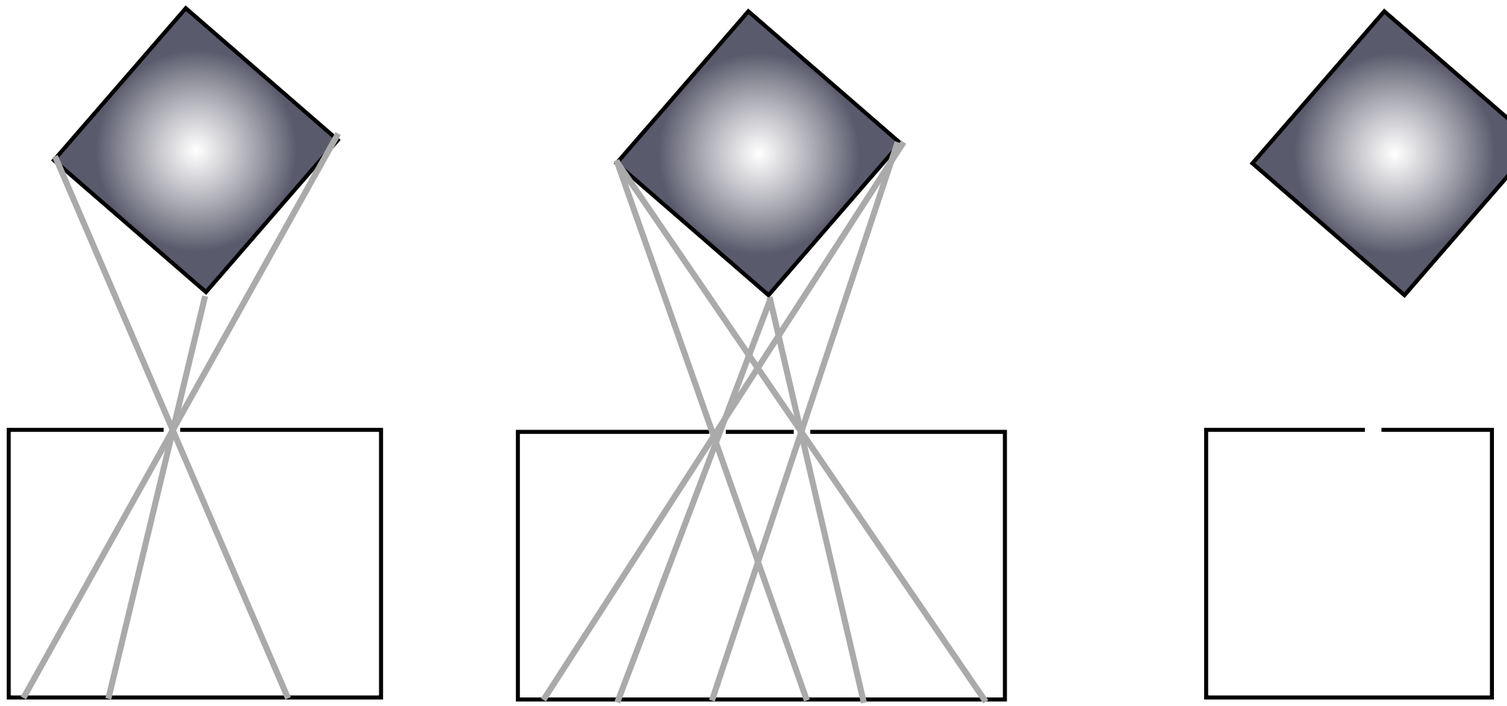

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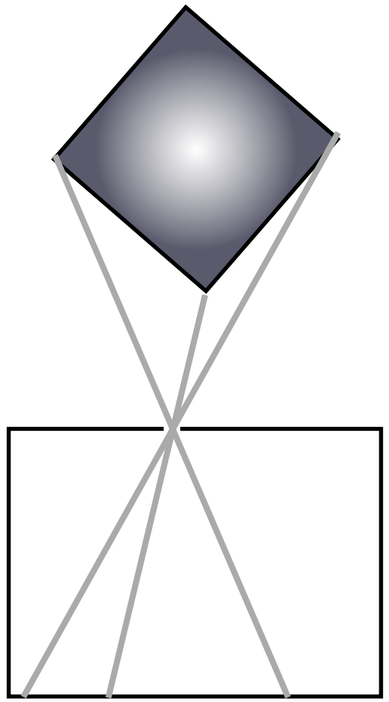

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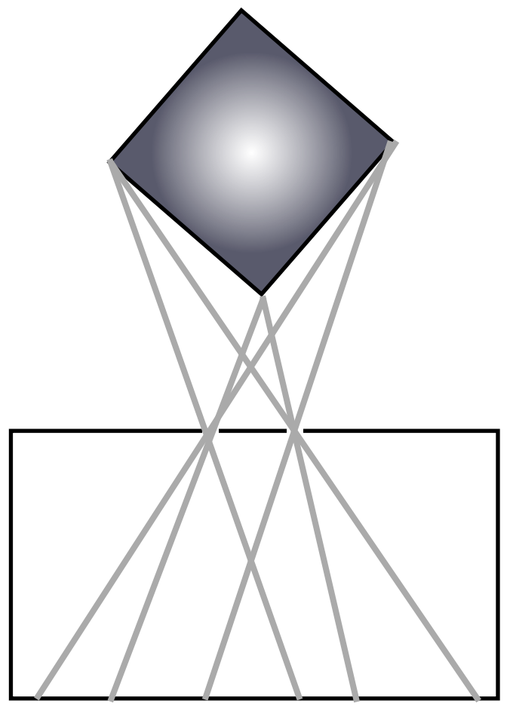

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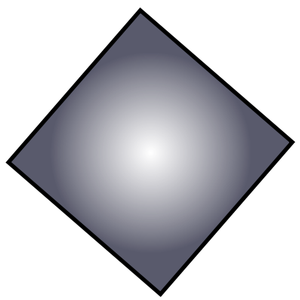

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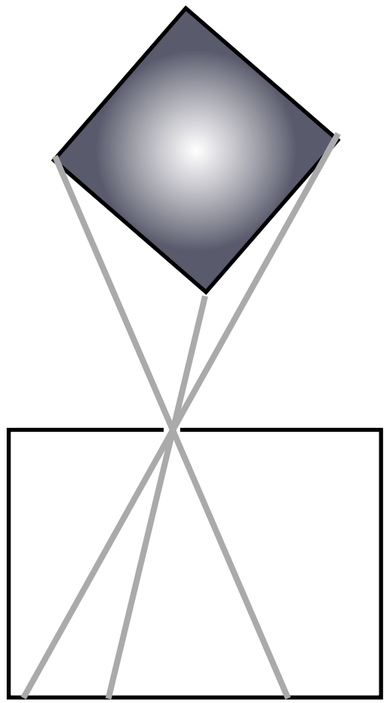

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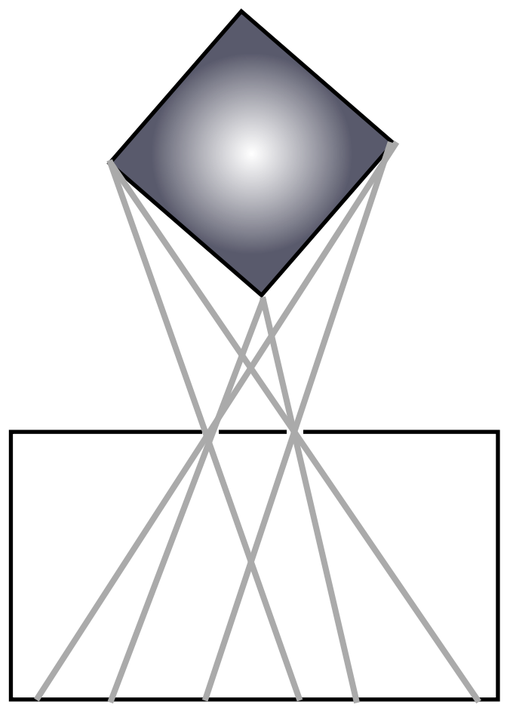

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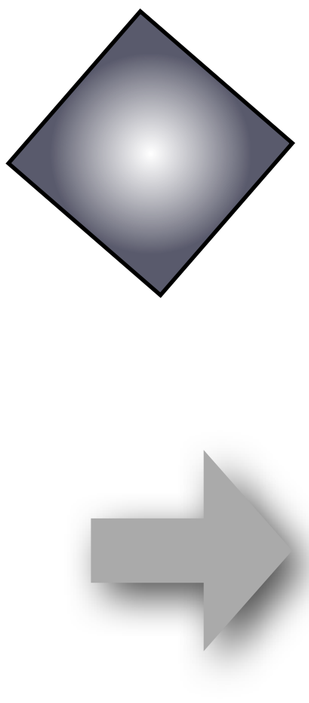

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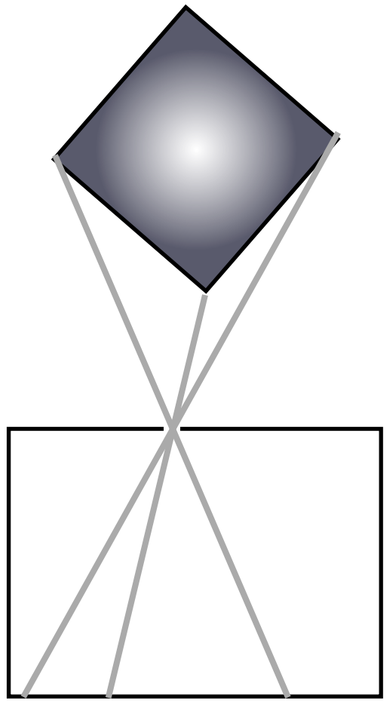

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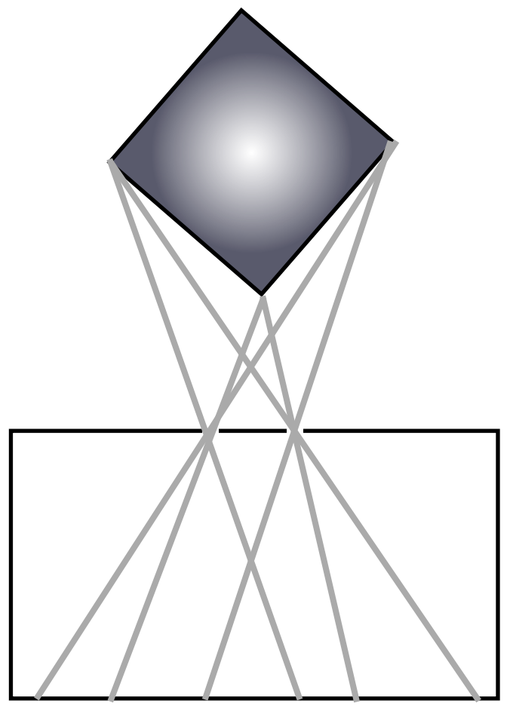

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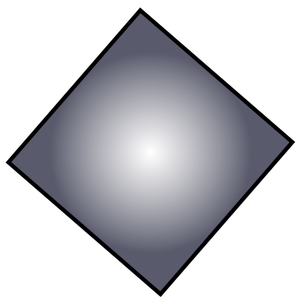

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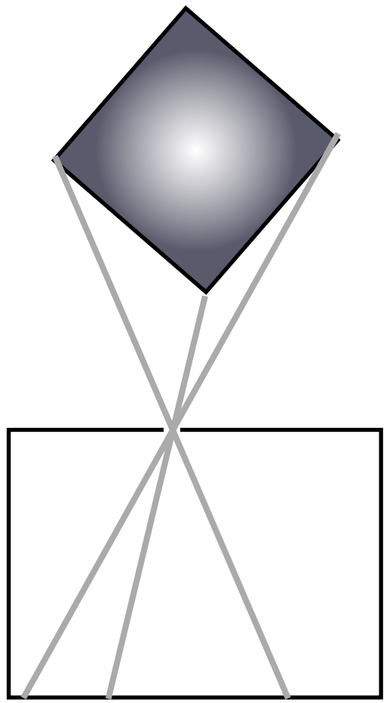

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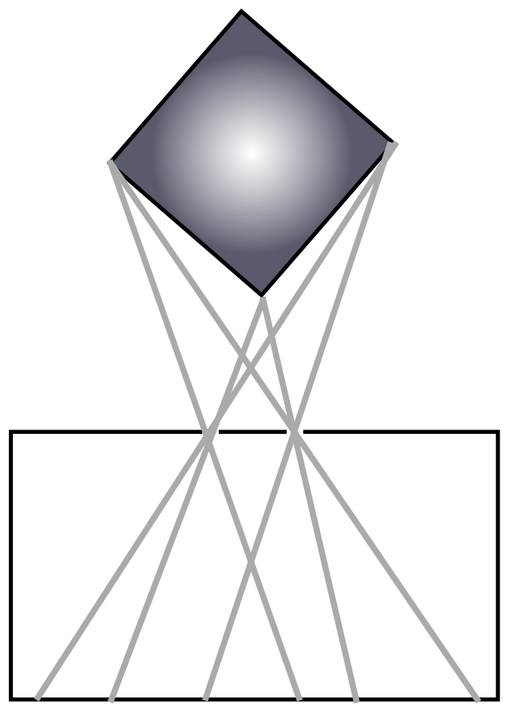

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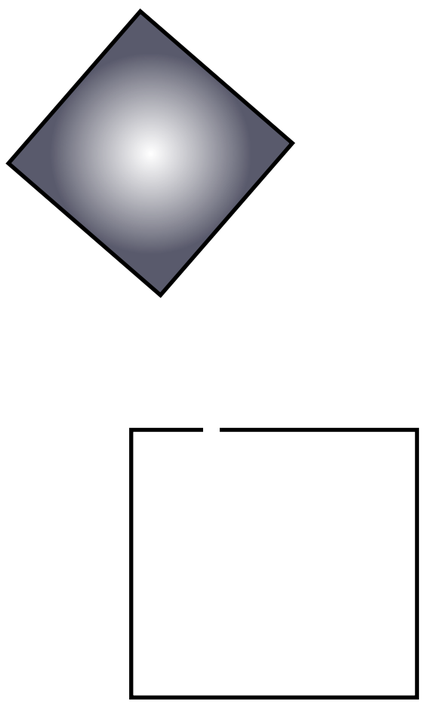

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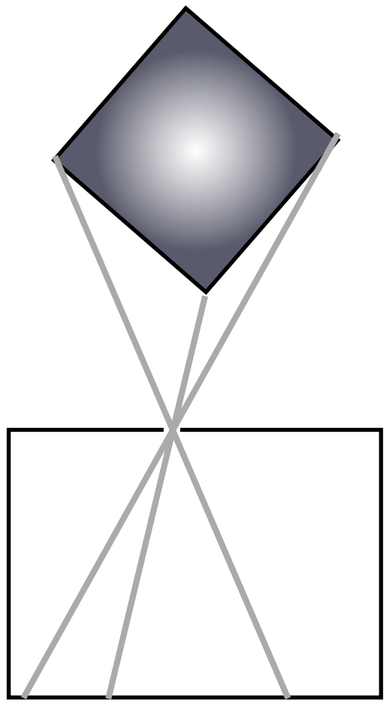

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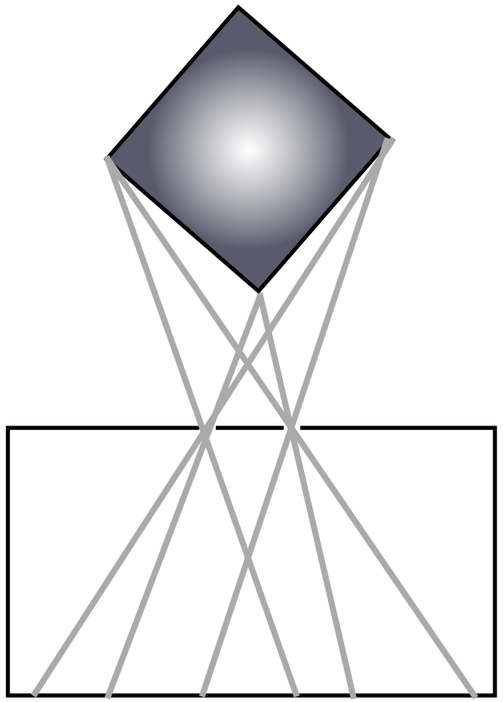

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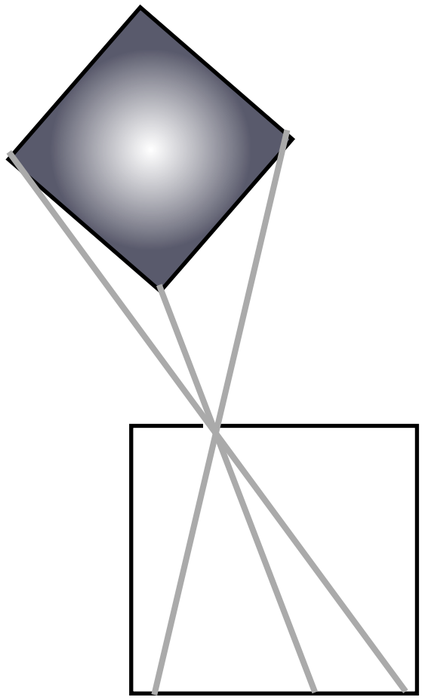

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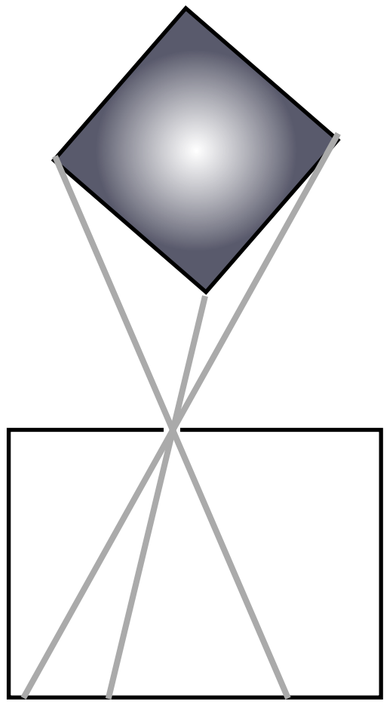

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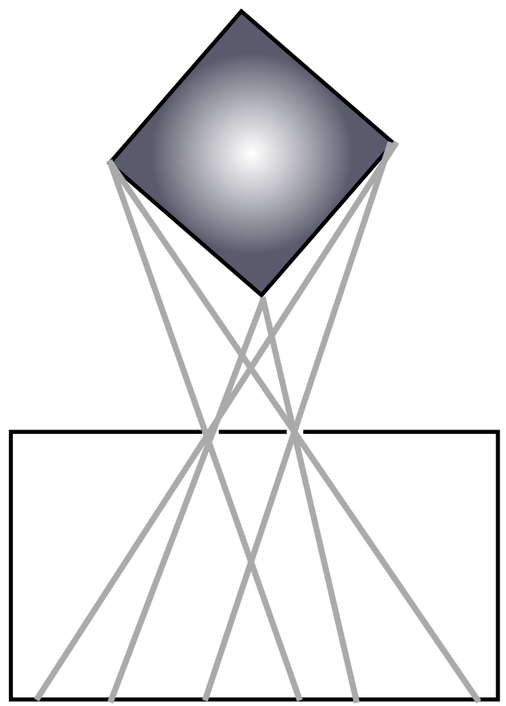

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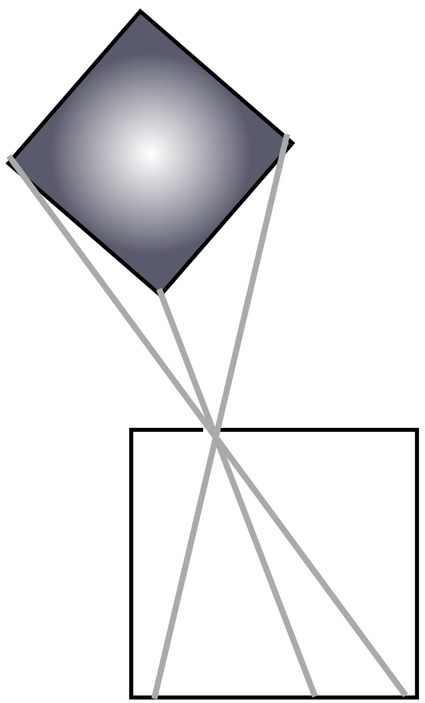

Motion Parrallax

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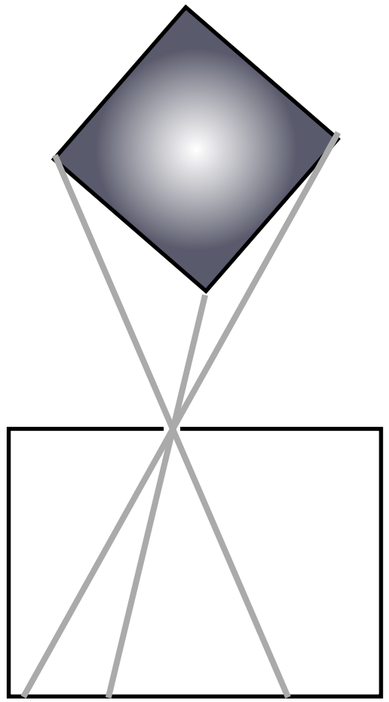
Adelson and Wang (1991)

Light field via a PinHole Camera



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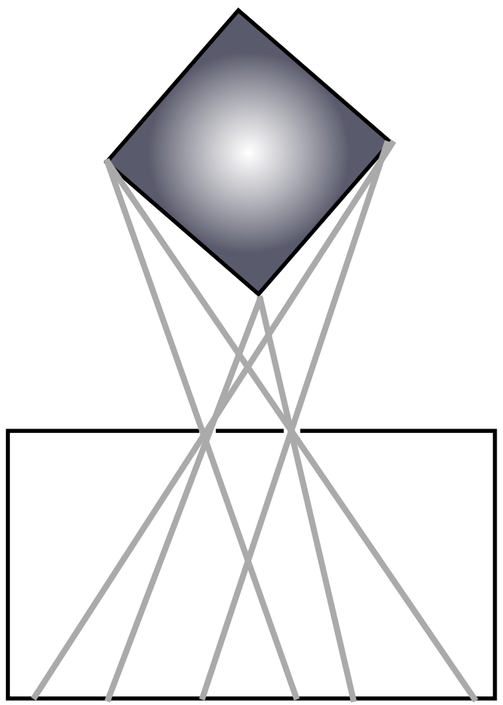

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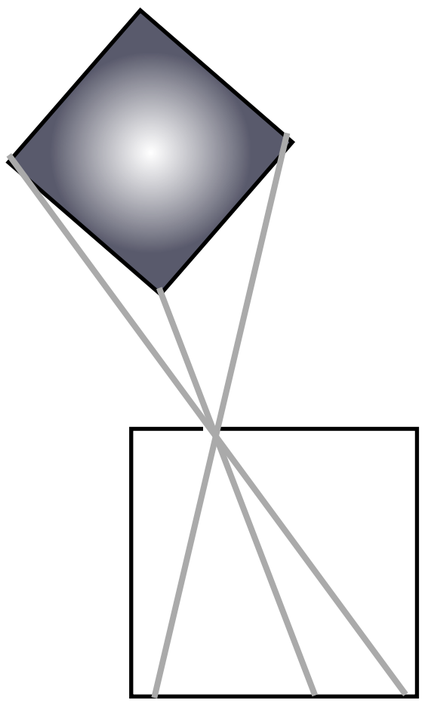
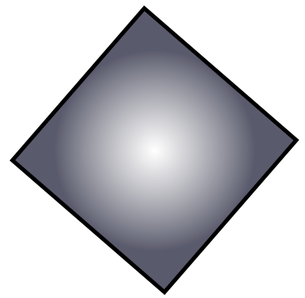


Motion Parrallax



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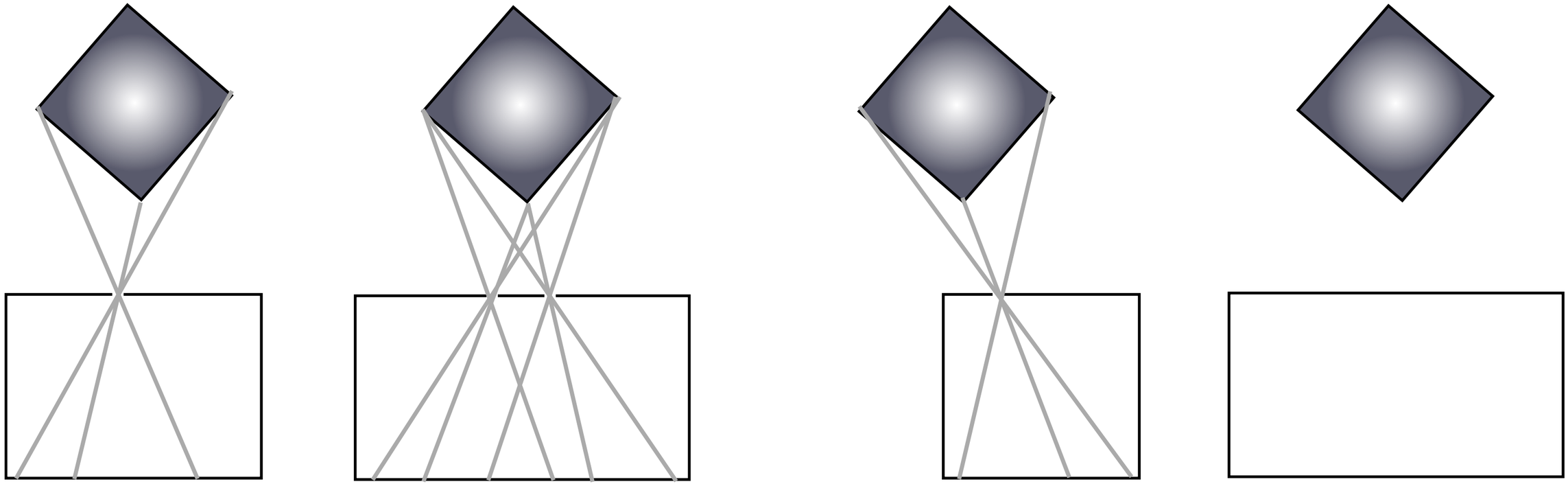
Light field via a PinHole Camera



Single Pinhole | Double Pinholes | Motion Parrallax

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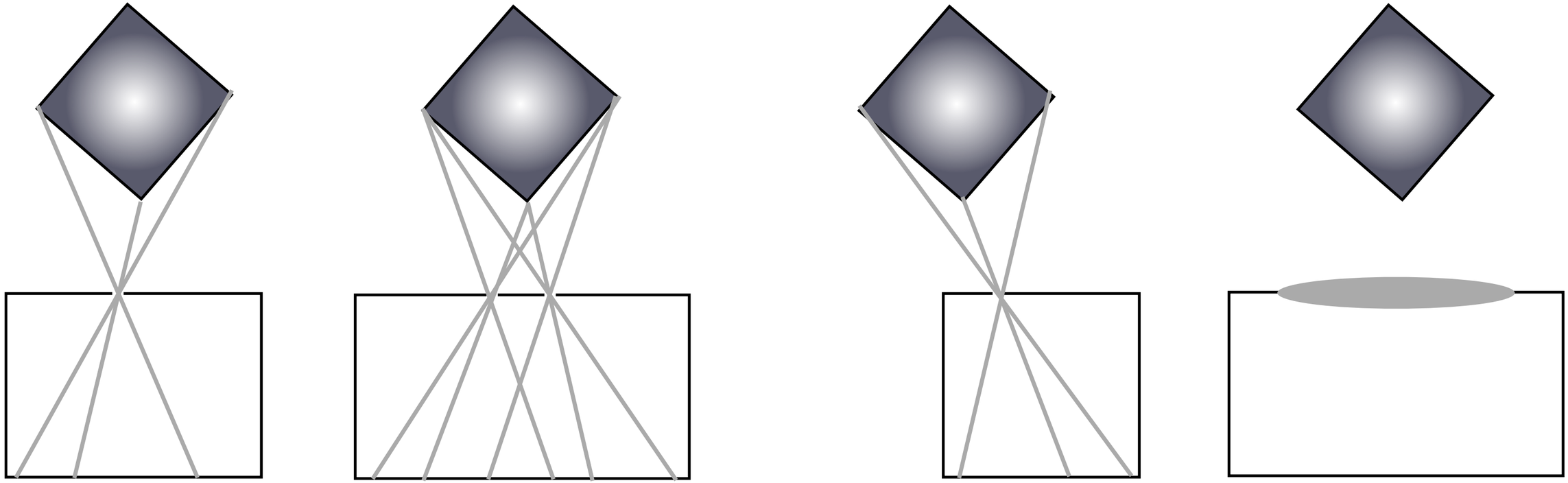

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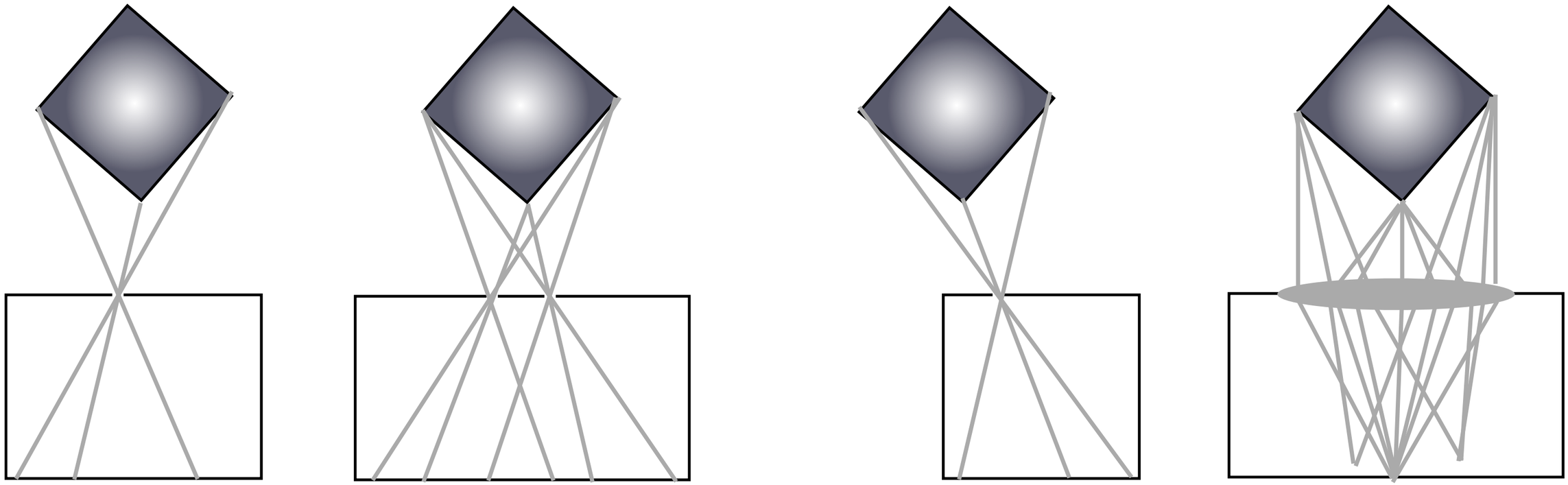

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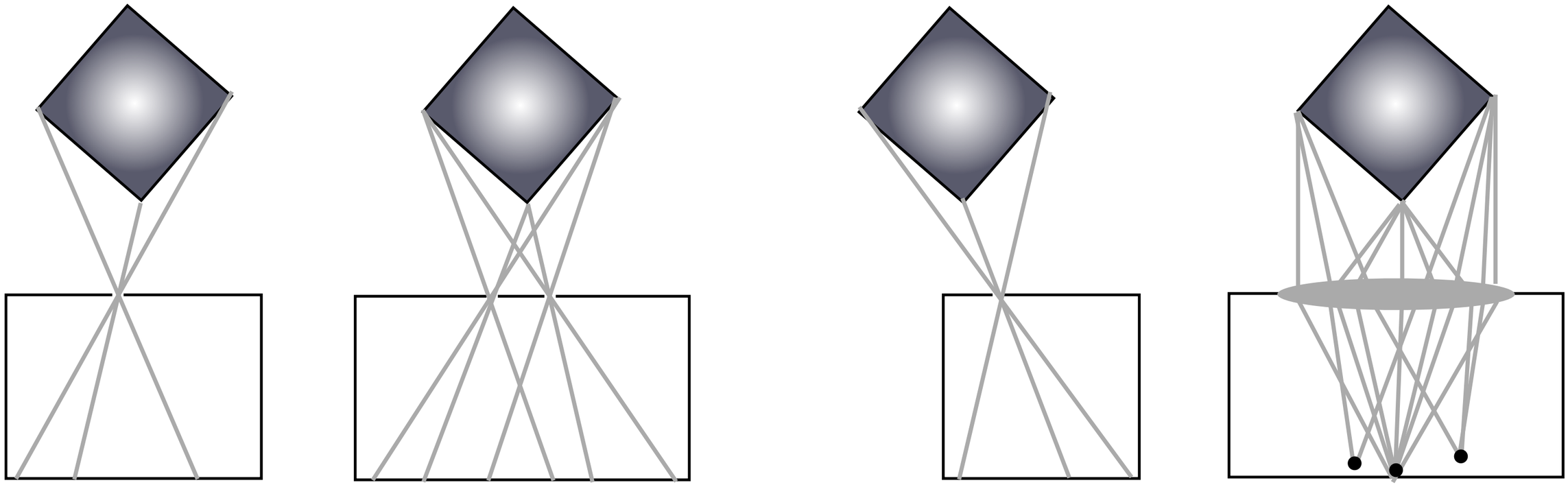

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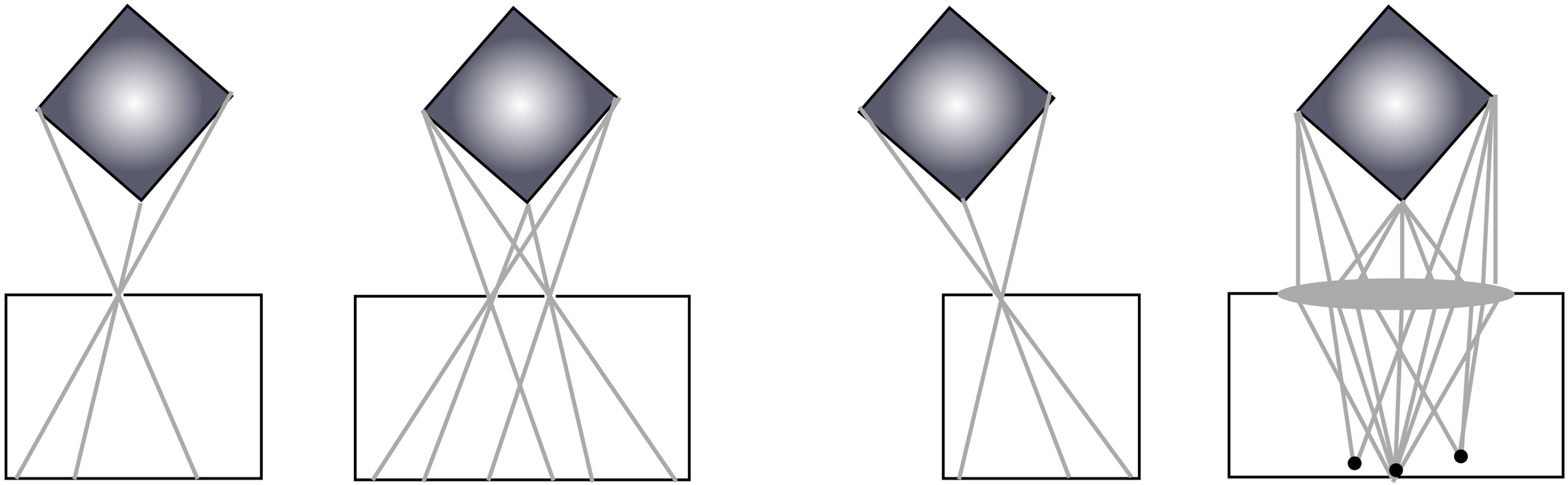

Single Pinhole | Double Pinholes | Motion Parrallax | With Lens

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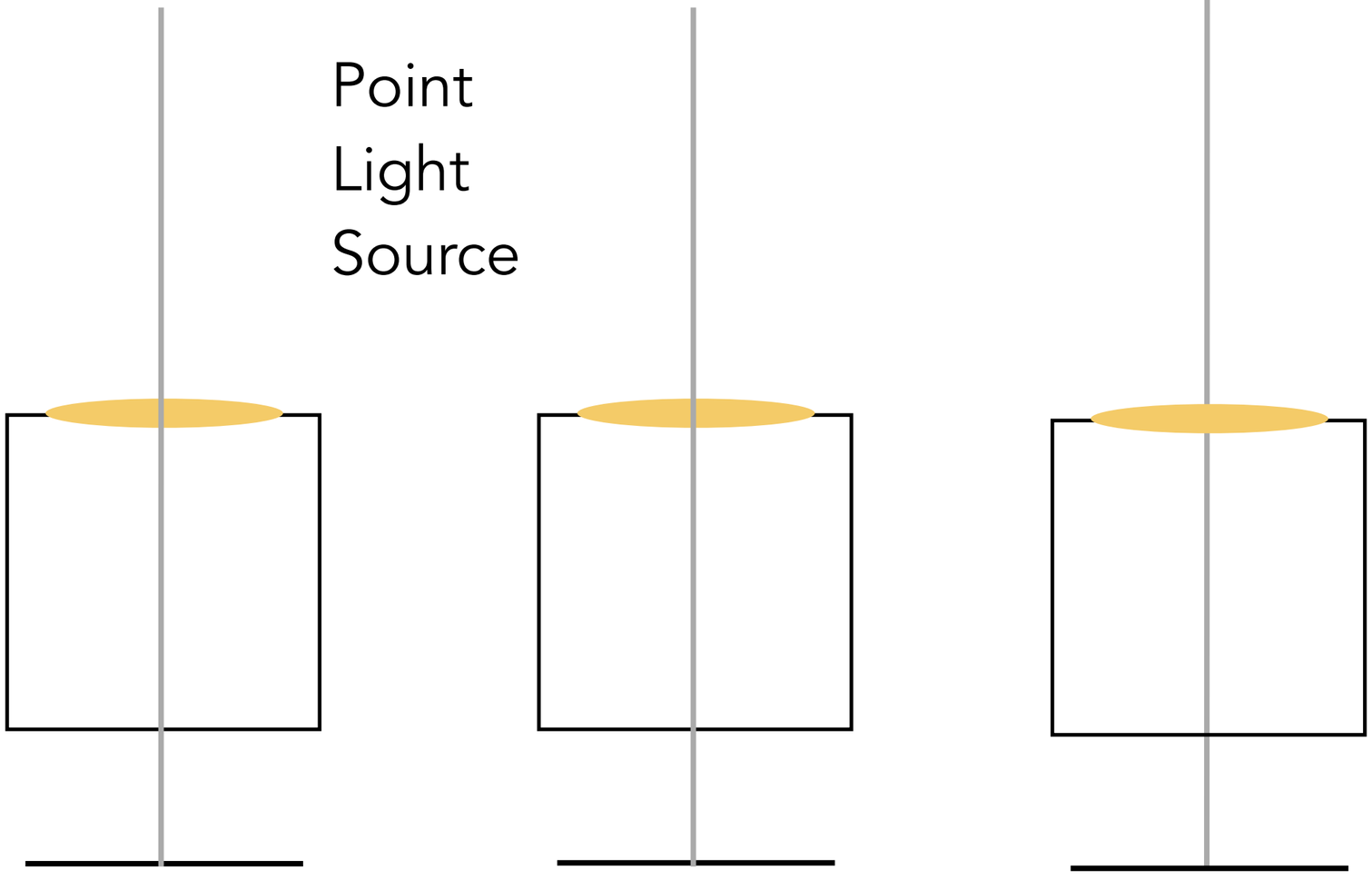
Adelson and Wang (1991)

Single Lens System (1)

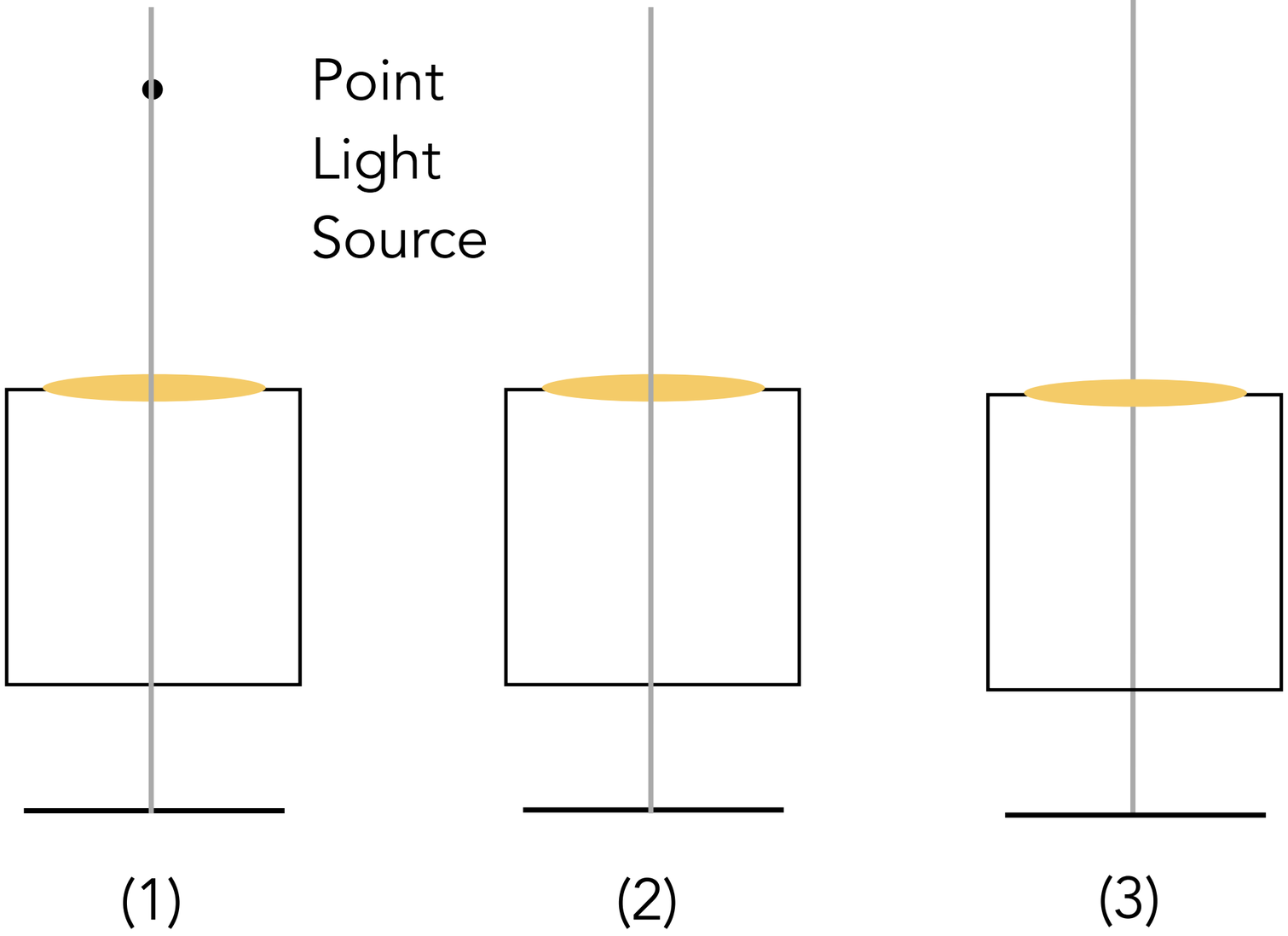
Point
Light
Source



(1) (2) (3)

Single Lens System (1)

- Point Light Source



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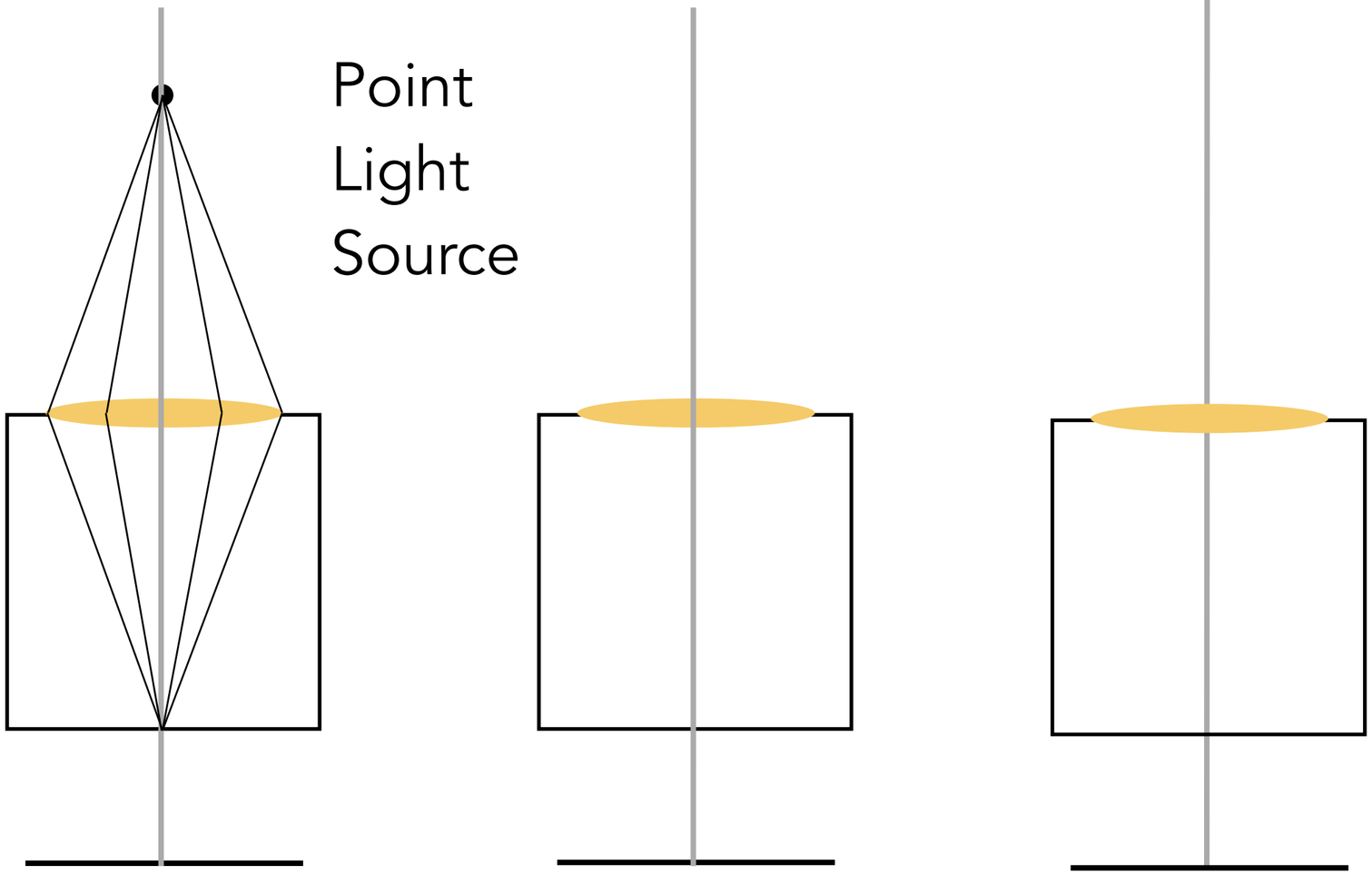
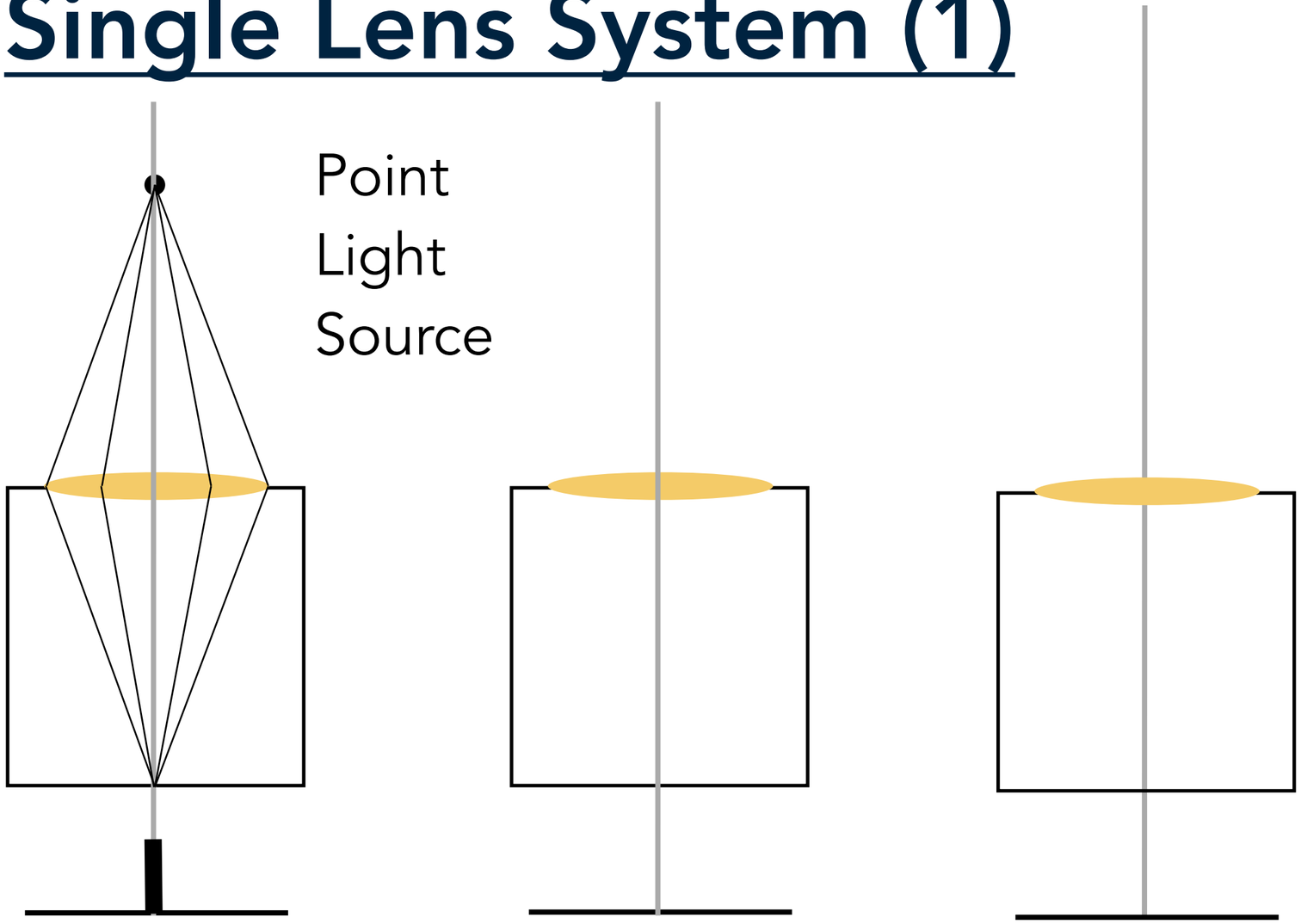


Single Lens System (1)



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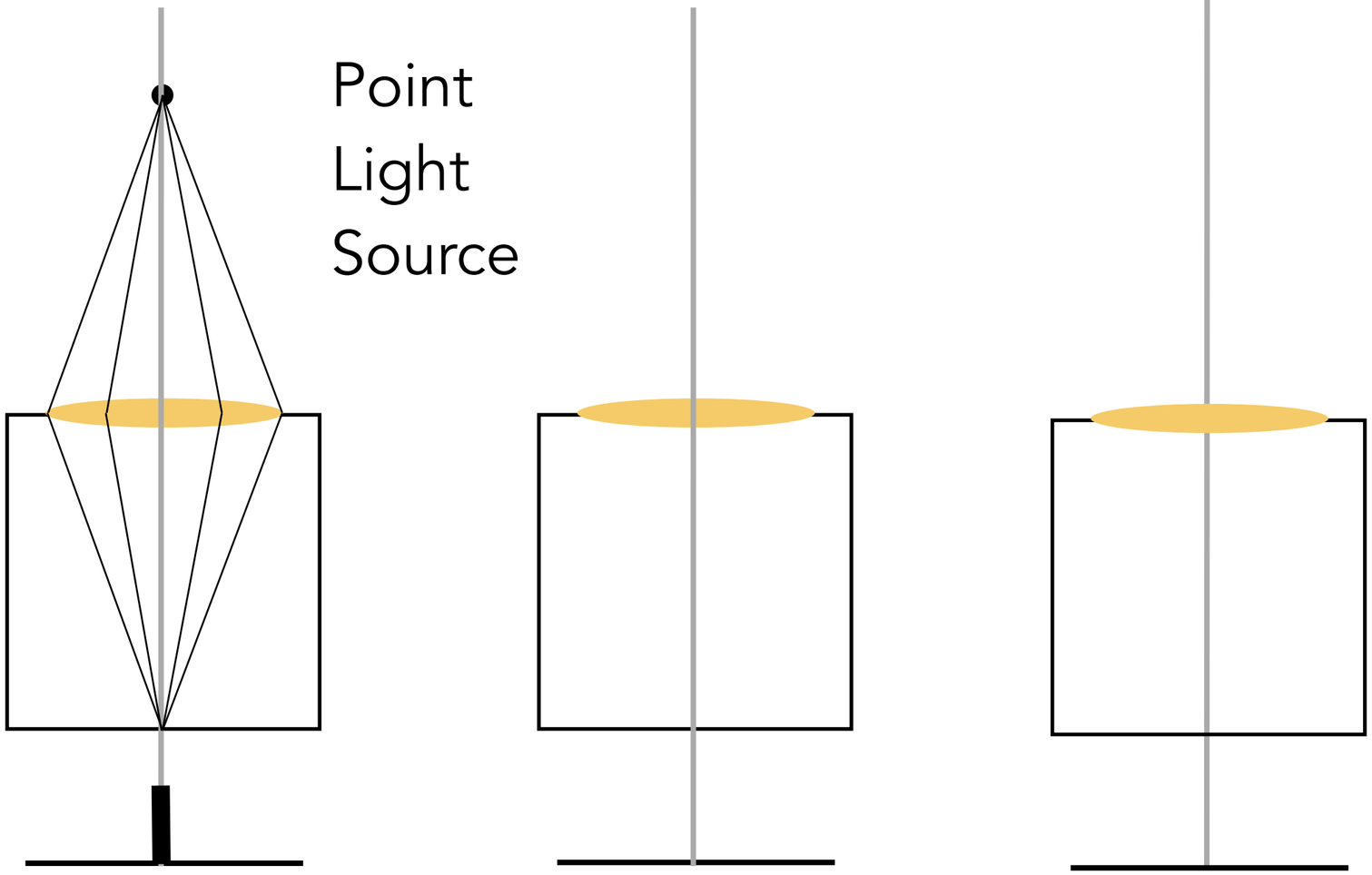
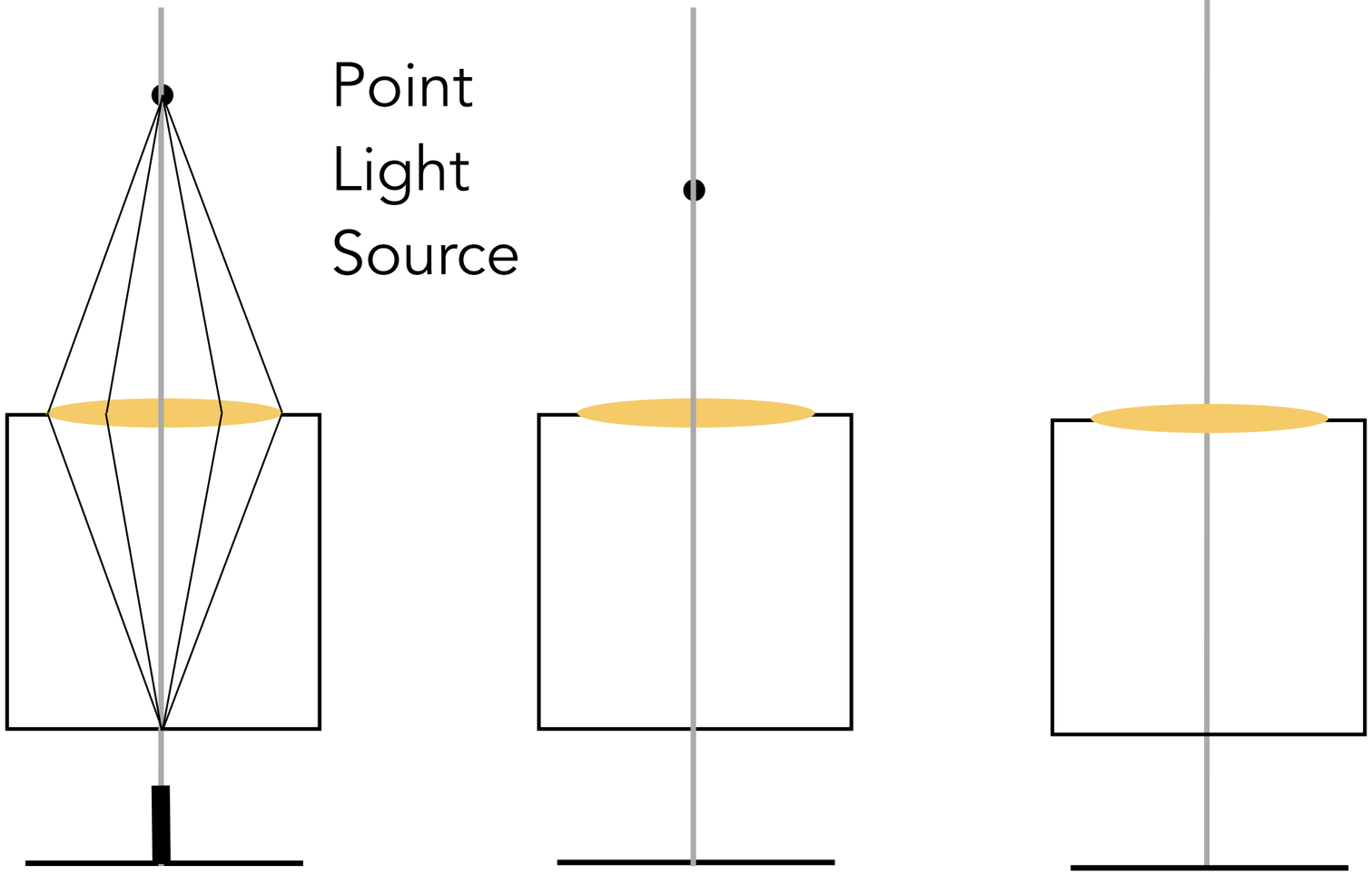


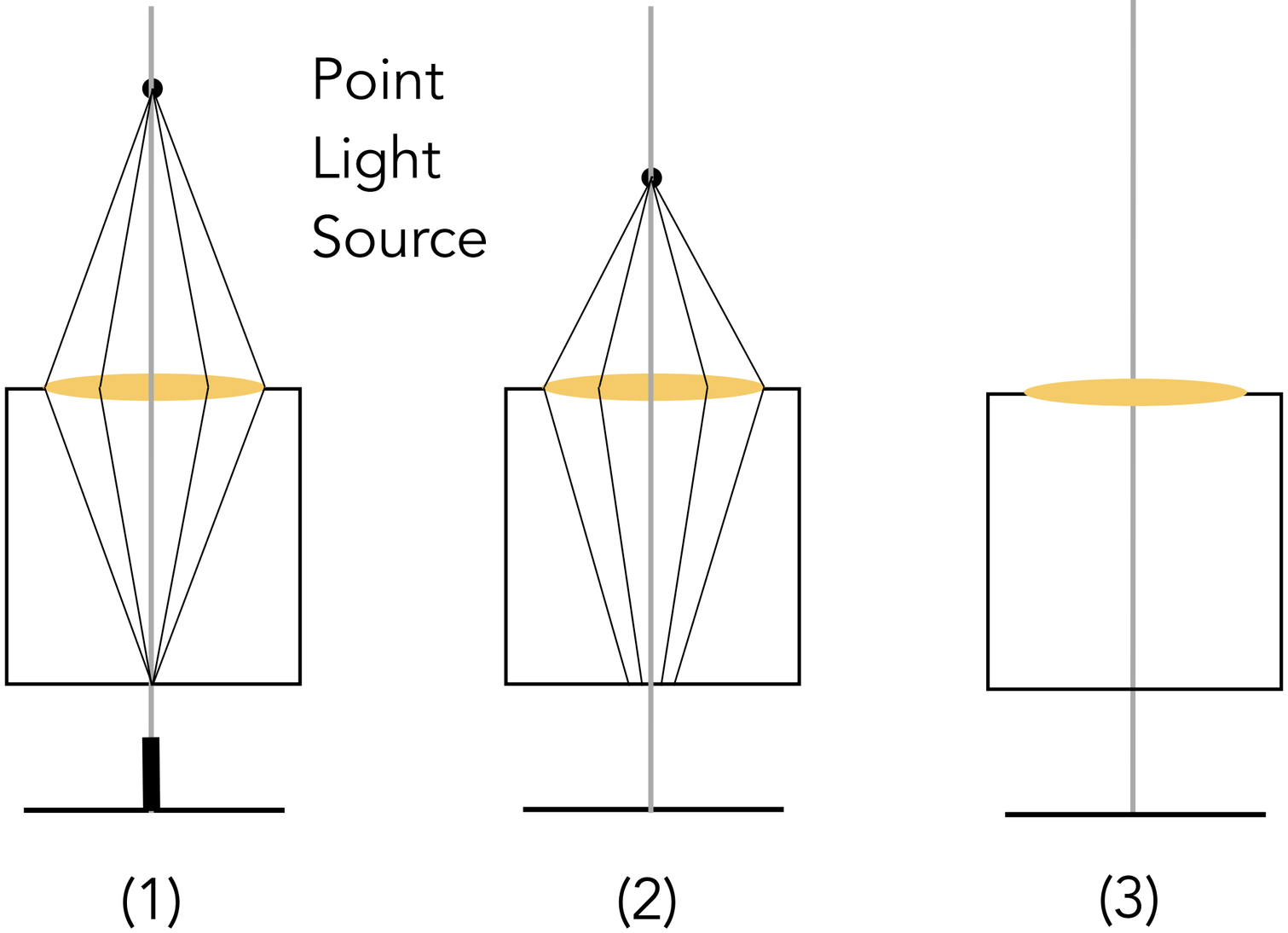
1. In-focus object; forms a Point Image.

Single Lens System (1)



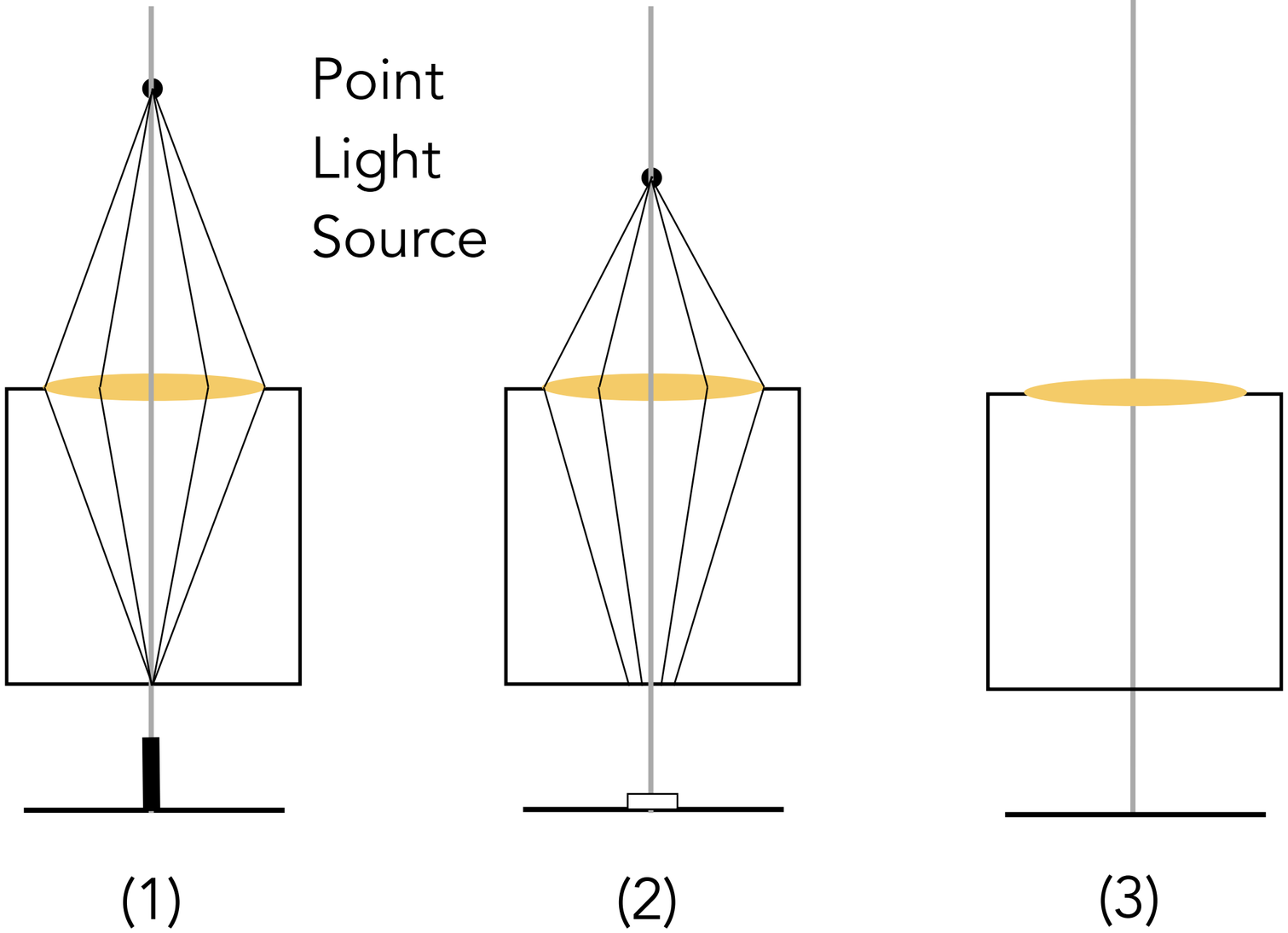
1. In-focus object; forms a Point Image.

Single Lens System (1)



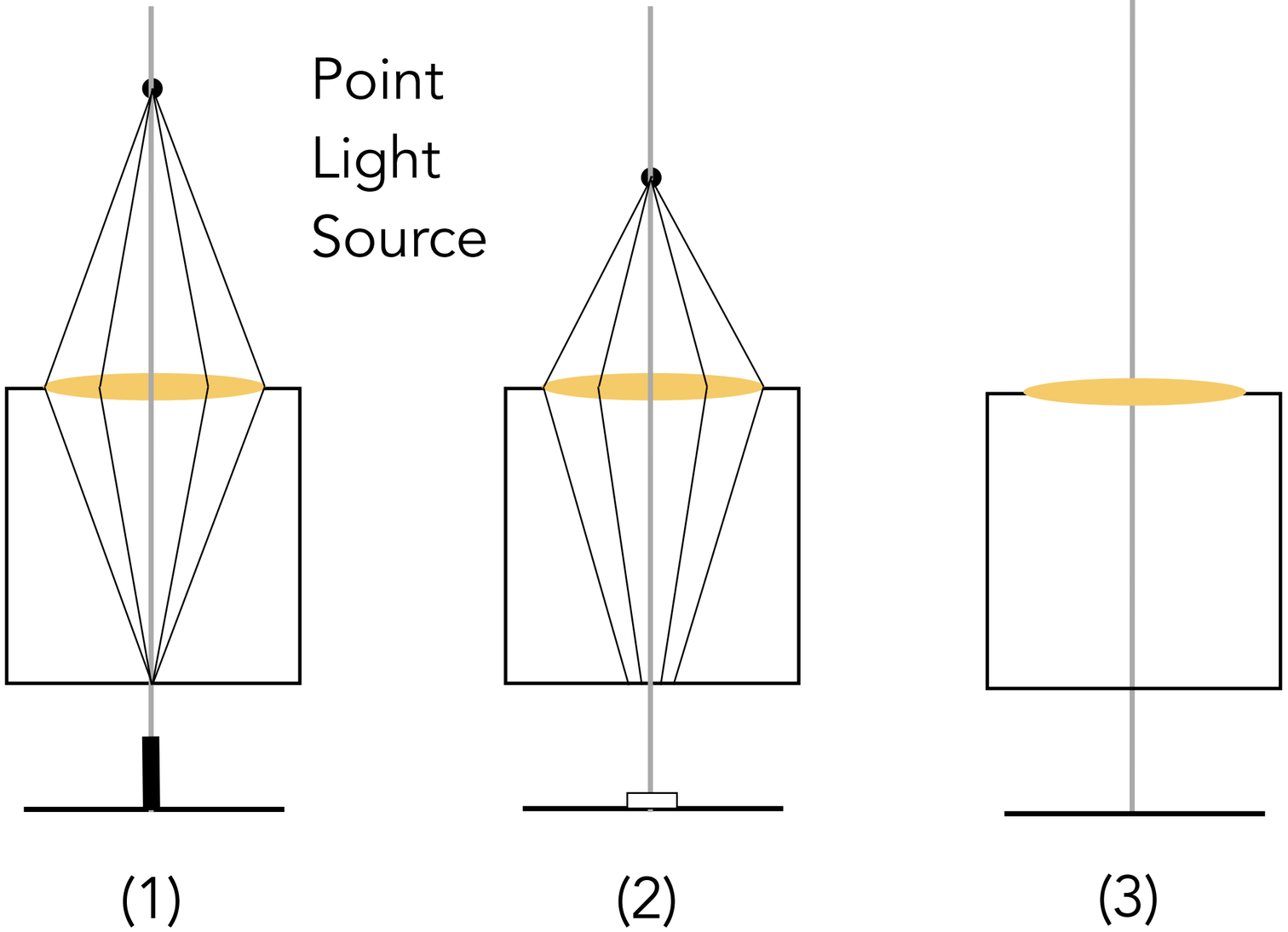
1. In-focus object; forms a Point Image.

Single Lens System (1)



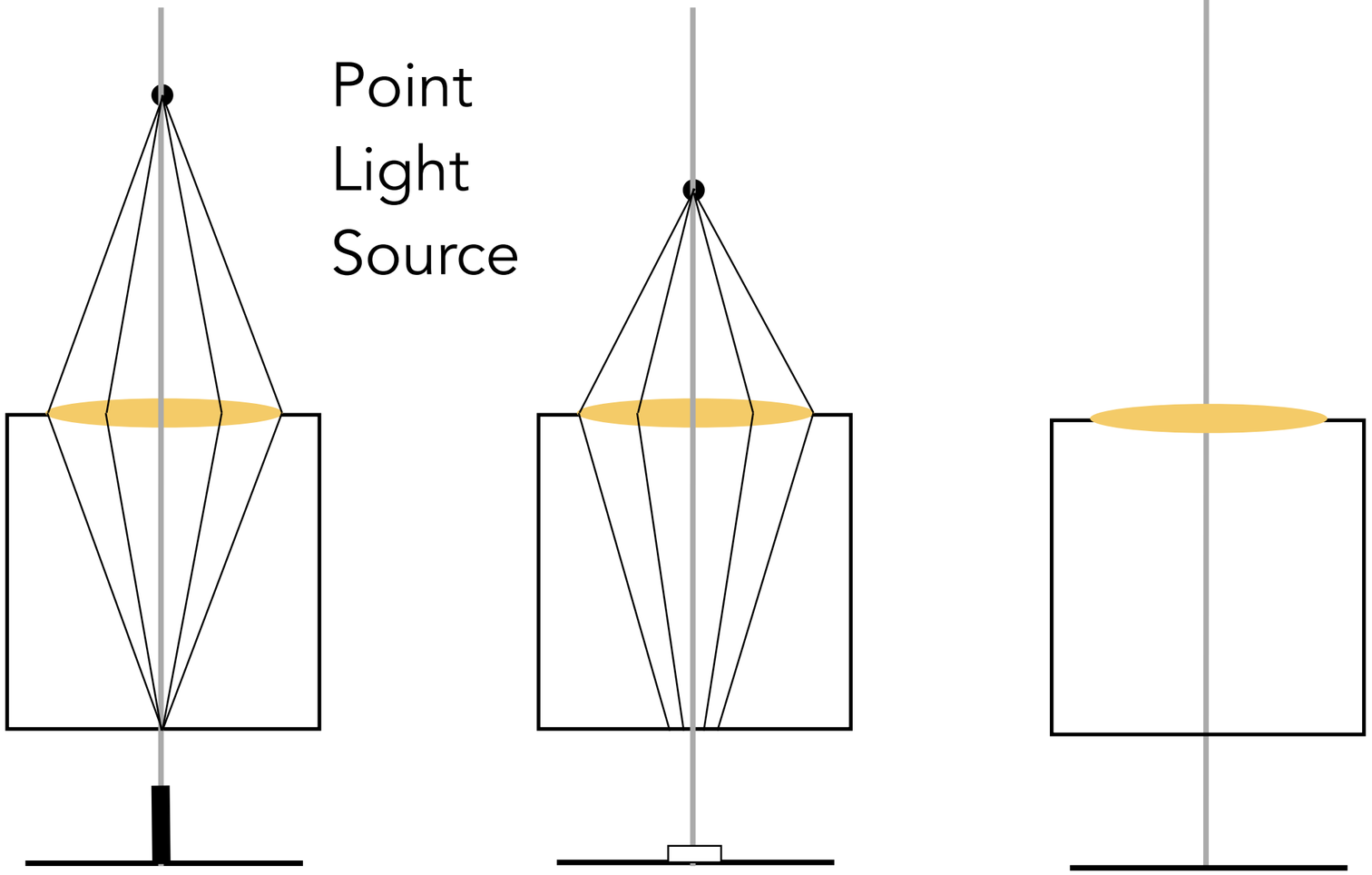
1. In-focus object; forms a Point Image.

Single Lens System (1)



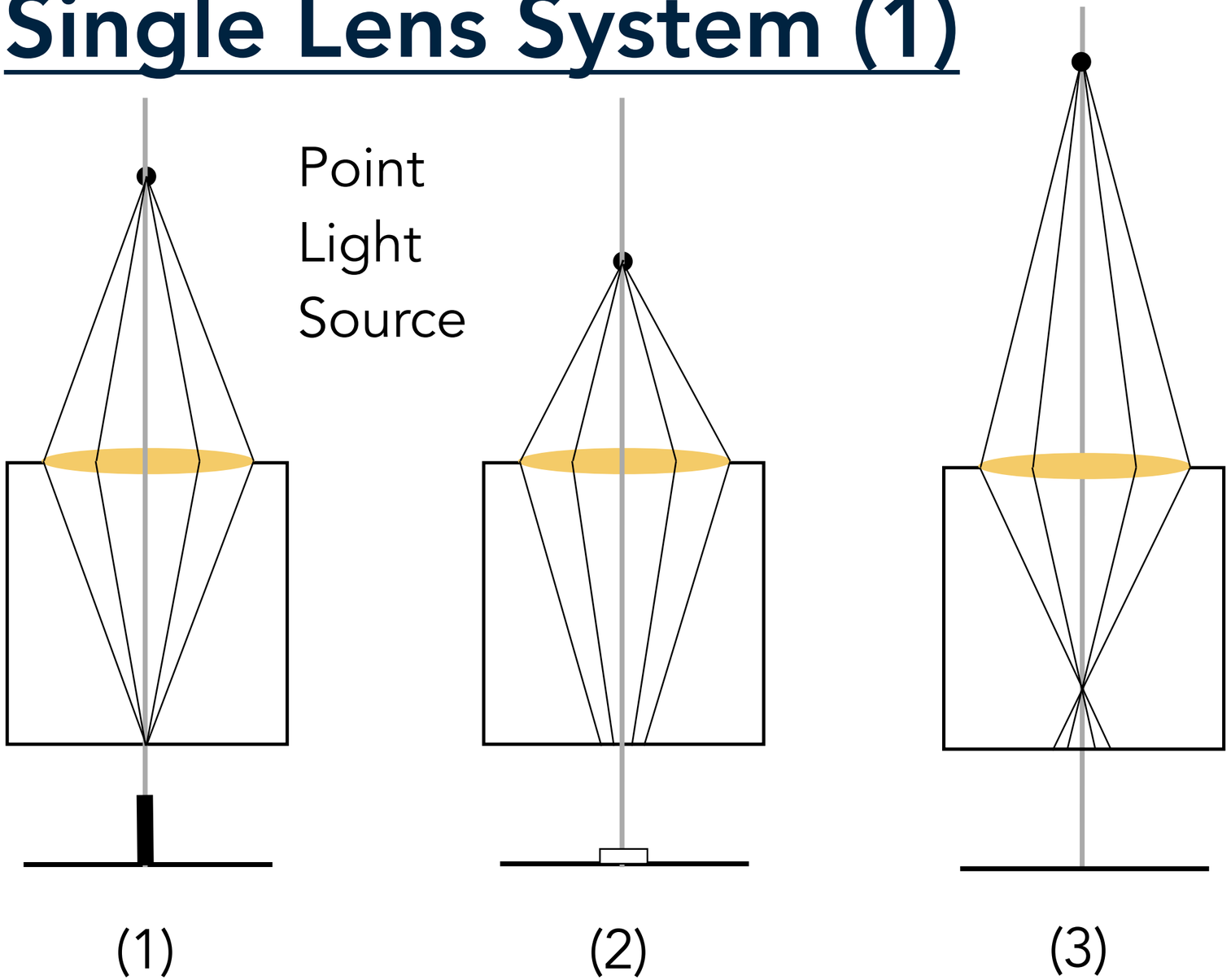
1. In-focus object; forms a Point Image.
2. Near object; blurred

Single Lens System (1)



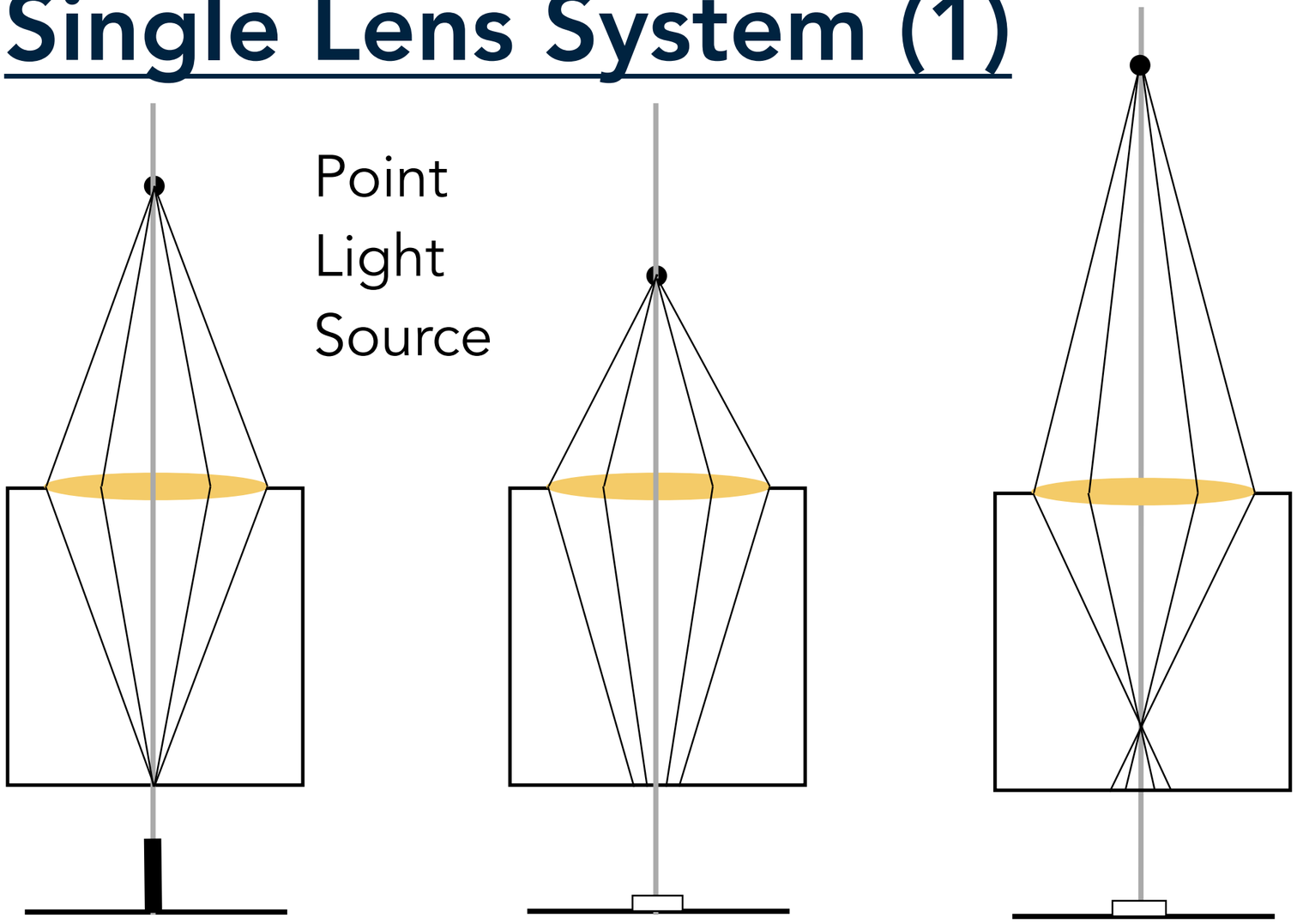
1. In-focus object; forms a Point Image.
2. Near object; blurred

Single Lens System (1)



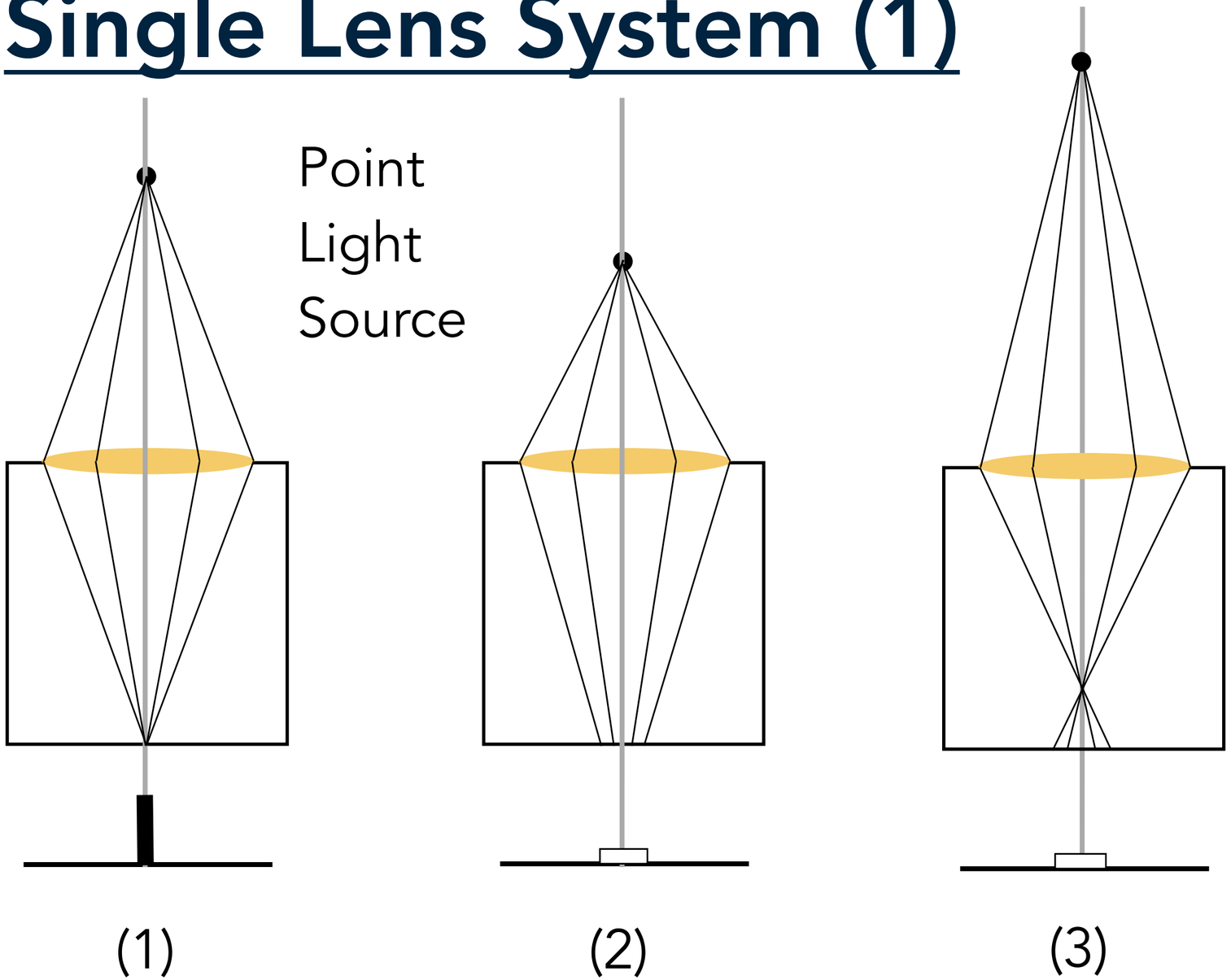
1. In-focus object; forms a Point Image.
2. Near object; blurred

Single Lens System (1)



1. In-focus object; forms a Point Image.
2. Near object; blurred

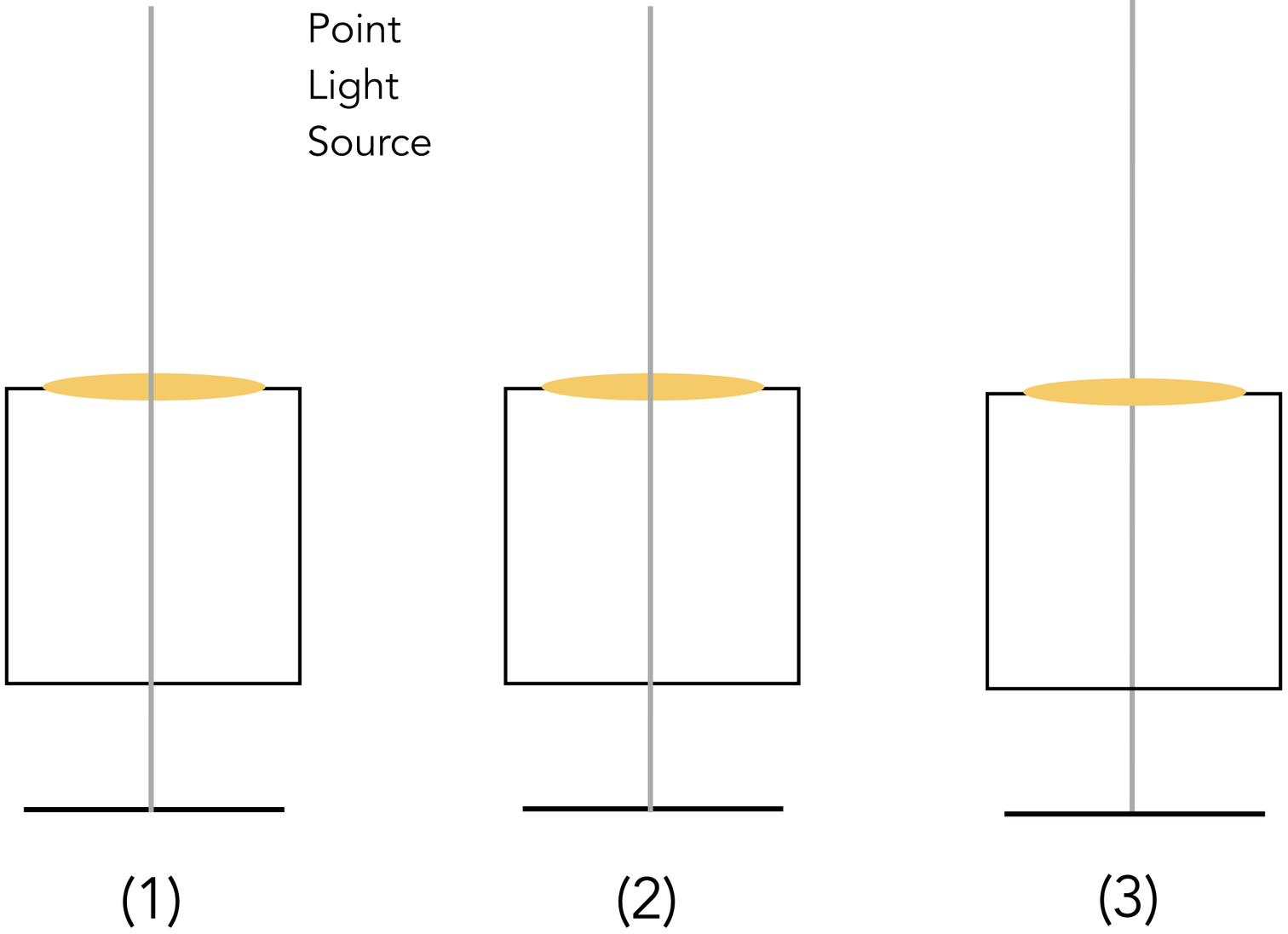
Single Lens System (1)



1. In-focus object; forms a Point Image.
2. Near object; blurred
3. Far object; blurred

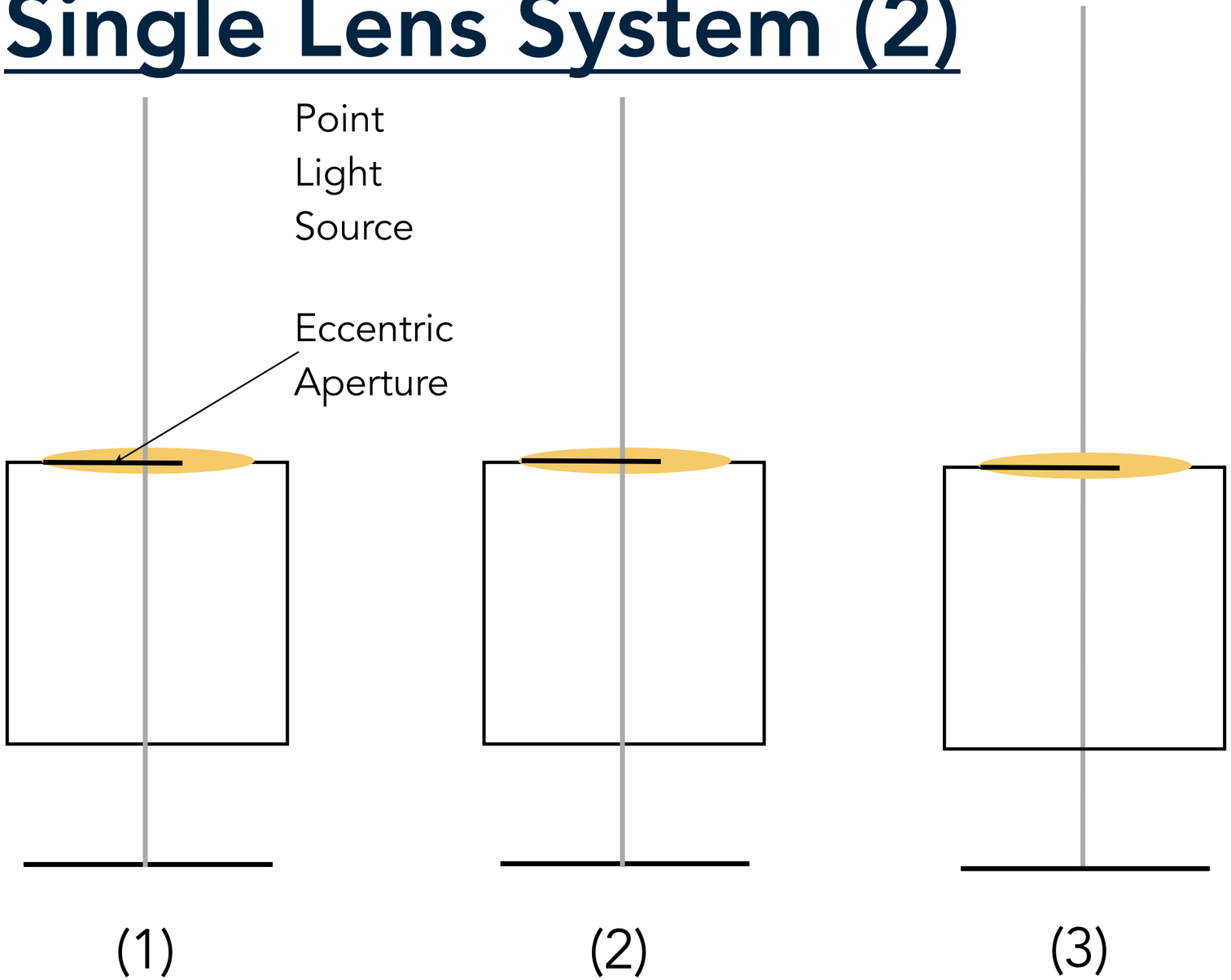
Single Lens System (2)

Point
Light
Source



(1) (2) (3)

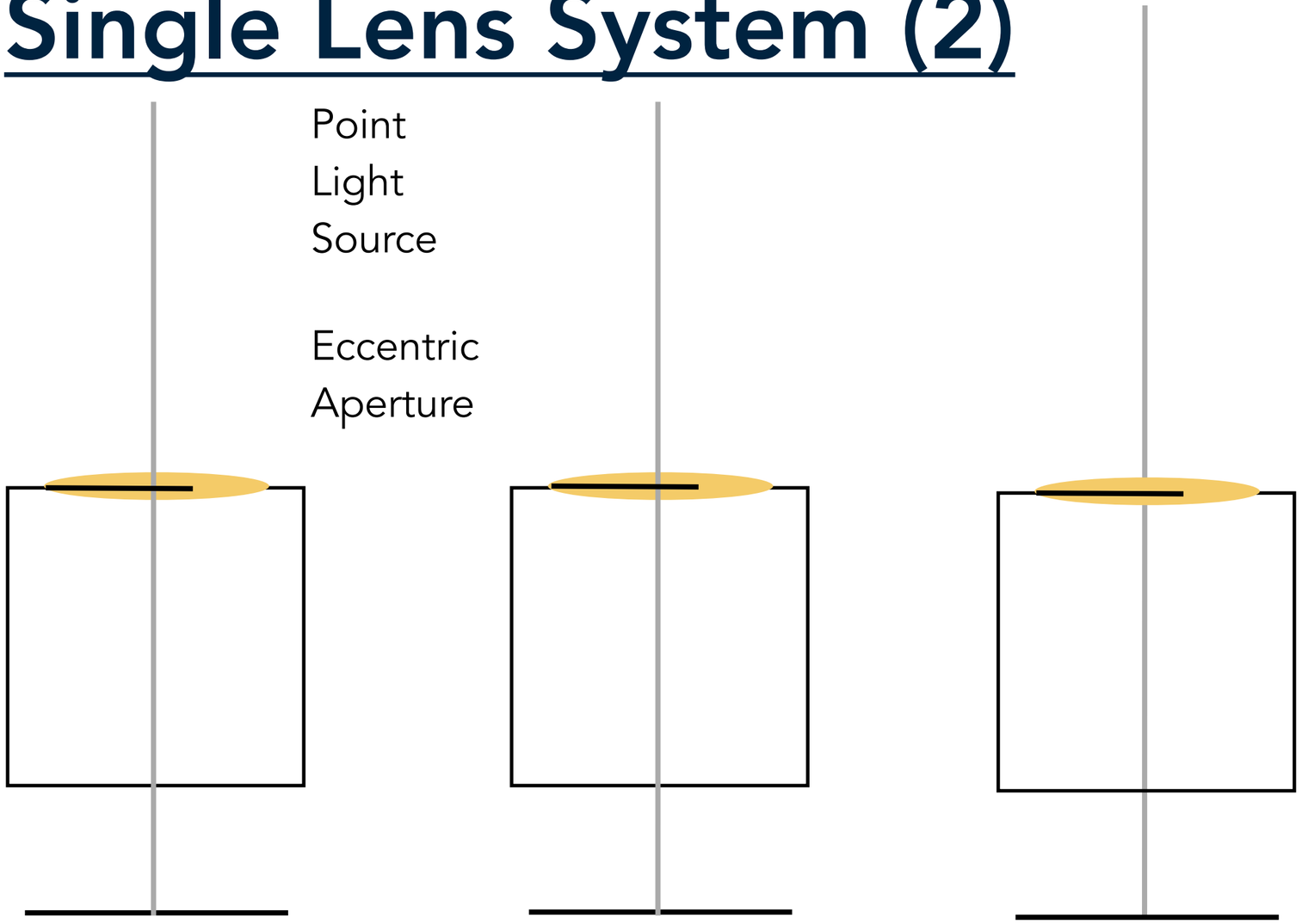
Single Lens System (2)



Single Lens System (2)

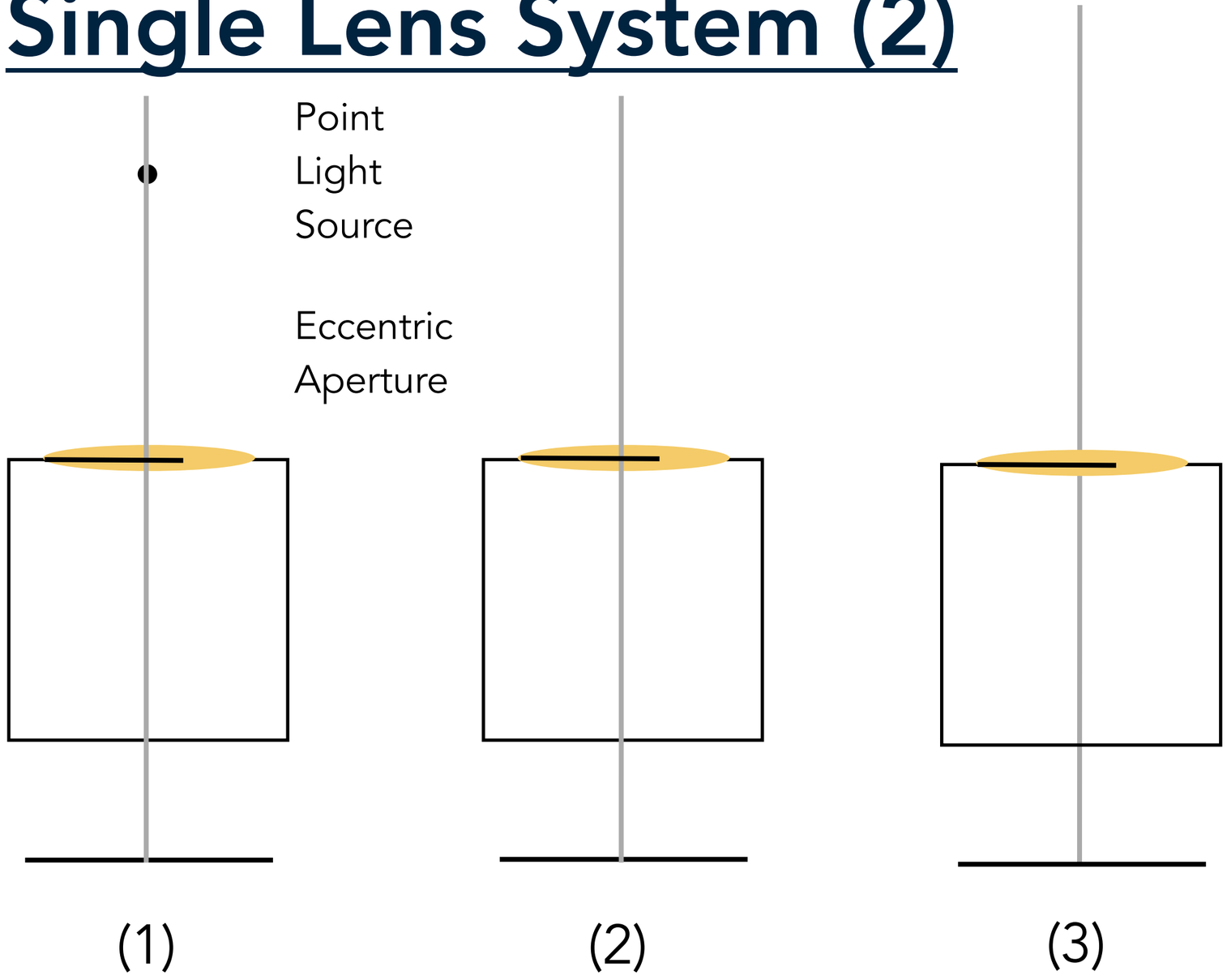
Point
Light
Source

Eccentric
Aperture

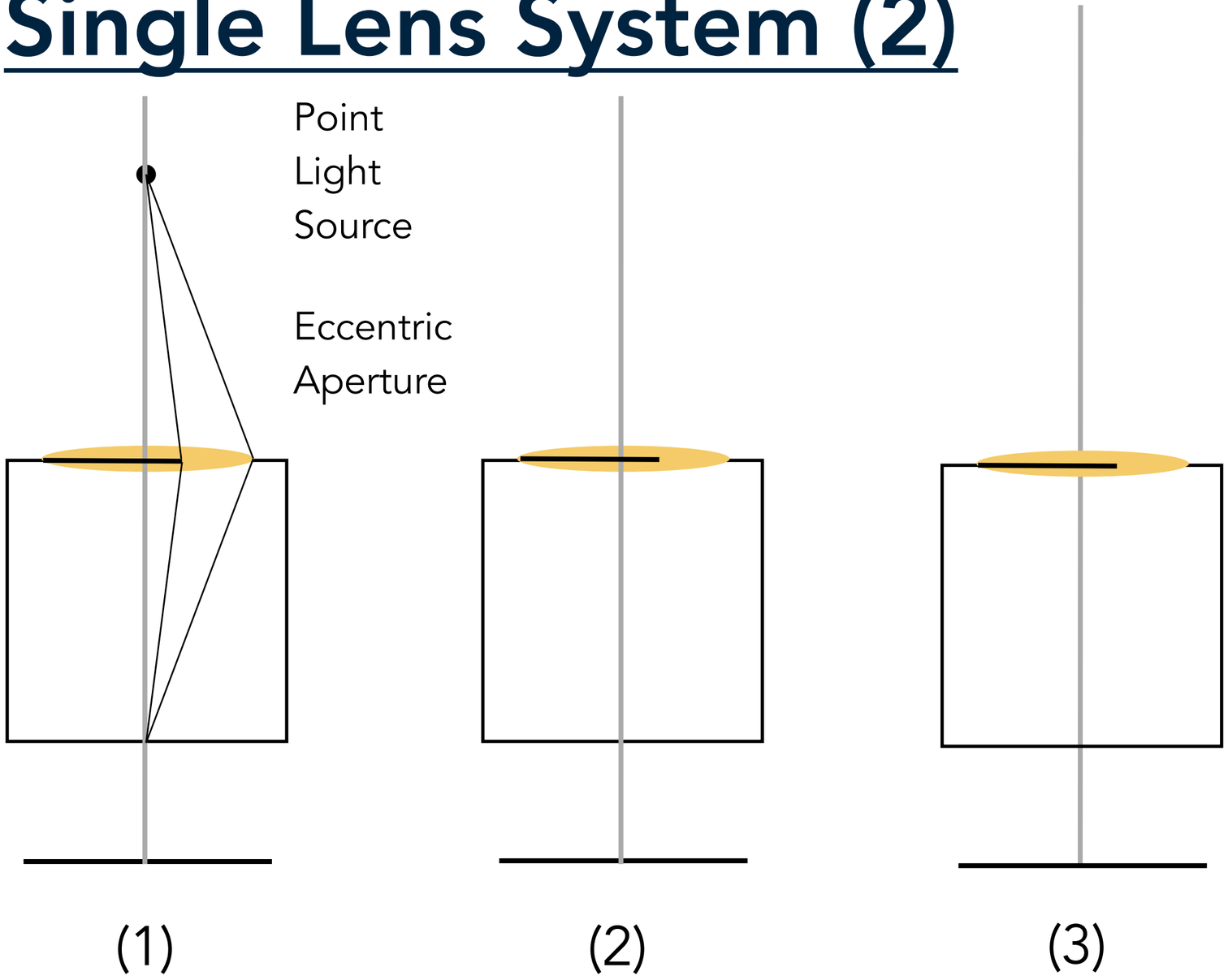


(1) (2) (3)

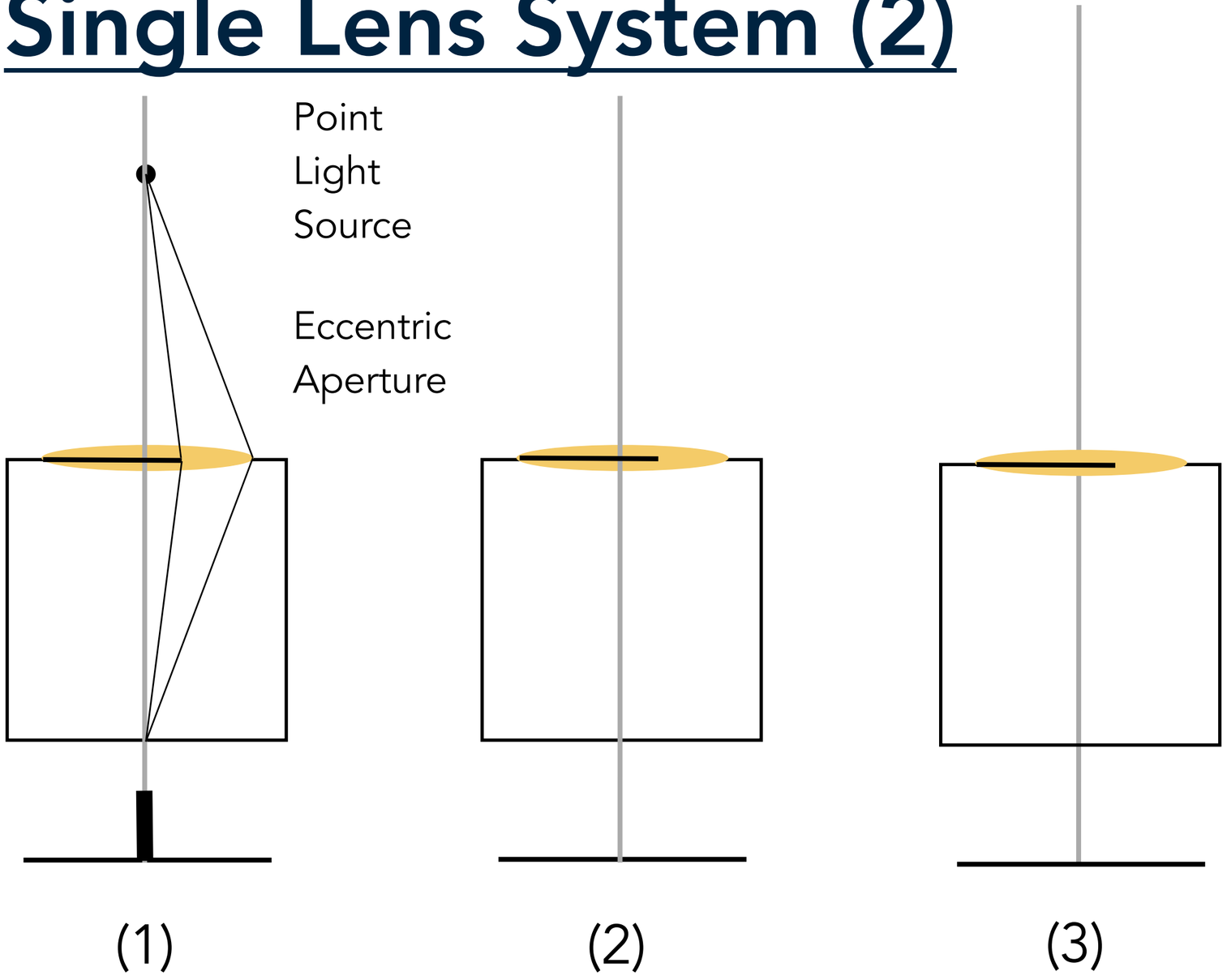
Single Lens System (2)



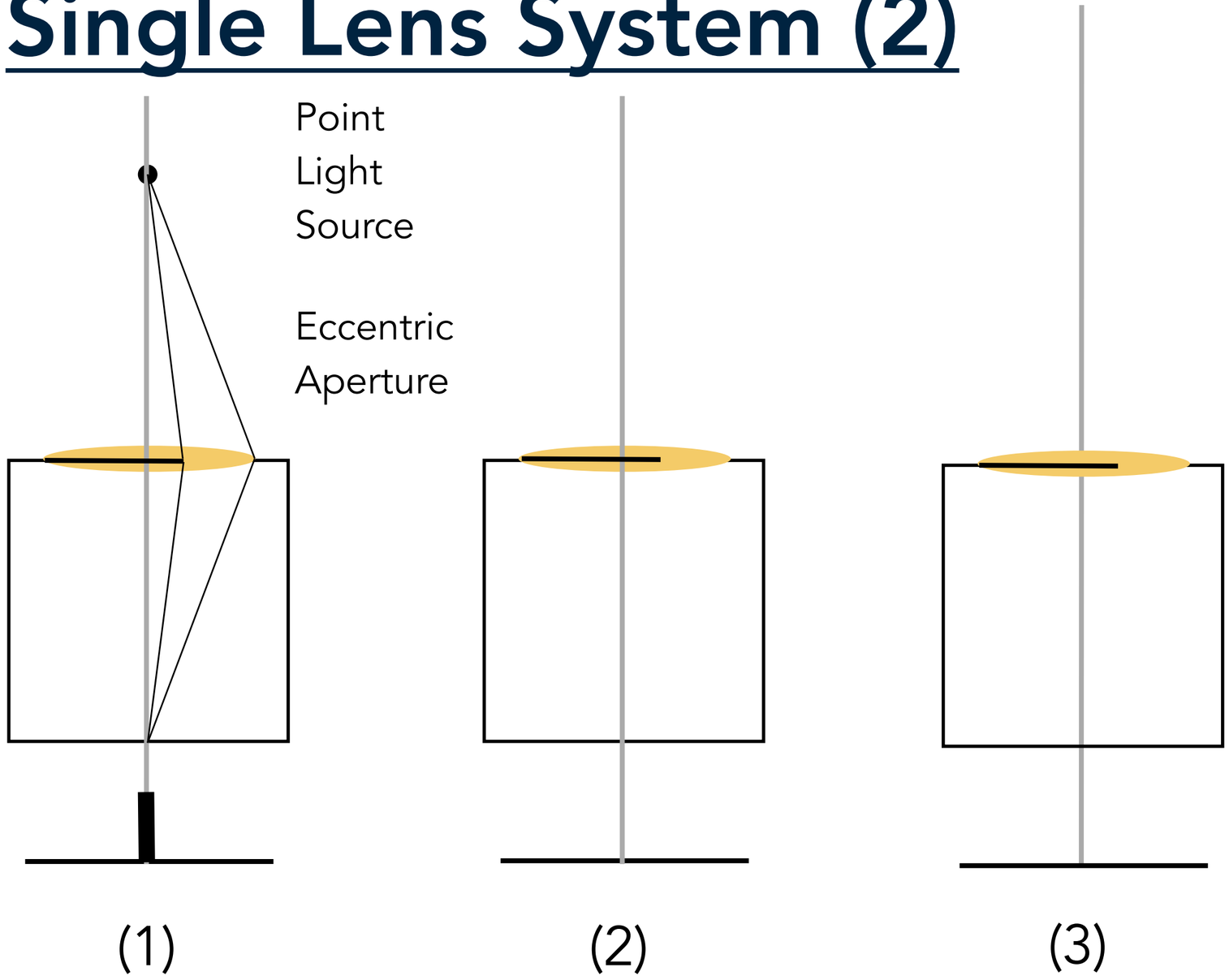
Single Lens System (2)



Single Lens System (2)

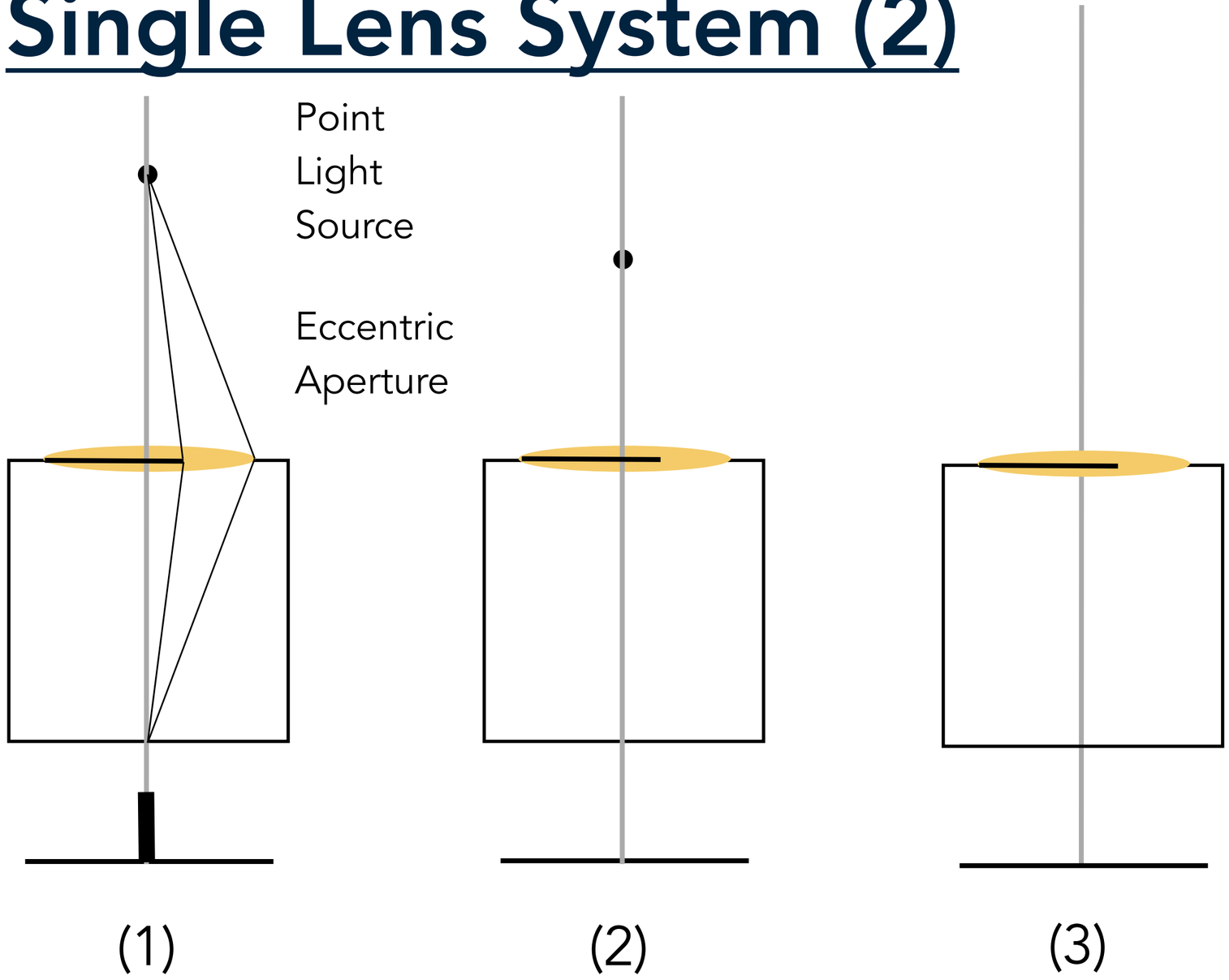


Single Lens System (2)



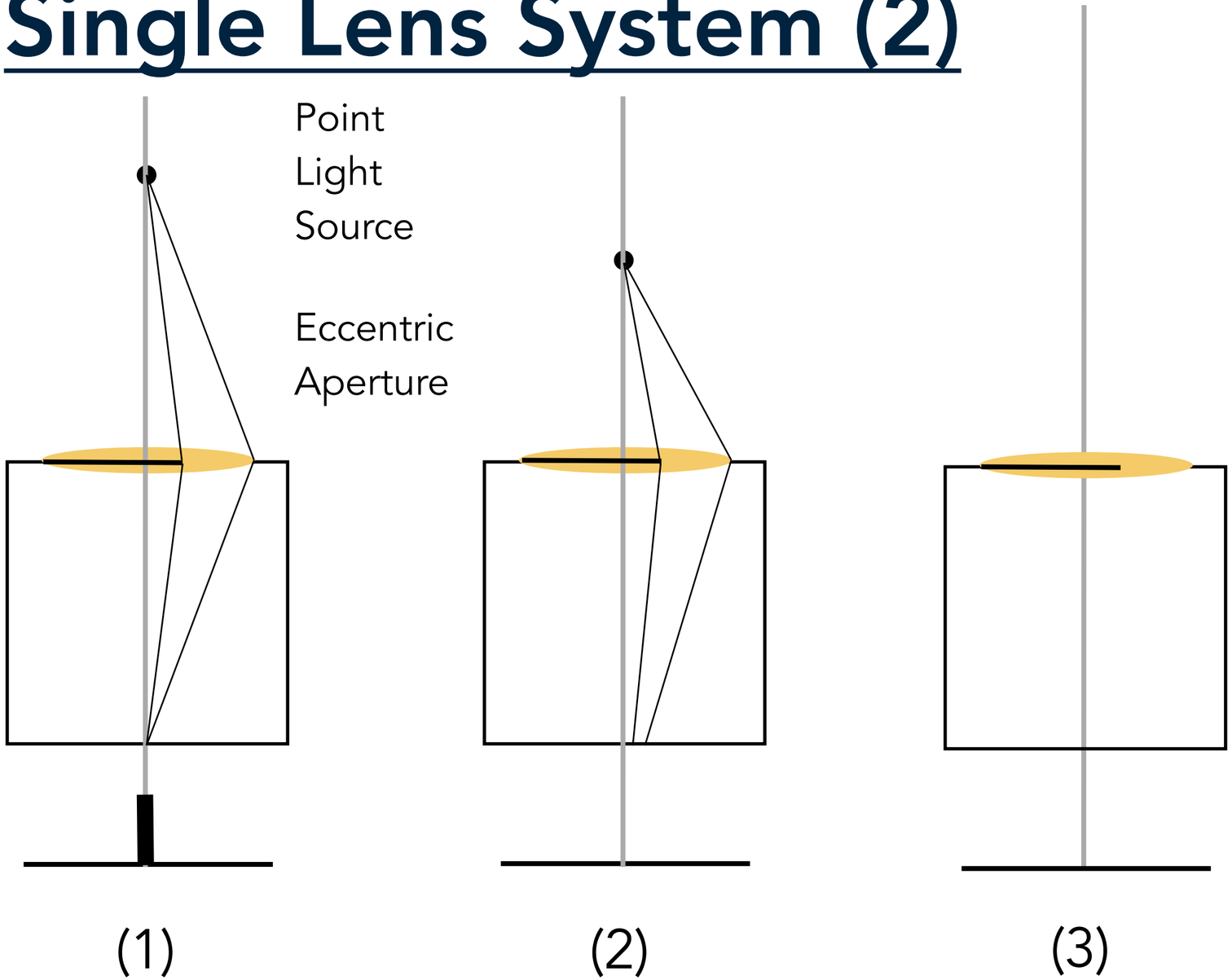
1. In-focus object; forms a Point Image.

Single Lens System (2)



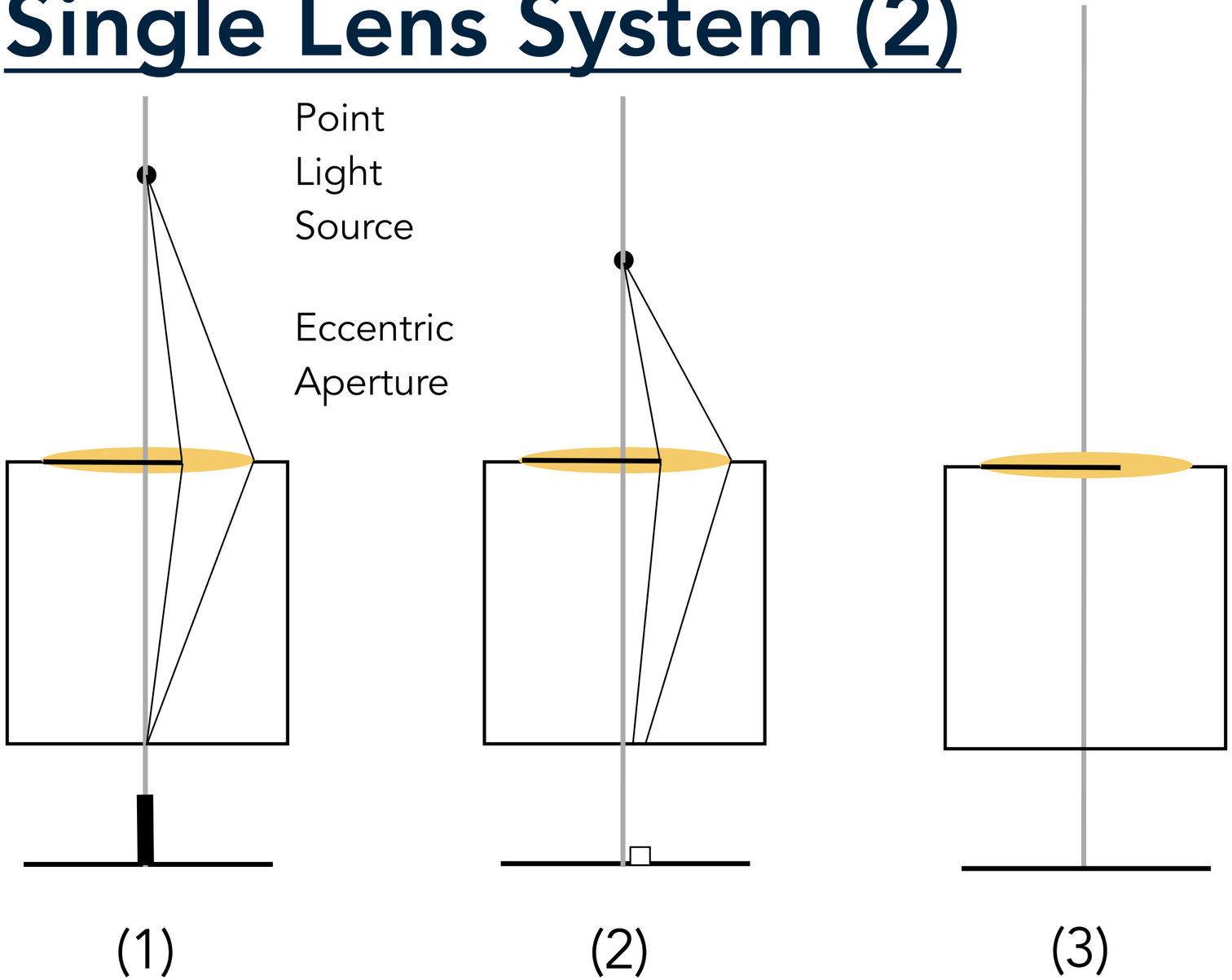
1. In-focus object; forms a Point Image.

Single Lens System (2)



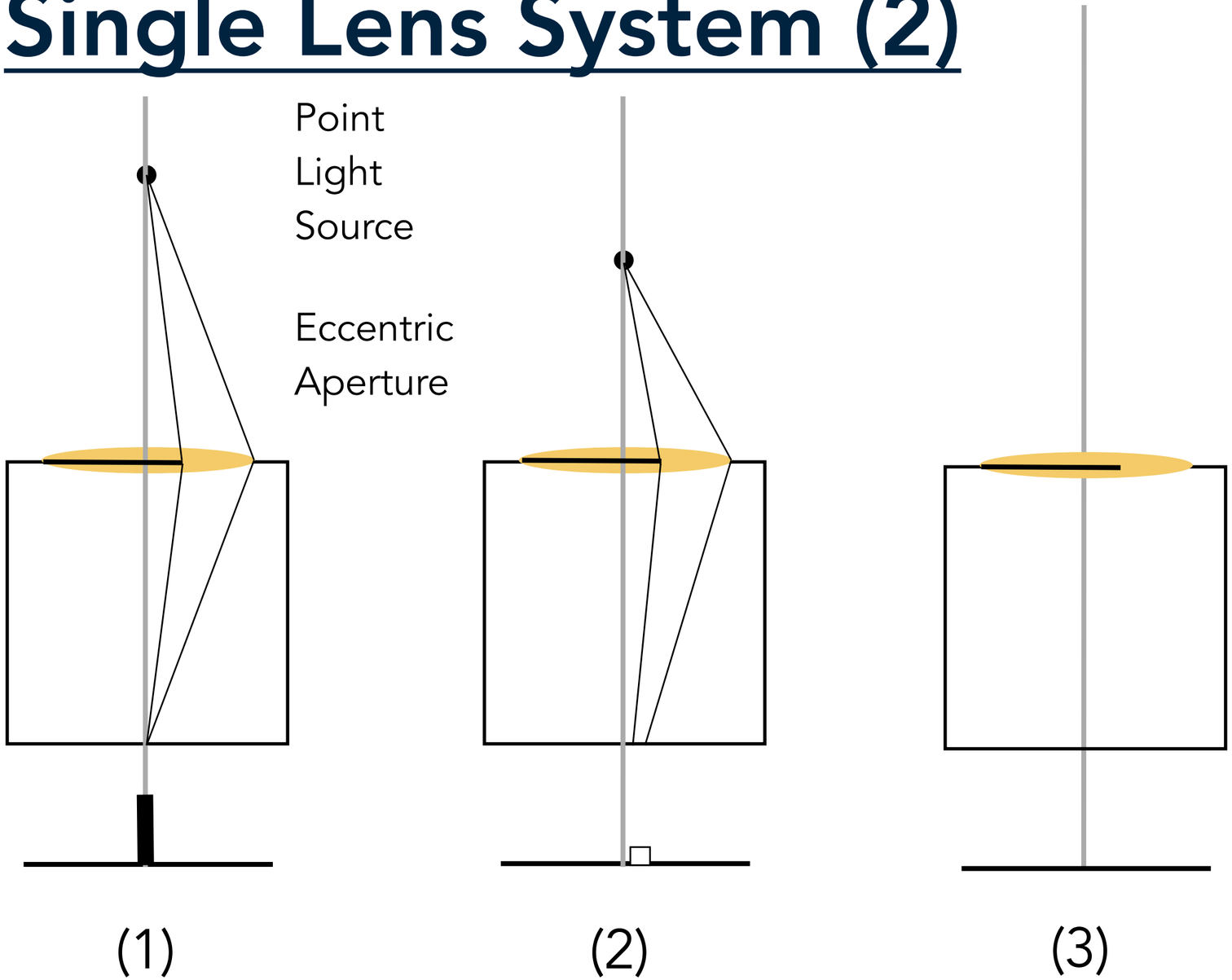
1. In-focus object; forms a Point Image.

Single Lens System (2)



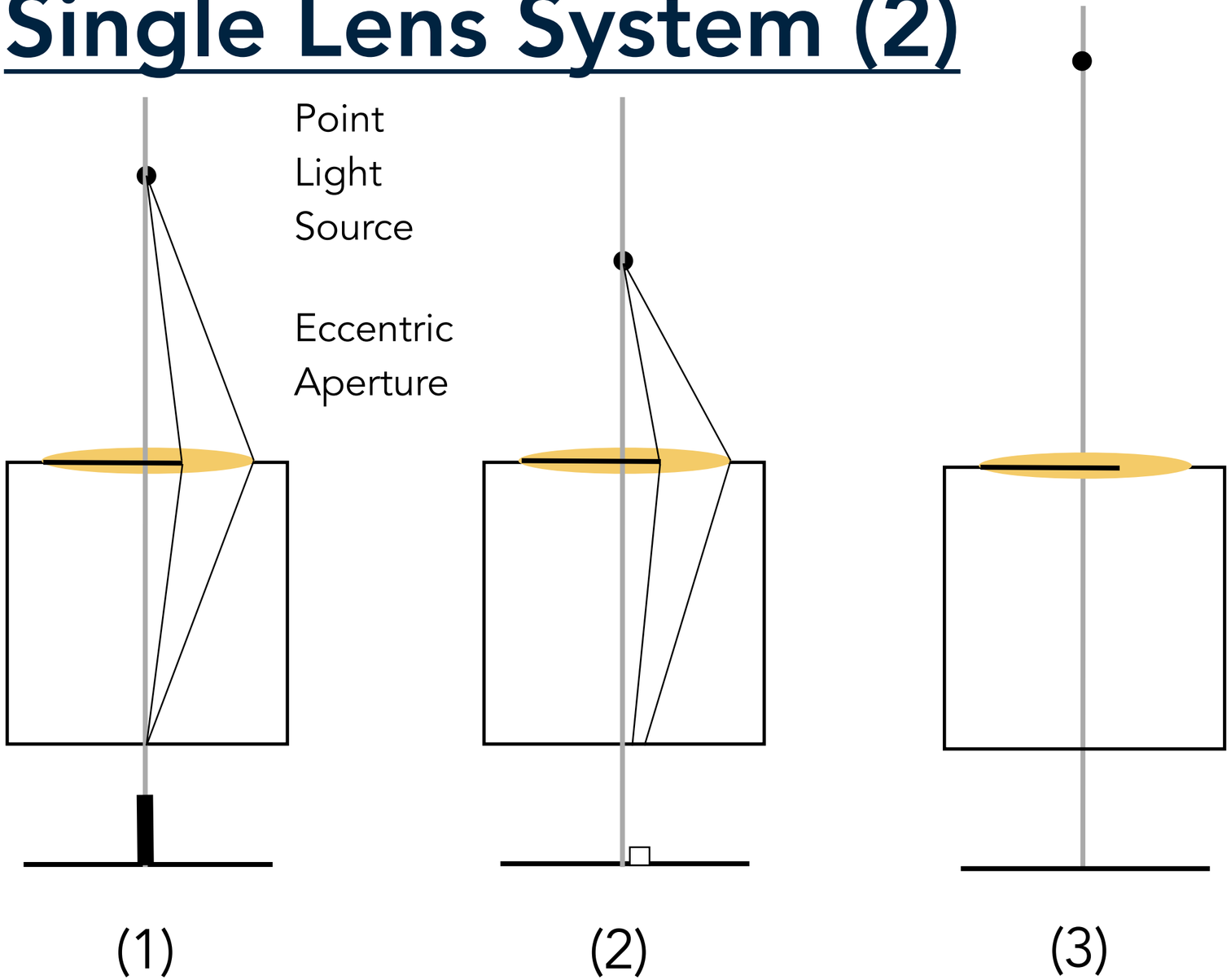
1. In-focus object; forms a Point Image.

Single Lens System (2)



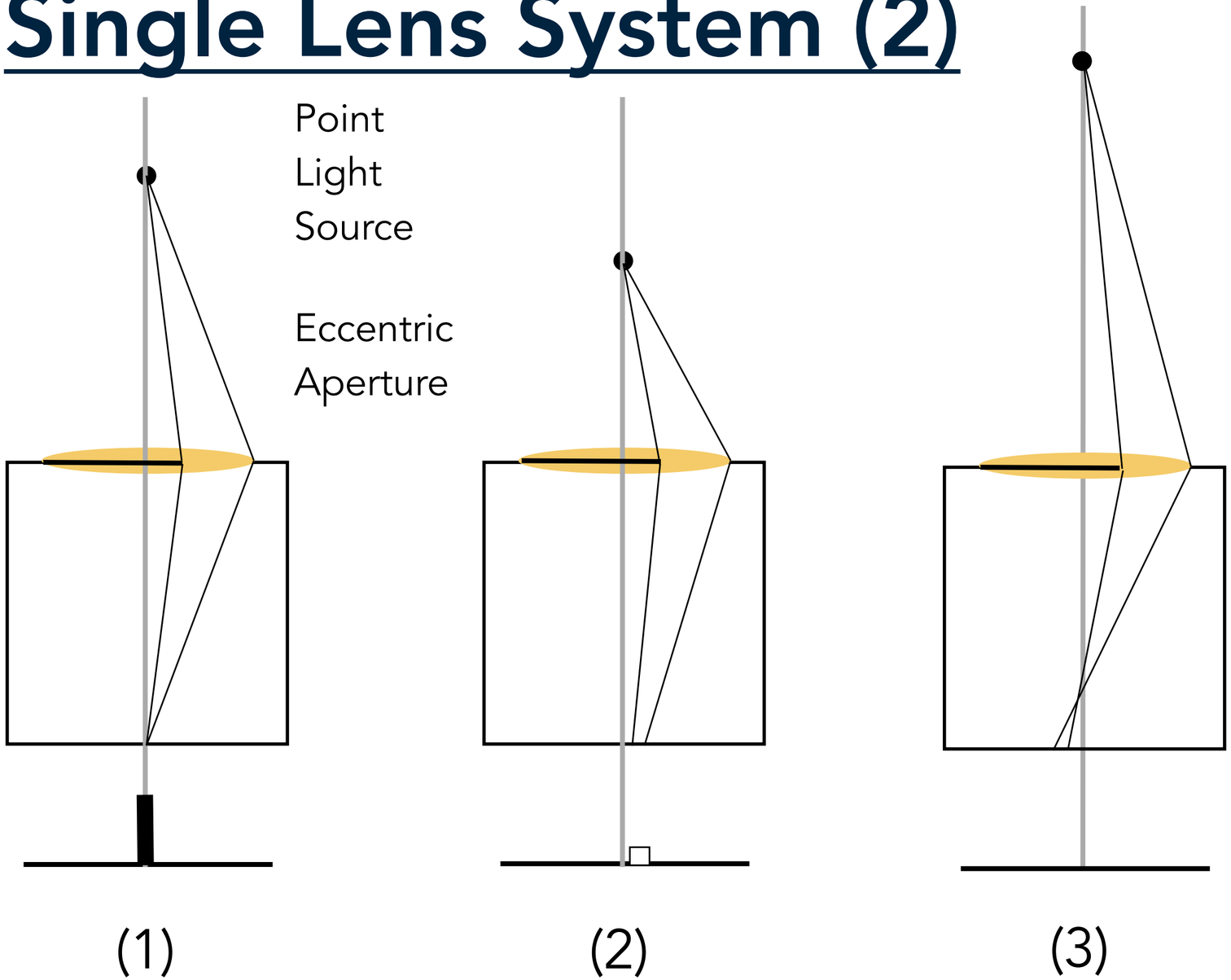
1. In-focus object; forms a Point Image.
2. Near object; blurred, to the right

Single Lens System (2)



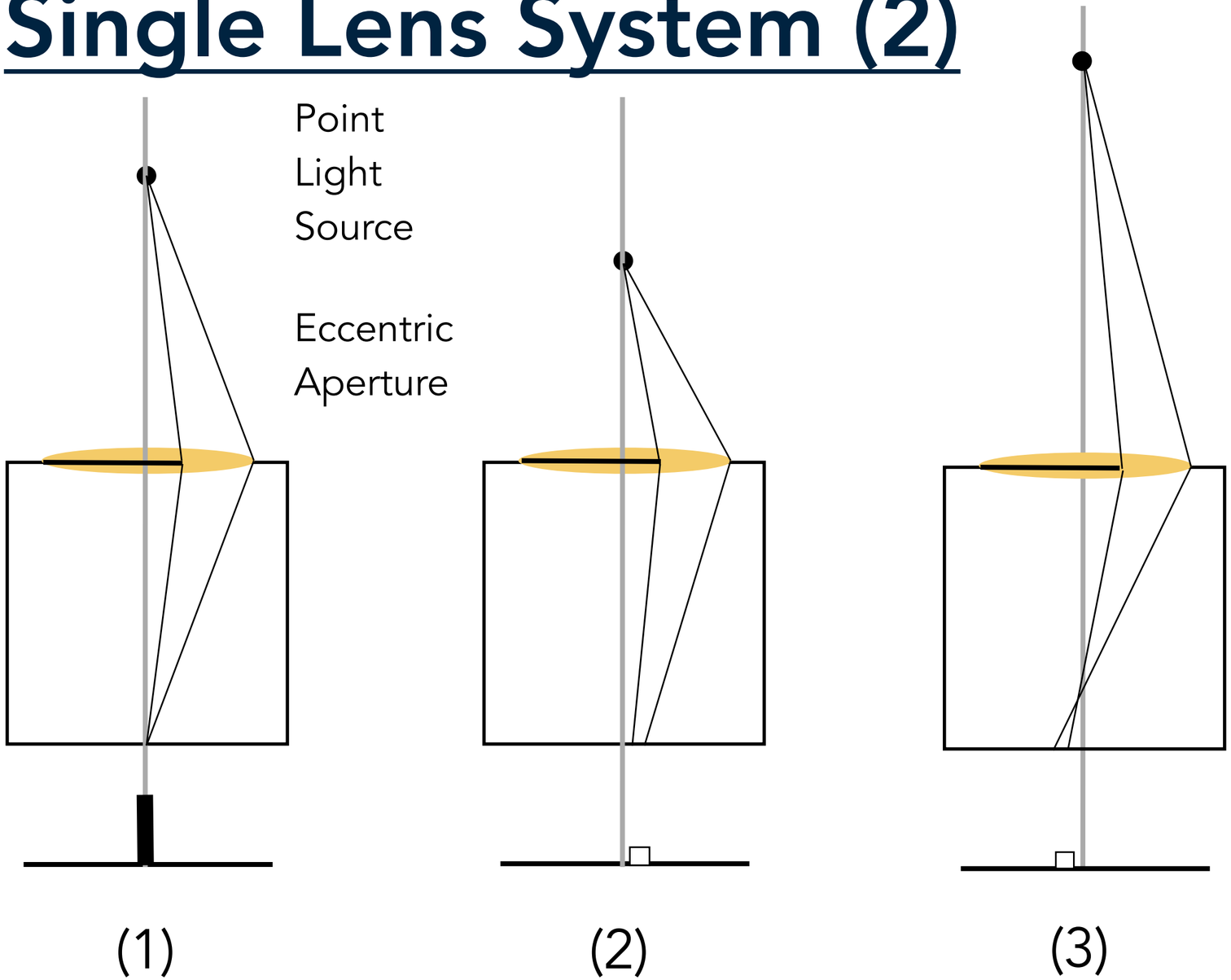
1. In-focus object; forms a Point Image.
2. Near object; blurred, to the right

Single Lens System (2)



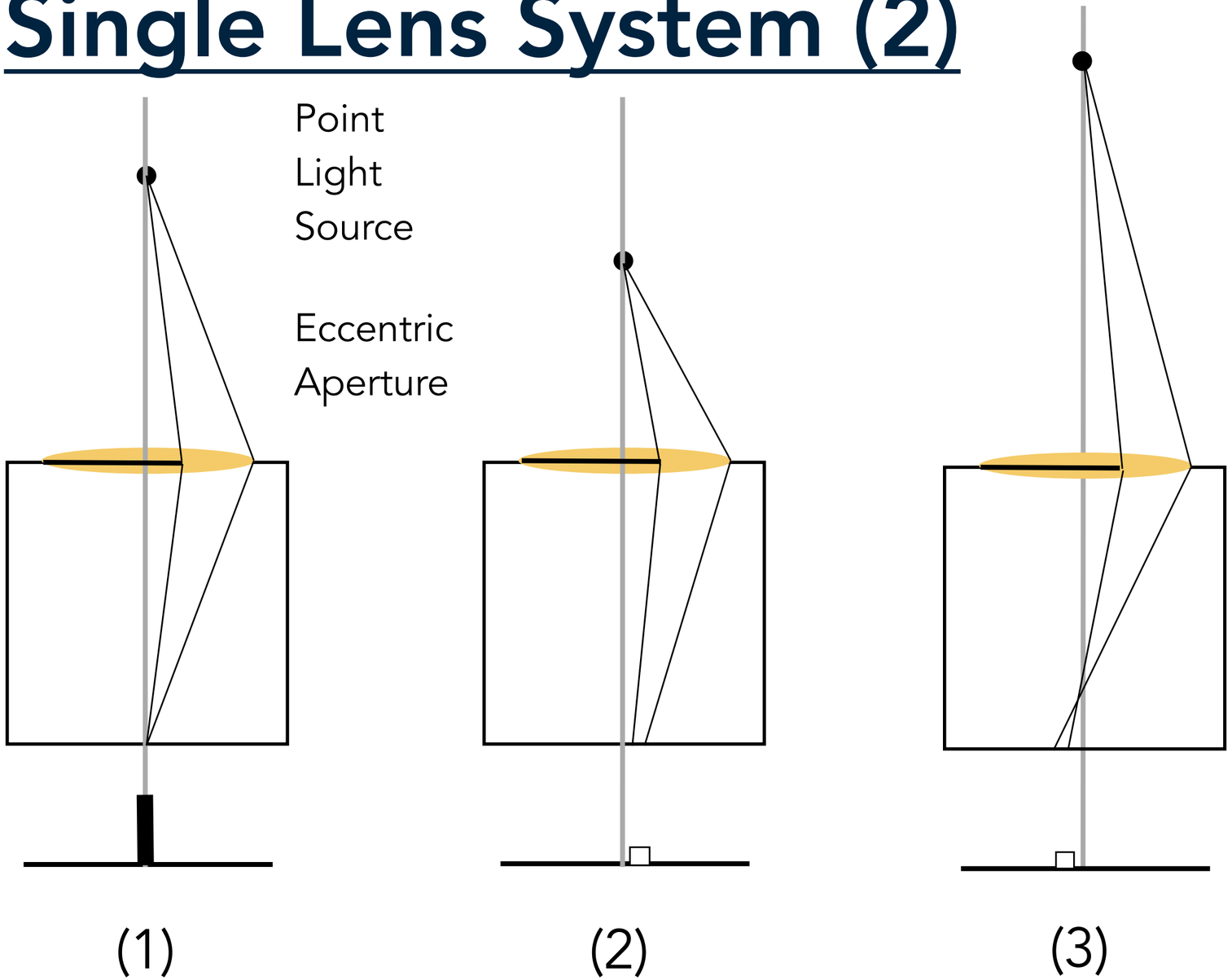
1. In-focus object; forms a Point Image.
2. Near object; blurred, to the right

Single Lens System (2)



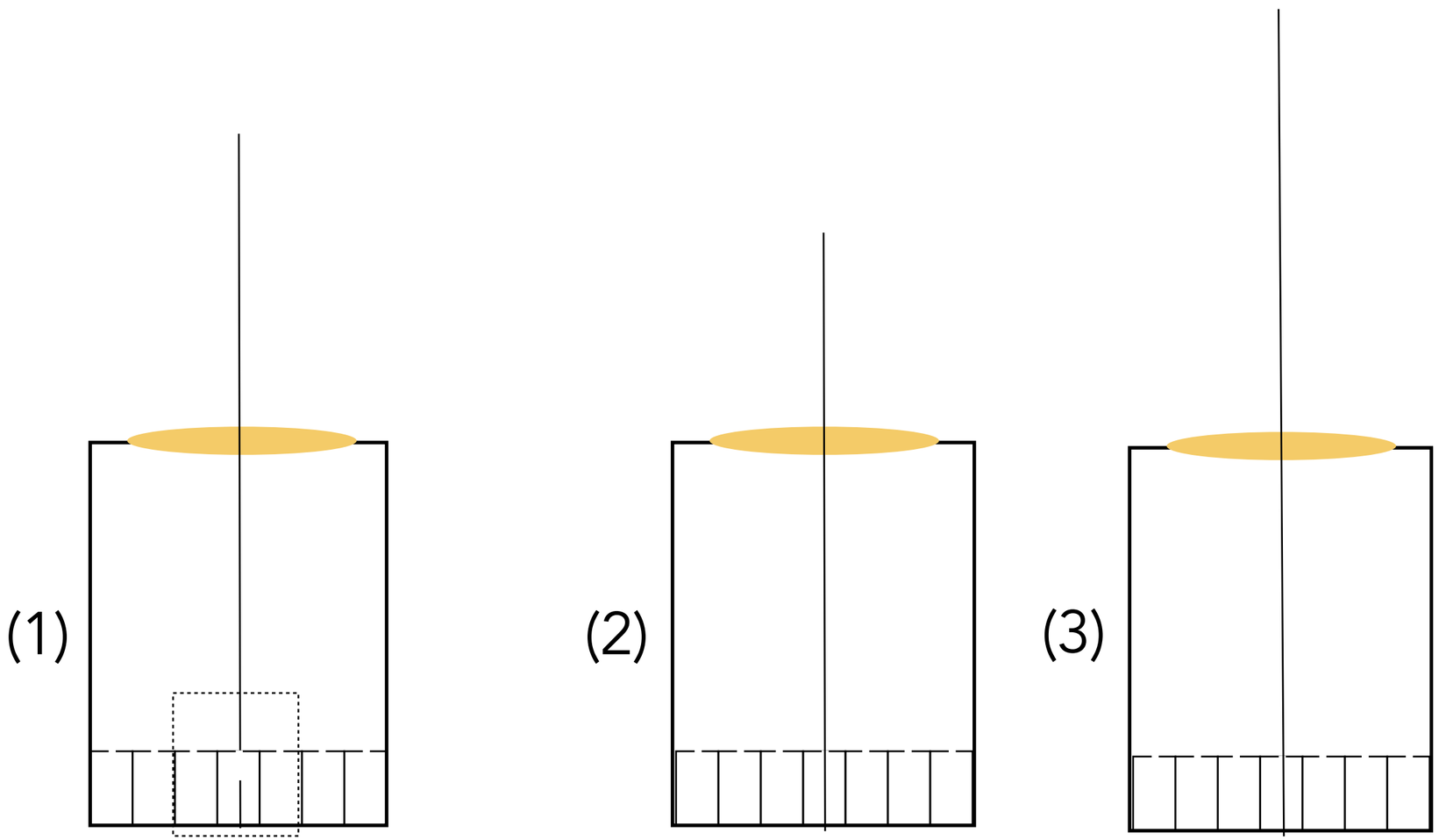
1. In-focus object; forms a Point Image.
2. Near object; blurred, to the right

Single Lens System (2)



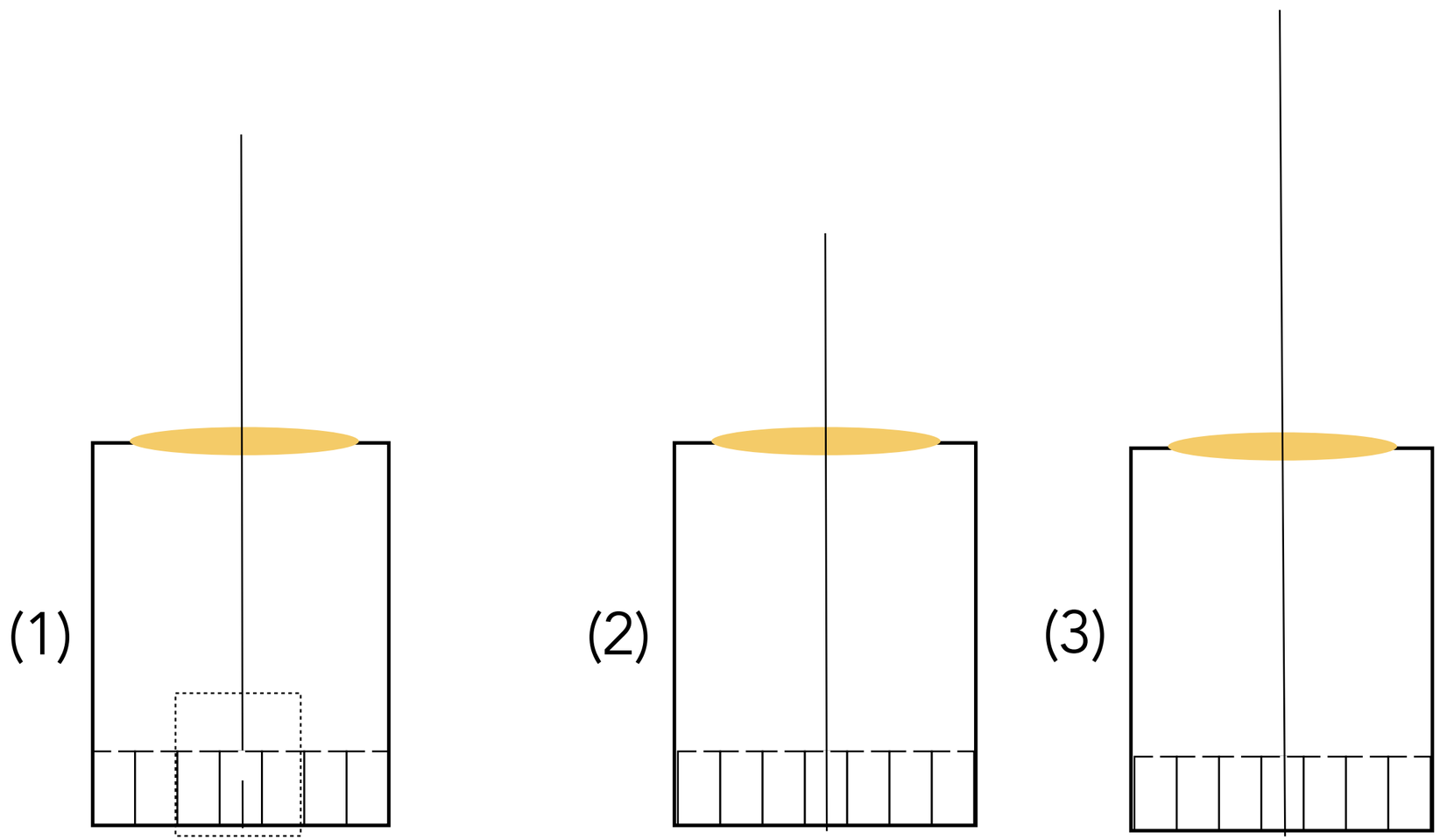
1. In-focus object; forms a Point Image.
2. Near object; blurred, to the right
3. Far object; blurred, to the left

Encode Direction and Intensity



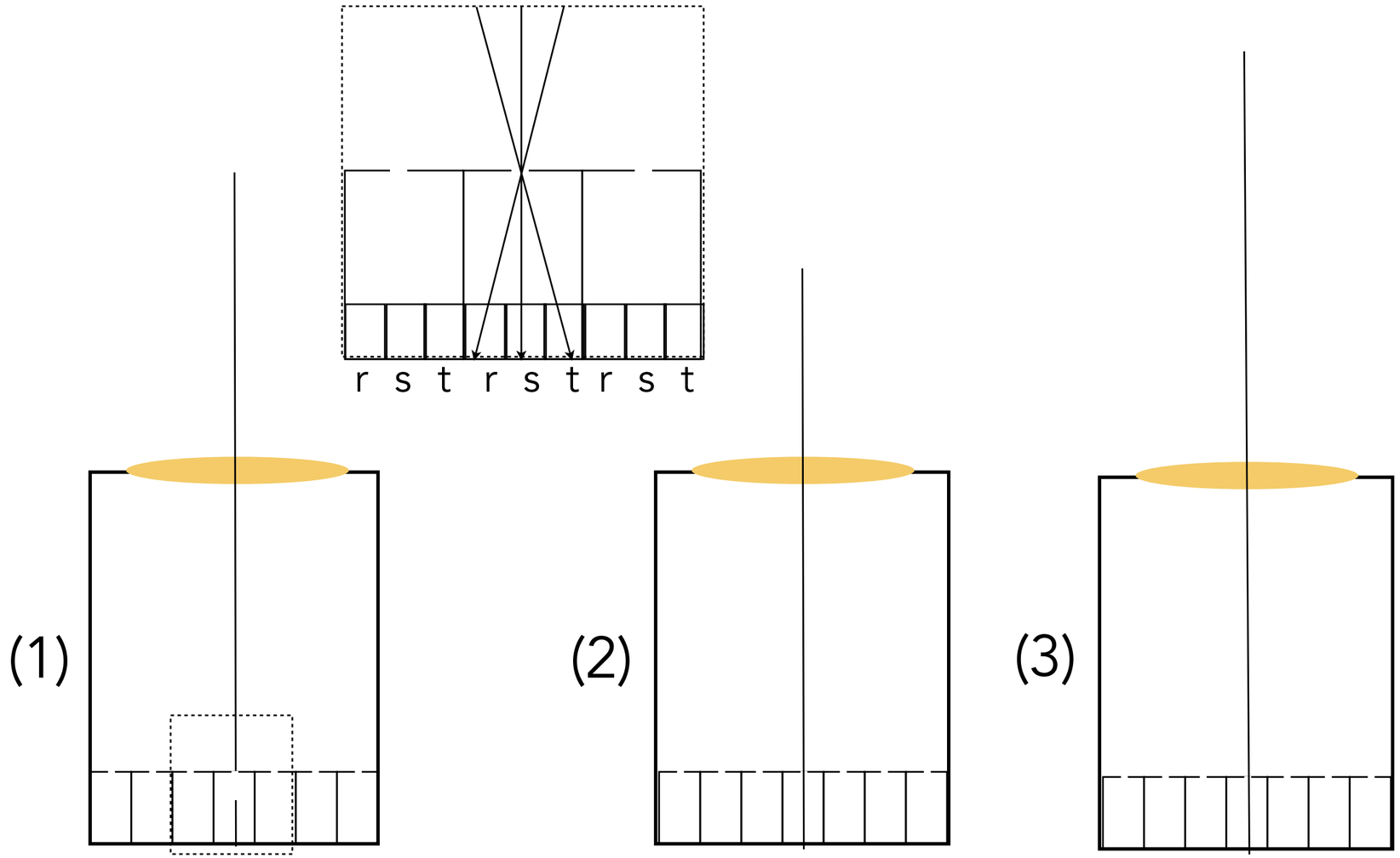
Encode Direction and Intensity

★ We add a miniature pinhole at the image plane



Encode Direction and Intensity

- We add a miniature pinhole at the image plane



Encode Direction and Intensity

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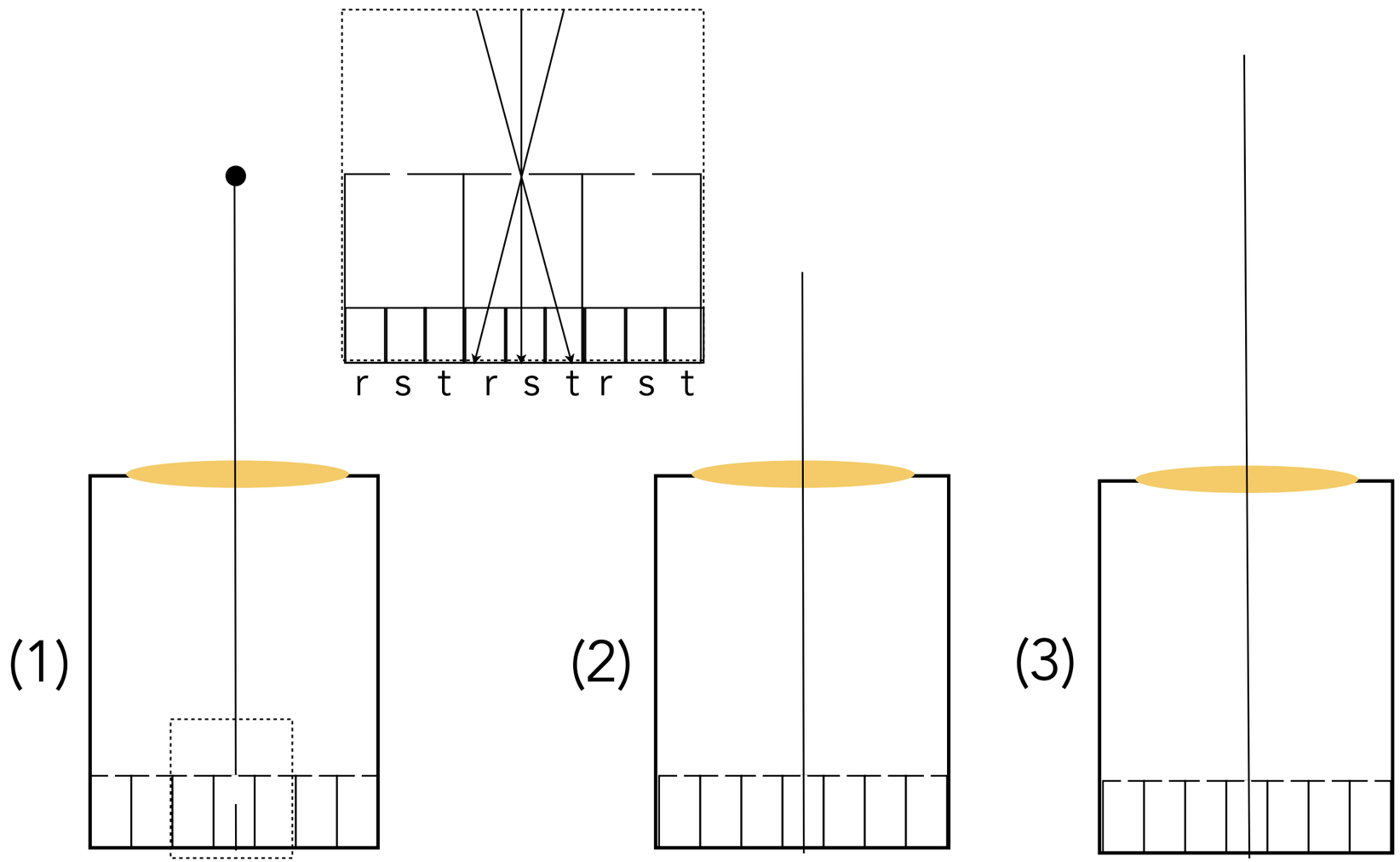
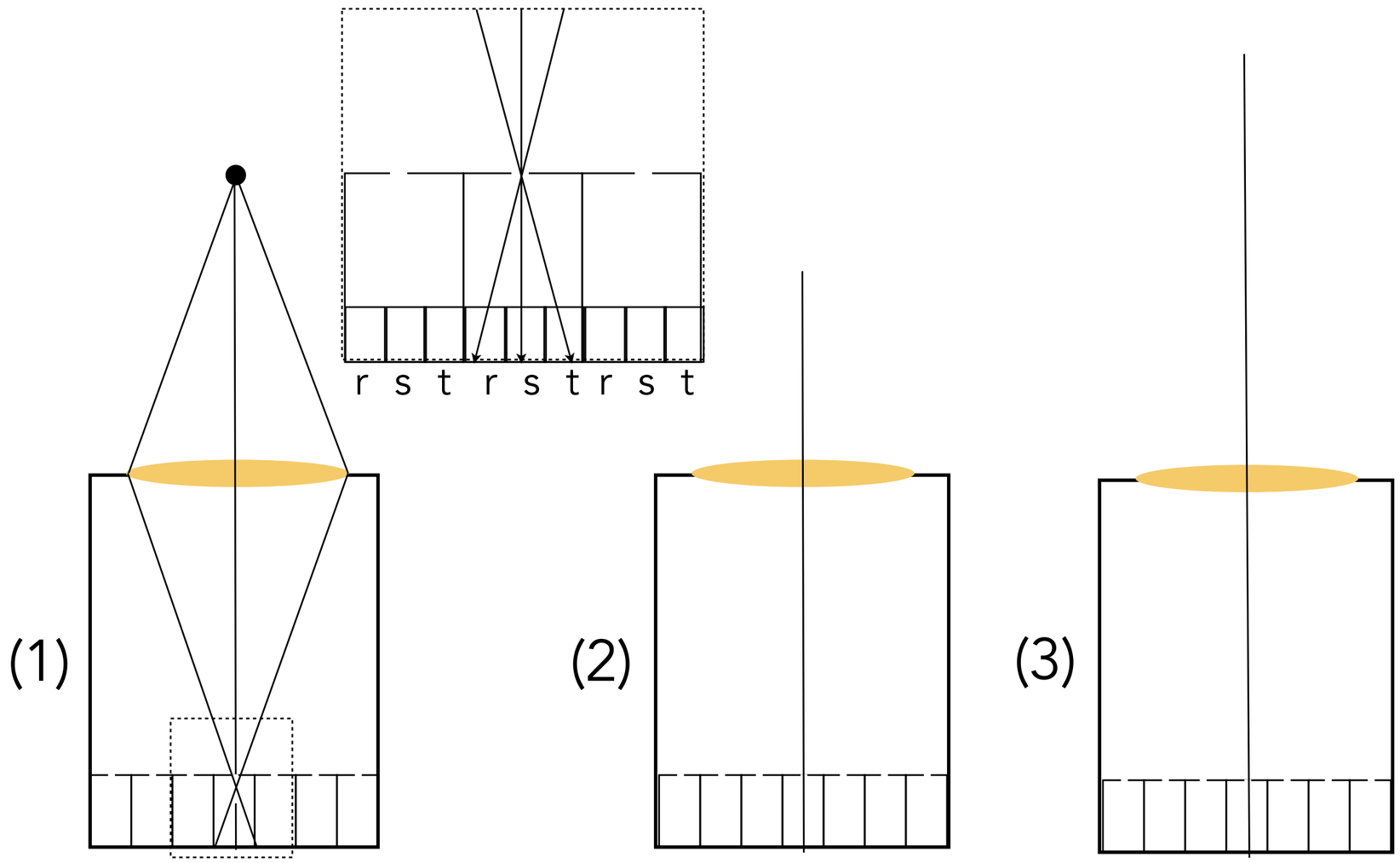


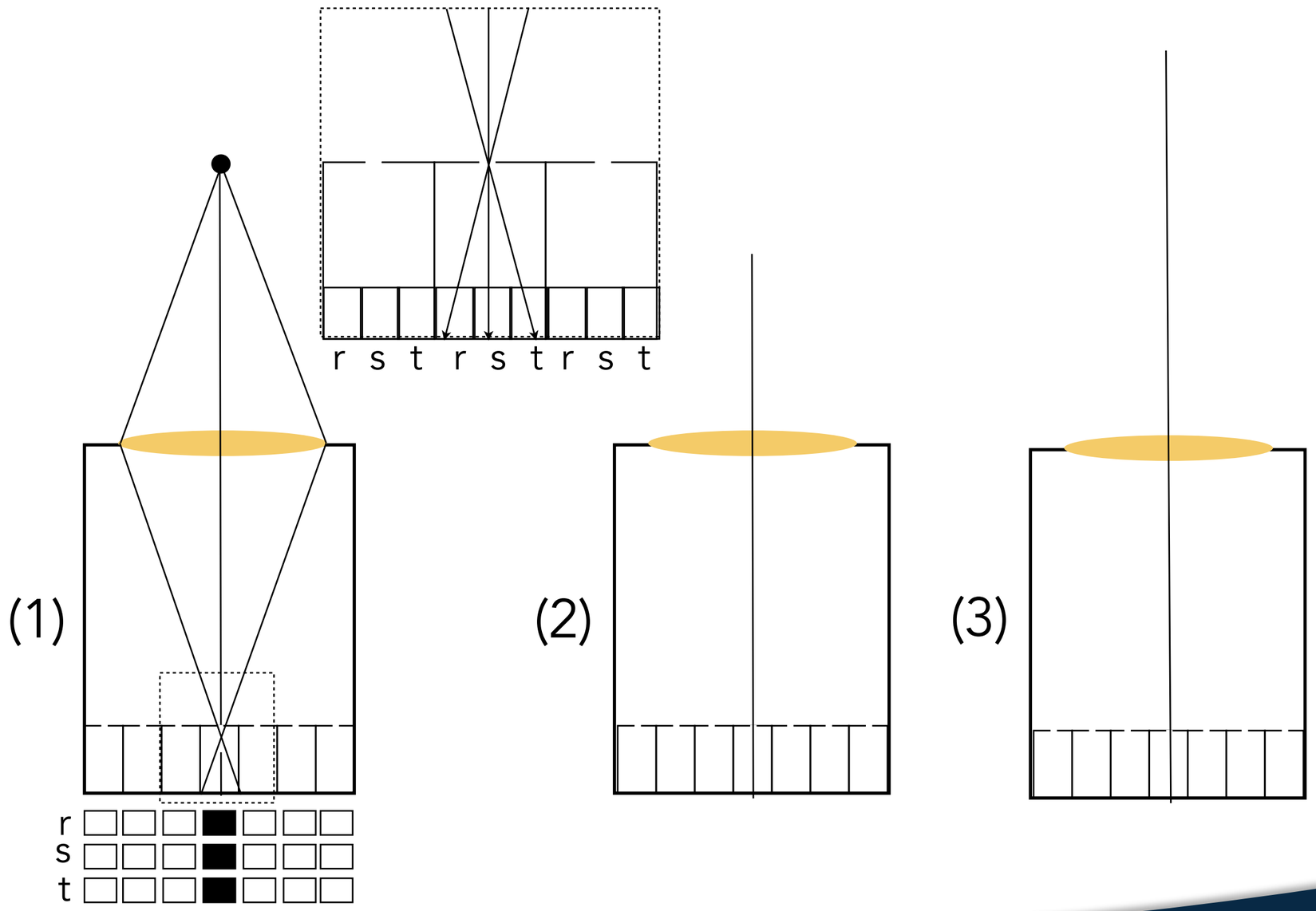
Encode Direction and Intensity

- We add a miniature pinhole at the image plane



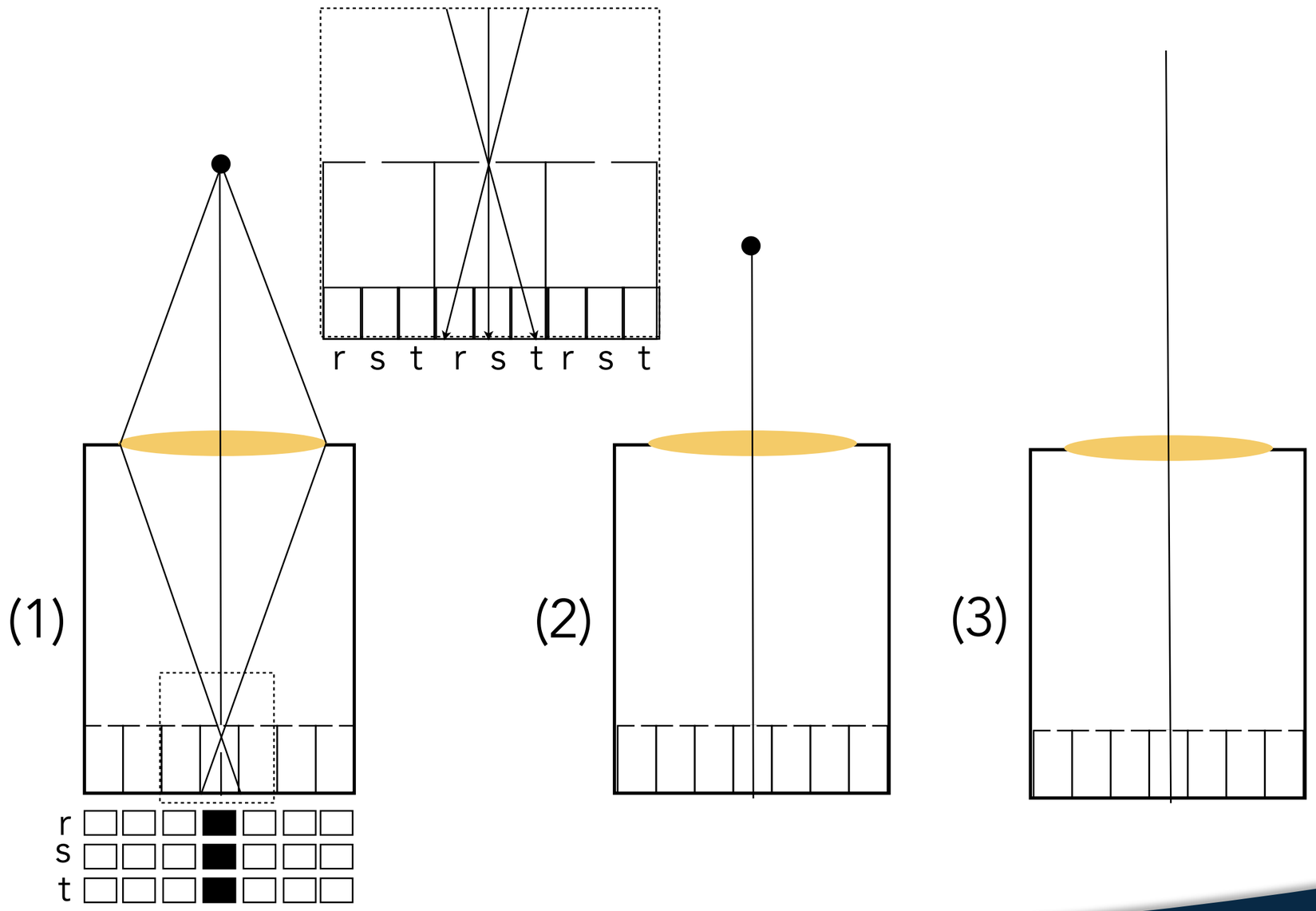
Encode Direction and Intensity

- We add a miniature pinhole at the image plane



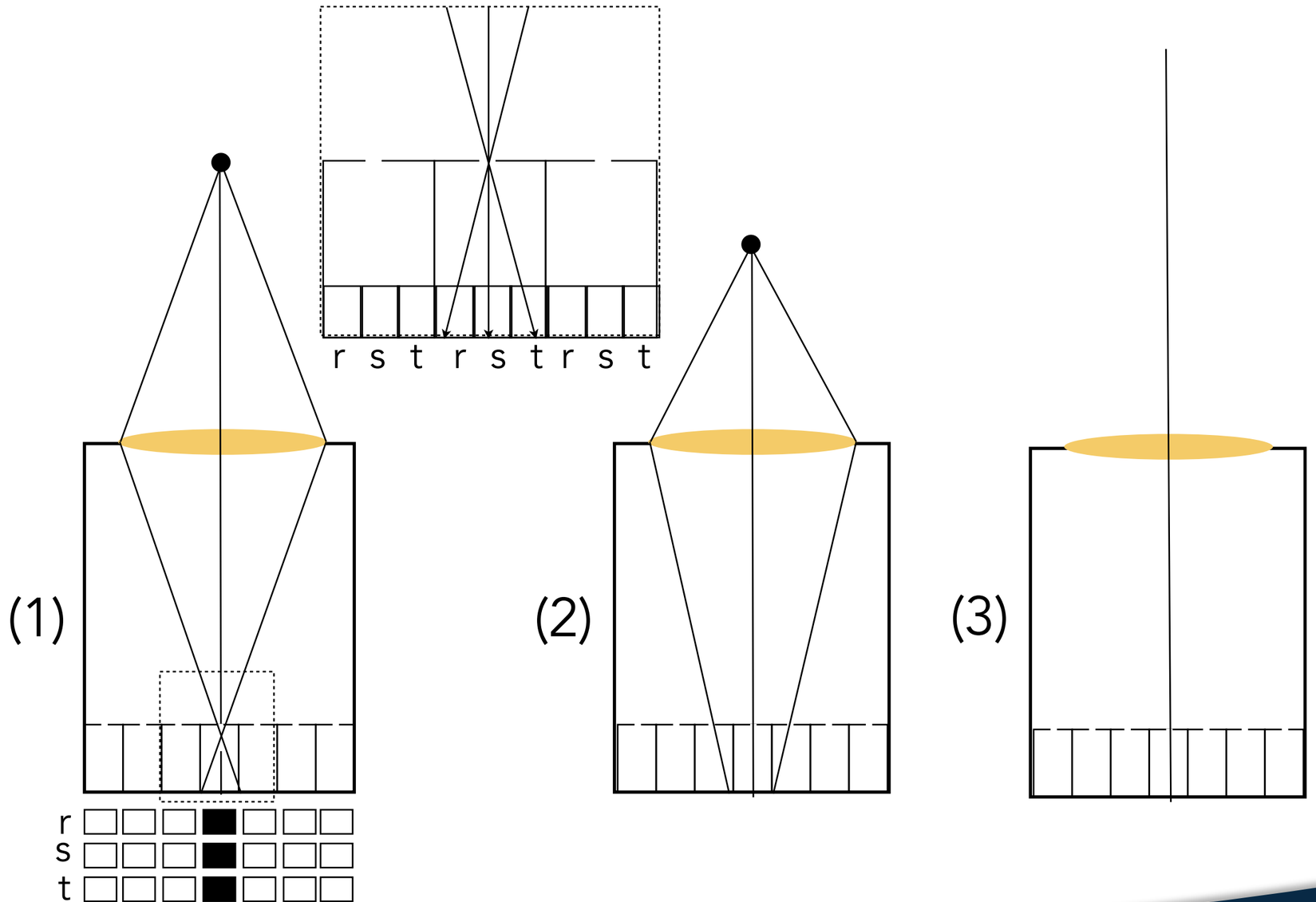
Encode Direction and Intensity

- We add a miniature pinhole at the image plane



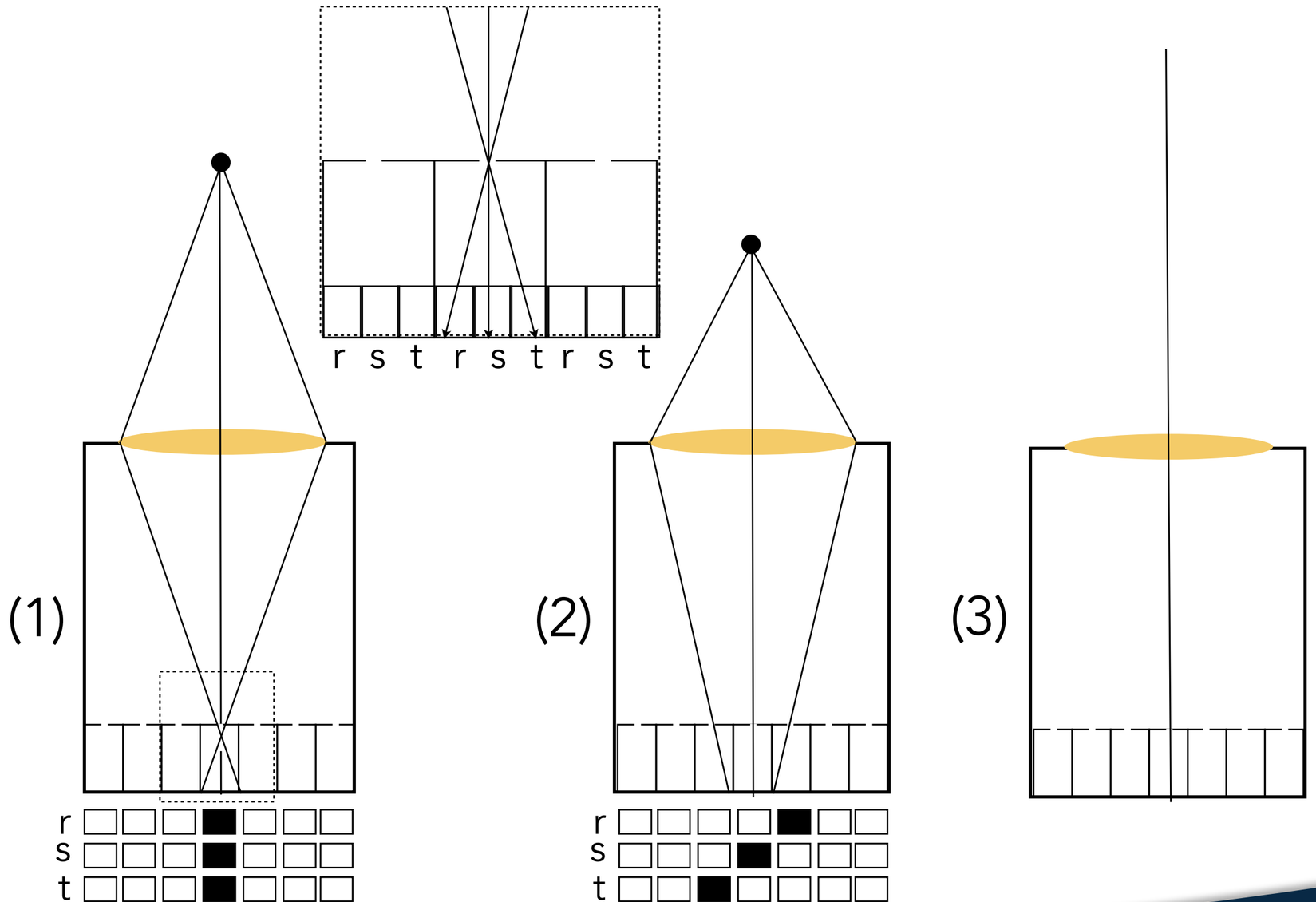
Encode Direction and Intensity

- We add a miniature pinhole at the image plane



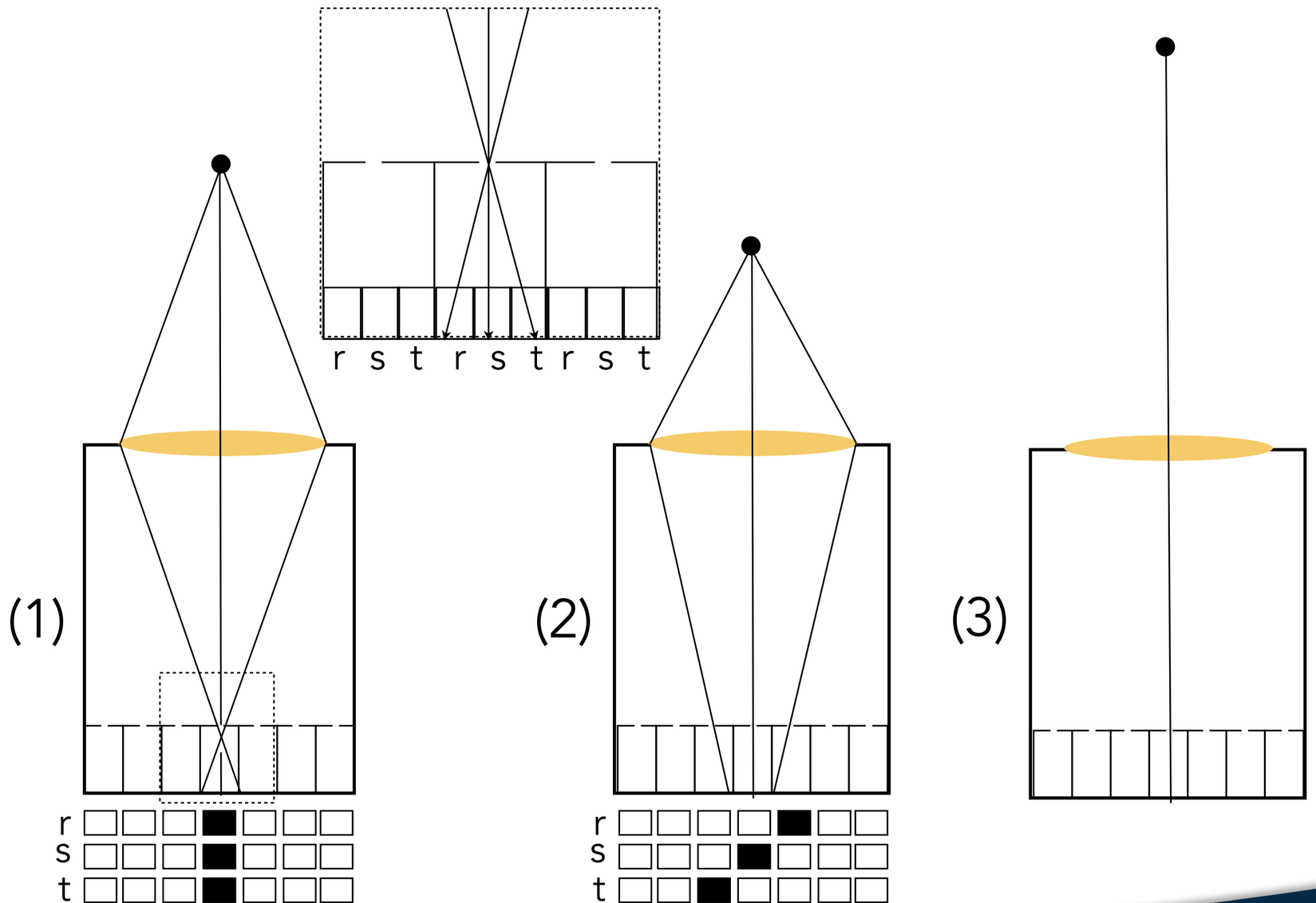
Encode Direction and Intensity

- We add a miniature pinhole at the image plane



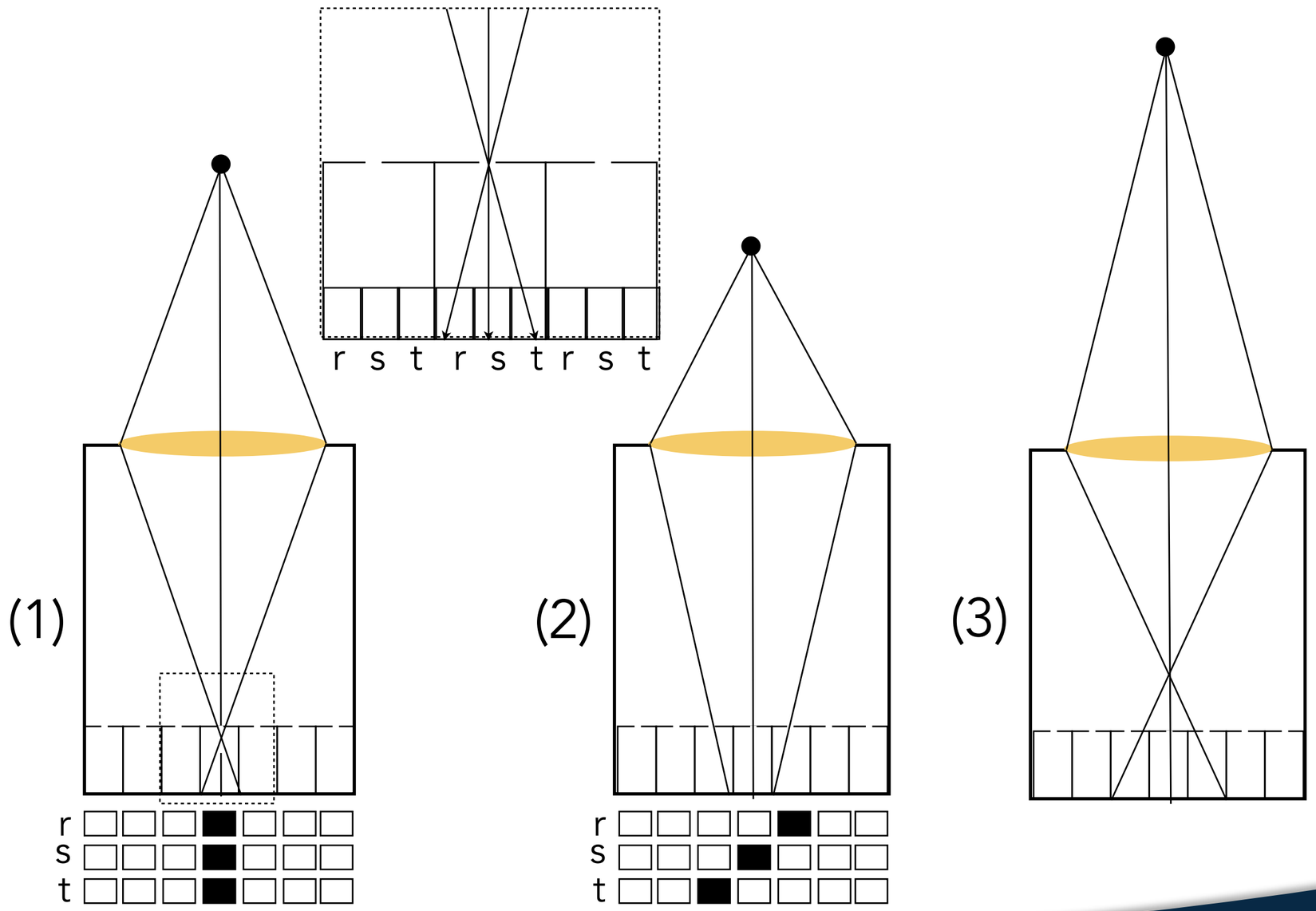
Encode Direction and Intensity

- We add a miniature pinhole at the image plane



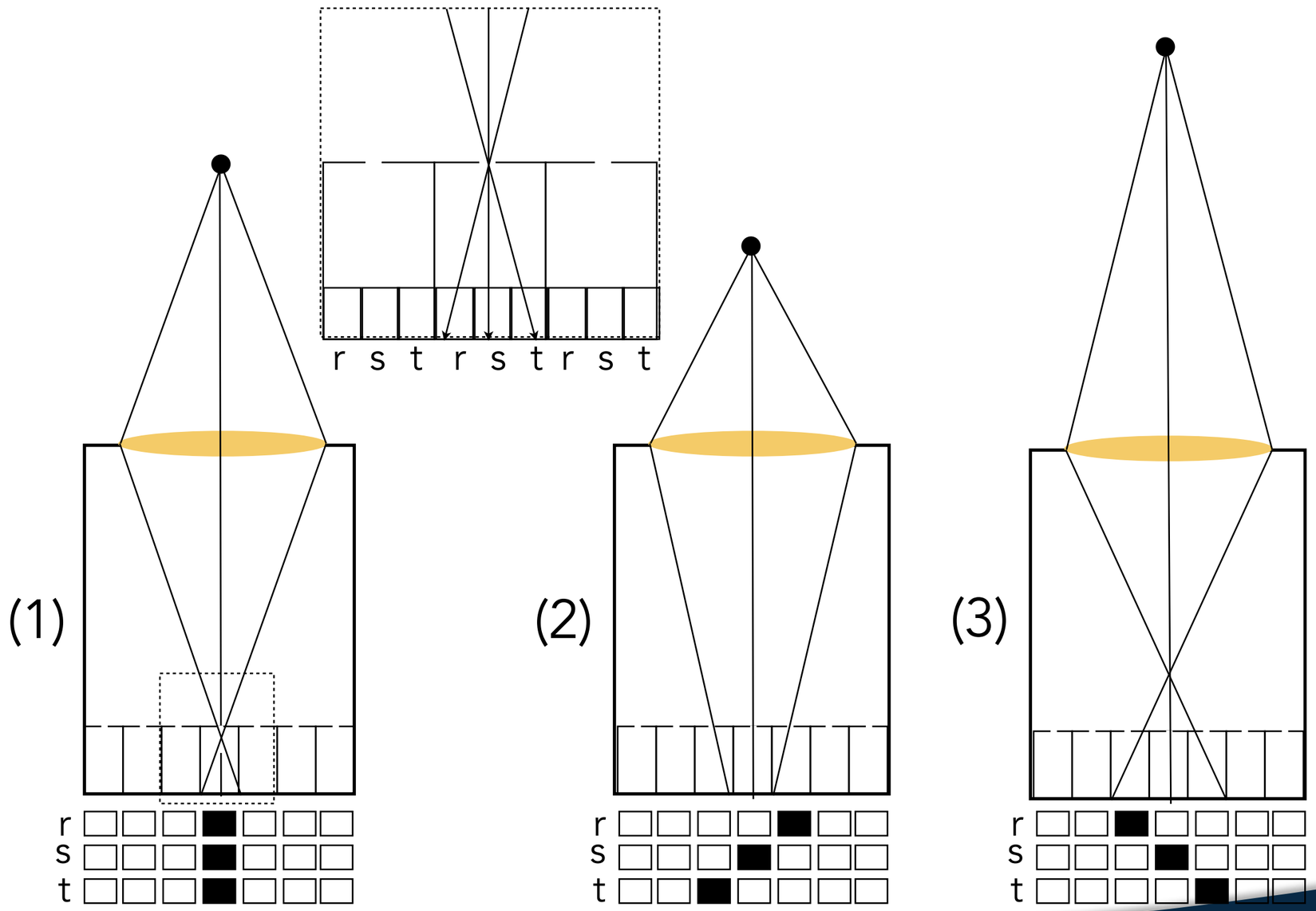
Encode Direction and Intensity

- We add a miniature pinhole at the image plane

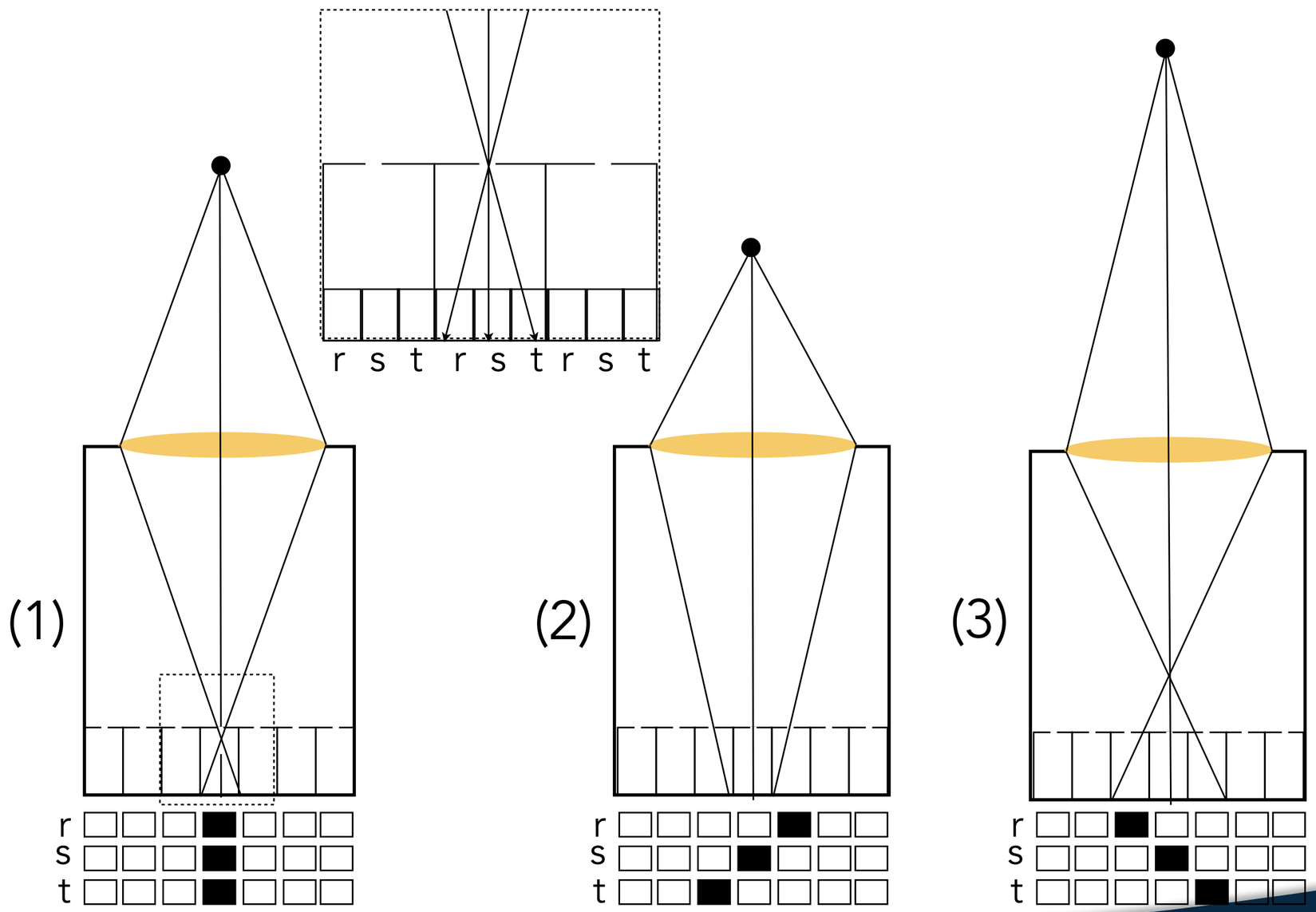


Encode Direction and Intensity

- We add a miniature pinhole at the image plane



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

Subject

Main Lens

Photosensor

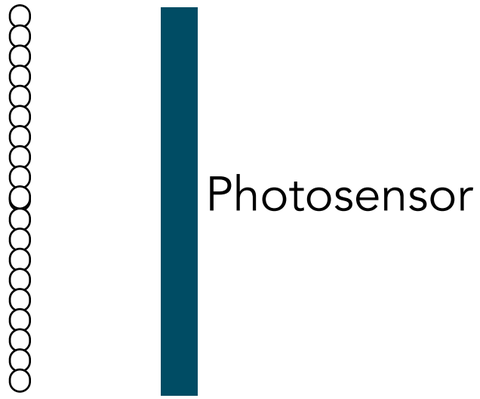
A Light-field / Plenoptic Camera (Ng et al. 2005)

http://en.wikipedia.org/wiki/Lenticular_lens

Lens and Microlens

Subject

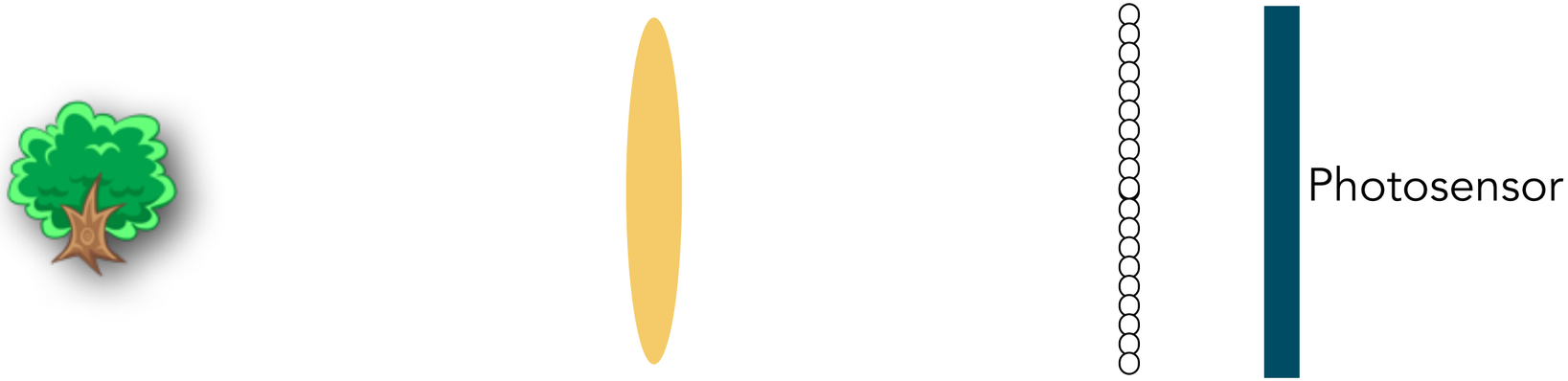
Main Lens



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

http://en.wikipedia.org/wiki/Lenticular_lens

Lens and Microlens



Subject

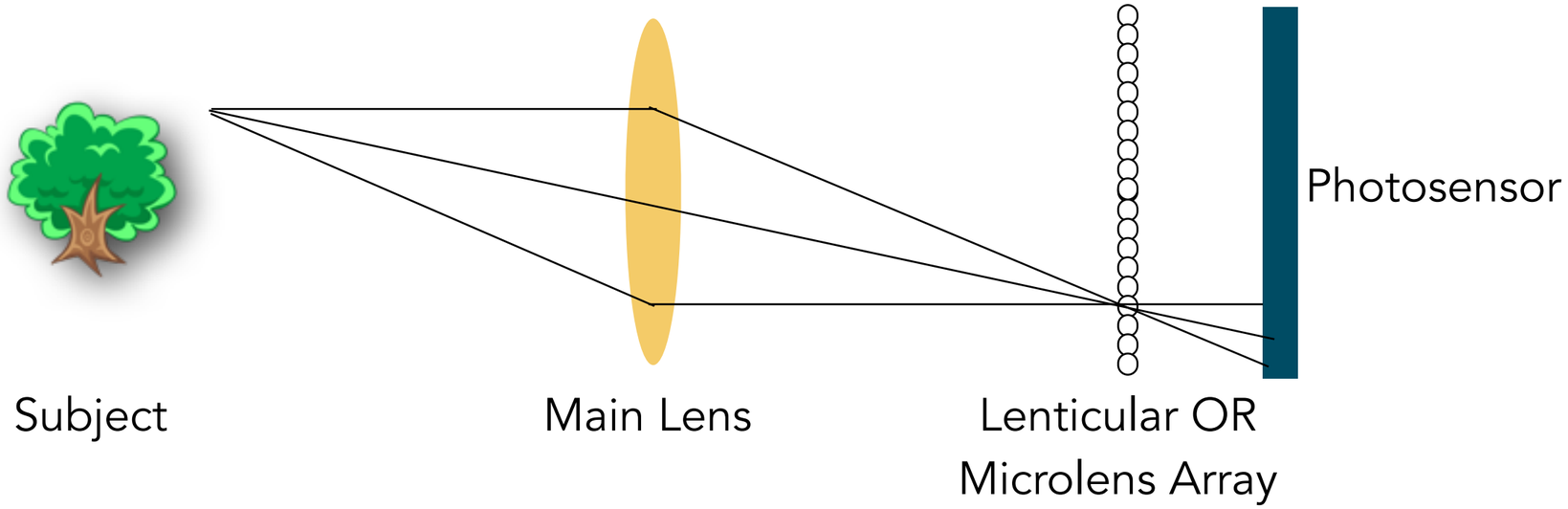
Main Lens

Lenticular OR
Microlens Array

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

http://en.wikipedia.org/wiki/Lenticular_lens

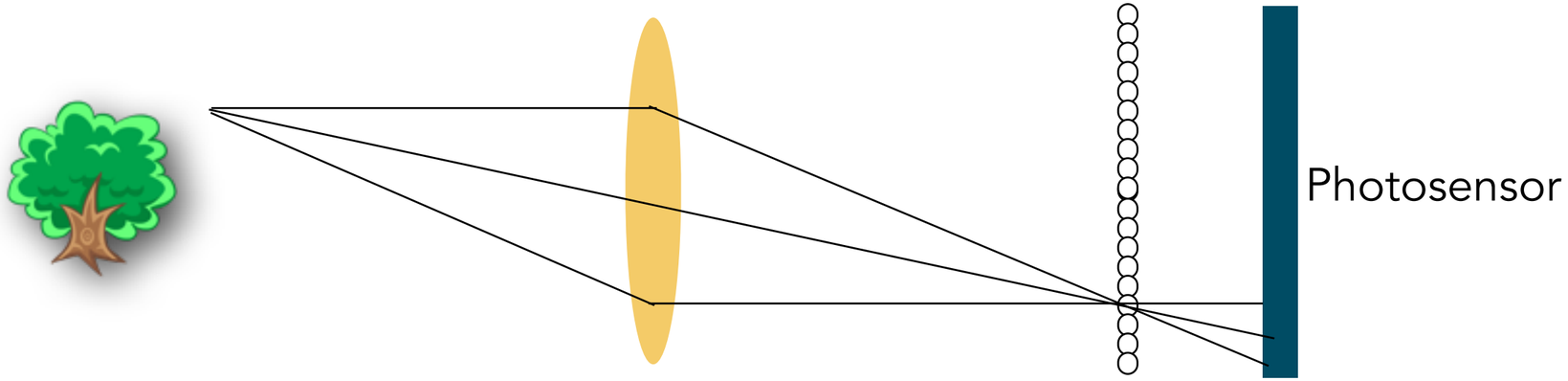
Lens and Microlens



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

http://en.wikipedia.org/wiki/Lenticular_lens

Lens and Microlens

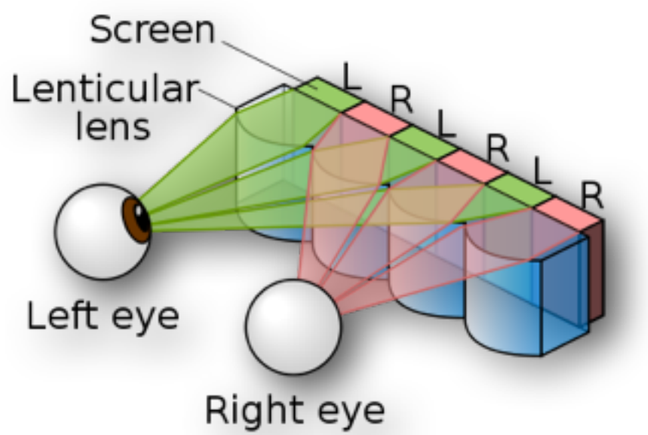


Subject

Main Lens

Lenticular OR
Microlens Array

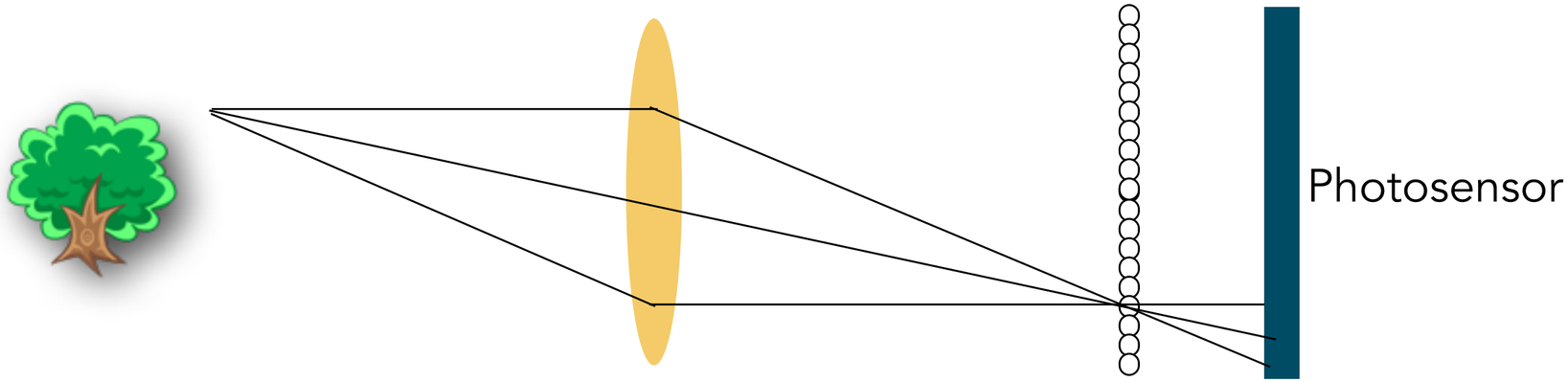
A Light-field /
Plenoptic Camera
(Ng et al. 2005)



Lectincular Array
used in lenticular printed cards

http://en.wikipedia.org/wiki/Lenticular_lens

Lens and Microlens

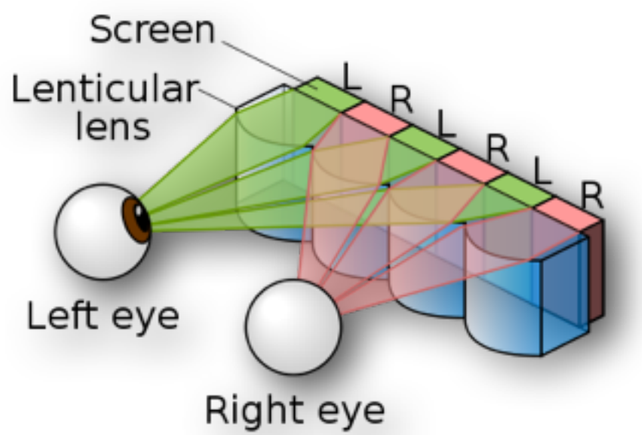


Subject

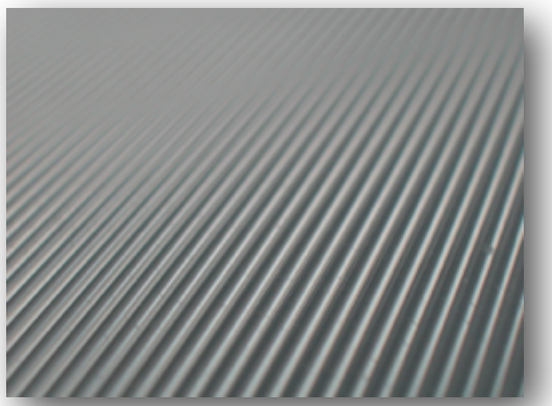
Main Lens

Lenticular OR
Microlens Array

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



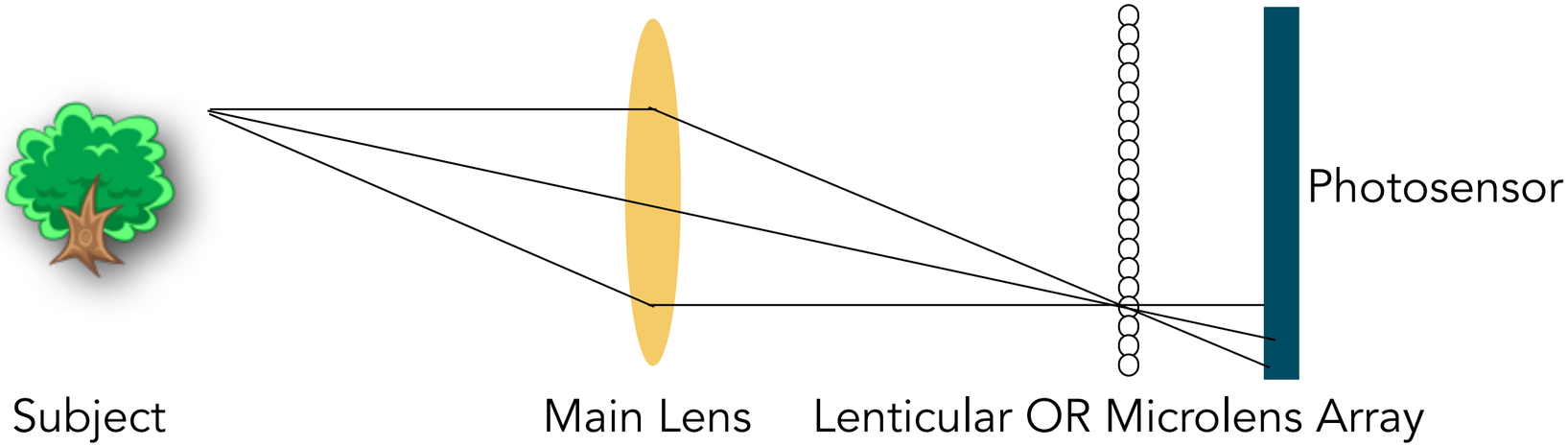
Lectincular Array
used in lenticular printed cards



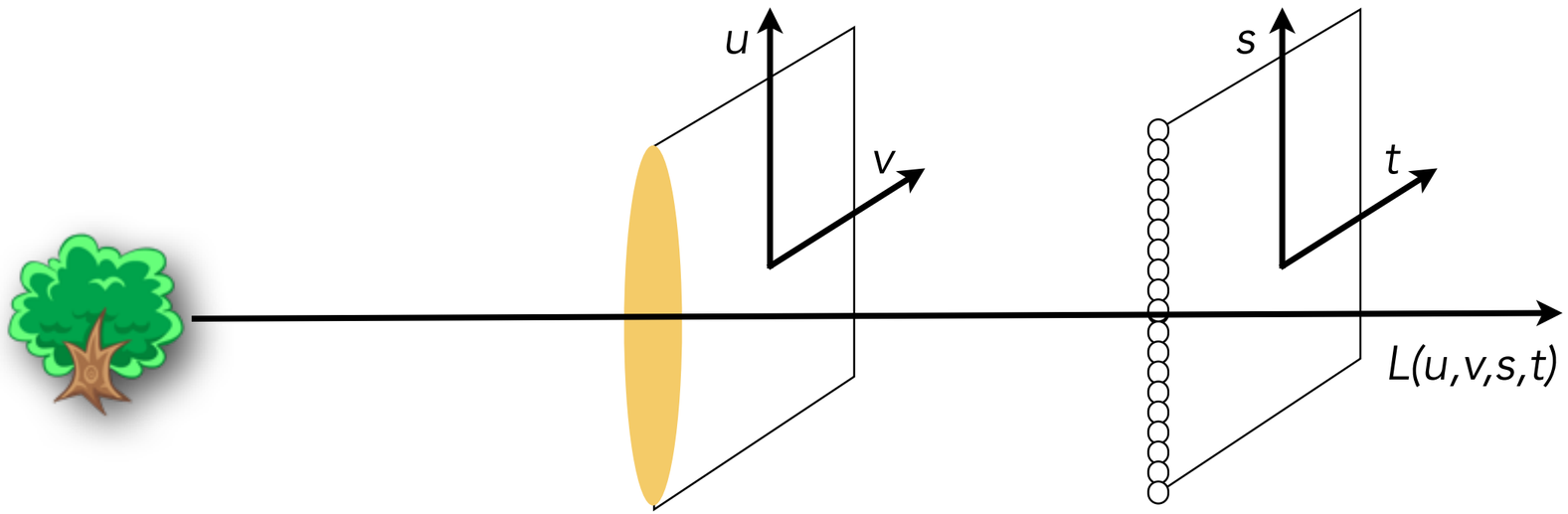
Cylindrical lenses to form a
Lenticular Array

http://en.wikipedia.org/wiki/Lenticular_lens

Lens and Microlens



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

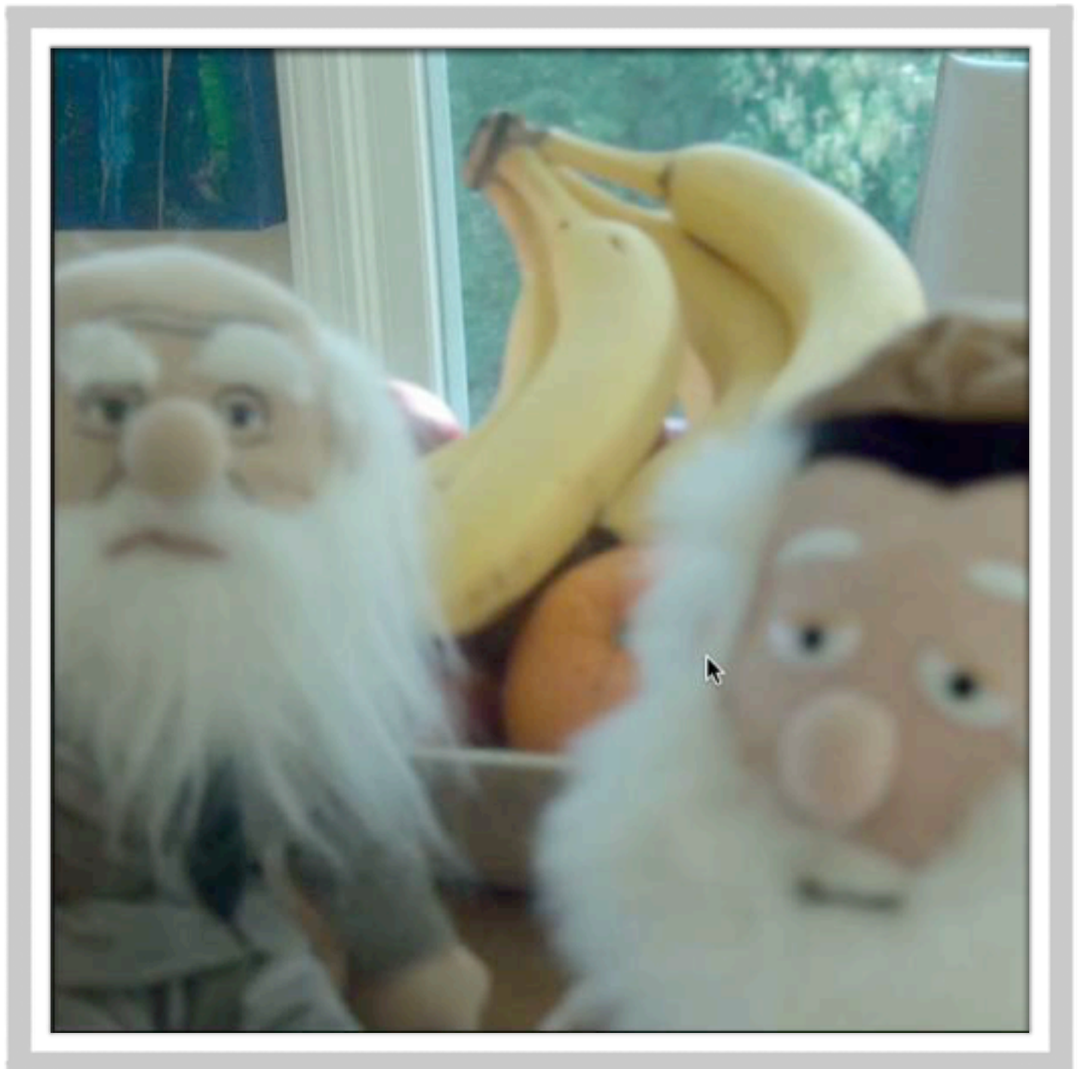


History of Light Field Camera

- ★ 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 Panoramagrams.
- ★ 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 Camera (Lytro)



- Allows for
  - refocussing images
  - showing parallax

12

Summary

- ★ Discussed the different uses of a pinhole and a lens system to analyze the scene.
- ★ Showed the application of an eccentric aperture on a simple lens system.
- ★ Discussed a system with a lens with an array of pinhole camera to encode direction and intensity of the rays of light.
- ★ Desribed conceptually, how a 4D Light Field camera works.

https://commons.wikimedia.org

Further Information

- ★ 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] [DOI]
- ★ Ng, Levoy, et al. (2005), “Light field photography with a hand-held plenoptic camera” Stanford Tech Report CTSR 2005-02, 2005. [PDF][DOI]

commons.wikimedia.org/

Next Class

★ Connecting the dots.

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Credits

- ★ Lytro Camera and Software.
- ★ For more information, see
  - Richard Szeliski (2010) Computer Vision: Algorithms and Applications, Springer.
- ★ Some video retrieved from
  - http://commons.wikimedia.org/.
  - List will be available on website.

www.flickr.com/photos/neneonline/231886965/

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Georgia Institute of Technology

Computational Photography

Dr. Irfan Essa
Professor
School of Interactive Computing

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