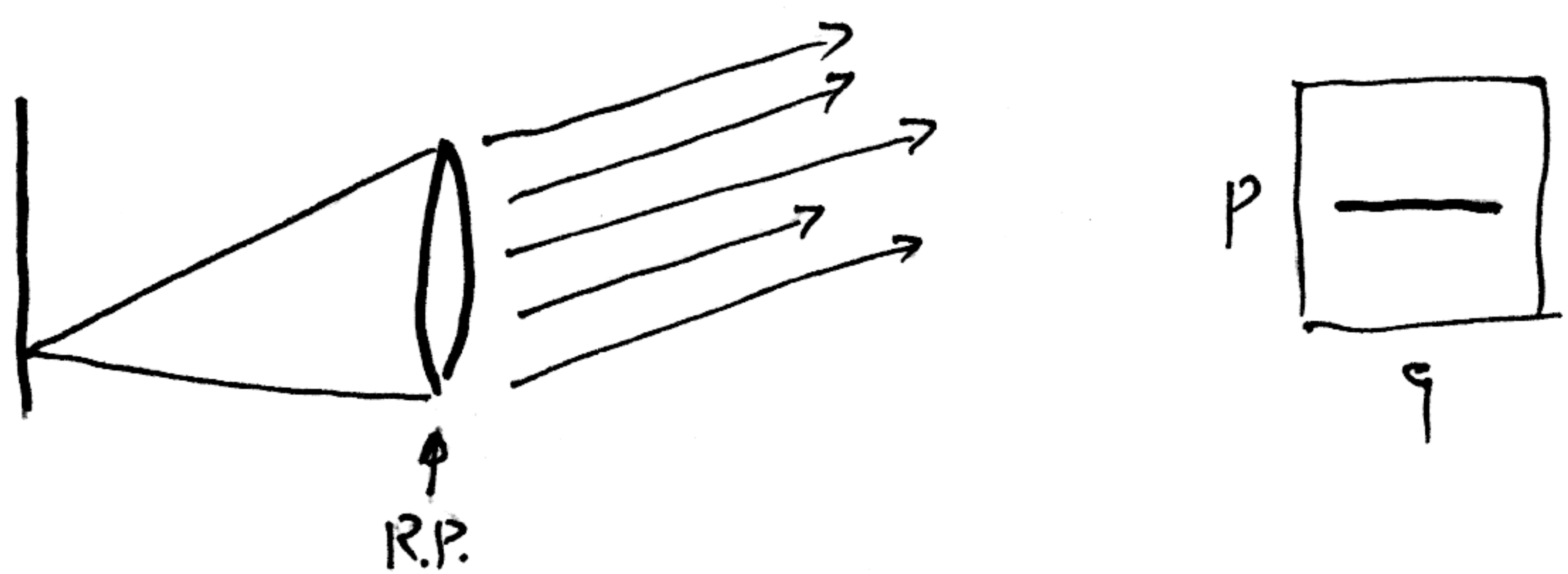
CS6640 Computational Photography

10. Light Field Photography

Choices in ray space

- **Photography involves choosing sets of rays at exposure time**
  - camera location
  - camera direction
  - aperture size
  - field of view
- **These decisions are about which rays to measure and how to group them together**



Example: camera focused at infinity

Choices in ray space

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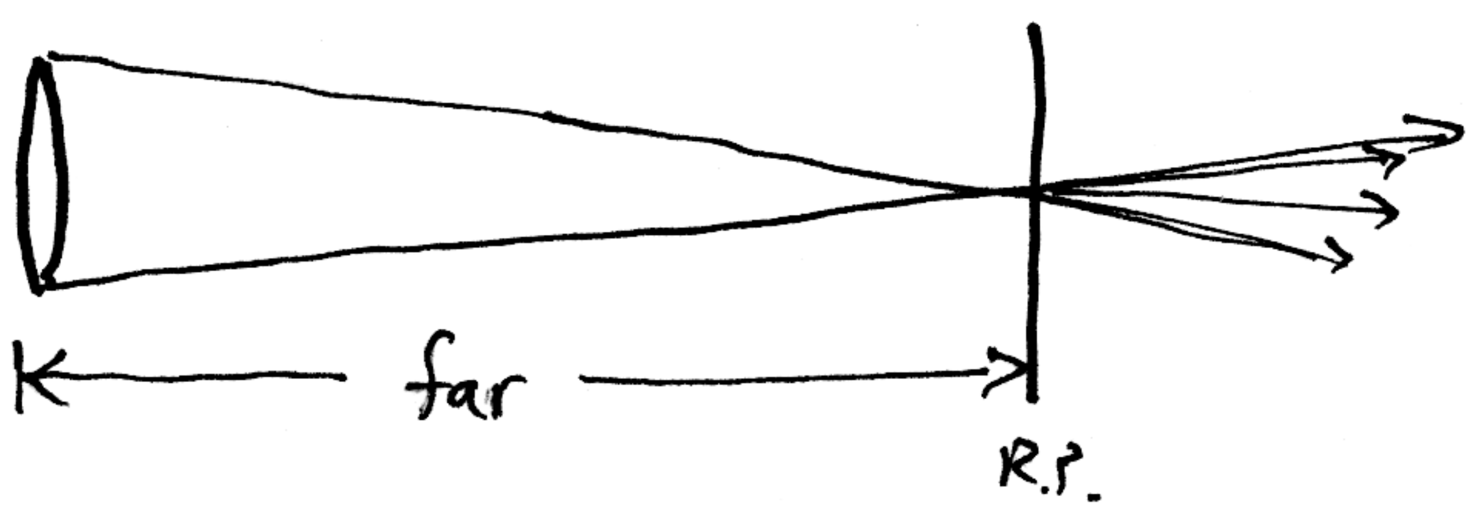

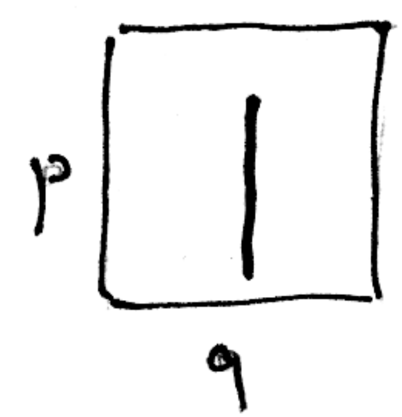

Example: distant camera focused at reference plane

Choices in ray space

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  - camera location
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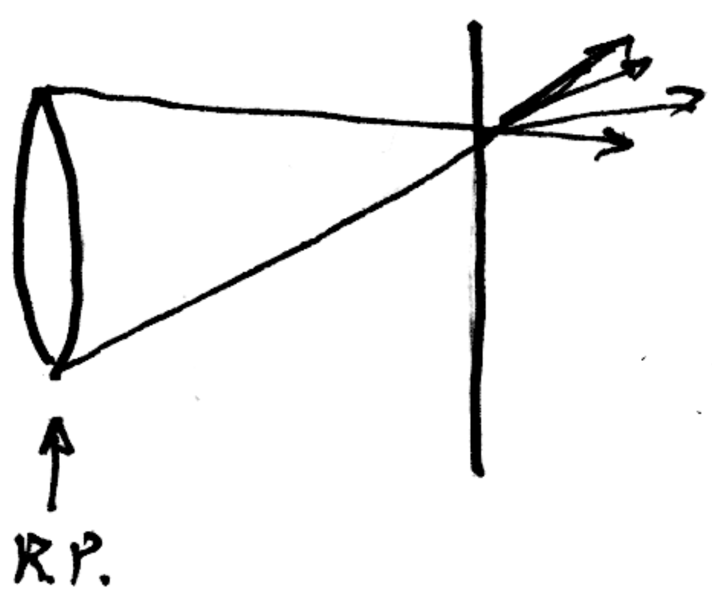
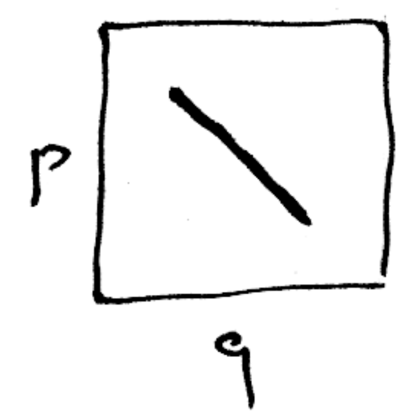
  - aperture size
  - field of view
- **These decisions are about which rays to measure and how to group them together**

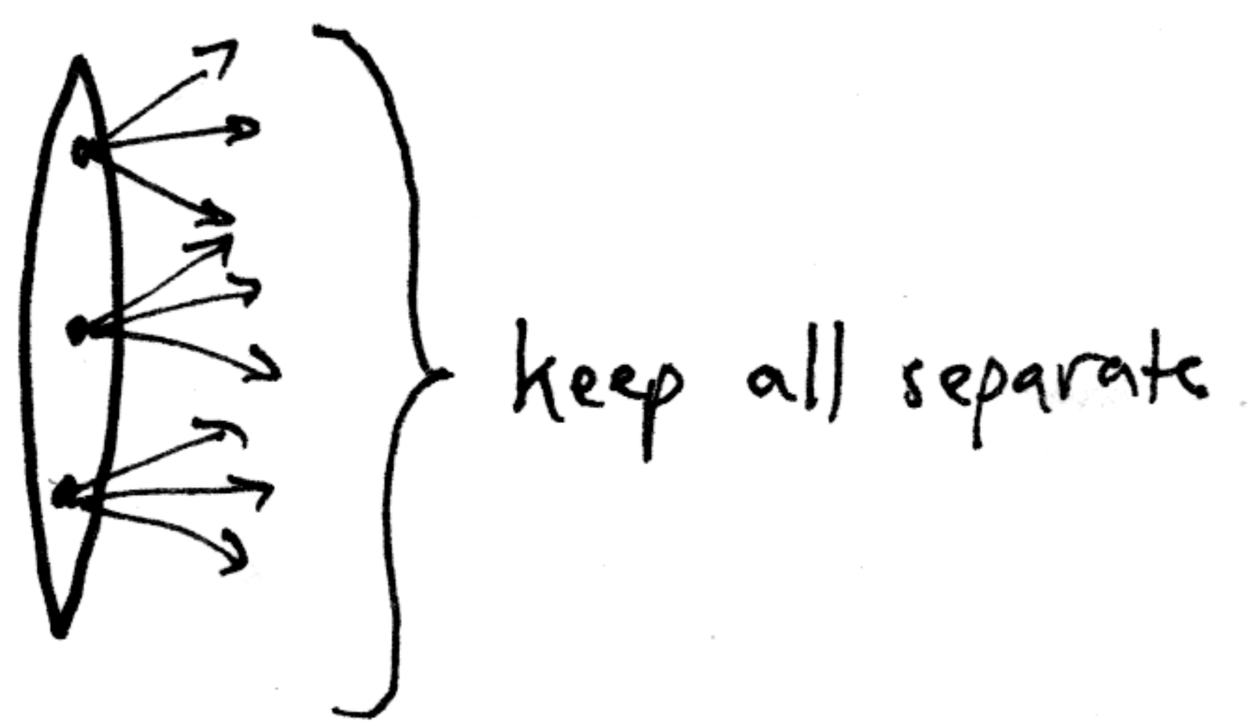




Example: camera focused at finite distance

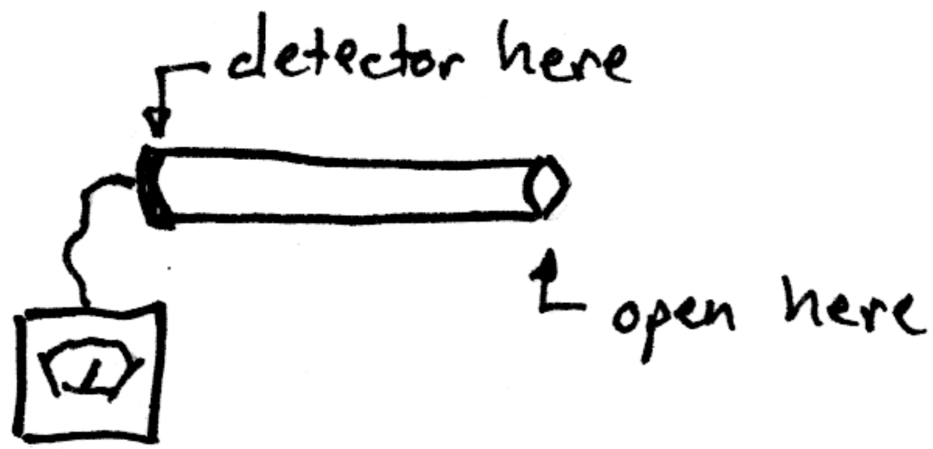
Not choosing

- **Light field photography: do not choose rays at exposure time**
- **Measure all light available, without integrating**
  or at least, integrating as little as possible
- **Measure light flowing along all rays entering the camera**
- **Do any desired integration later**



Radiance field

- **Measure radiance with a detector like this:**



- **Radiance is a function of**

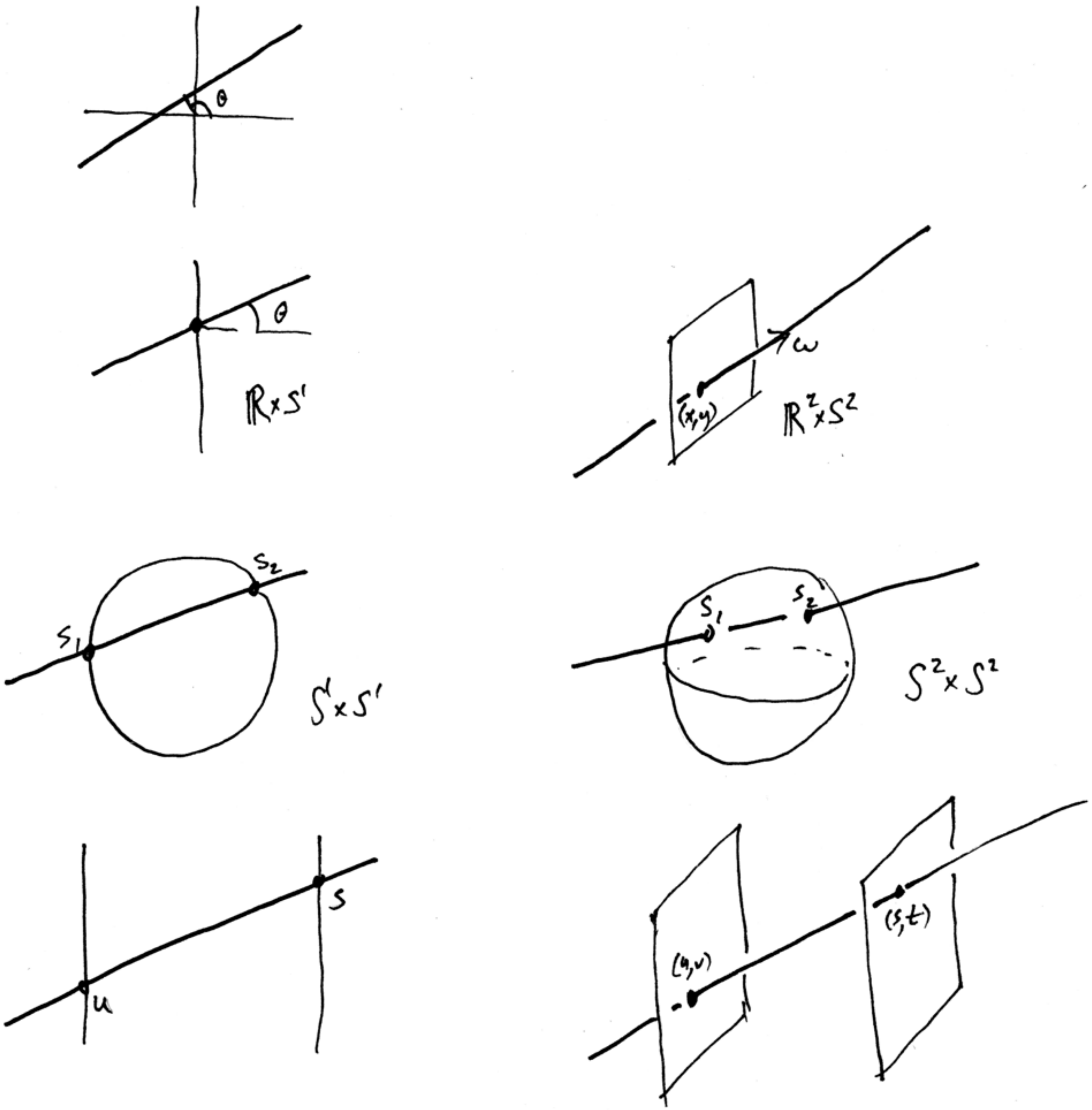
  where you position it (R^3)

  which way you point it (S^2)

  that amounts to 5 dimensions
- **However, radiance is invariant along lines**
- **Radiance is a function of which line you put the detector on**

  that amounts to 4 dimensions

Parameterizing lines



Linespace is topologically distinct from R4.

Therefore all these parameterizations have singularities or do not cover the whole space.

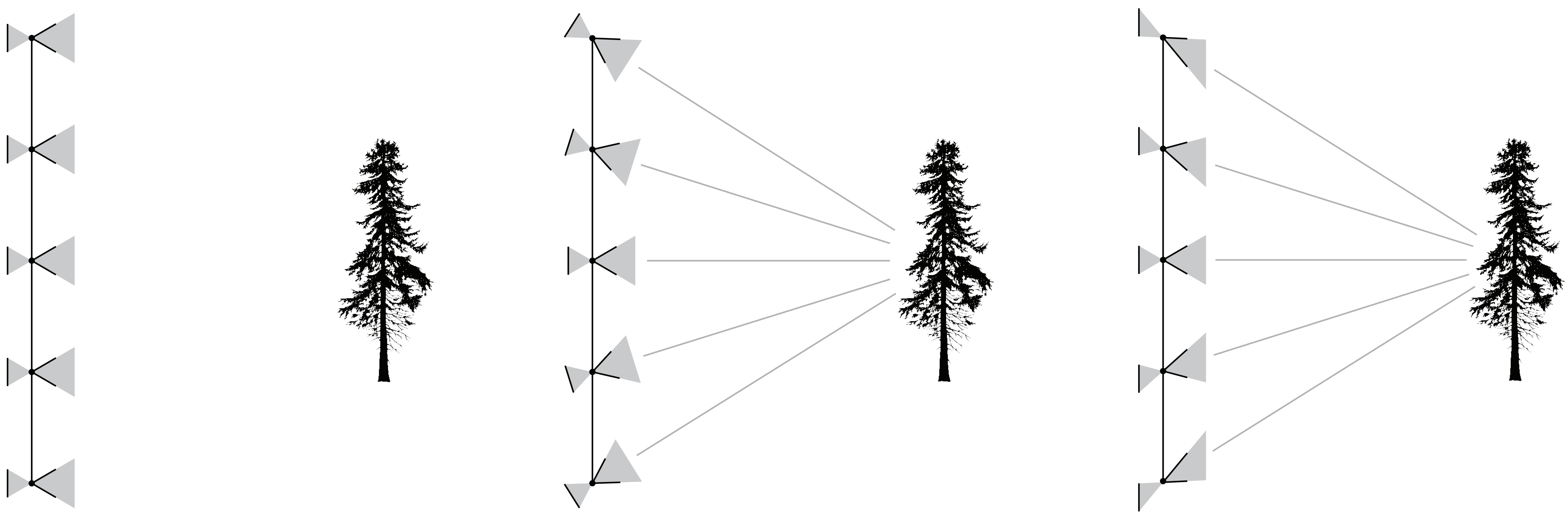
What does each one miss?

Light fields in graphics

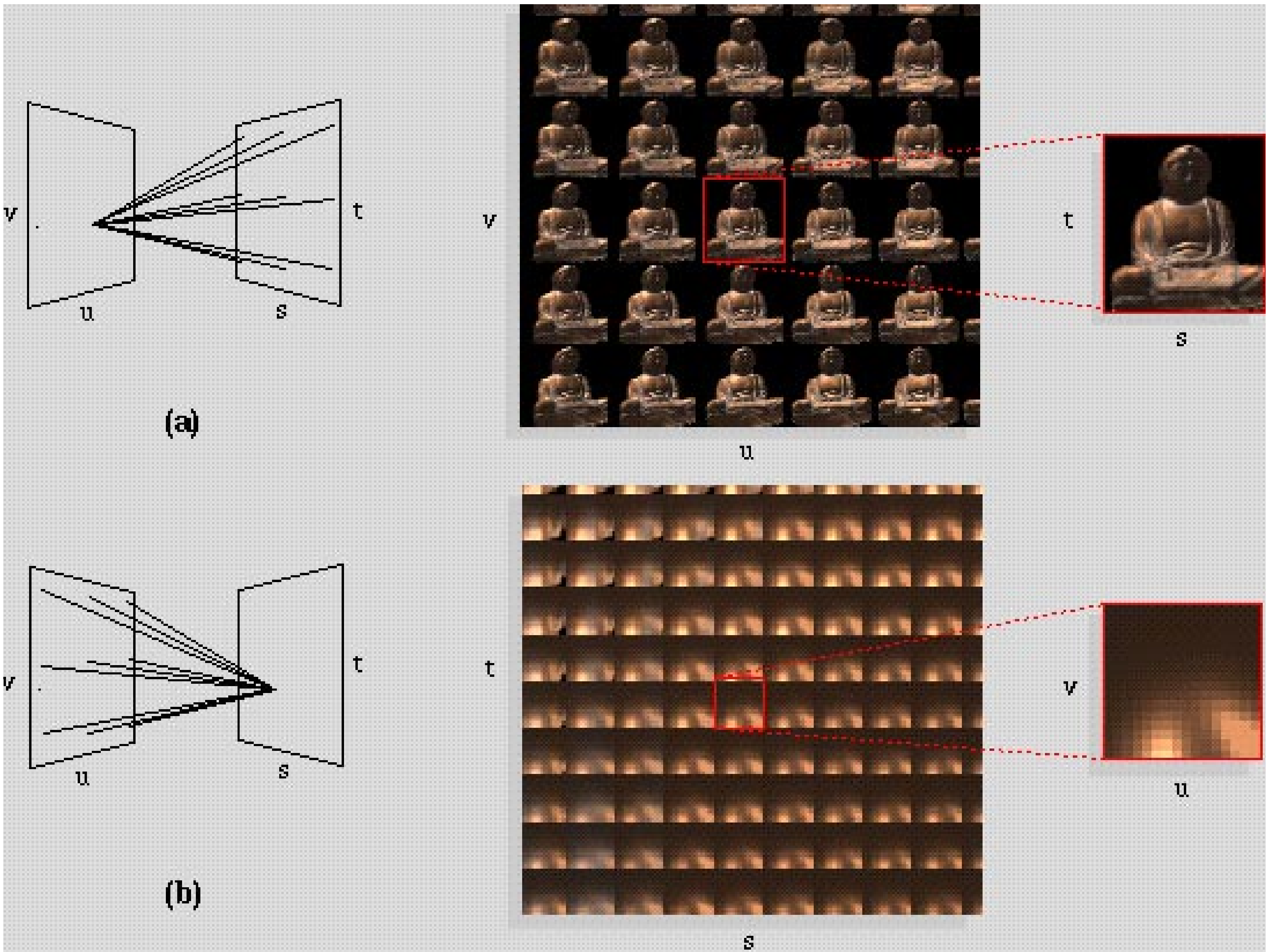
- **Sample radiance with a (*u*,*v*,*s*,*t*) 2-plane parameterization**
  think with a signal processing mentality
  it's all about sampling and reconstructing this 4D function
- **Light Field** [Levoy & Hanrahan 96] **and Lumigraph** [Gortler et al. 96]
- **Plenoptic function** [Adelson & Bergen 91]
- **Integral Photography** [Lippman 1908]

Capturing light fields

- **First approach: moving cameras or camera arrays**
- **Moving camera vs. moving & aiming vs. moving & shifting**
  moving & shifting gives (*u*,*v*,*s*,*t*) parameterization directly

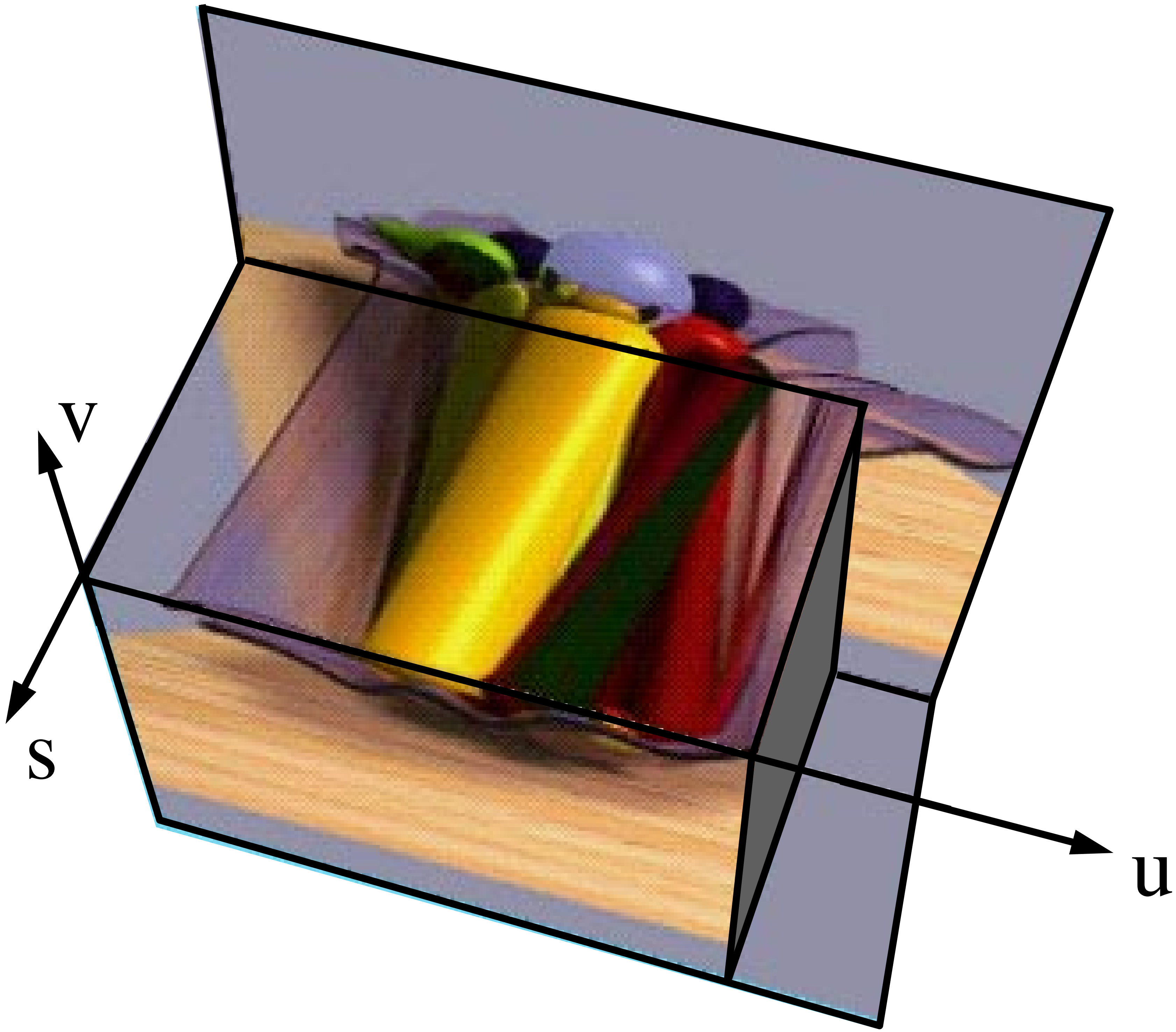


Slices of a light field: (u,v) and (s,t)



Levoy & Hanrahan 96

Slices of a light field: (u,s)



Gortler et al. 96

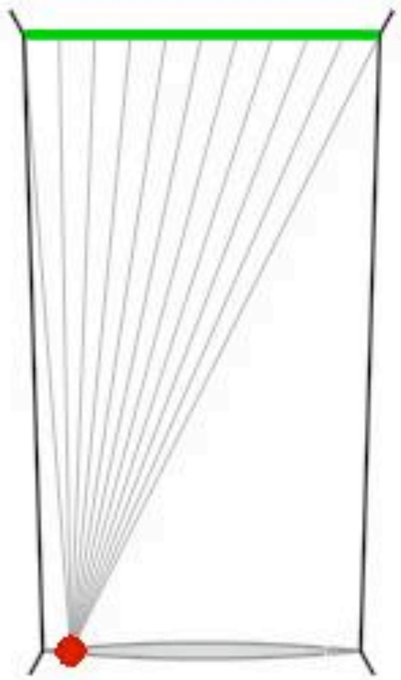
What to do with light field

- **Obvious: move camera around on (*u*,*v*) plane**

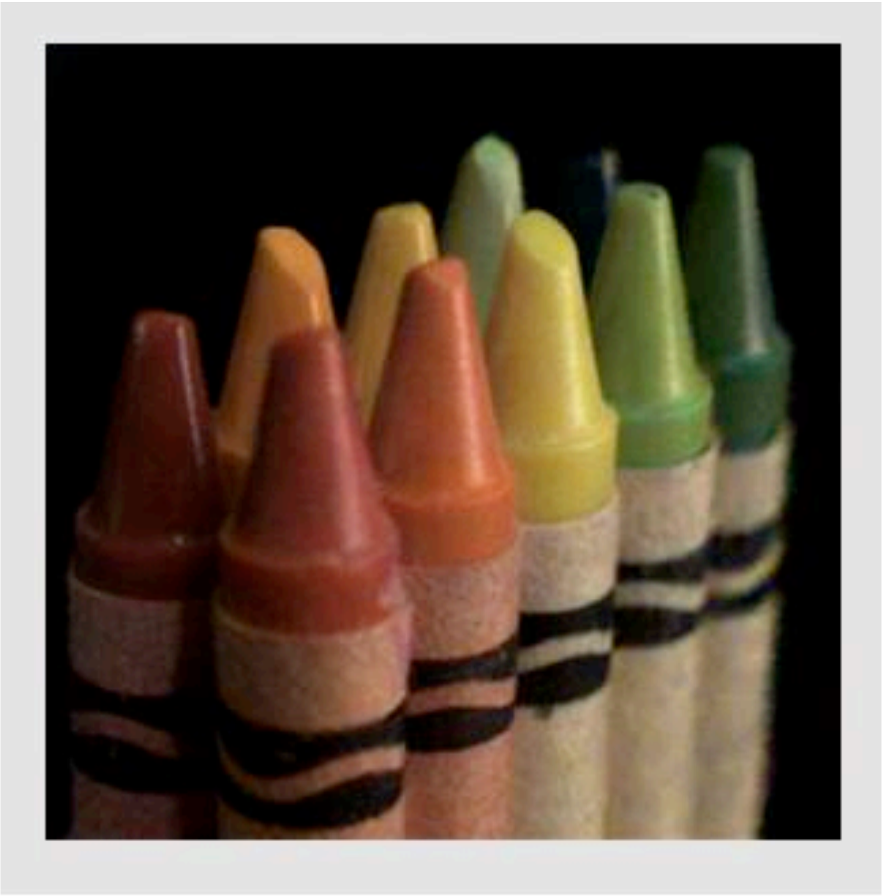
  interpolate between images

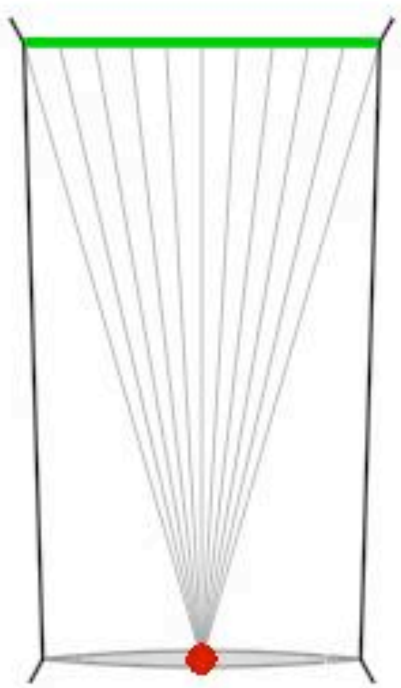
  quality will depend on sampling rate relative to aperture size

- **In 4D space this is bilinear interpolation along the *u* and *v* directions only**

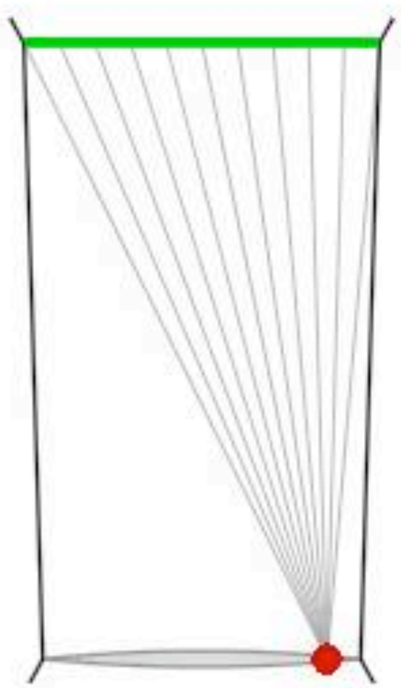


Marc Levoy





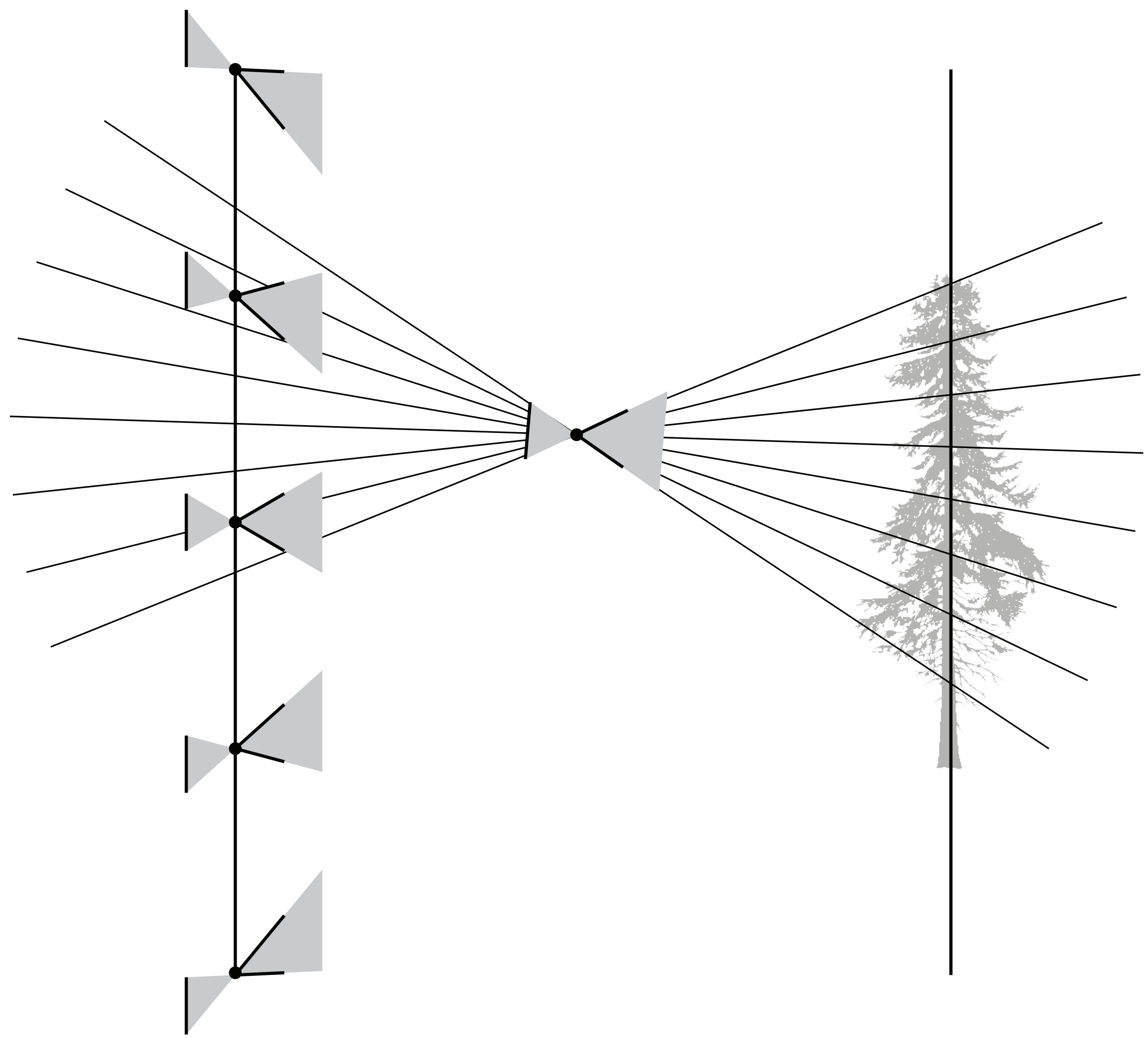
Marc Levoy



Marc Levoy

What to do with light field

- **Less obvious: move the camera anywhere you want**
  - after all, you have all the rays recorded separately
  - quality will depend on sampling rate relative to aperture size
- **In 4D space this is slicing along a non-axis-aligned plane**



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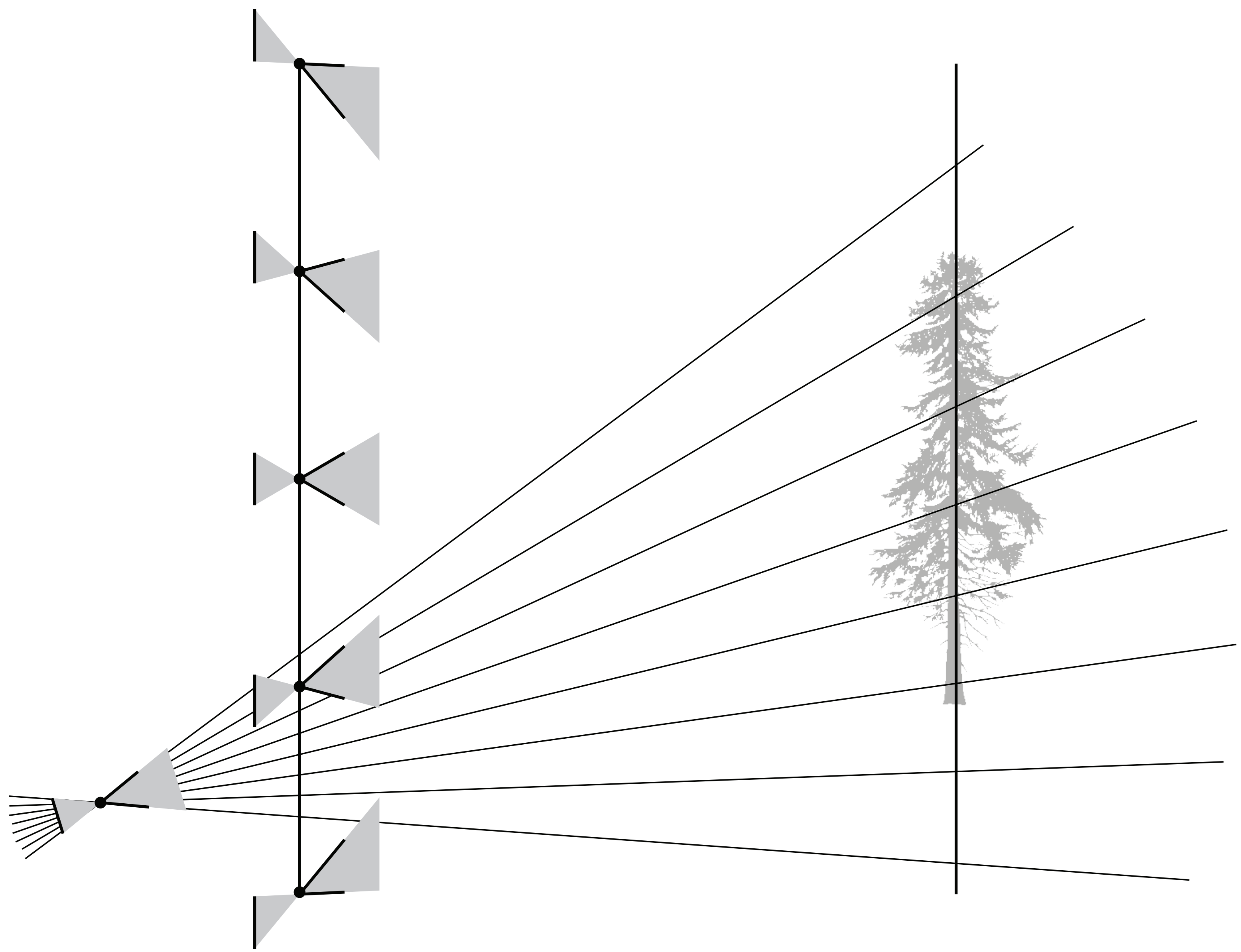
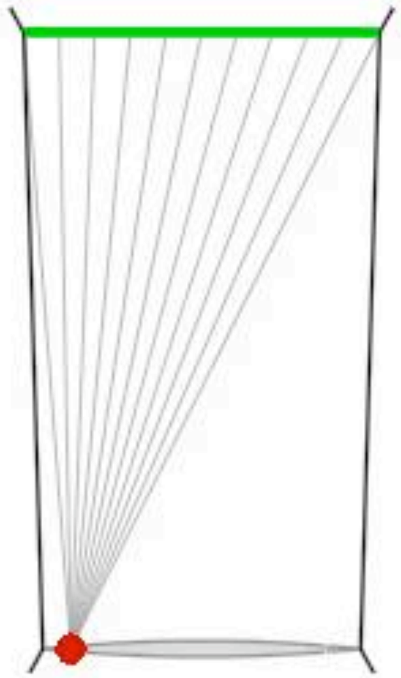
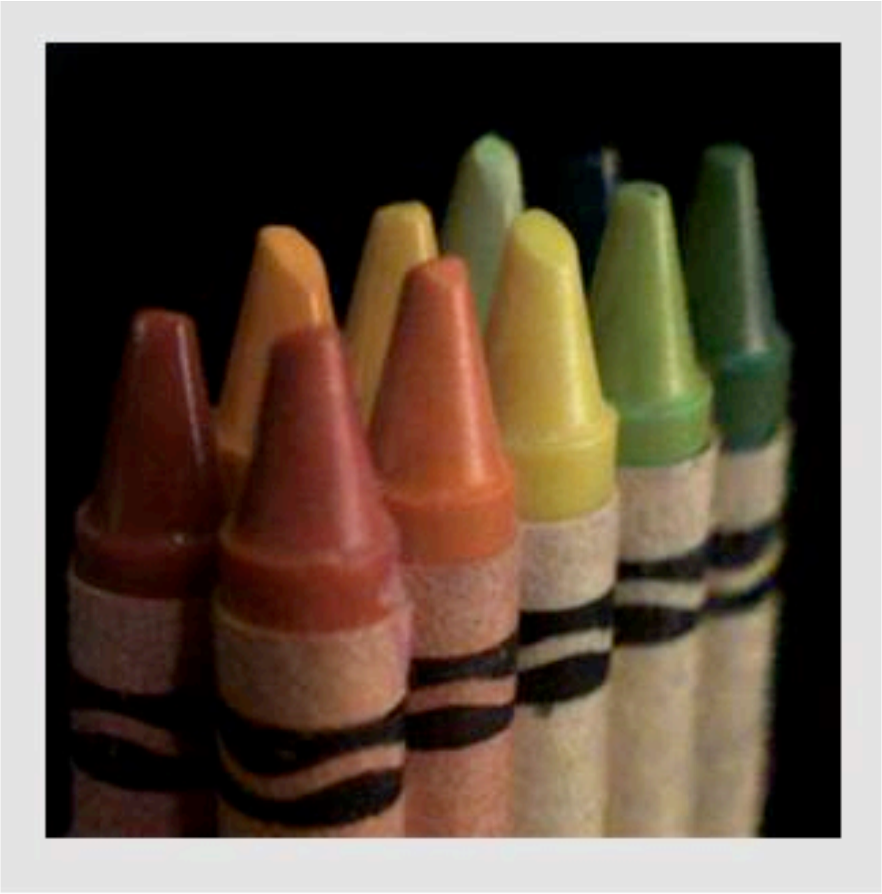
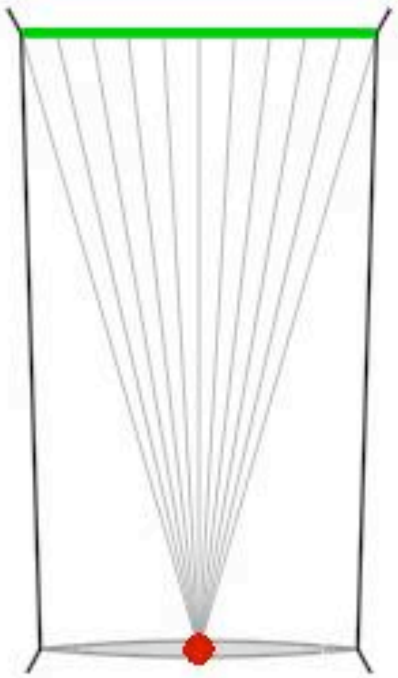


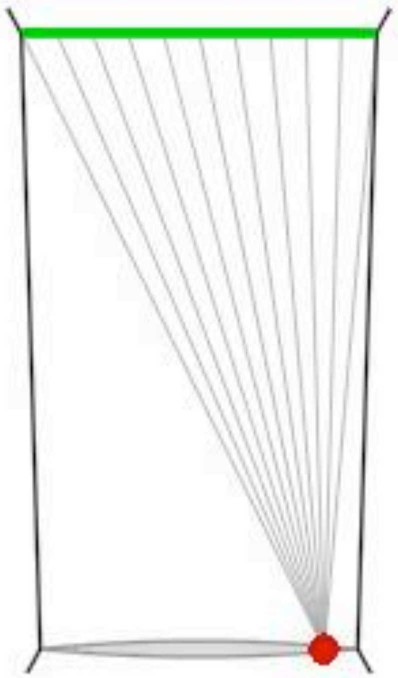


Marc Levoy





Marc Levoy



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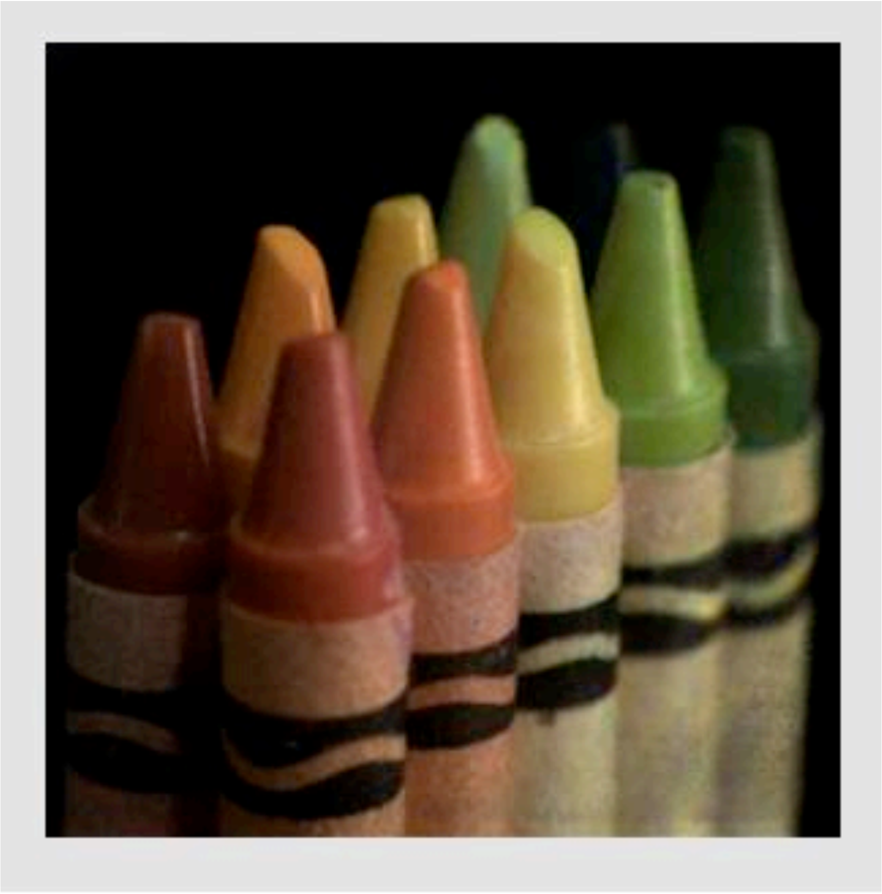

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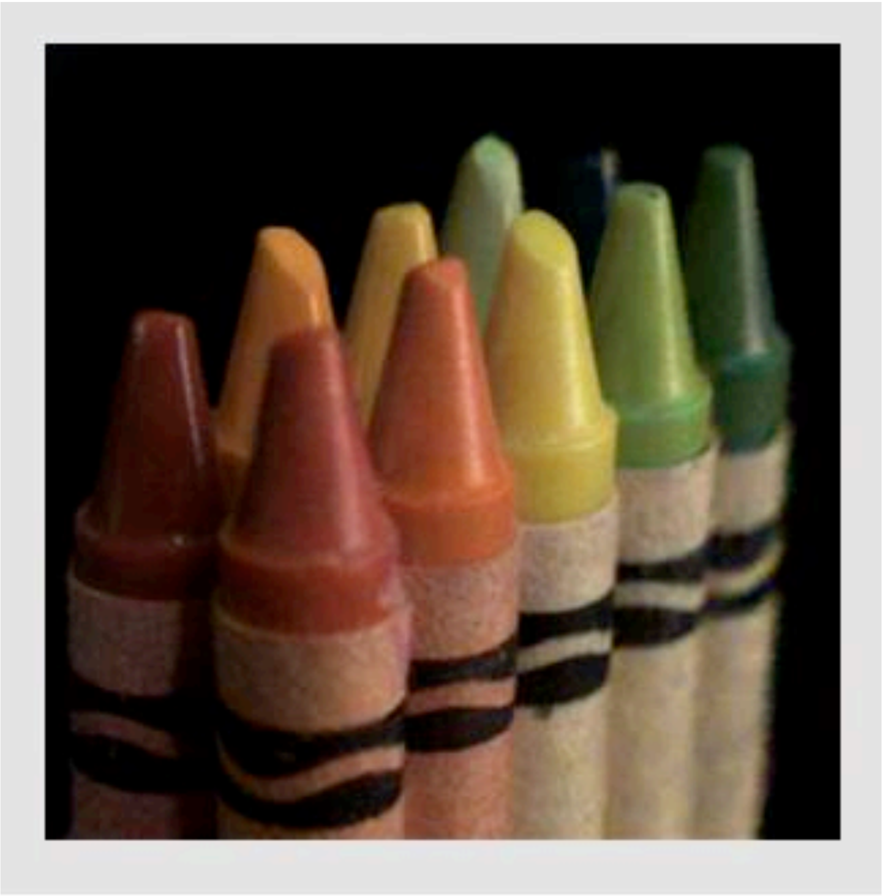

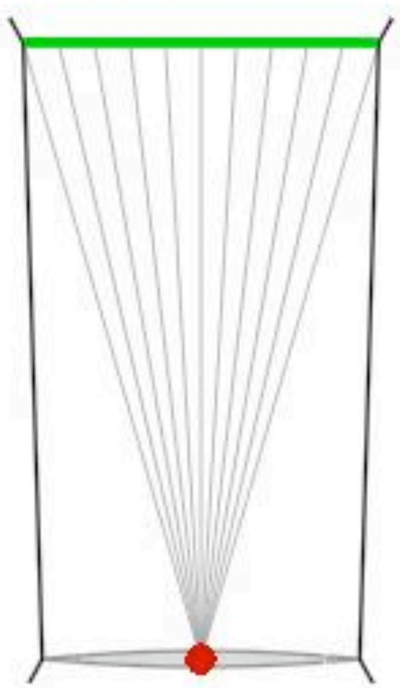

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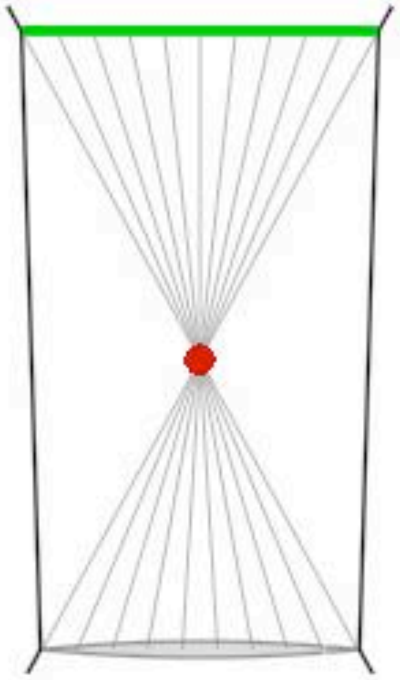


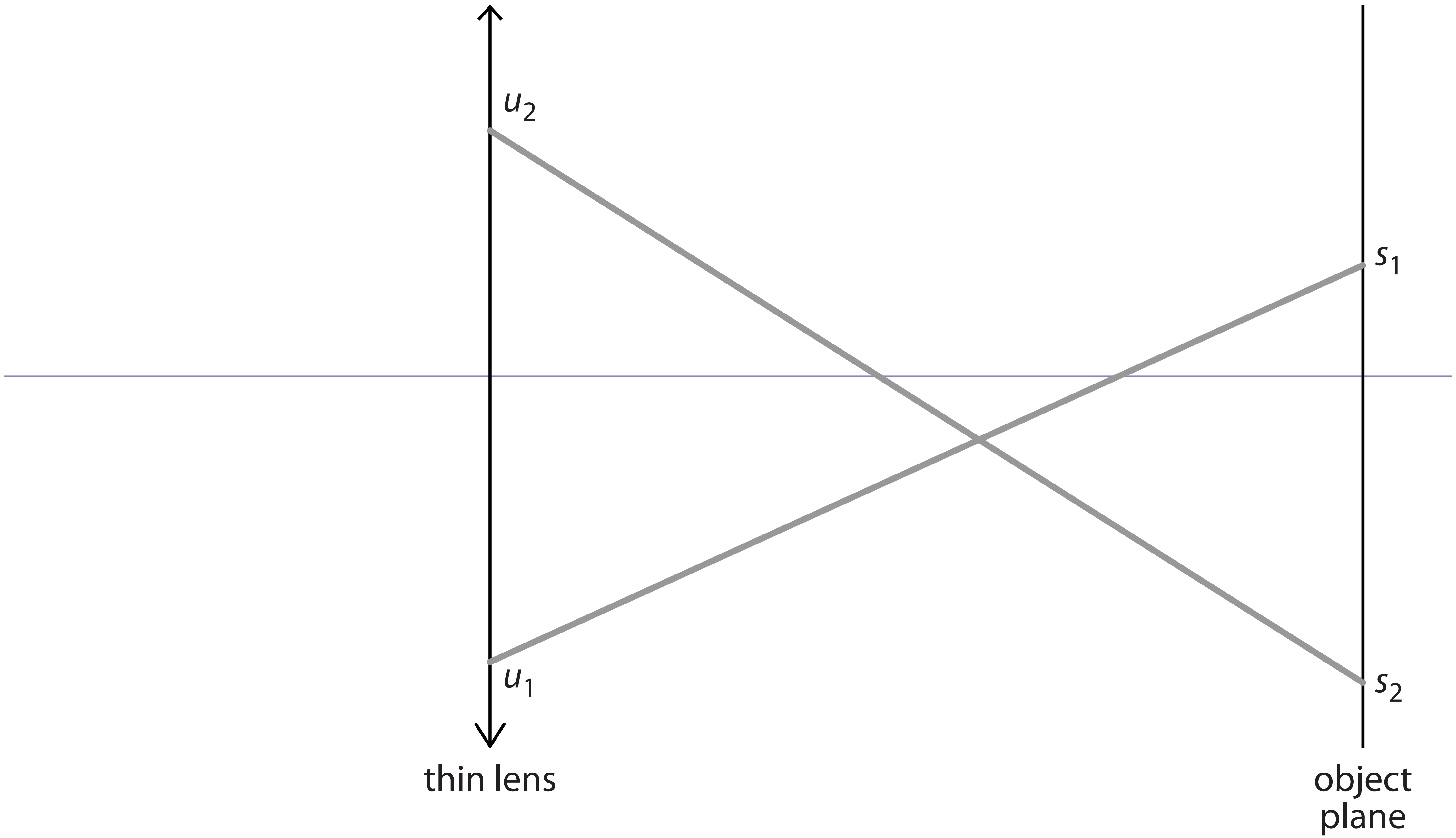
Marc Levoy

What to do with light field

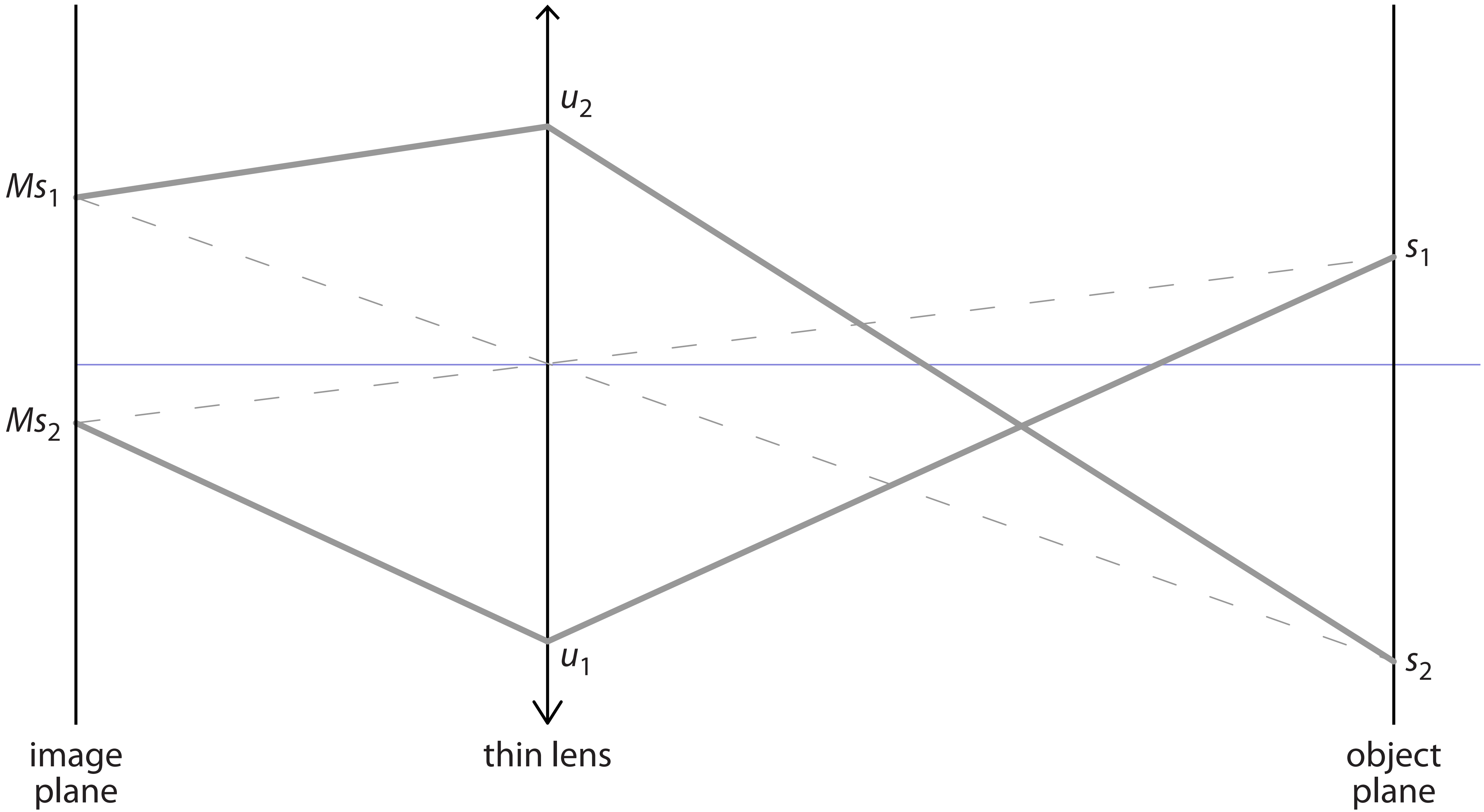
- **Also perhaps non-obvious: create shallow depth of field**
- **Synthetic aperture integration**
  integrate over rays through an imaginary large aperture
  (cf. synthetic aperture radar)

Vaish et al CVPR 04

Light field camera



Light field camera



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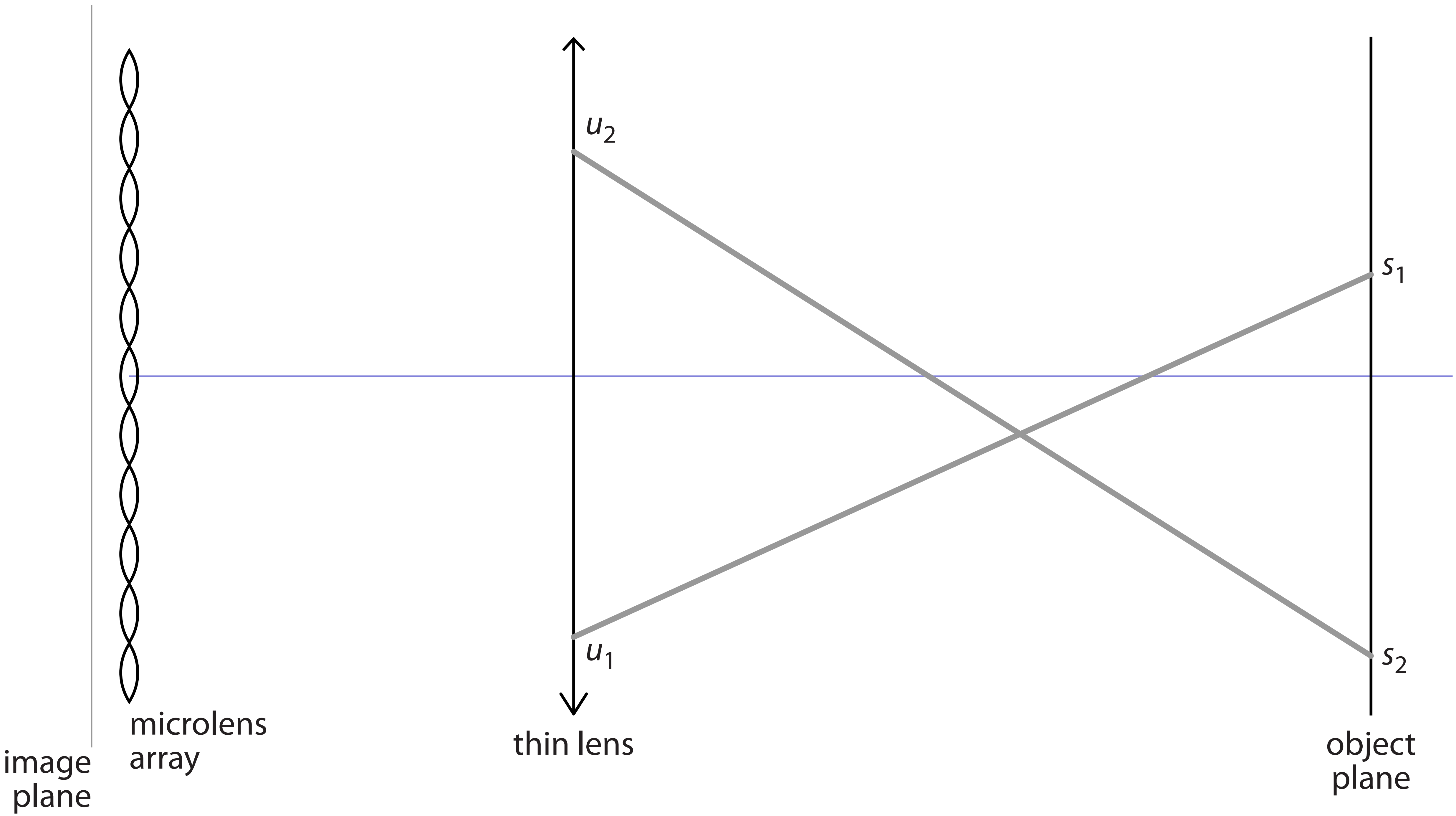

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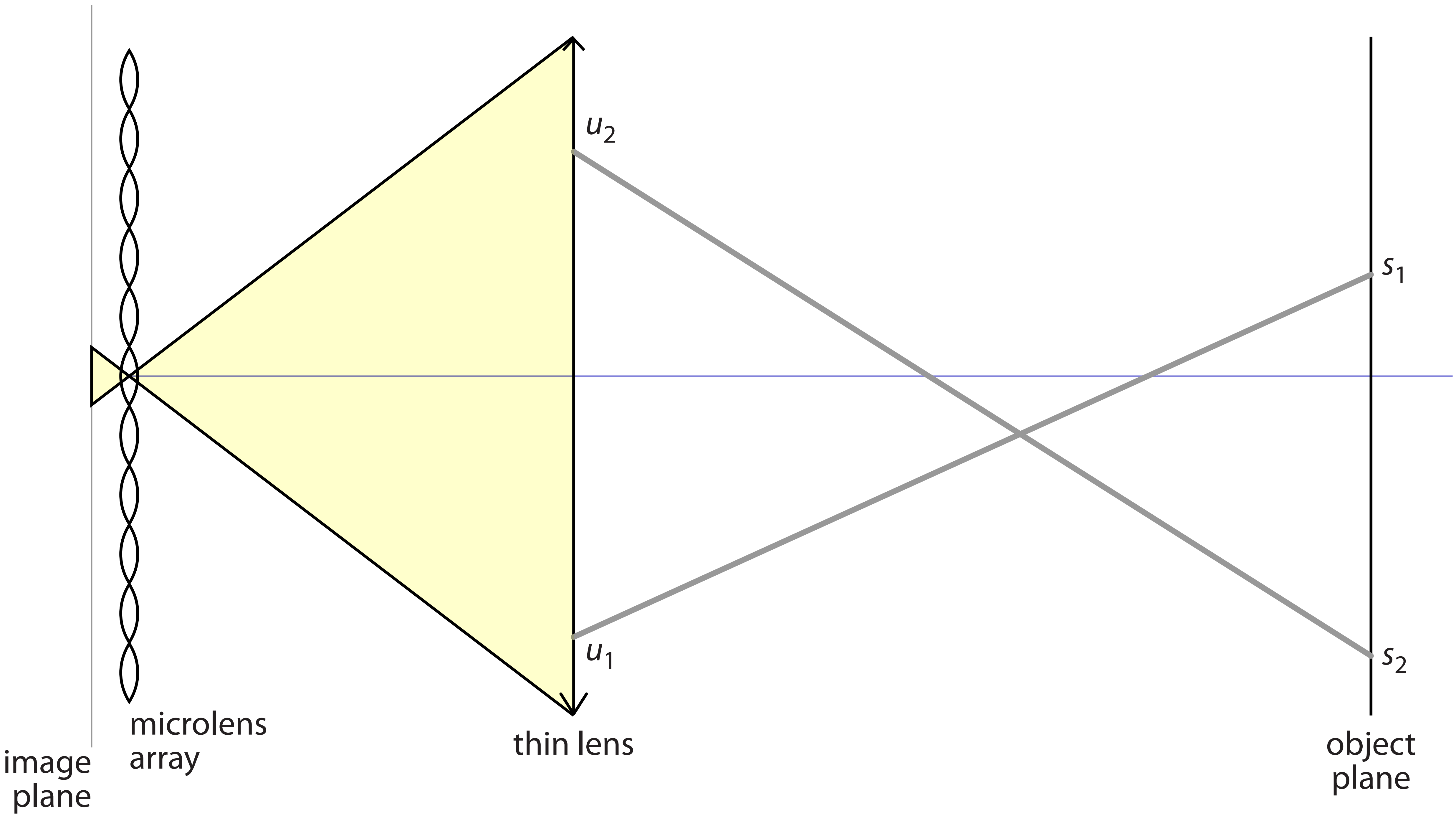

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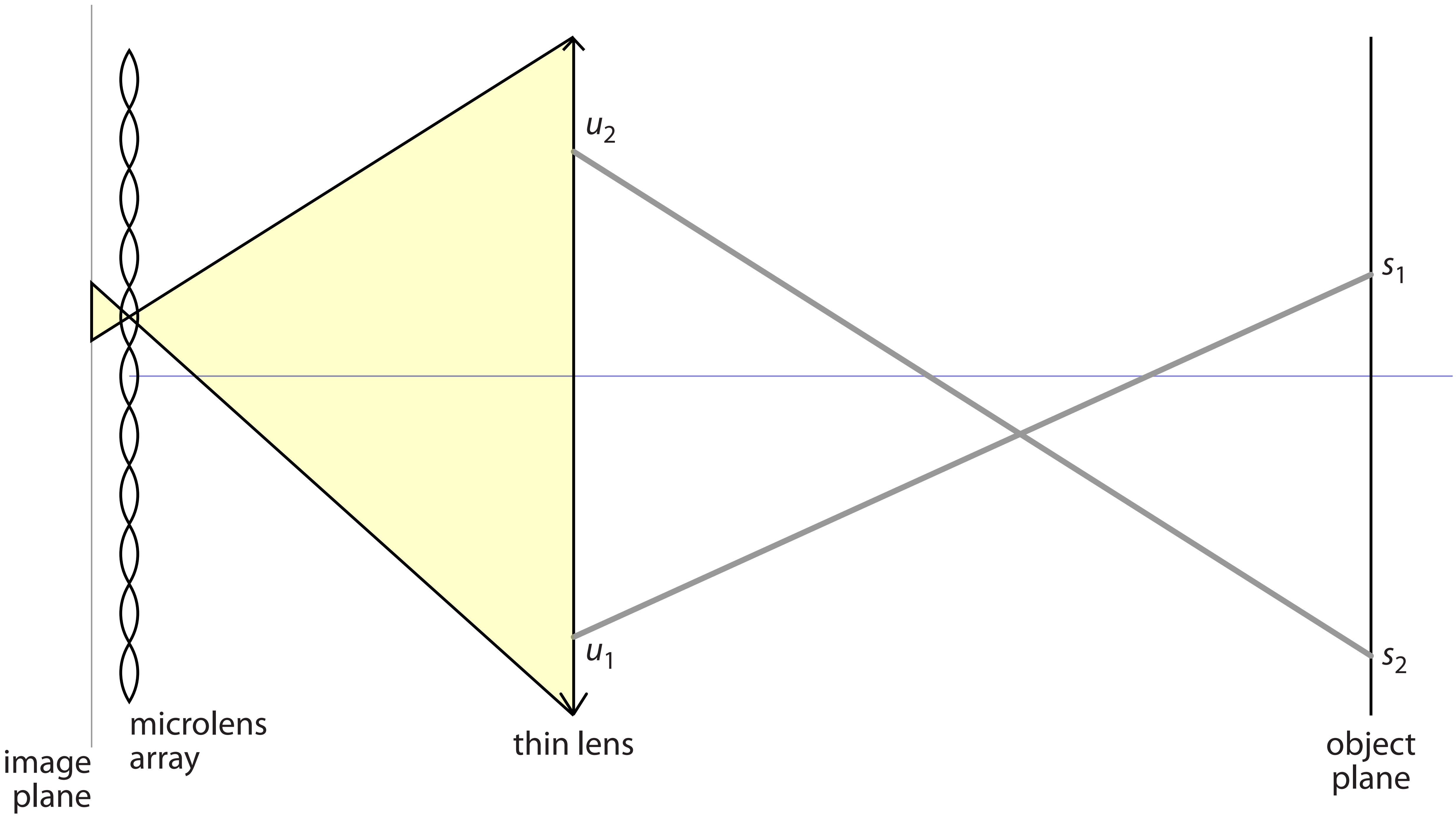

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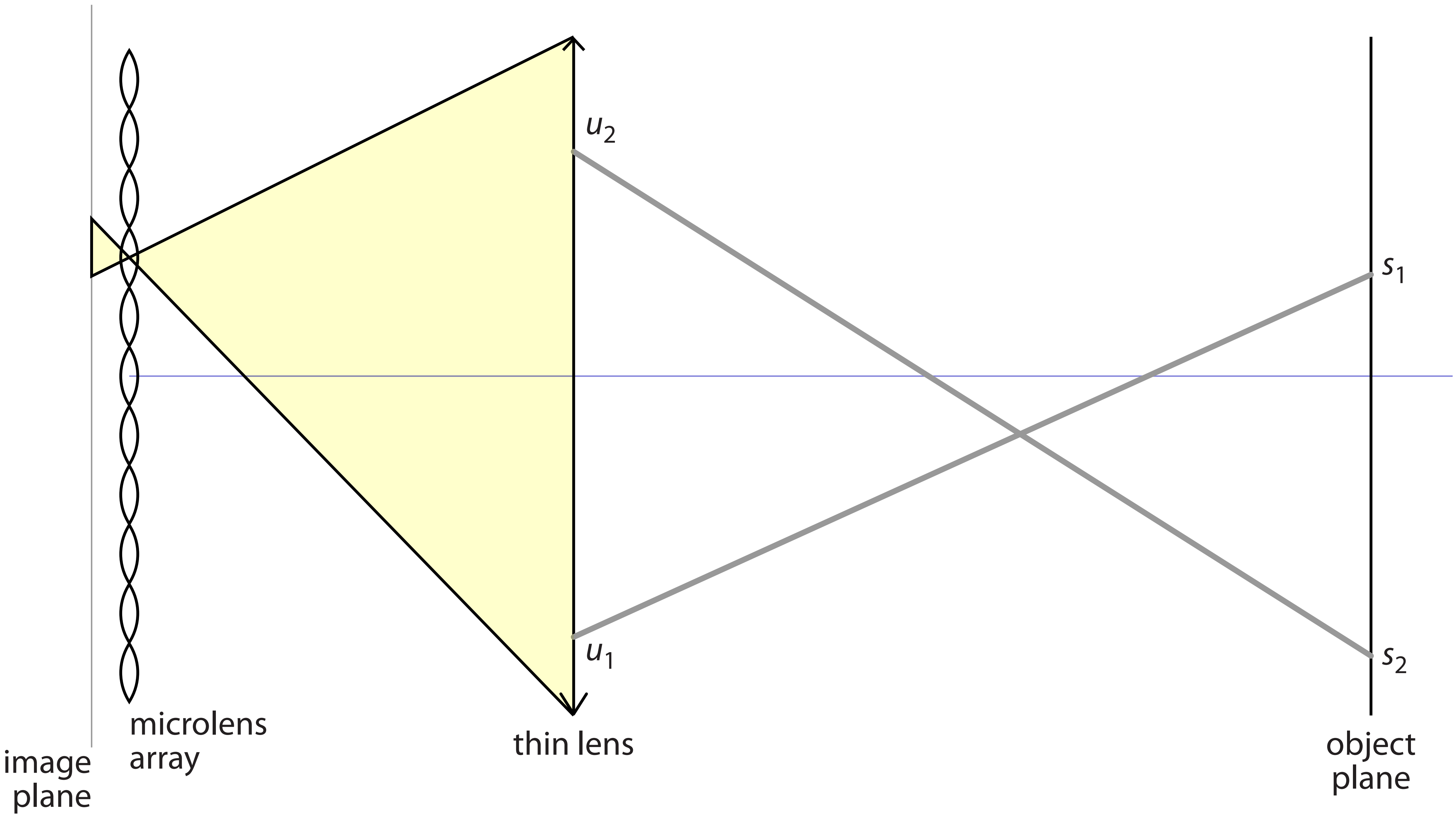

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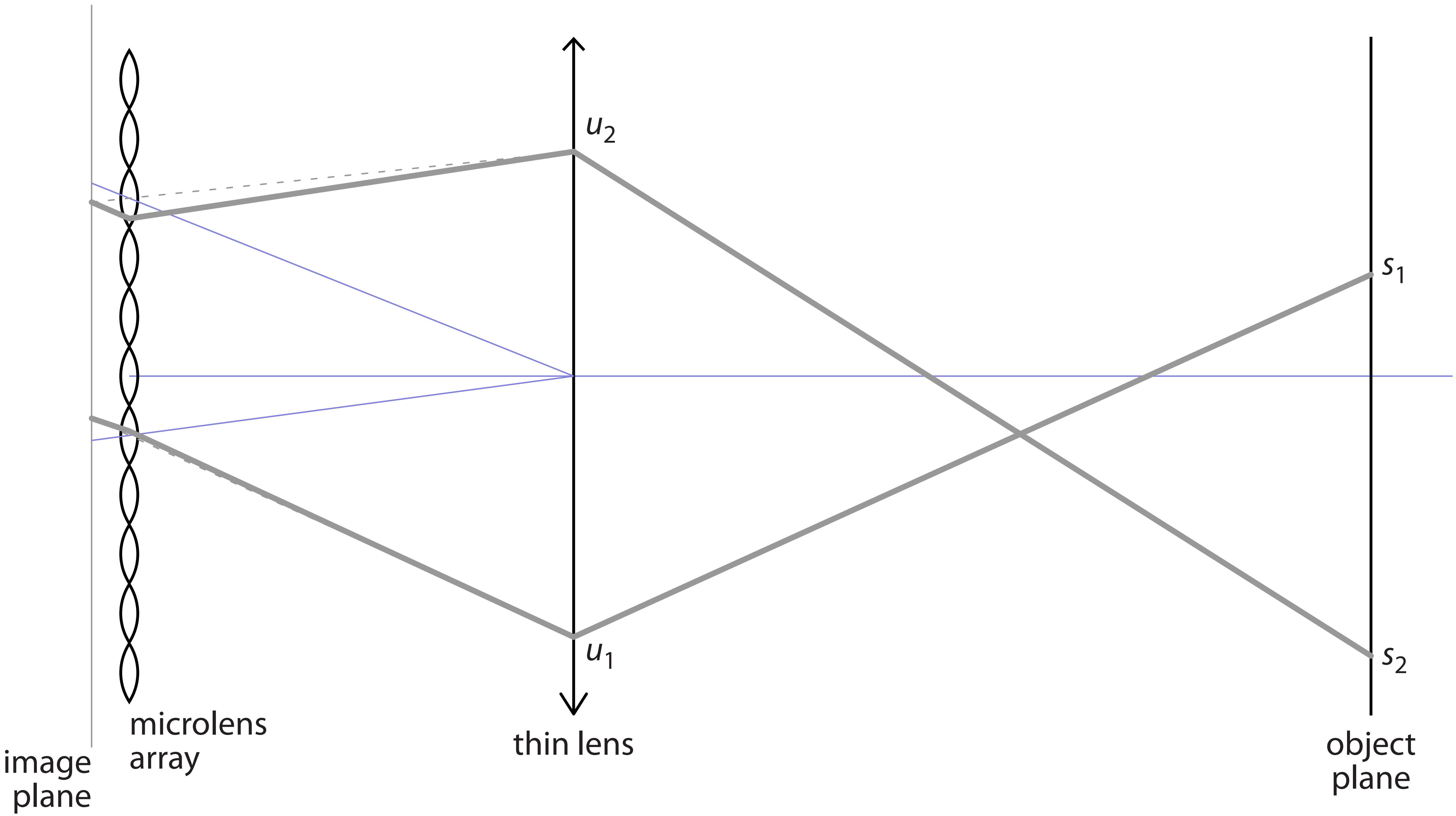

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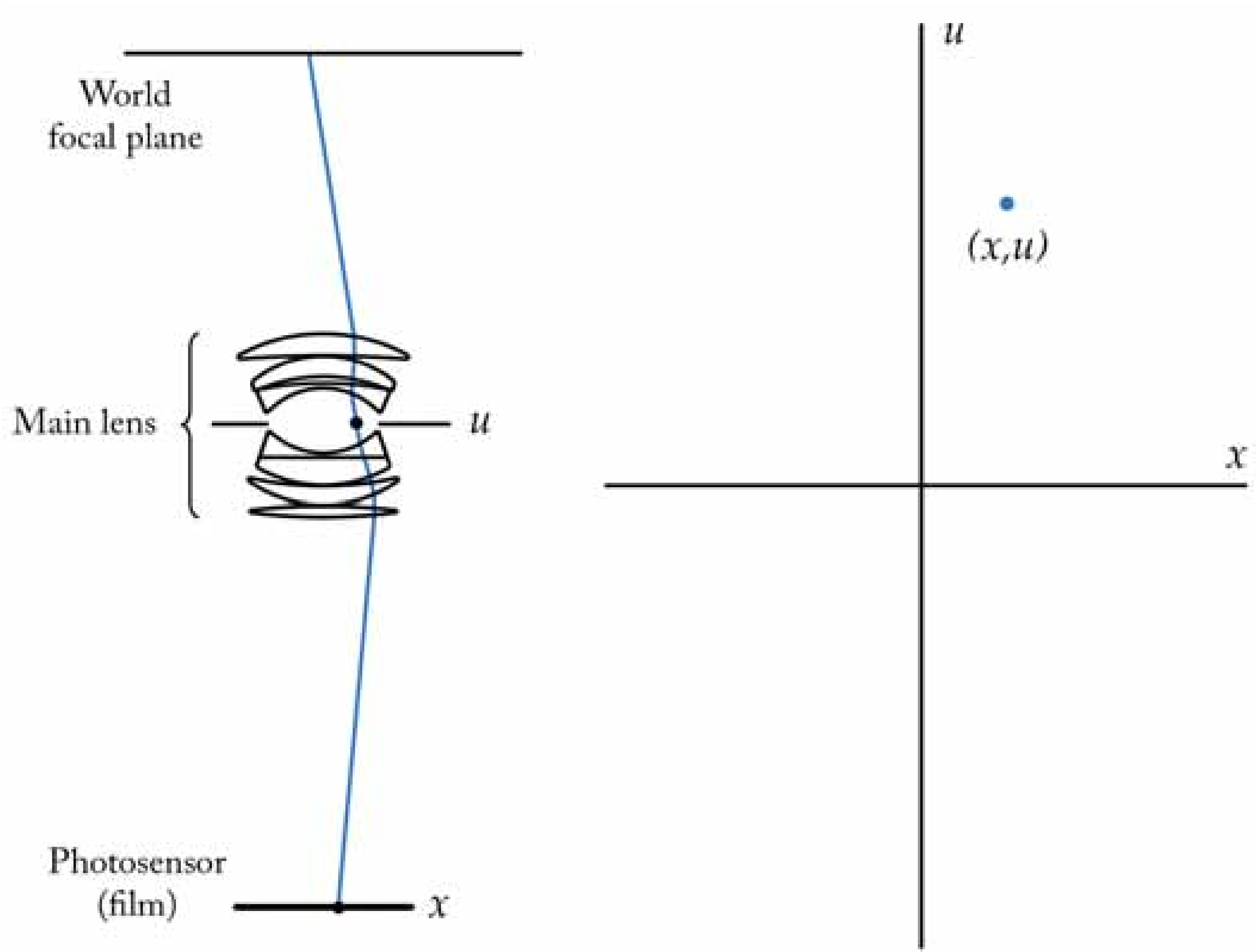

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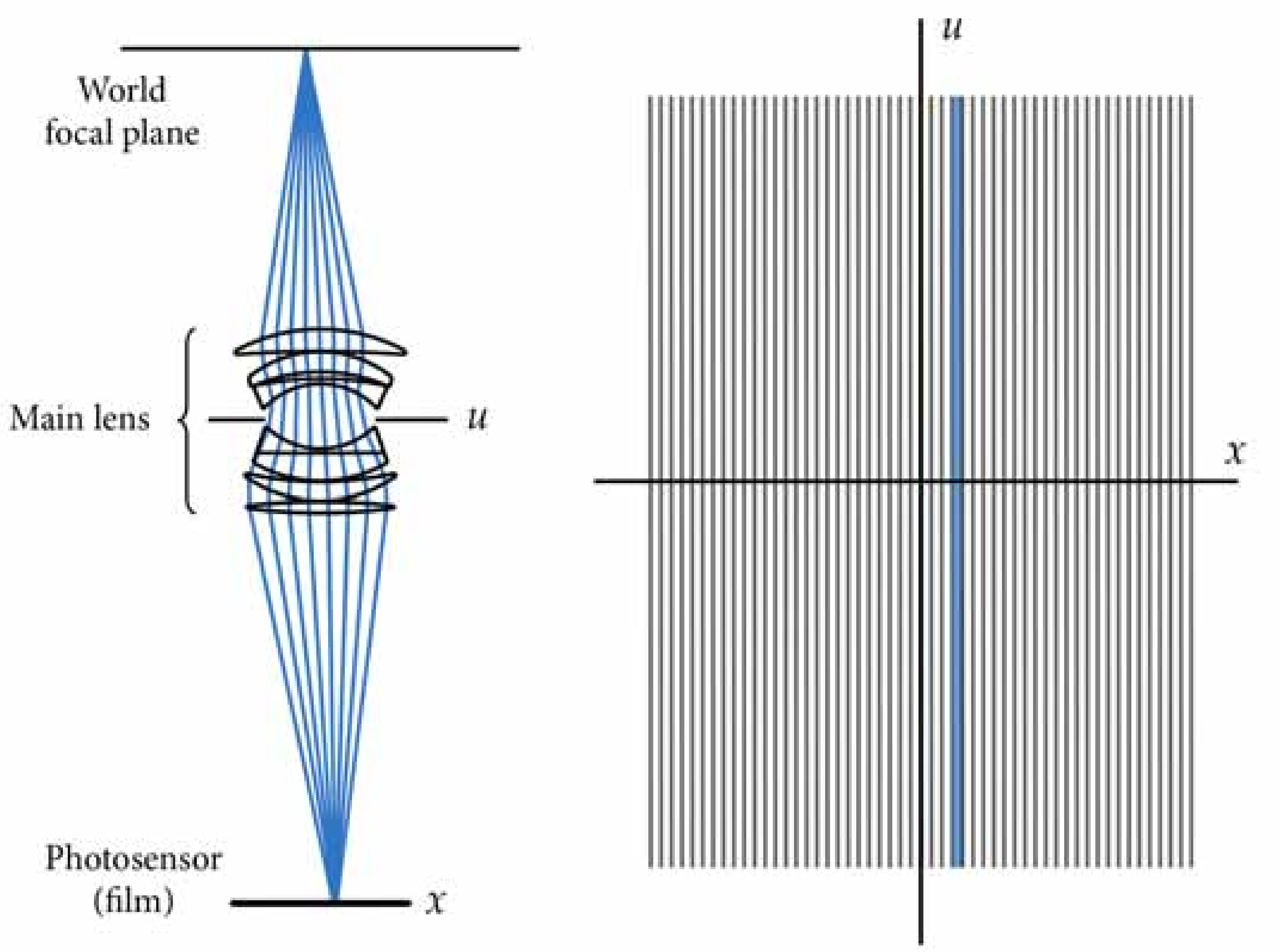

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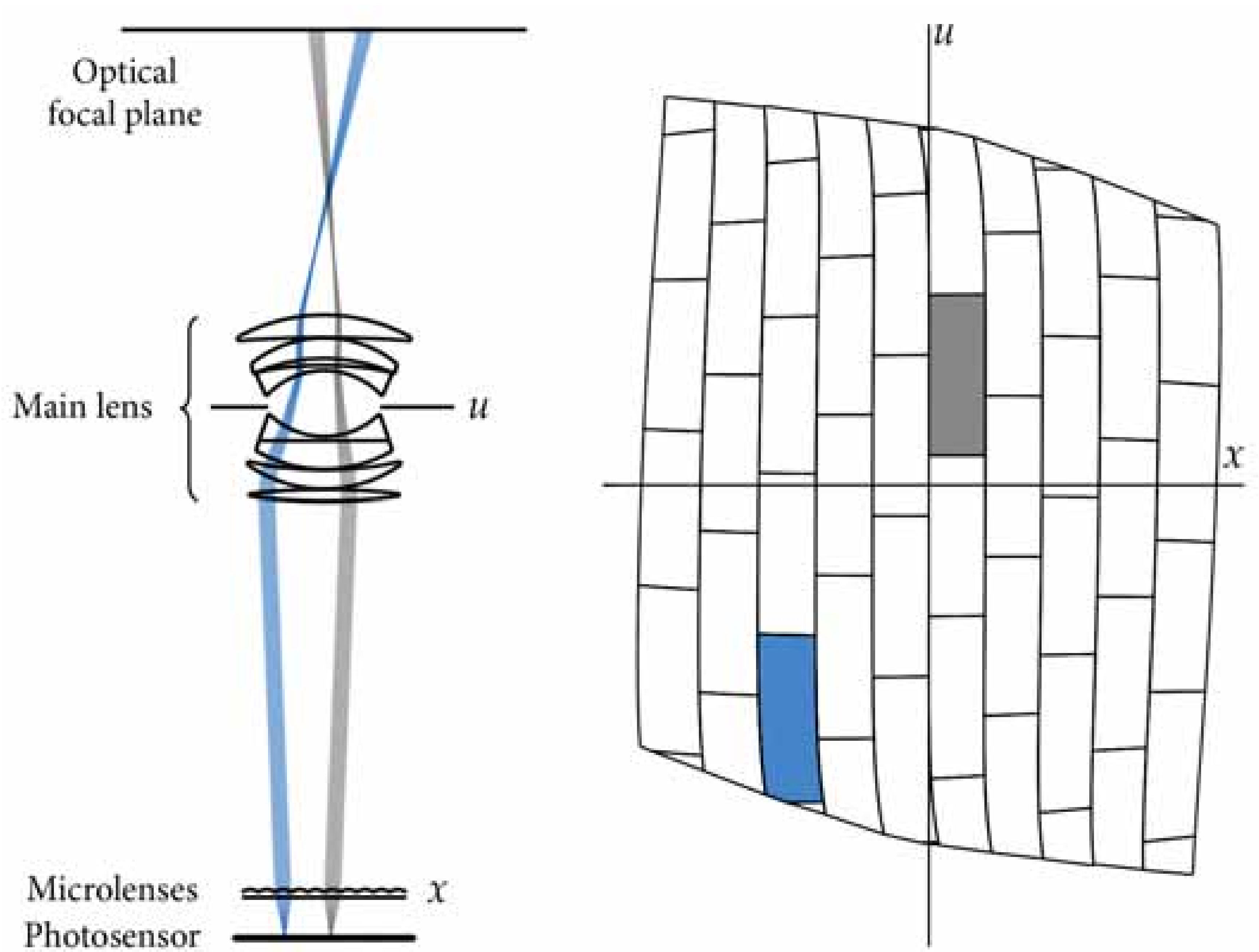
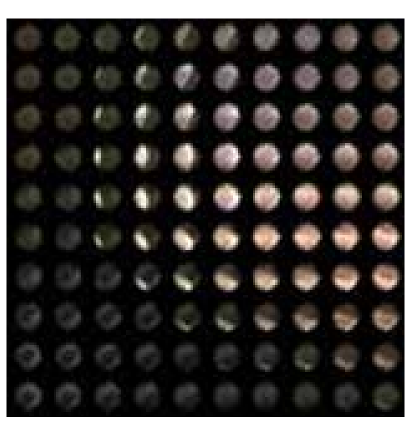
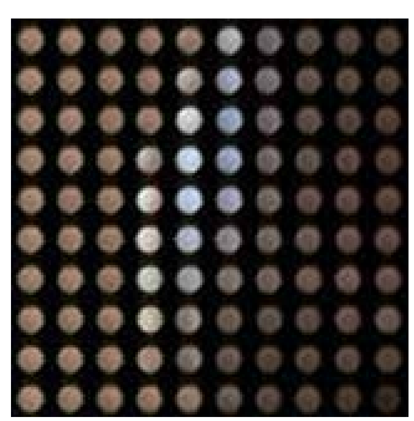


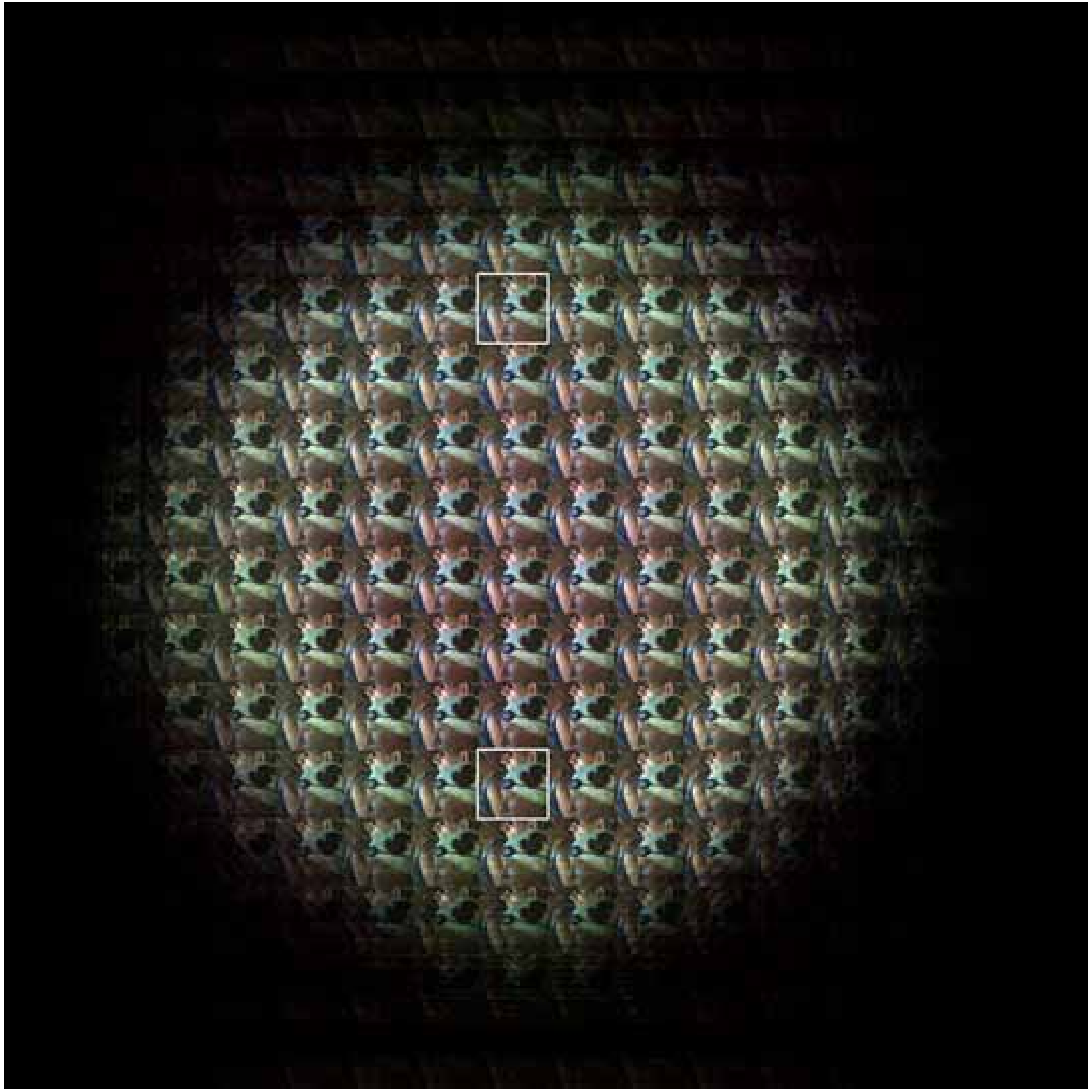
[Ren Ng thesis]

Light field camera native image: (s,t) is outer loop; (u,v) is inner loop





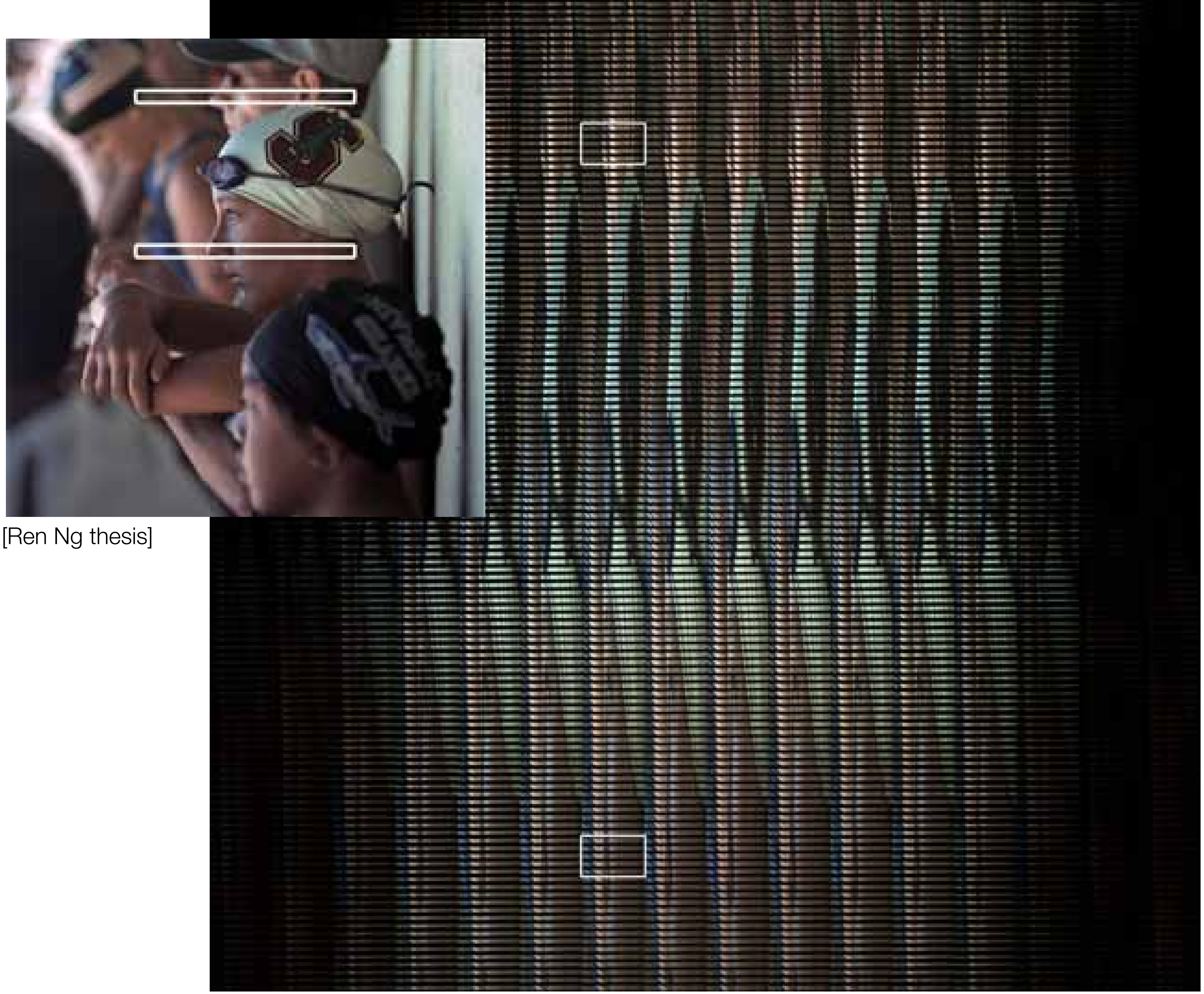
Characteristic behavior: objects at the focus plane become constant-colored circles; more distant points look like inverted views of a small area of the image.



Transposed image: (u,v) is the outer loop, (s,t) is the inner loop.

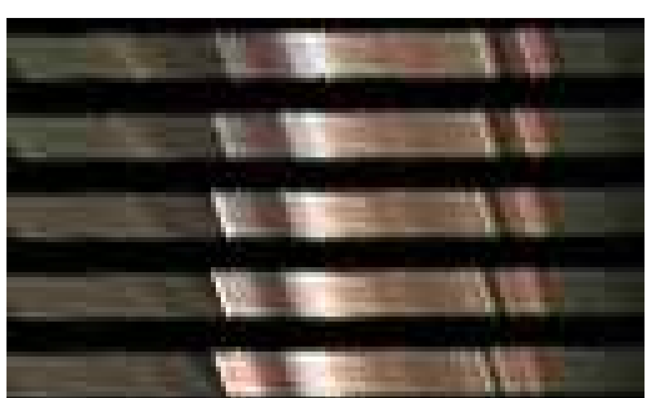
[Ren Ng thesis]

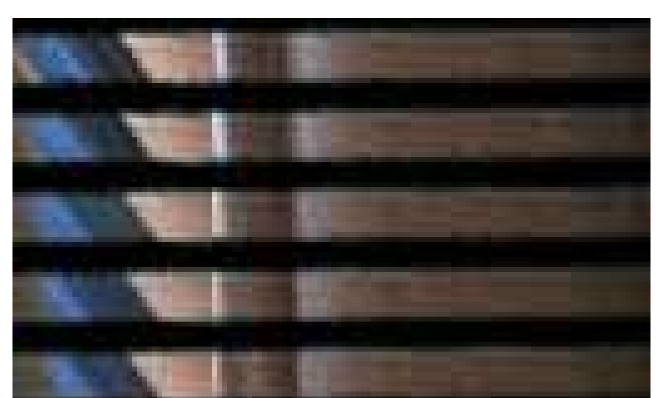
Characteristic behavior: the constant-uv images correspond to cameras located at different positions in the lens's entrance pupil. Note vertical parallax between these two images.



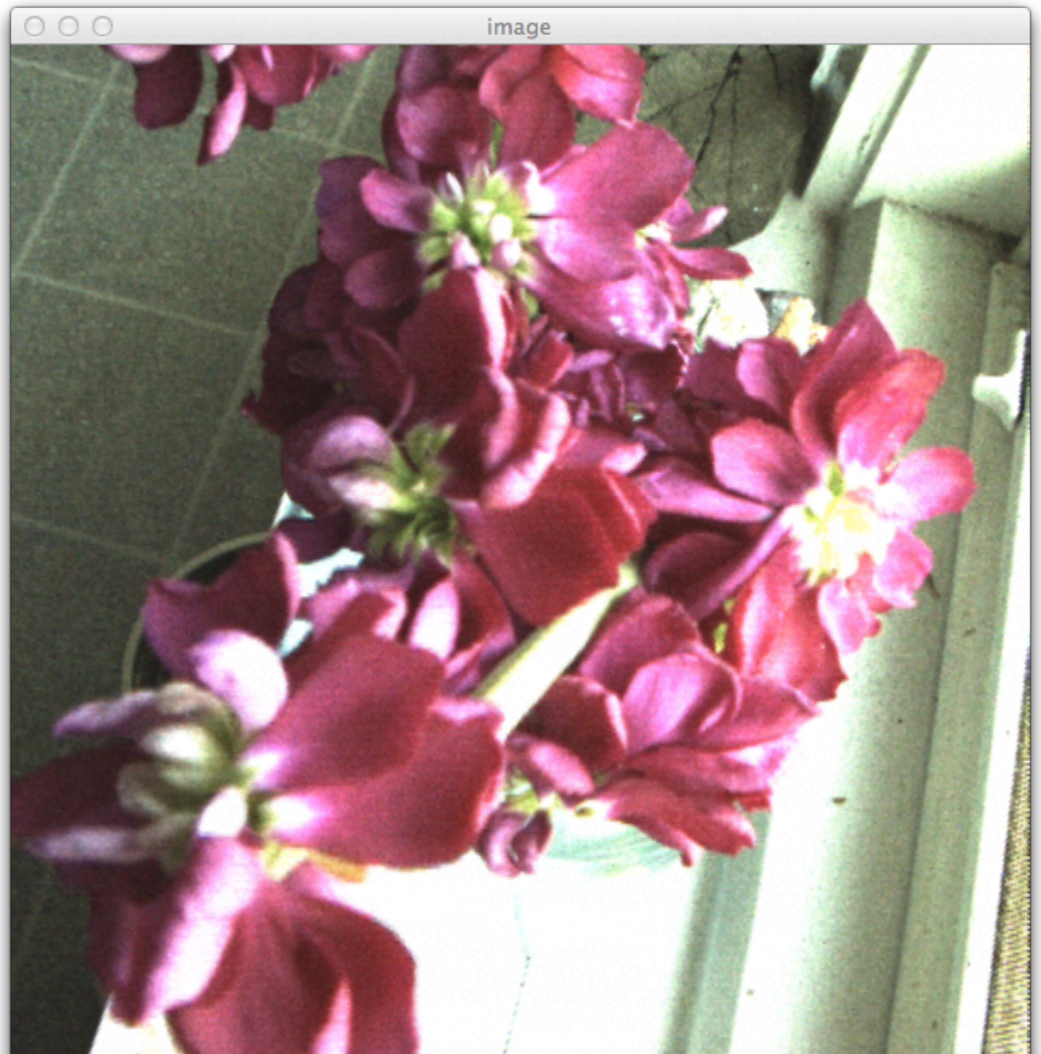
[Ren Ng thesis]

Epipolar plane format: (v,t) is the outer loop and (s,u) is the inner loop.





Characteristic behavior: points in scene become lines with slope depending on distance. Objects at focus plane produce vertical features; more distant objects produce negative slopes.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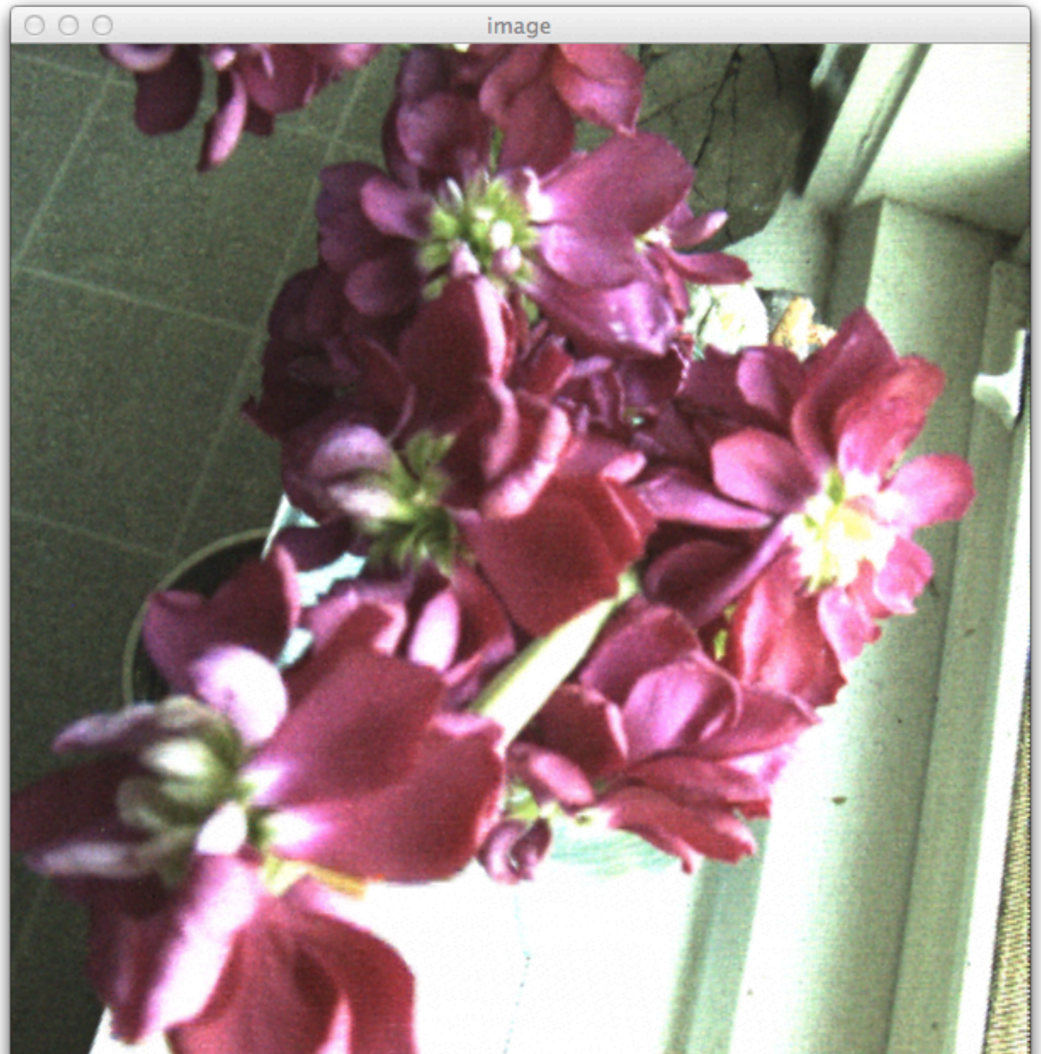
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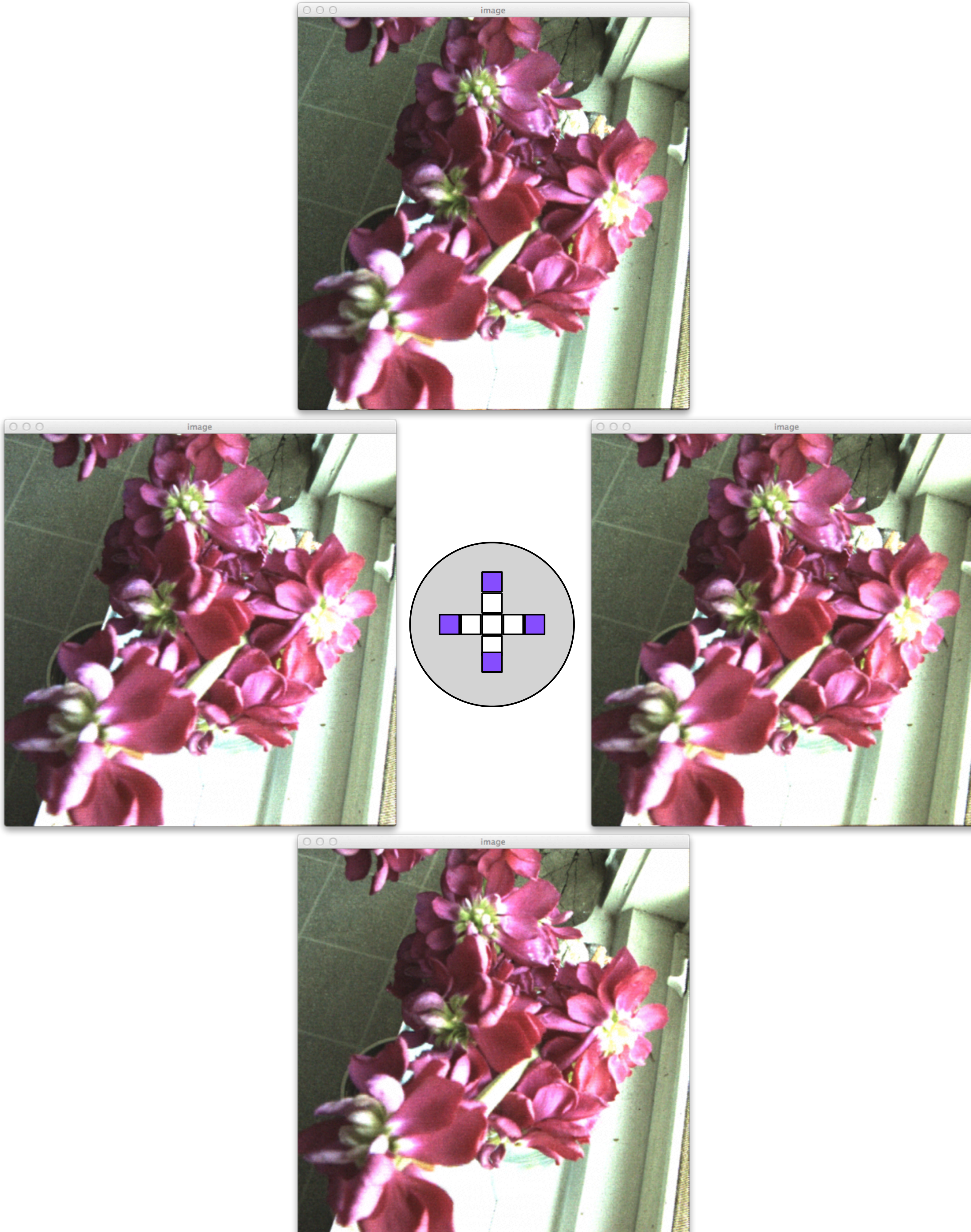
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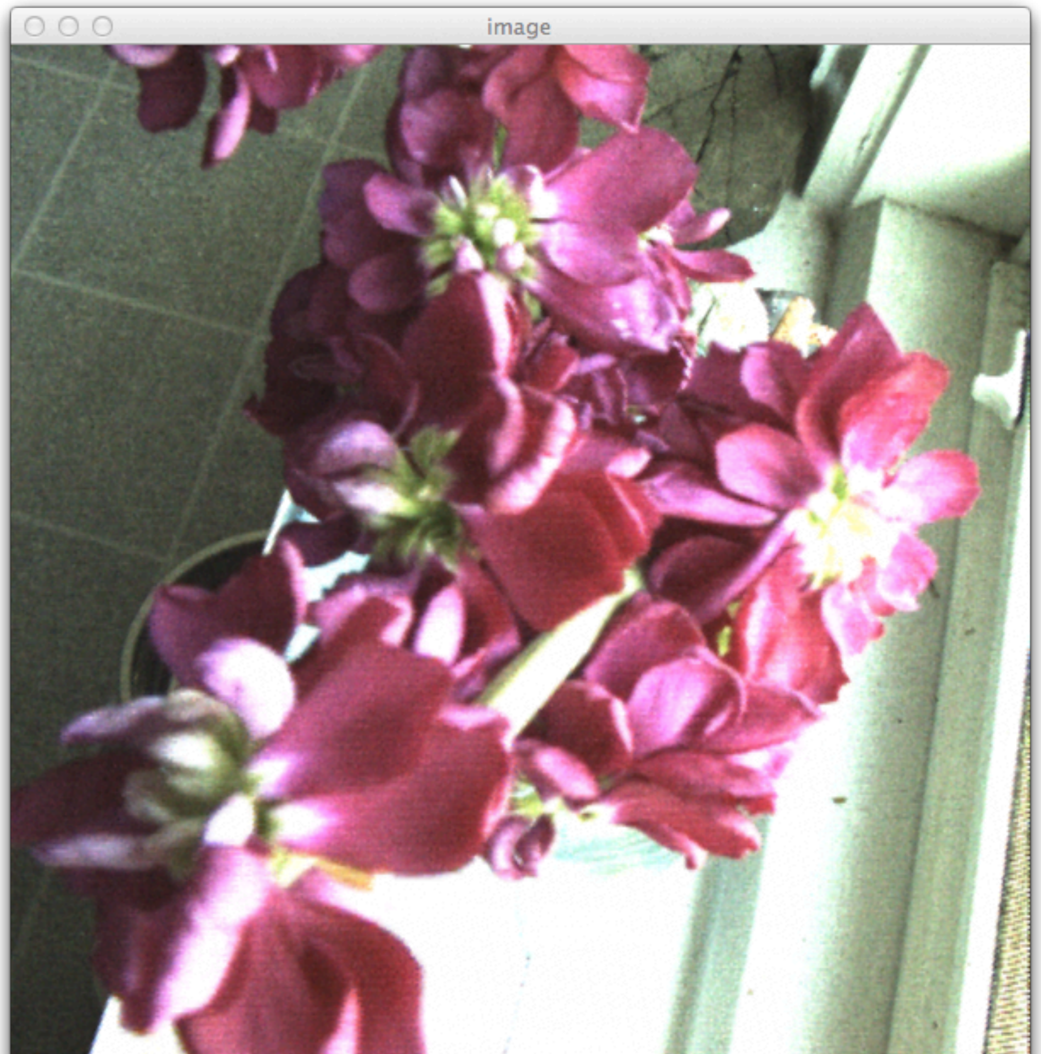
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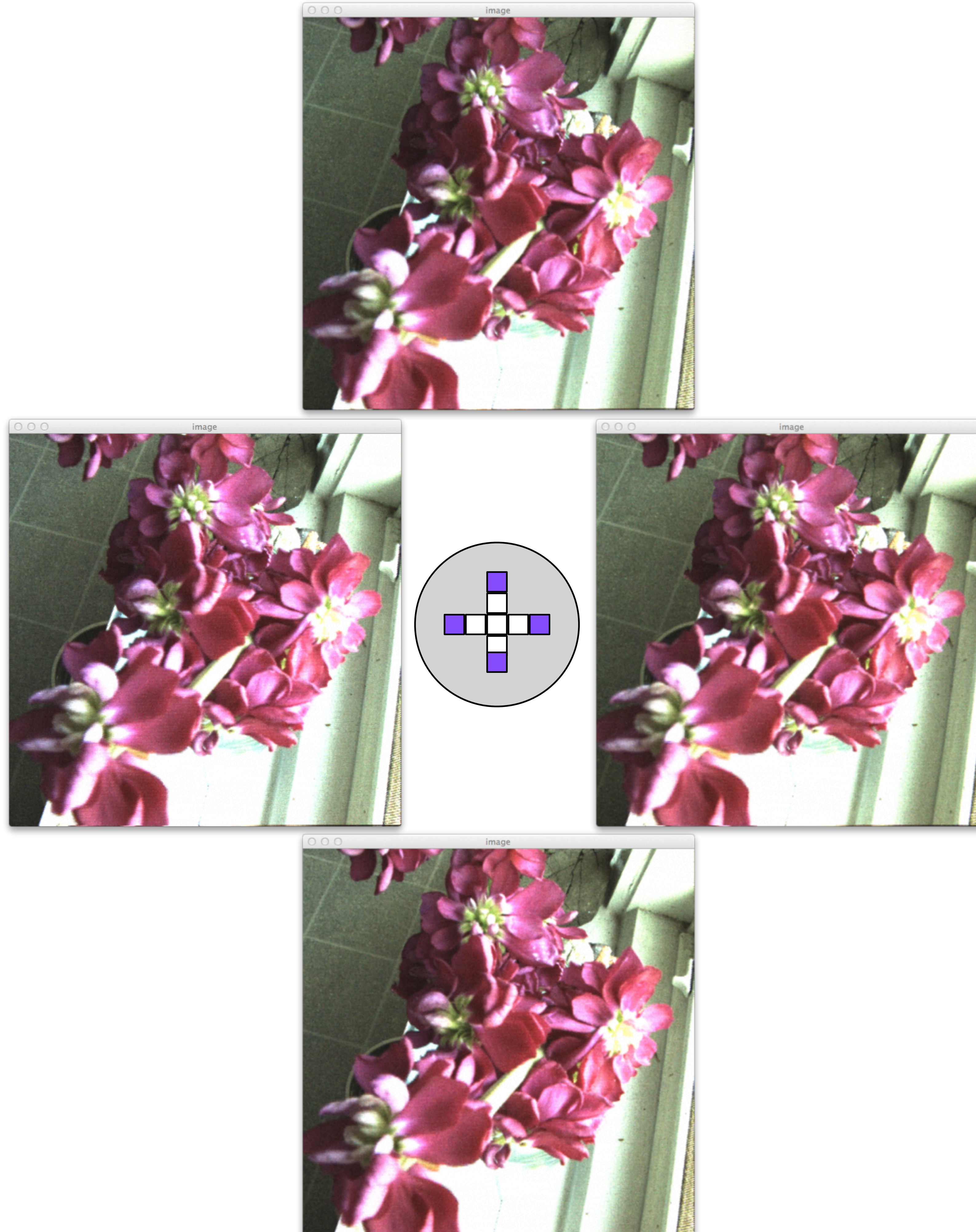
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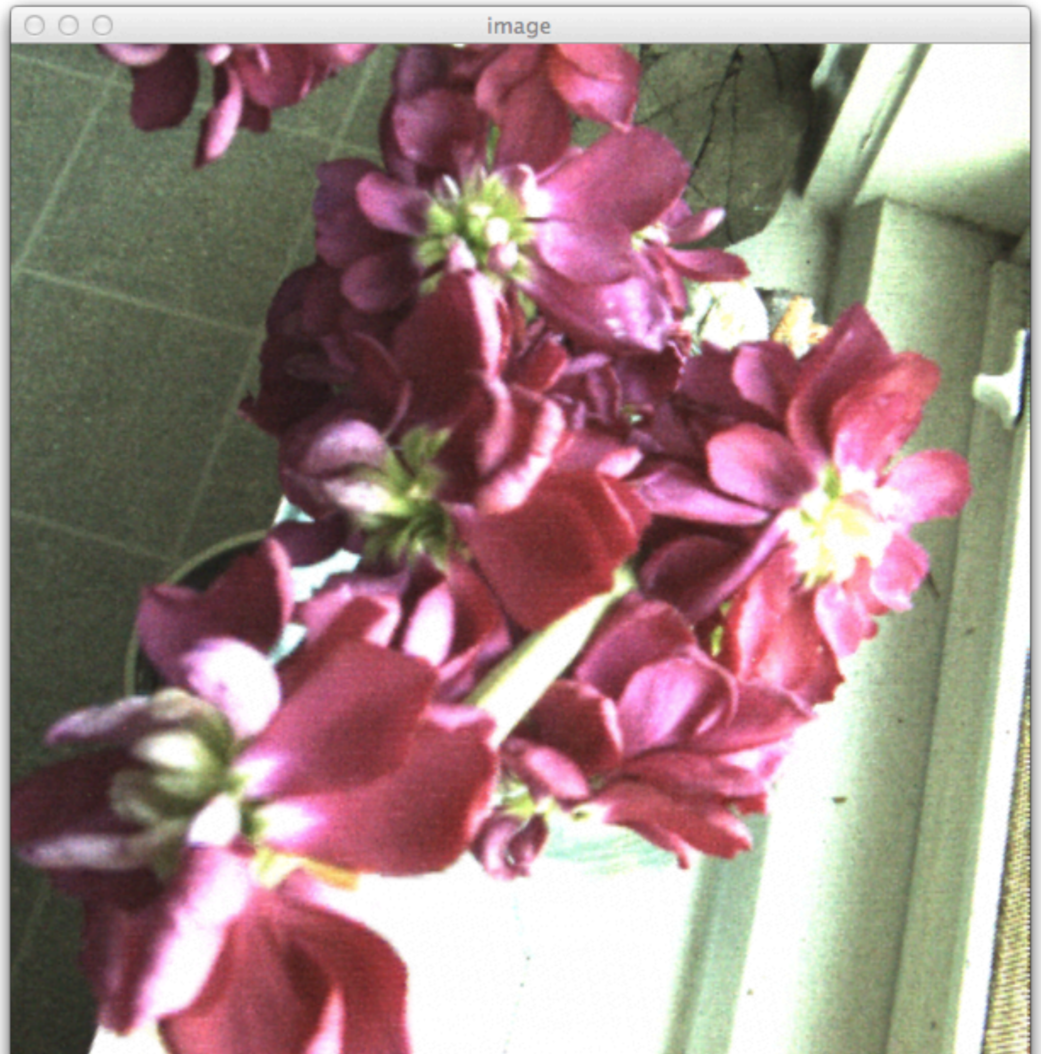
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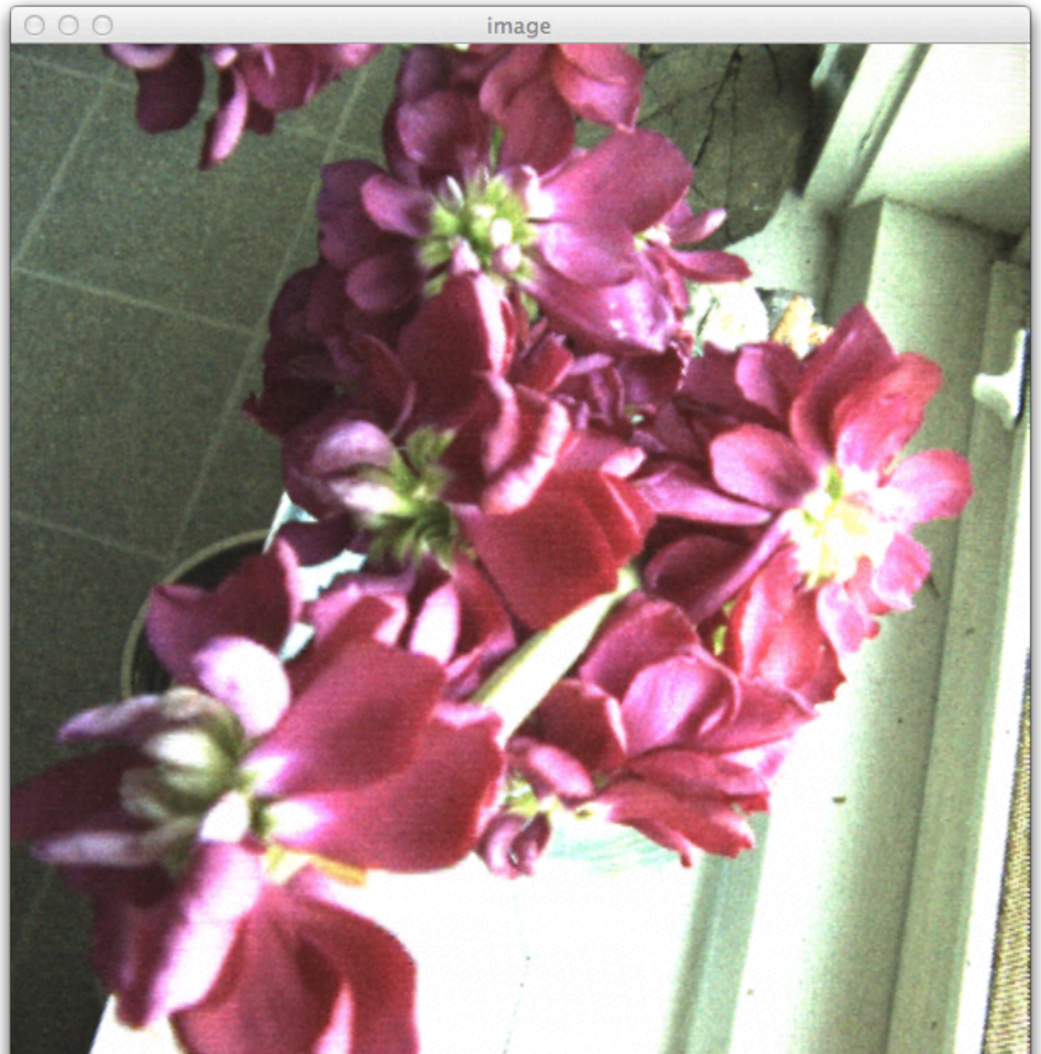
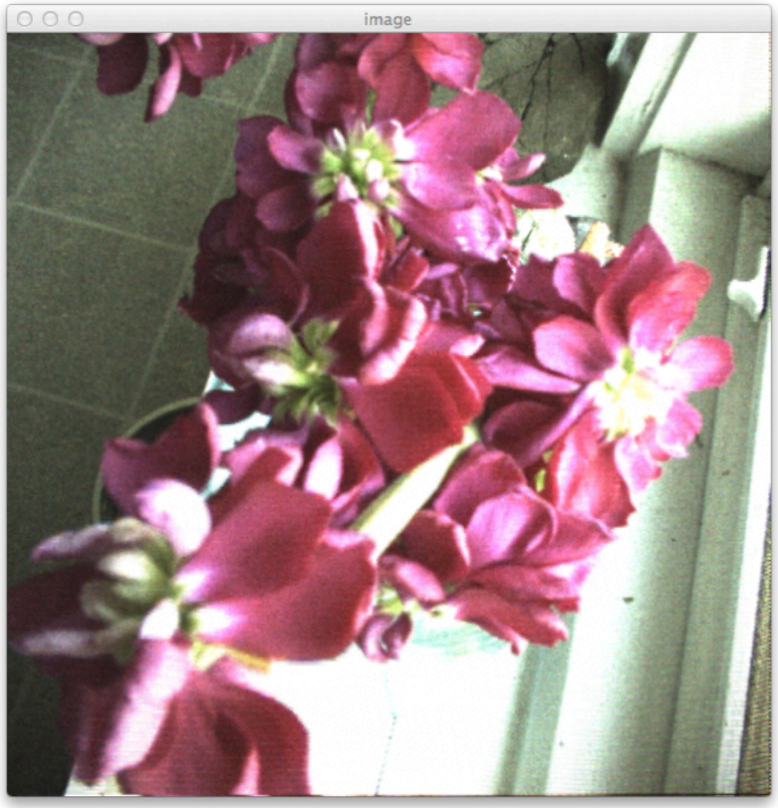
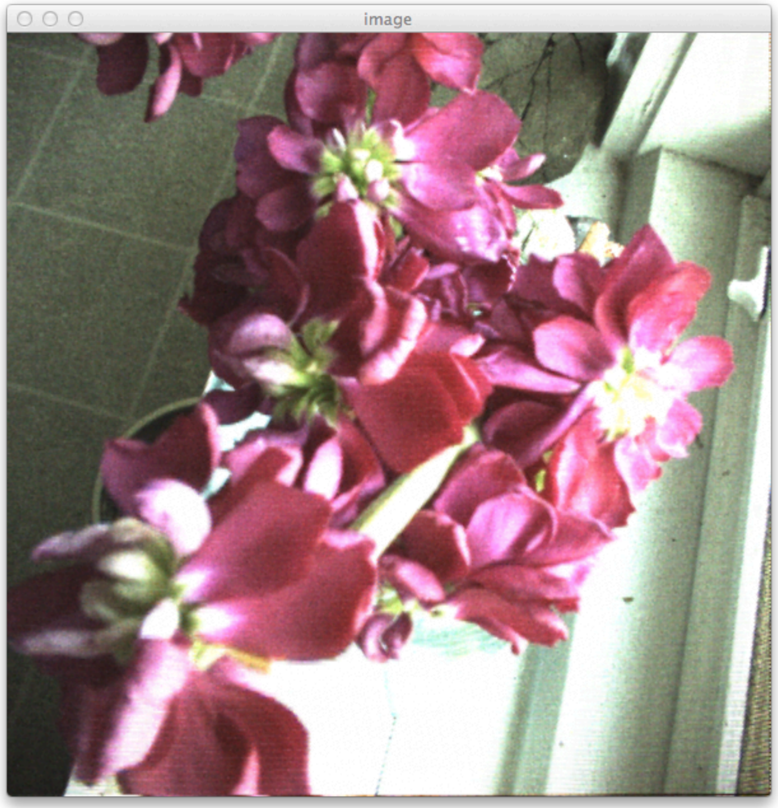




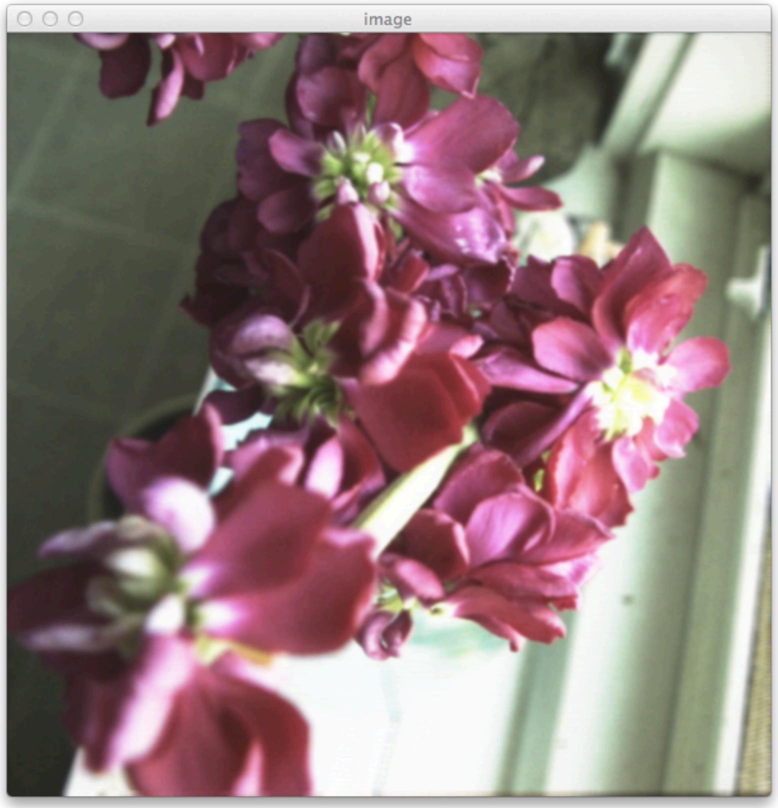
closer viewpoint ($\alpha = 0.9$)

farther viewpoint ($\alpha = 1.1$)



closer viewpoint (α = 0.9)

farther viewpoint (α = 1.1)



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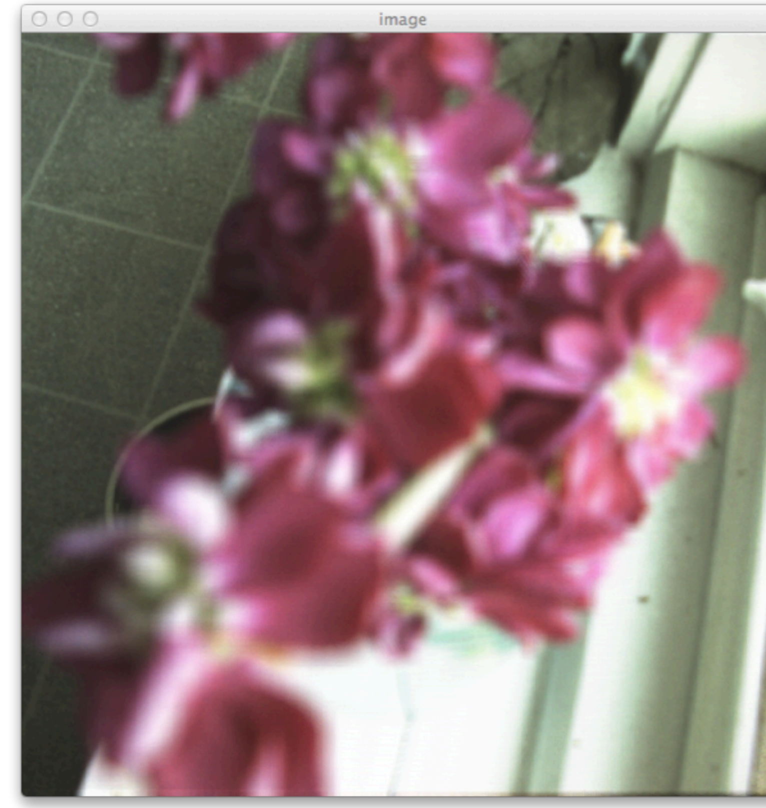
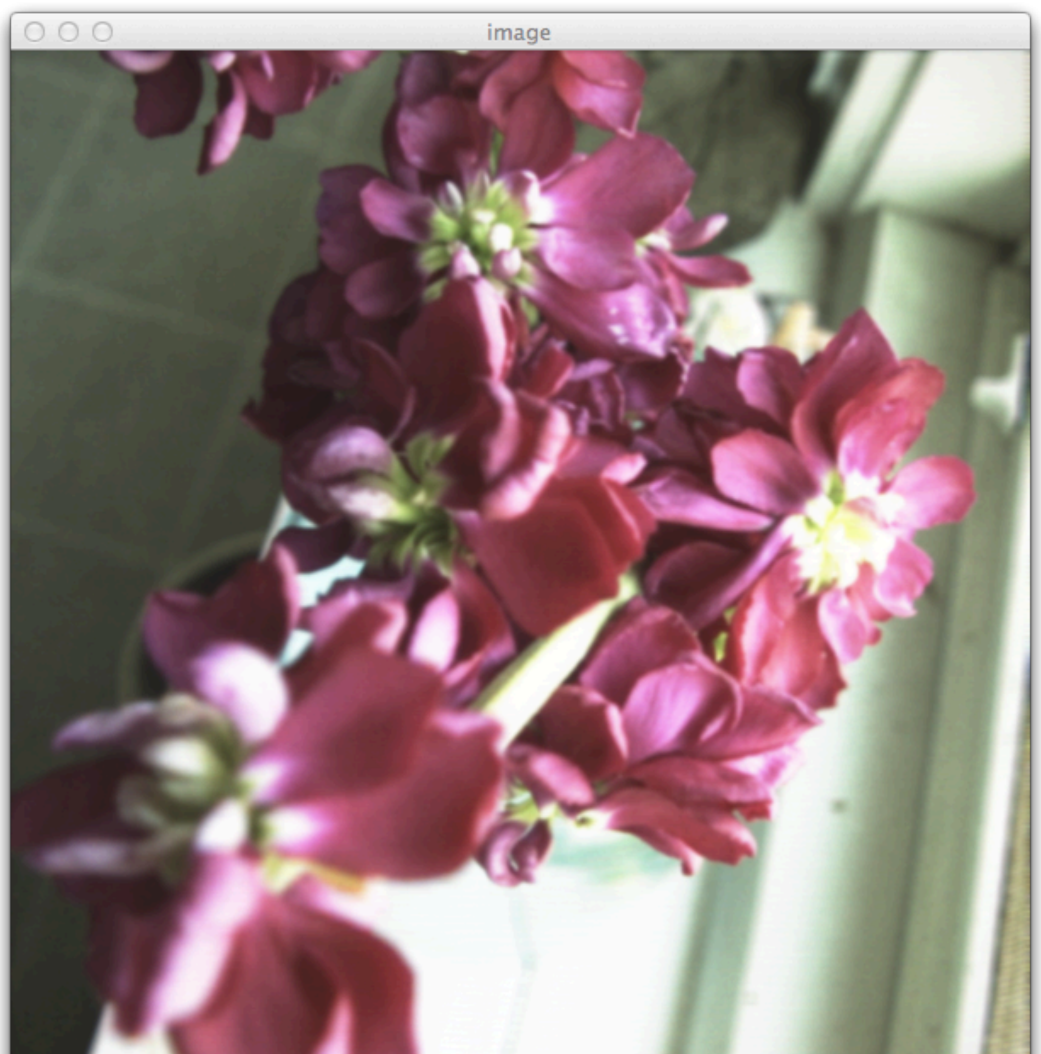
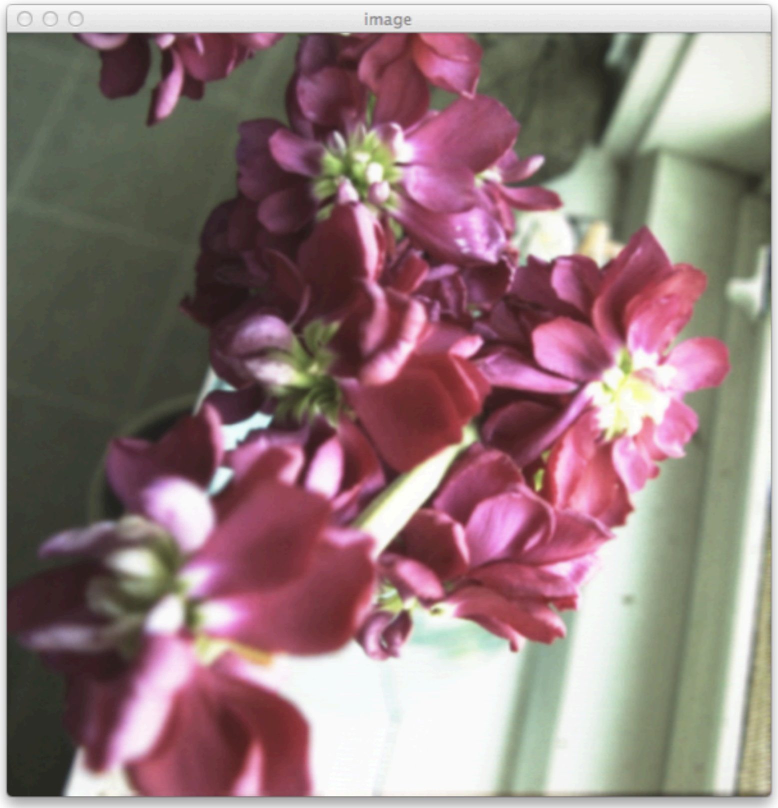
closer focus



farther focus (α = 1.1)

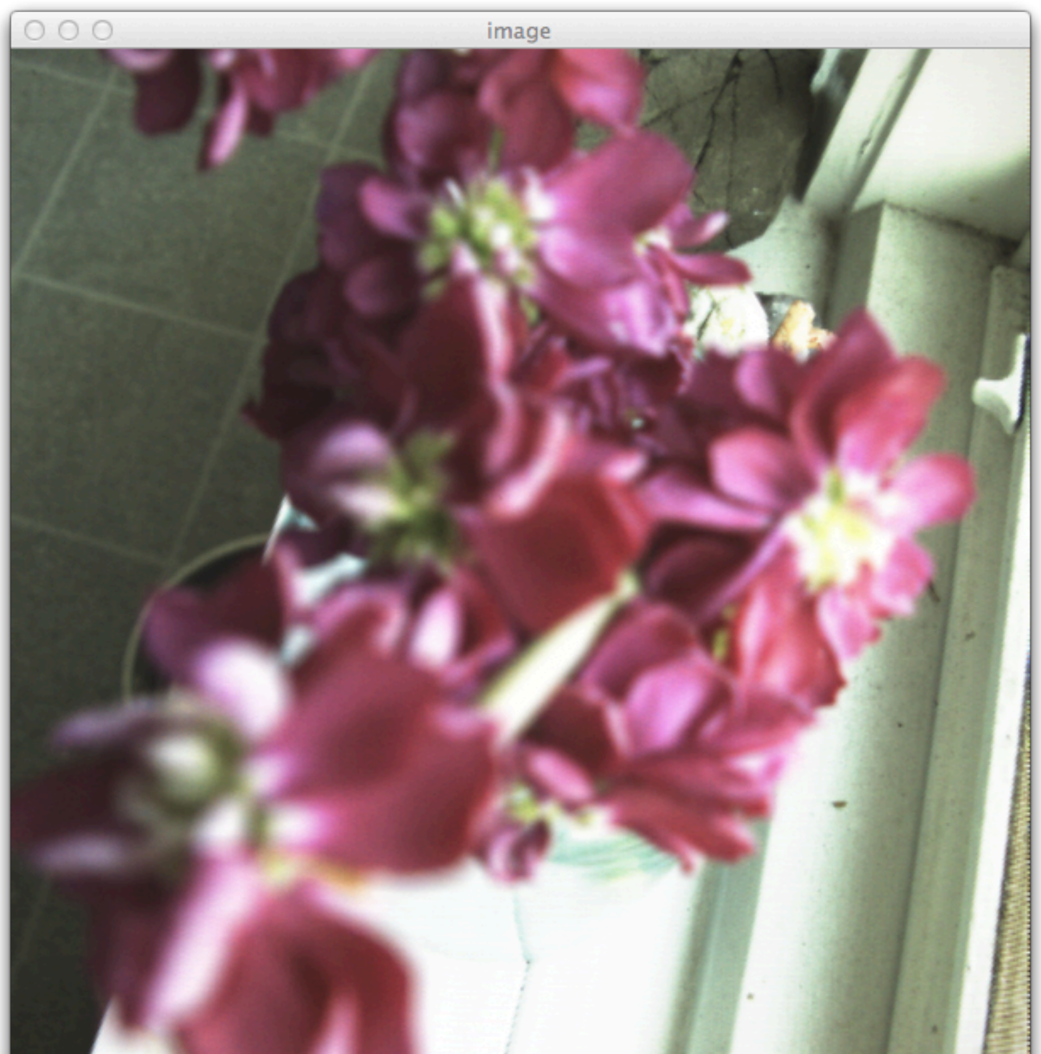


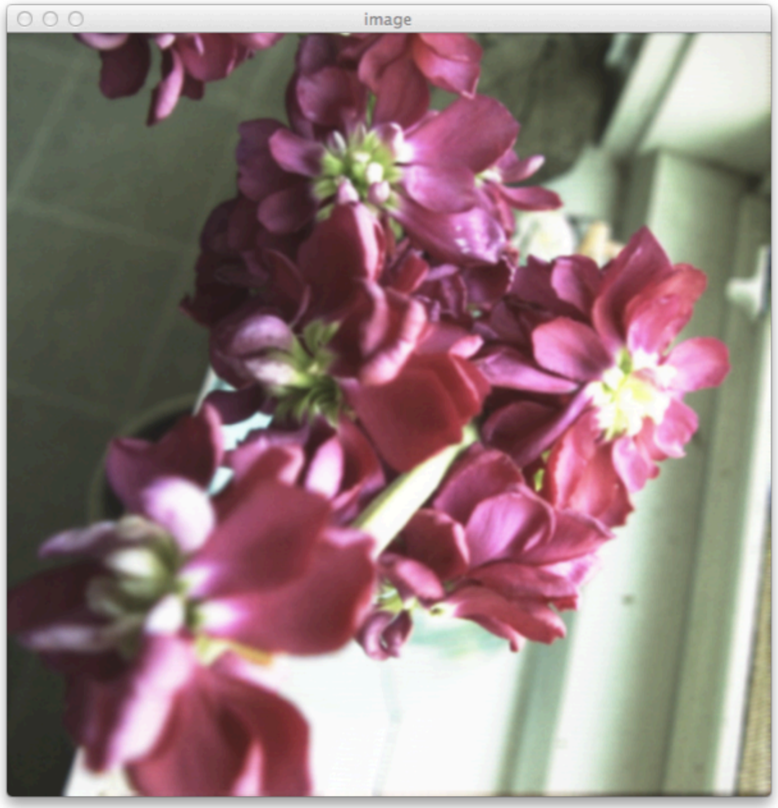


closer focus (α = 0.9)

closer focus

farther focus (α = 1.1)





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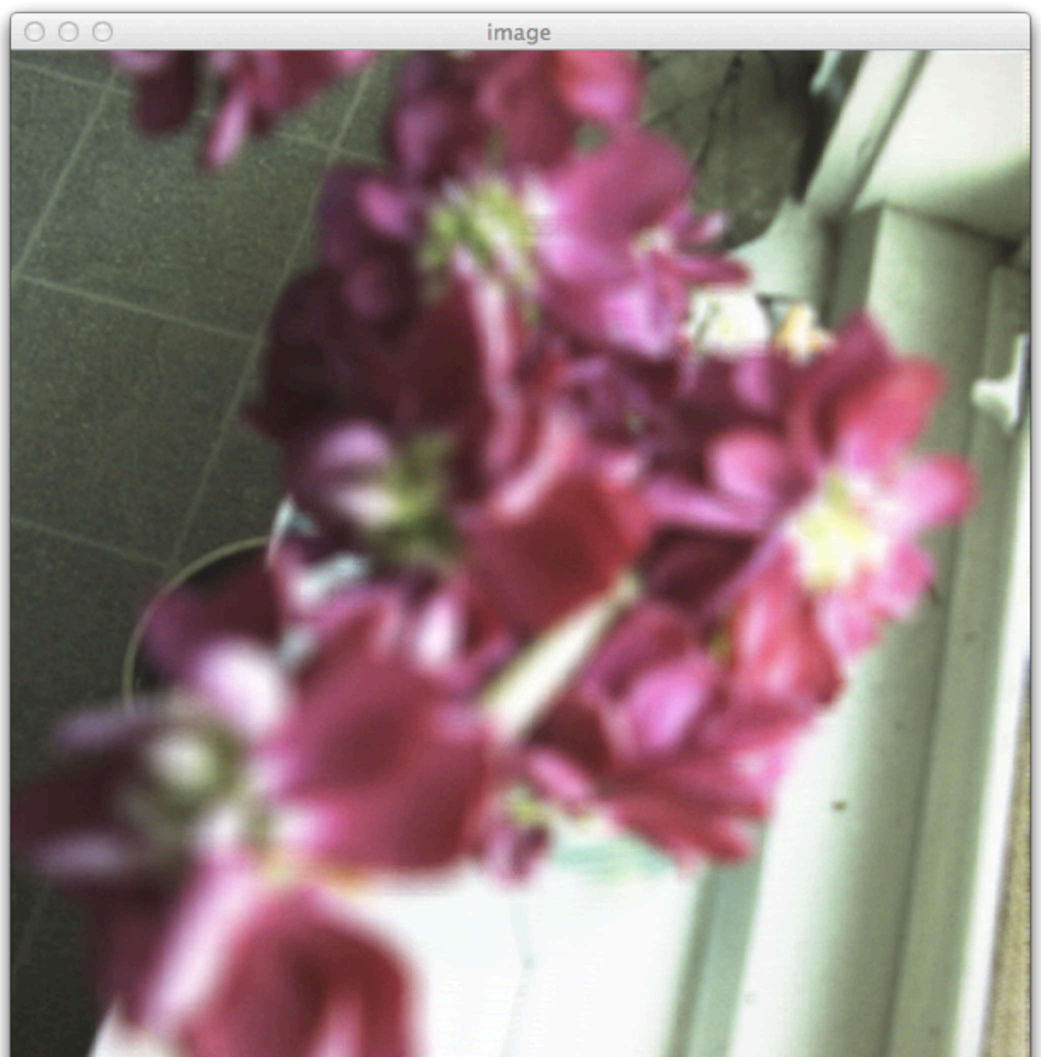

Depth of field and sub-apertures