# Computational Photography

## Introduction


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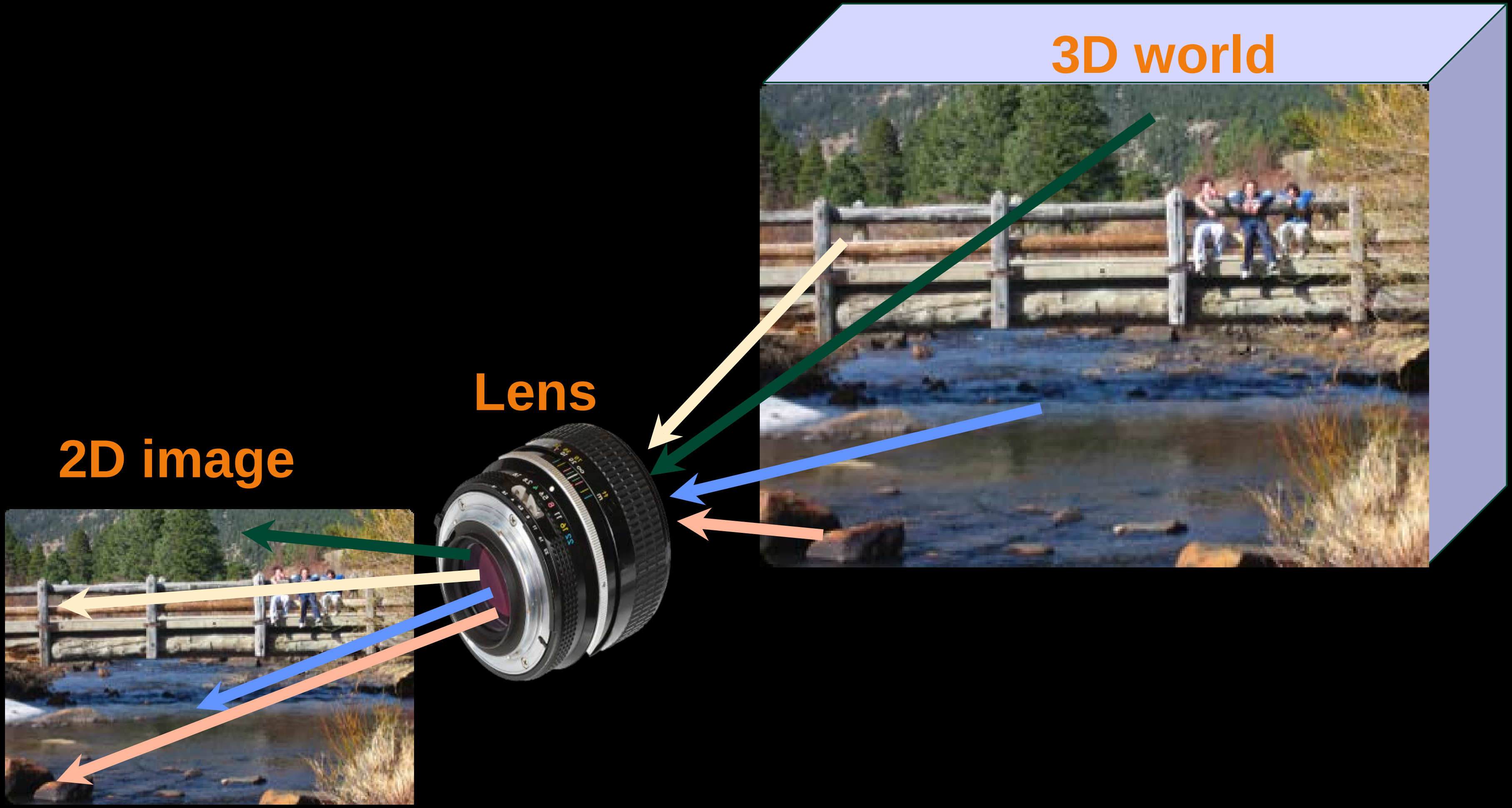
Technion

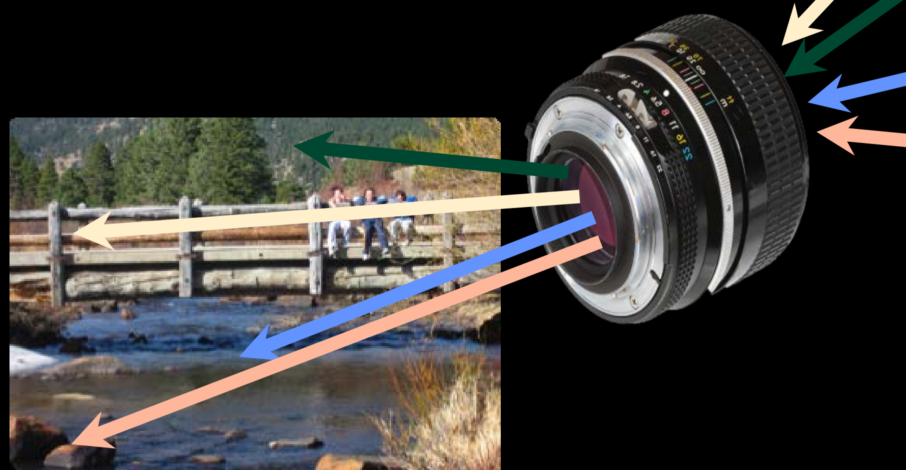
# Traditional imaging limitations

- 3D world -> 2D image. Loss of depth information



# Traditional imaging limitations

- 3D world -> 2D image. Loss of depth information
- Single view point



# Traditional imaging limitations

- **3D world -> 2D image. Loss of depth information**
- **Single view point**
- **Limited depth of field**

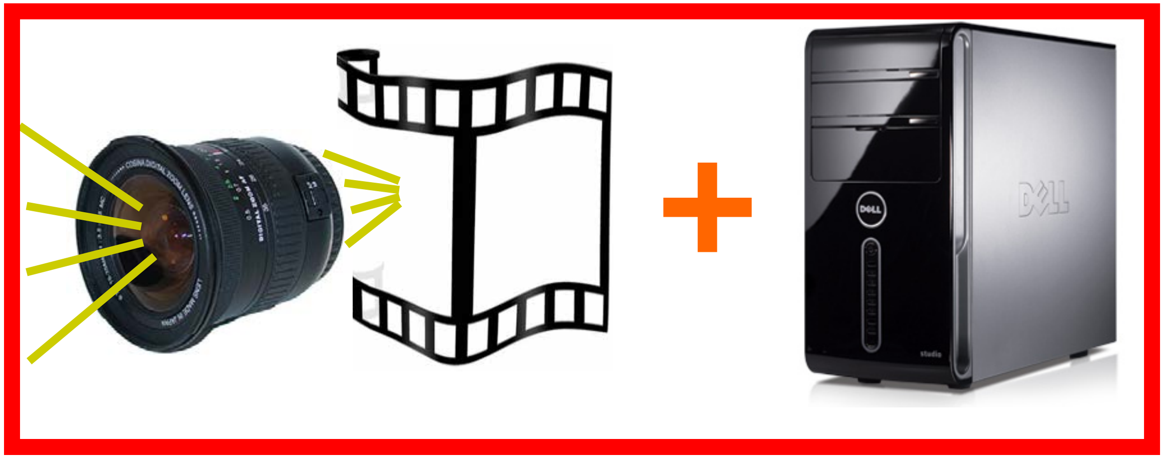
# Traditional imaging limitations

- 3D world -> 2D image. Loss of depth information
- Single view point
- Limited depth of field
- Motion blur
- Limited spatial resolution
- Noise
- 
- 
- 

# Traditional Photography

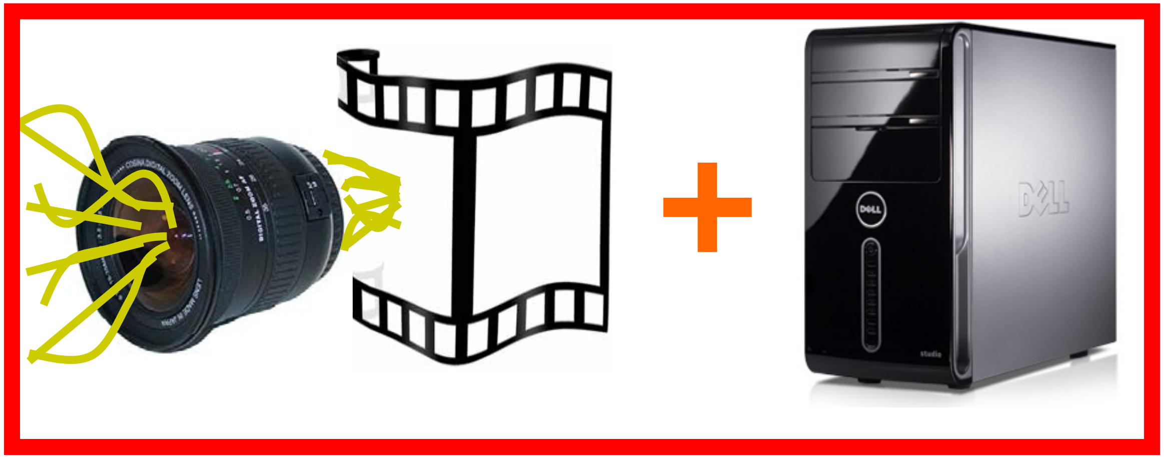
Optical Camera

# Computational Photography




Computational Camera

# Computational Photography



**Computational Camera**

**Redesign optics to account for computation**

**Compact camera**

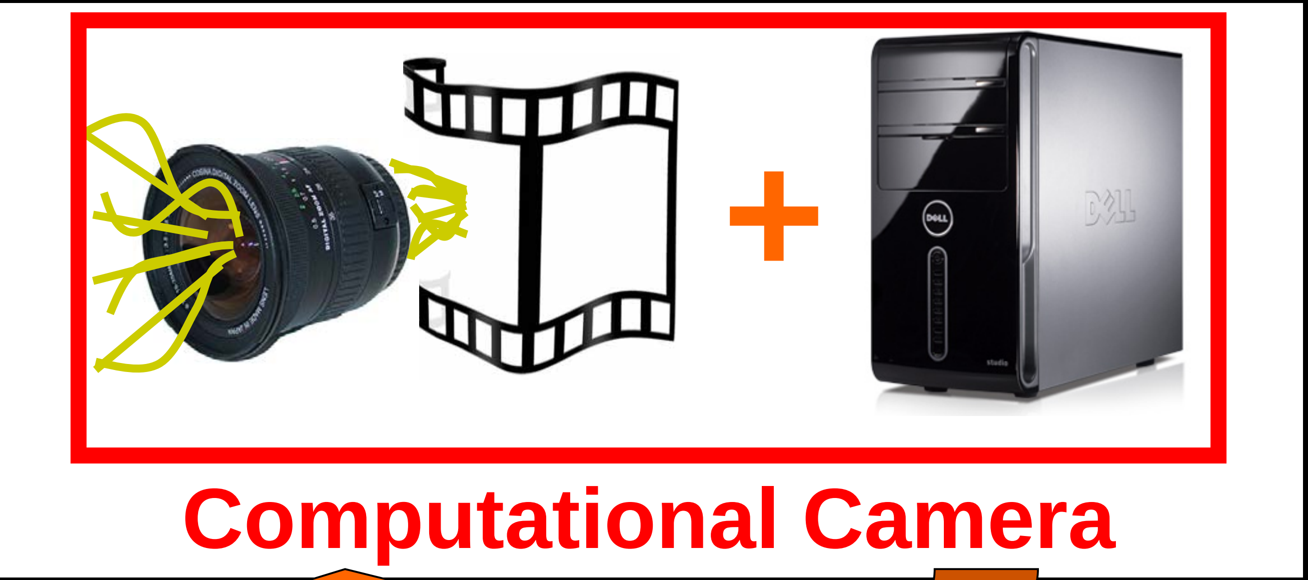
**Video camera**

**Telescope**

**Microscope**

**Medical Imaging CT / MRI**

# Computational Photography




**Redesign optics to account for computation**

**Goal:**

- **Break bounds on traditional optics using computation**
- **Develop unified mathematical theory for computational cameras**

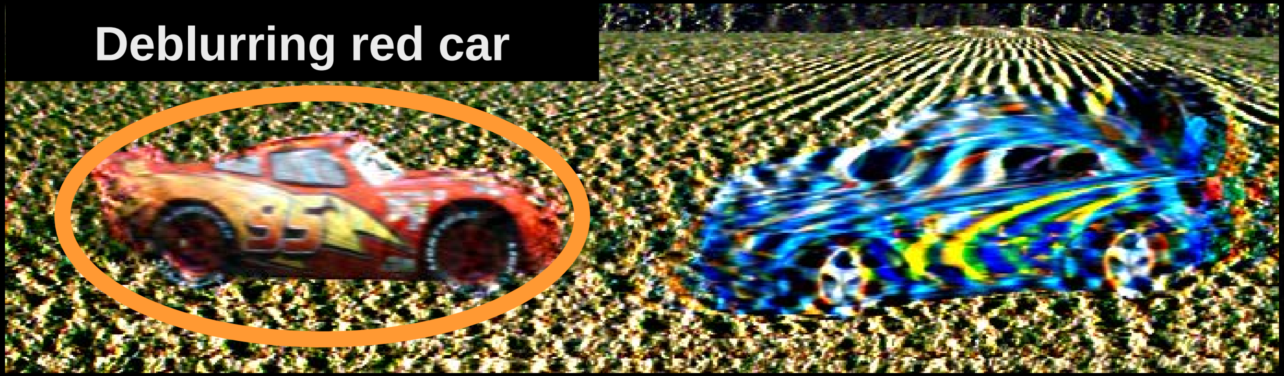
# Examples of computational imaging systems

# Overcoming motion blur

*Levin et al.* **Motion Invariant Photography** *SIGGRAPH, 2008.*

# Overcoming motion blur

*Levin et al.* **Motion Invariant Photography** *SIGGRAPH, 2008.*

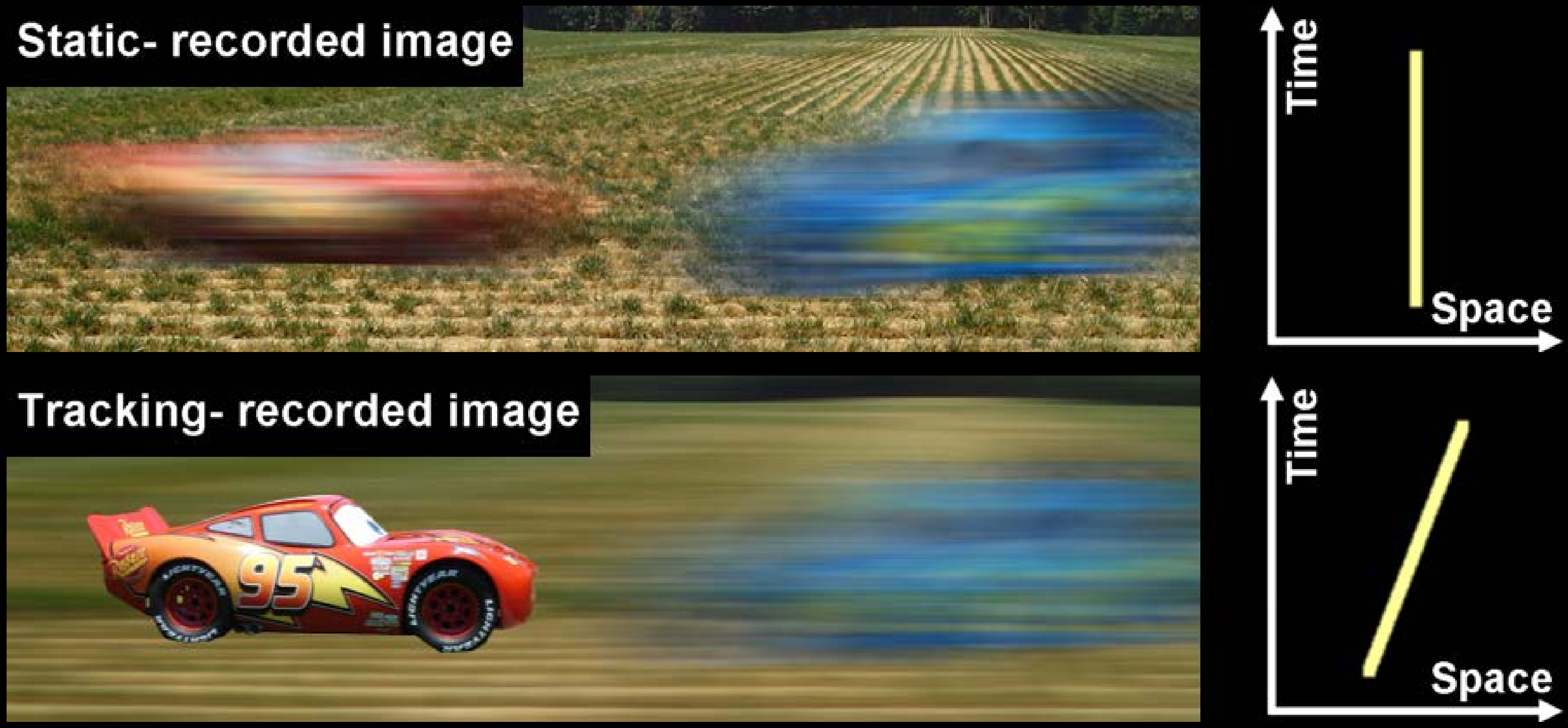



**Removing motion blur is hard:**

- **Need to know exact motion velocity (blur kernel)**
- **Need to segment image**

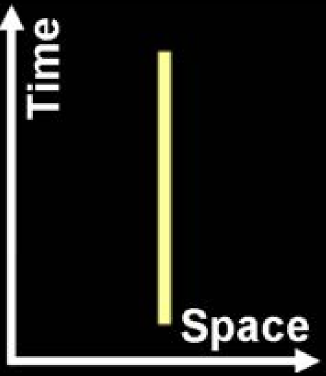
# Overcoming motion blur

*Levin et al.* **Motion Invariant Photography** *SIGGRAPH, 2008.*

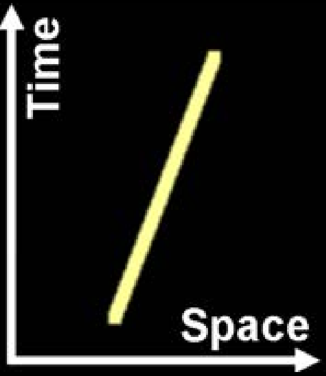


# Overcoming motion blur

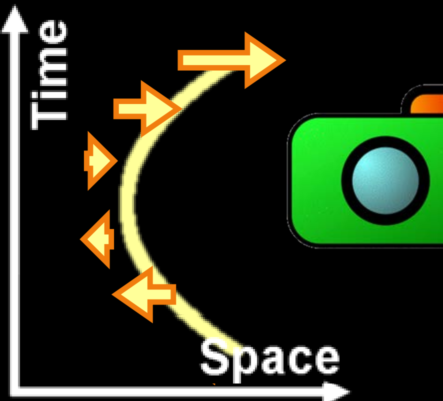
*Levin et al.* **Motion Invariant Photography** *SIGGRAPH, 2008.*



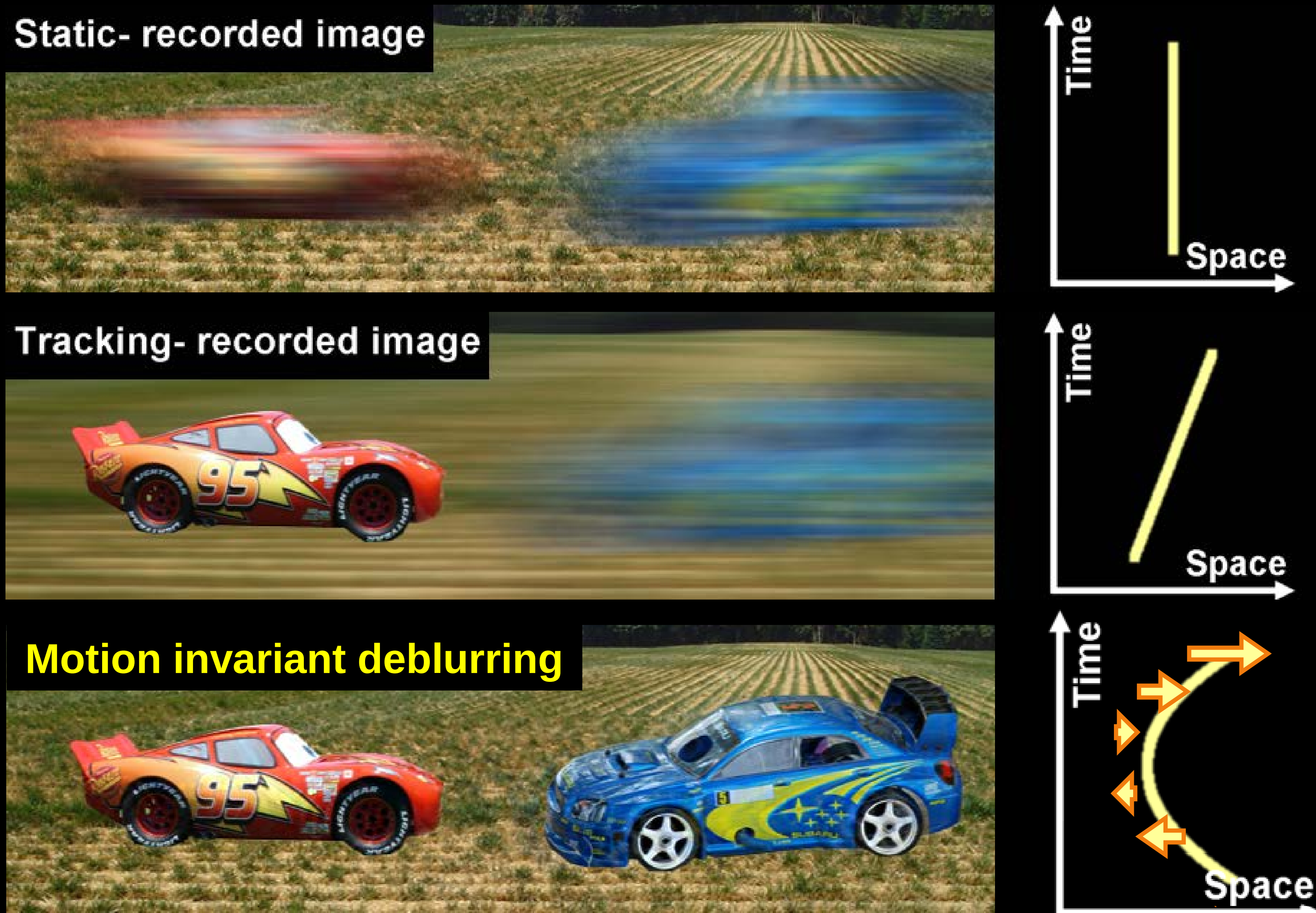






# Motion Invariant Photography

*Levin et al.* **Motion Invariant Photography** *SIGGRAPH, 2008.*



*Levin et al.* **Motion Invariant Photography** *SIGGRAPH, 2008.*

**Static camera**

**Unknown and variable blur**

**Our parabolic input**

**Blur invariant to velocity**

**Our output after deblurring**

***NON-BLIND deblurring***

# Defocus blur

# Lens and defocus

Lens' aperture

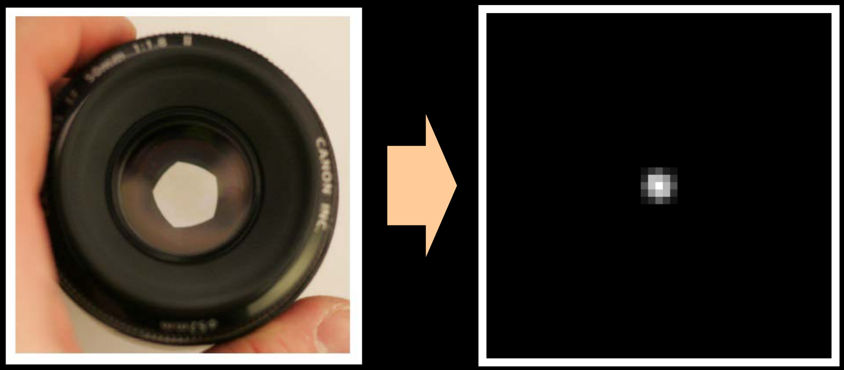
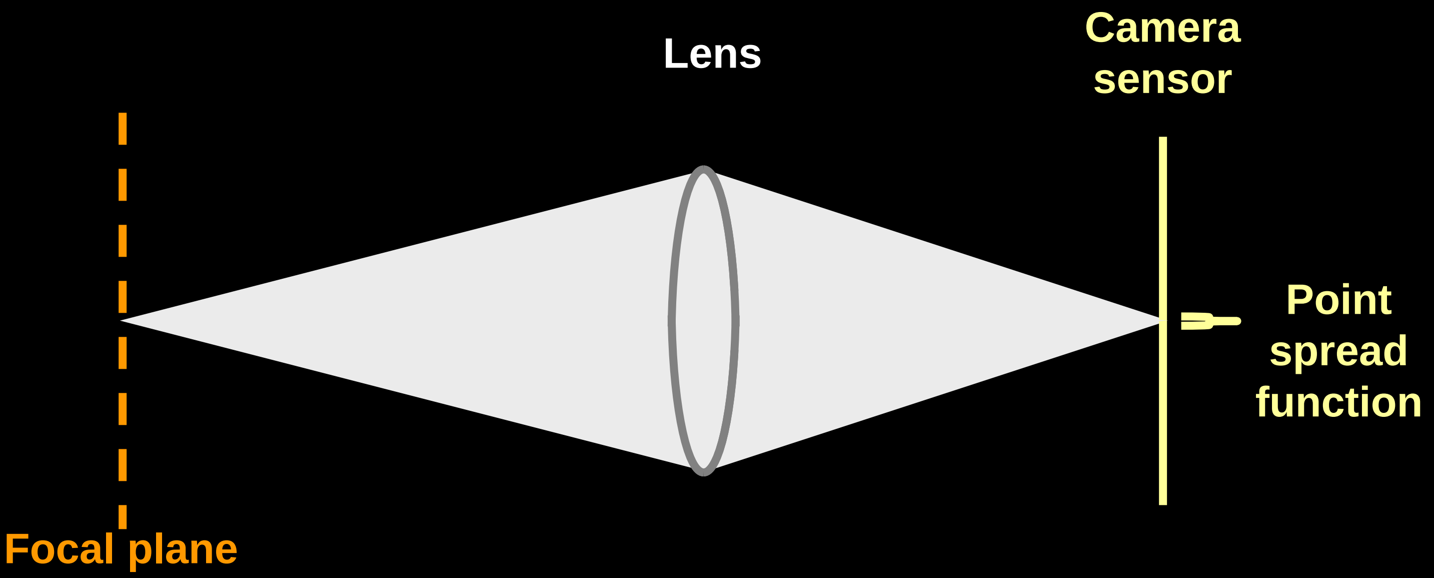


Image of a point light source



# Lens and defocus

Lens’ aperture

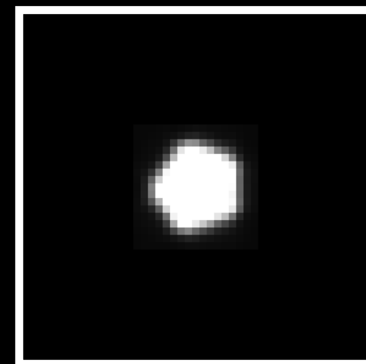
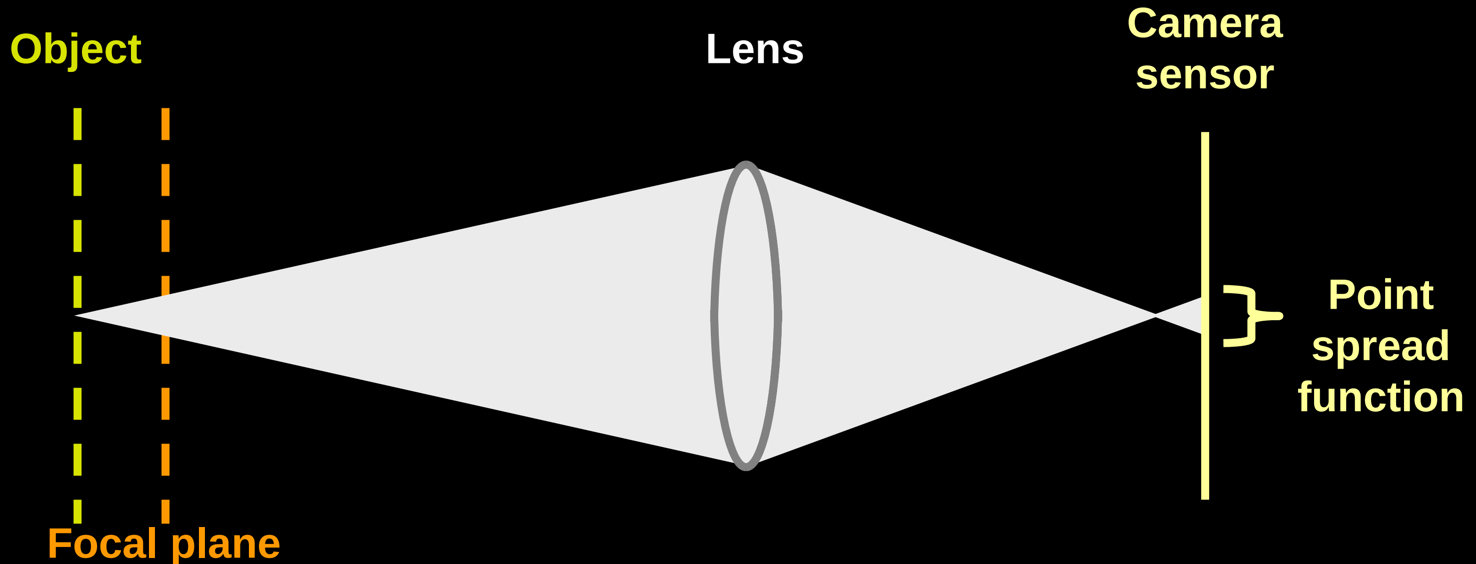


Image of a defocused point light source



# Lens and defocus

Lens' aperture

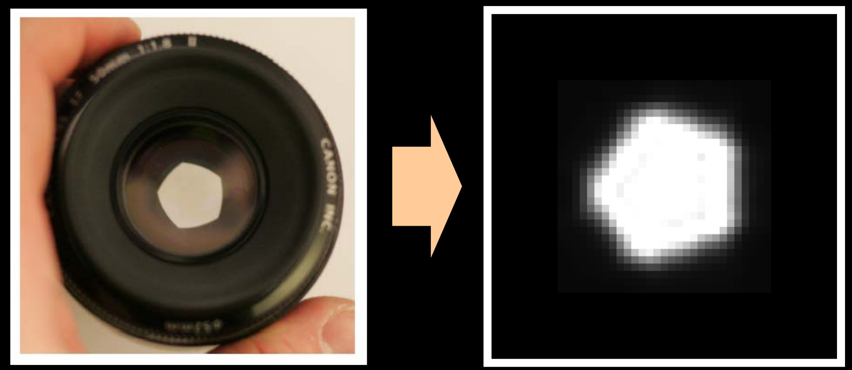
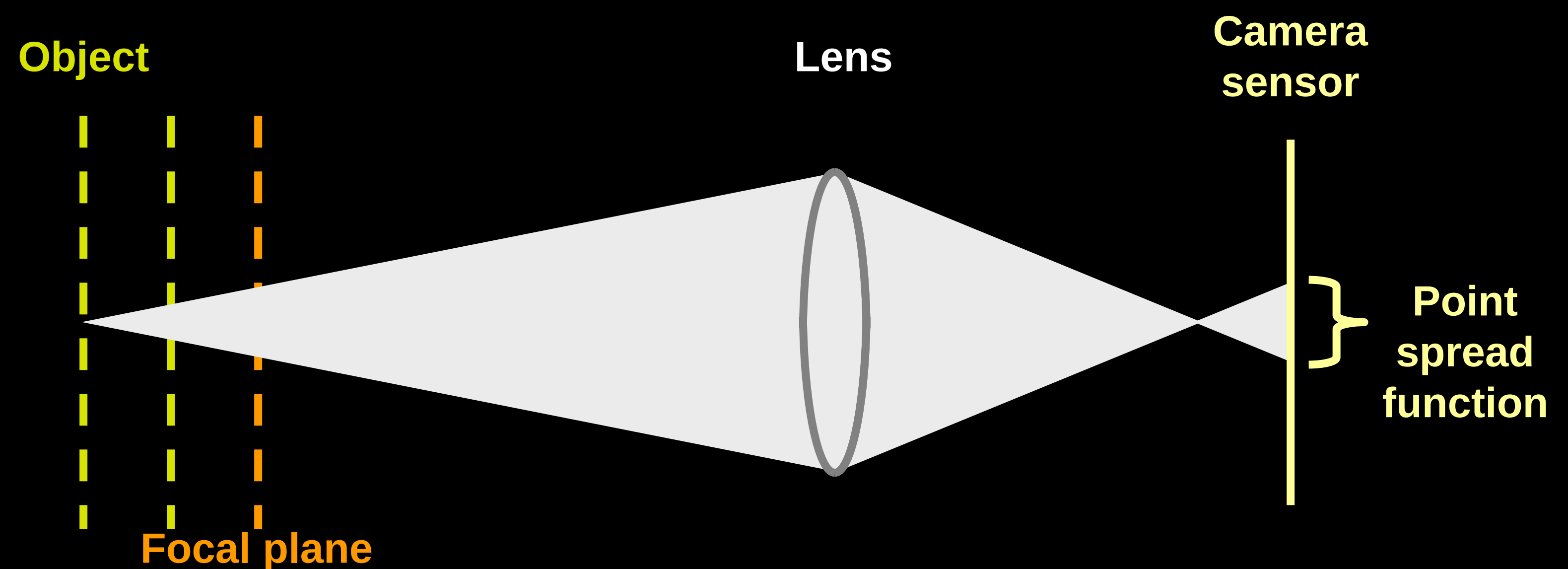


Image of a defocused point light source



# Lens and defocus

Lens’ aperture

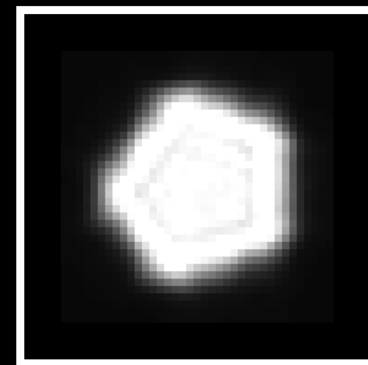
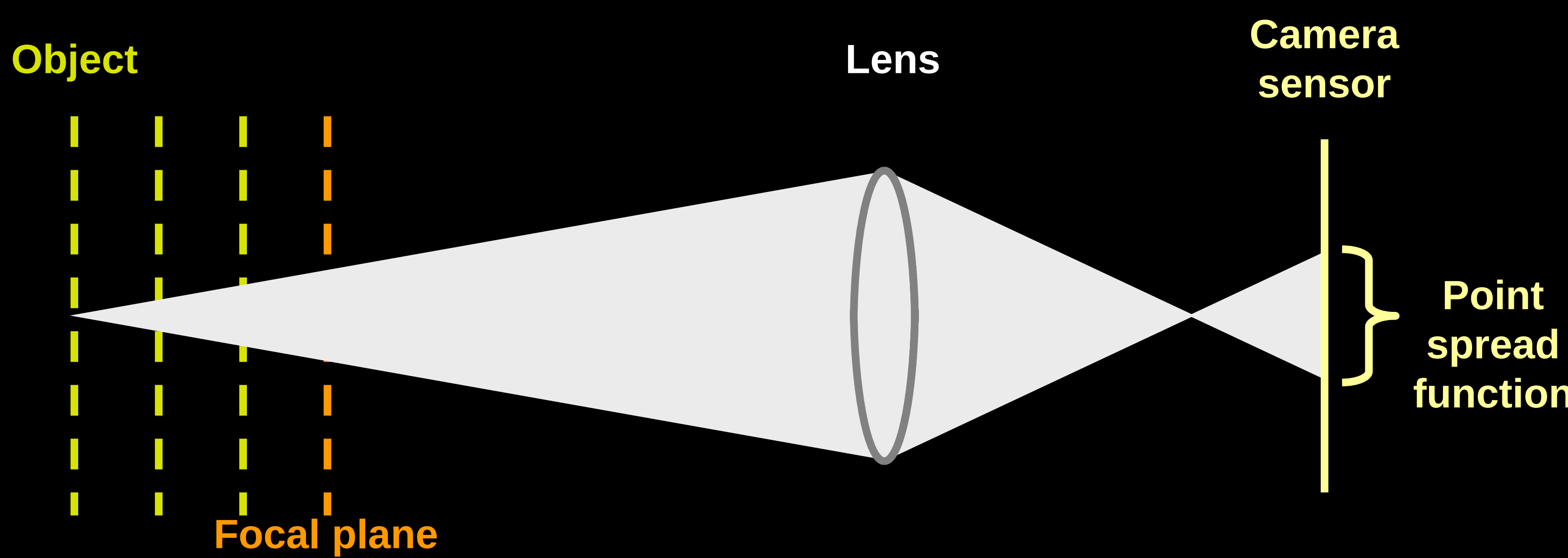


Image of a defocused point light source



# Lens and defocus

Lens’ aperture

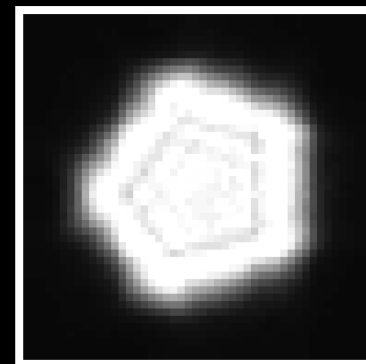
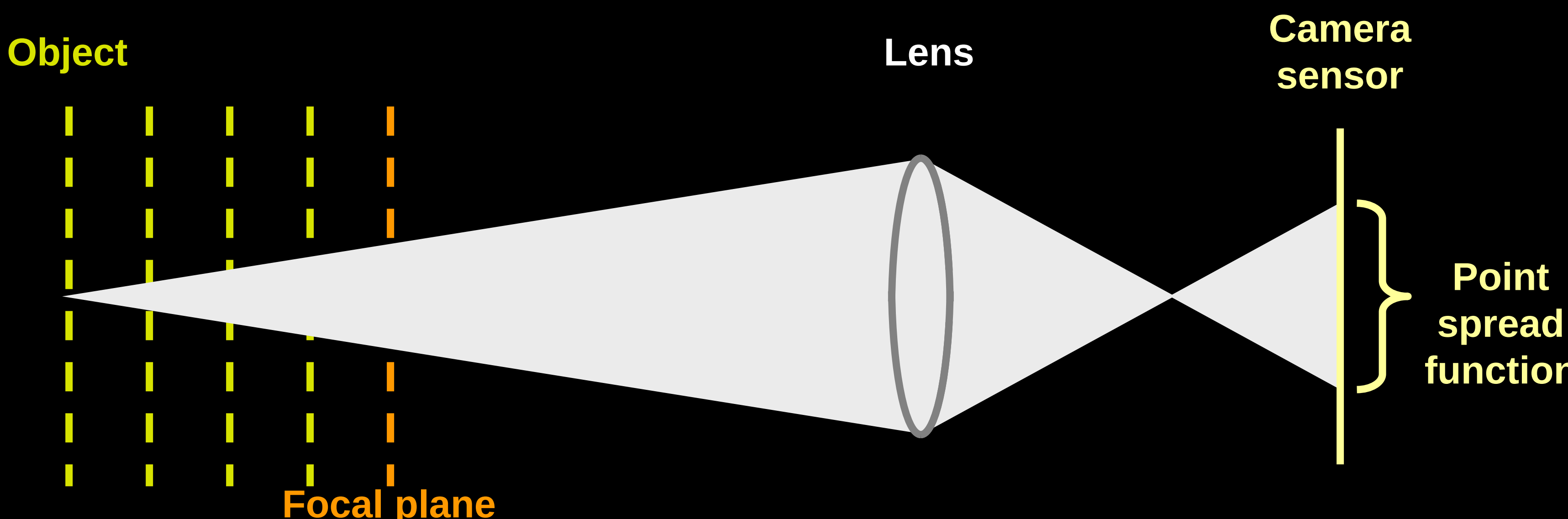


Image of a defocused point light source



# Depth and defocus


ill posed

**Depth from defocus:**

**Infer depth by analyzing local scale of defocus blur**

# Challenges

- Hard to discriminate a smooth scene from defocus blur

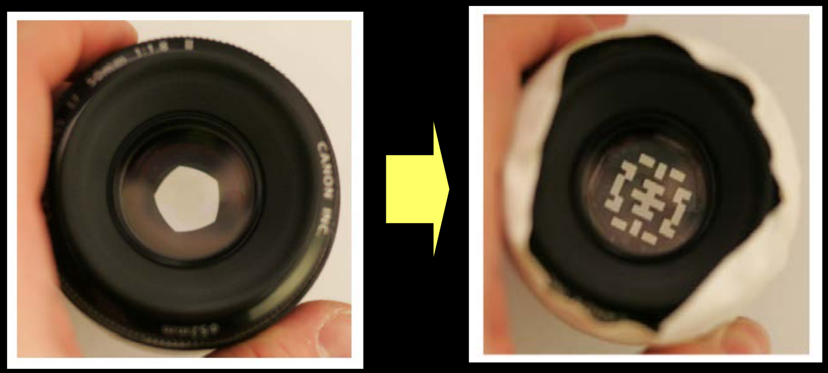

- Hard to undo defocus blur

Input

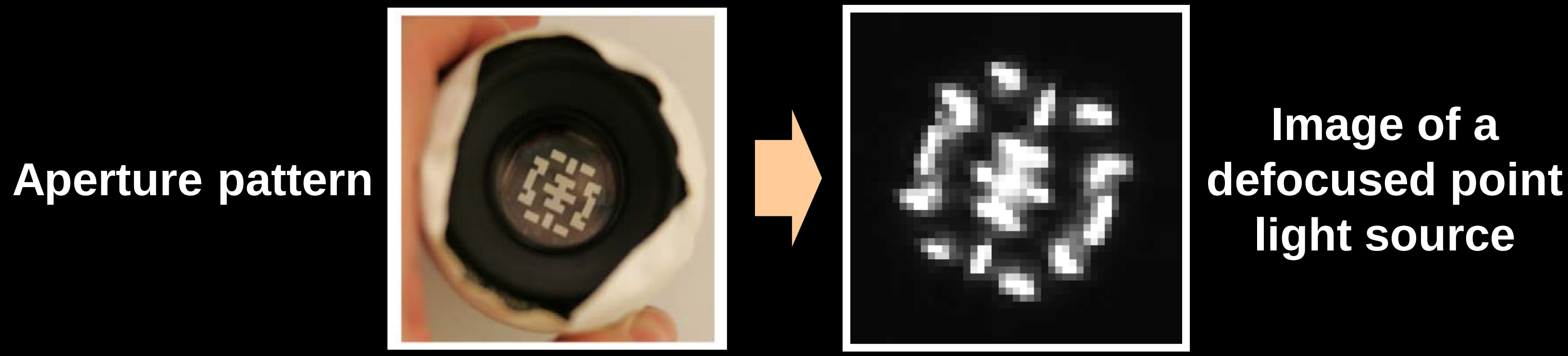
Ringing with conventional deblurring algorithm

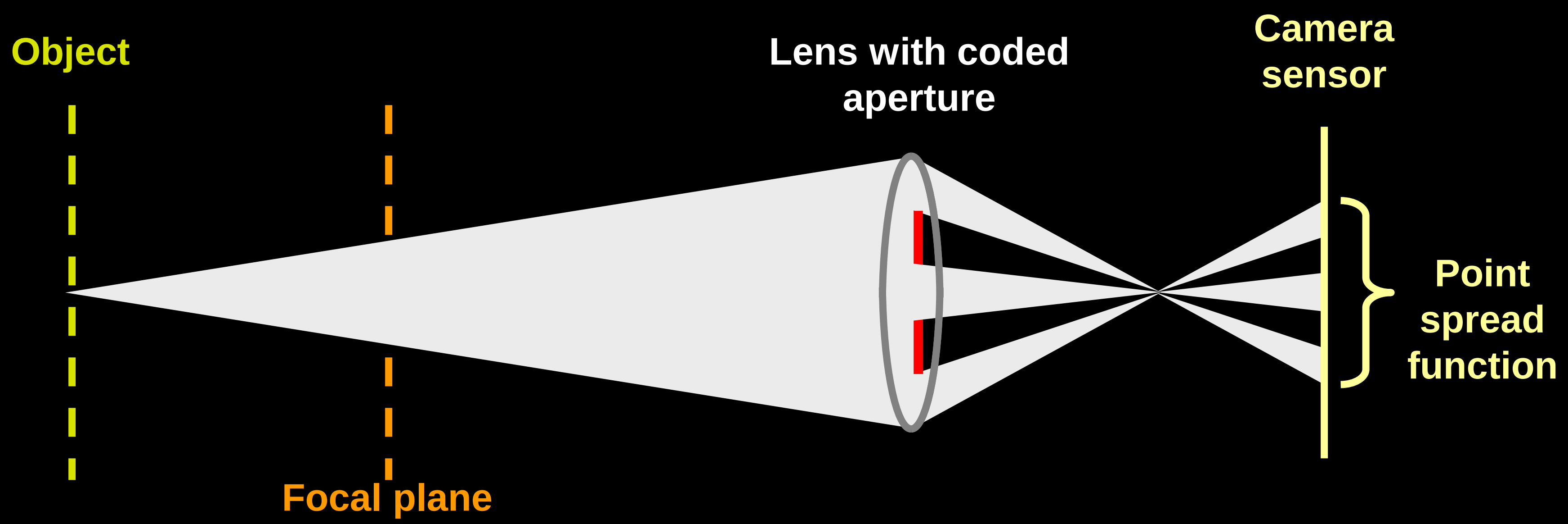
# Coded aperture

- Coded aperture (mask inside lens)
  - make defocus patterns different from natural images and easier to discriminate
  - defocus kernel preserves more high  frequencies



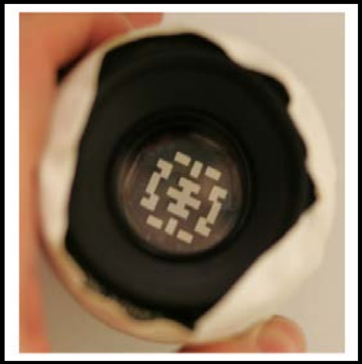
# Coded aperture: lens with occluder



# Coded aperture: lens with occluder

Aperture pattern



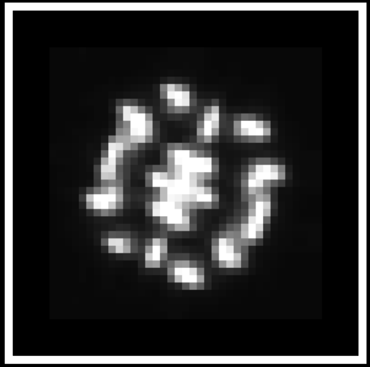
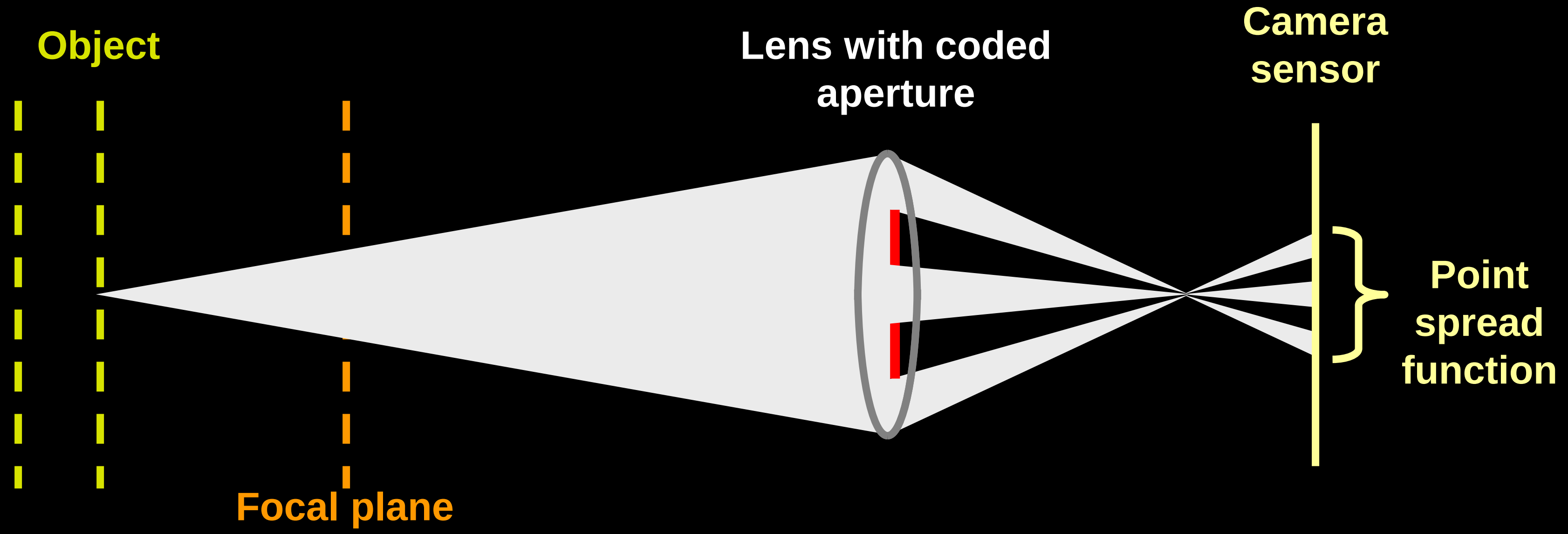


Image of a defocused point light source



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Aperture pattern

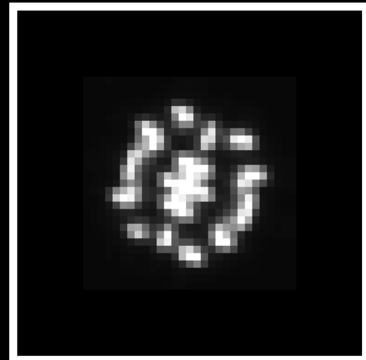
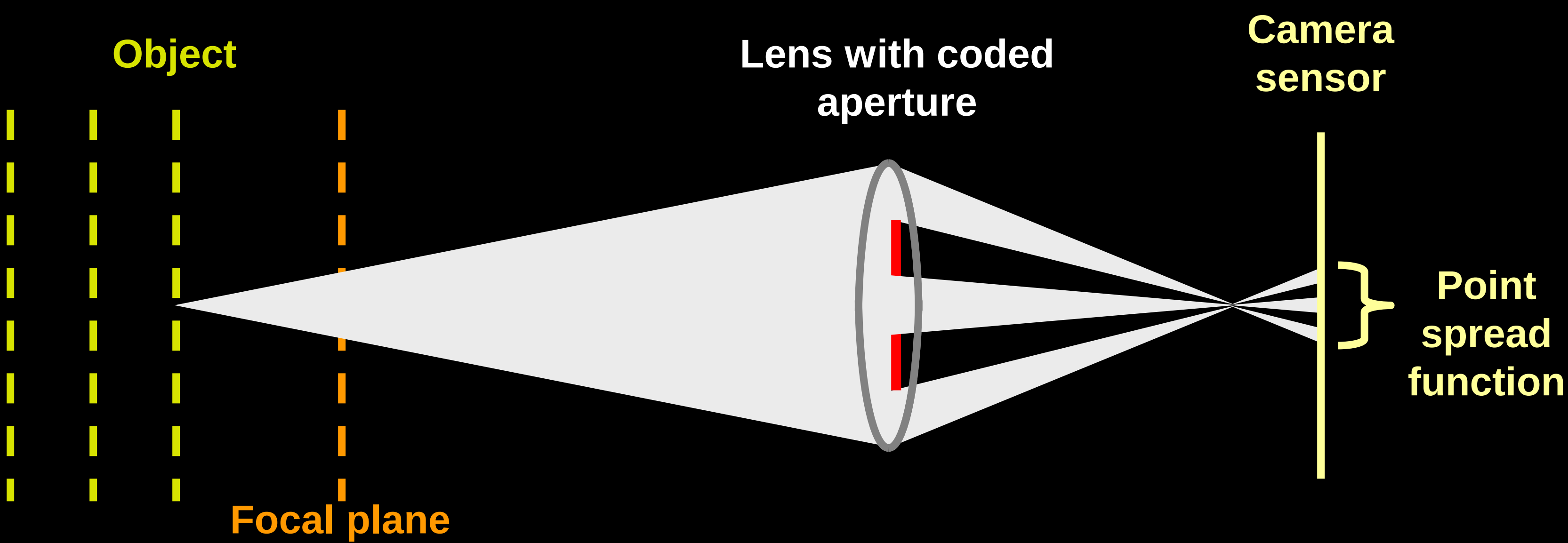


Image of a defocused point light source



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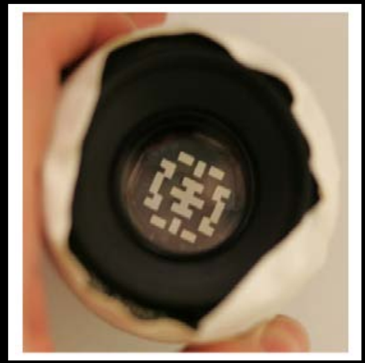
Aperture pattern



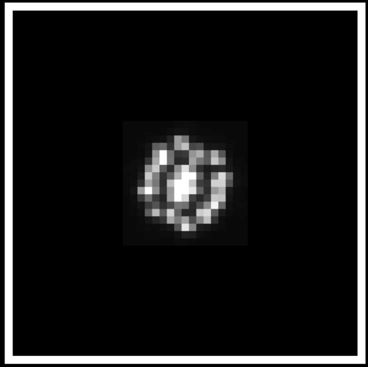
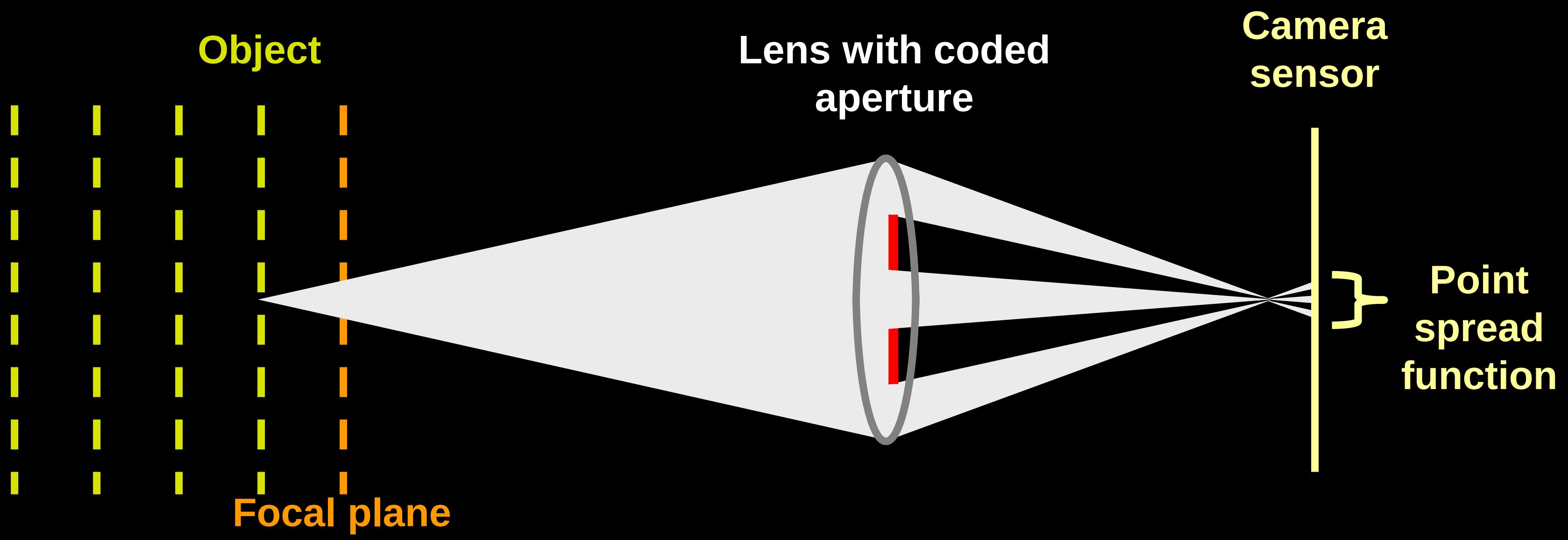


Image of a defocused point light source



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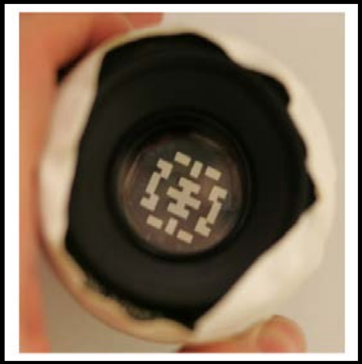
Aperture pattern



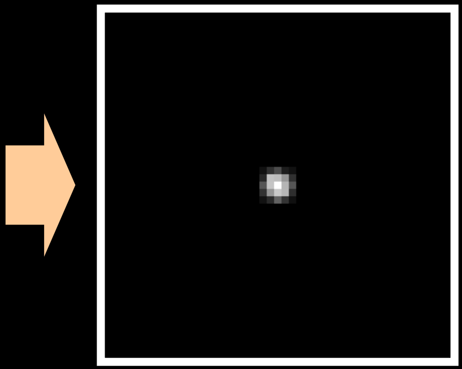
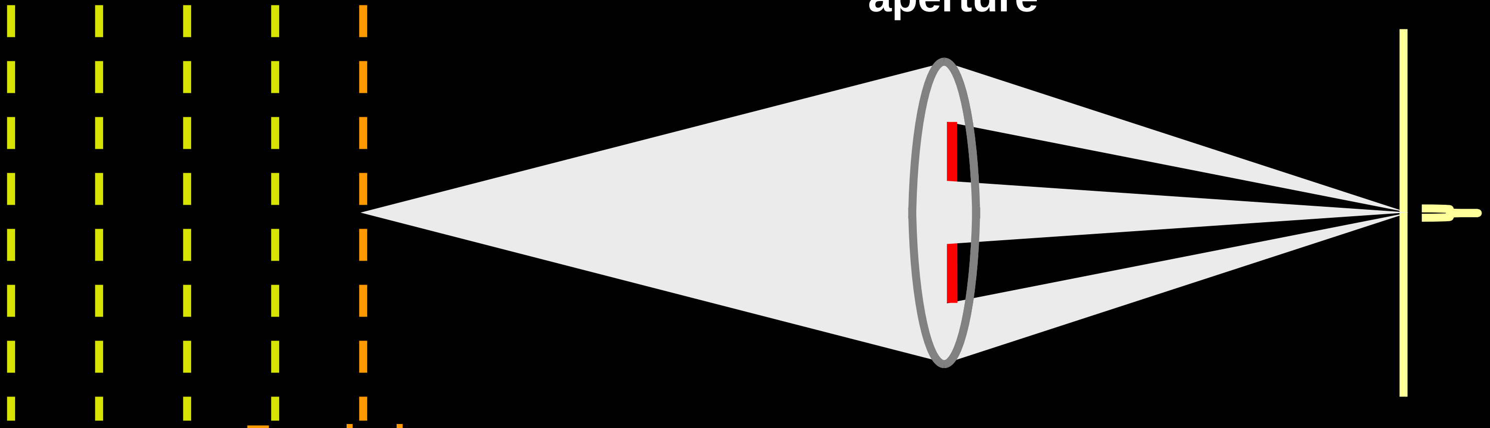
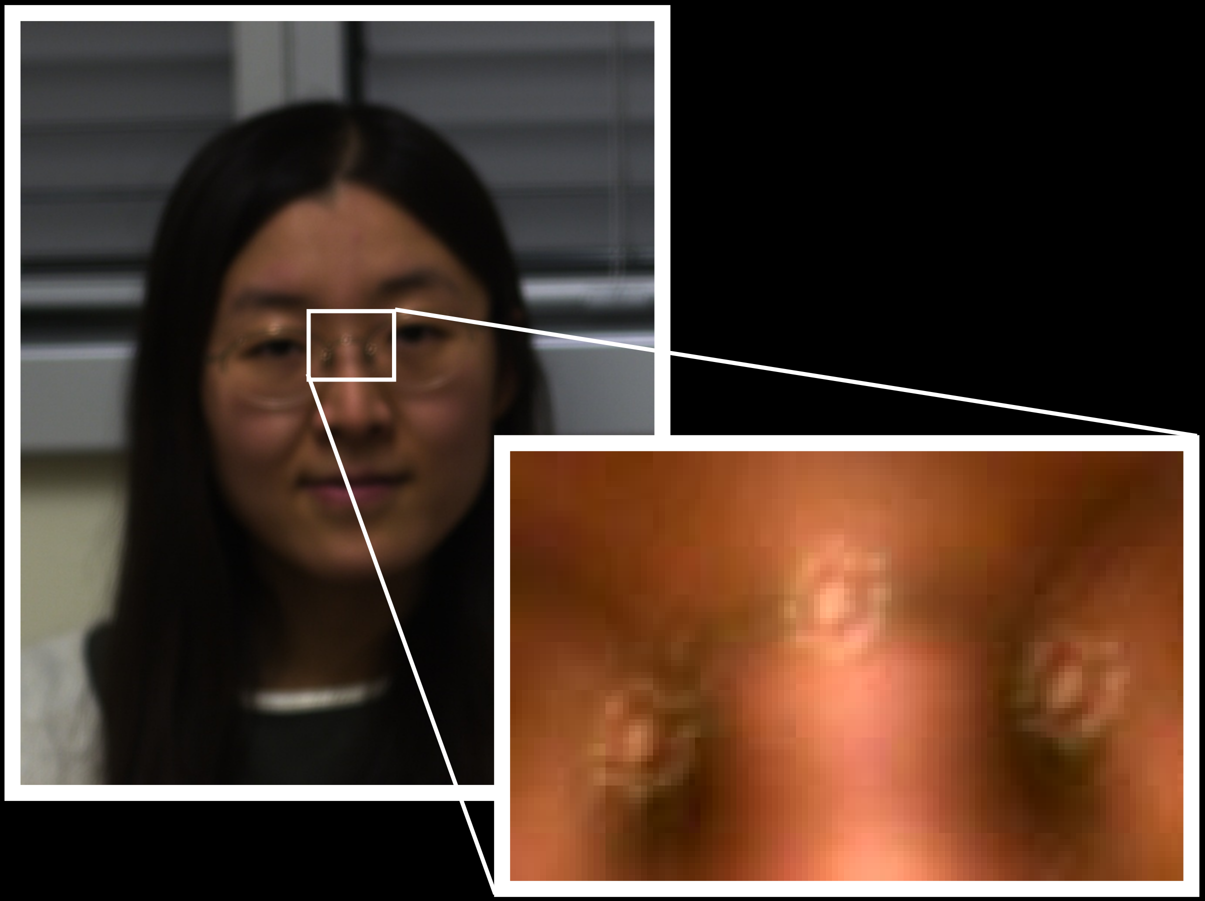


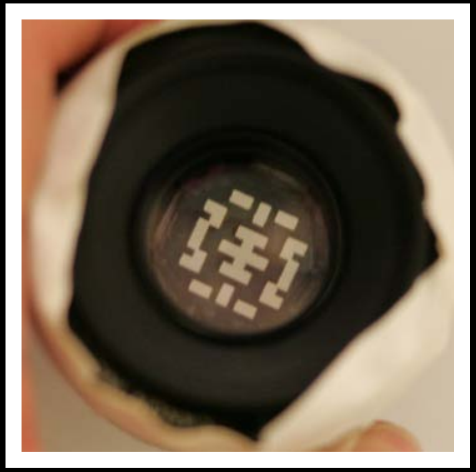
Image of a defocused point light source



# Defocused images $\neq$ natural images



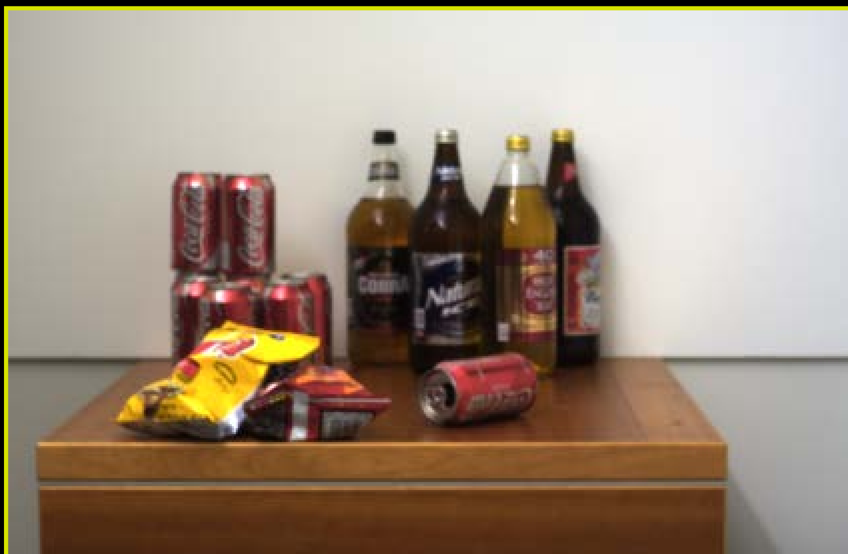
Captured Image



Aperture code

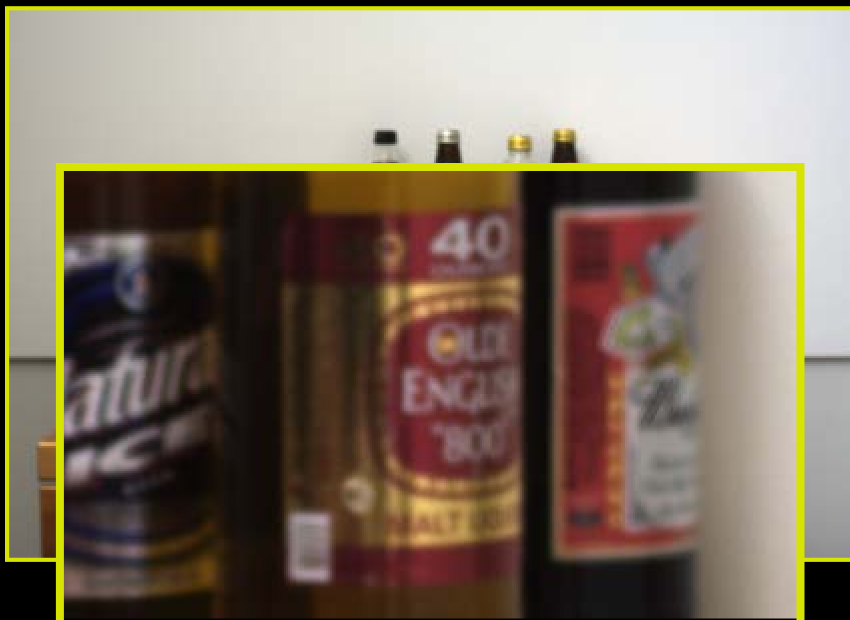
➡ We have strong priors on natural images and can make defocused images look differently

Single input image:



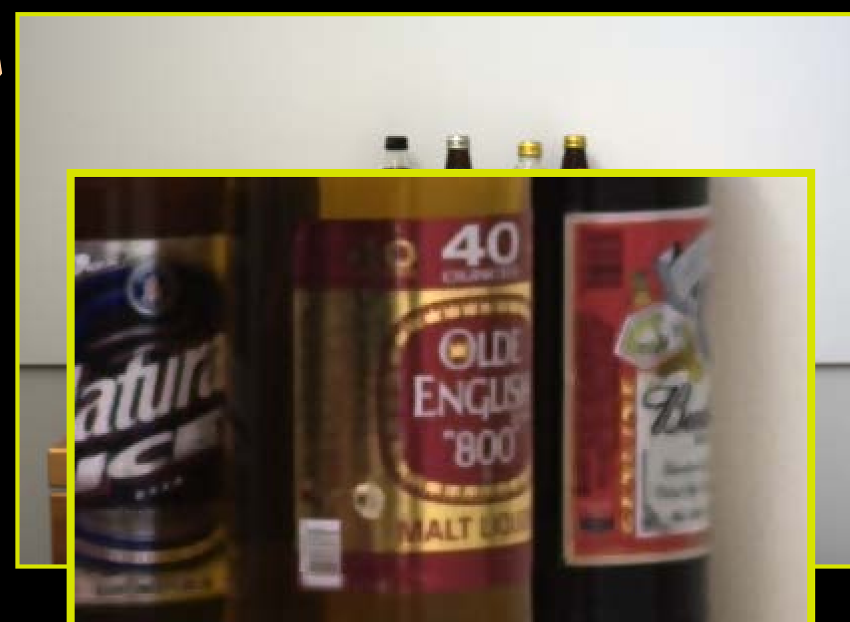
Output #1: Depth map

Single input image:



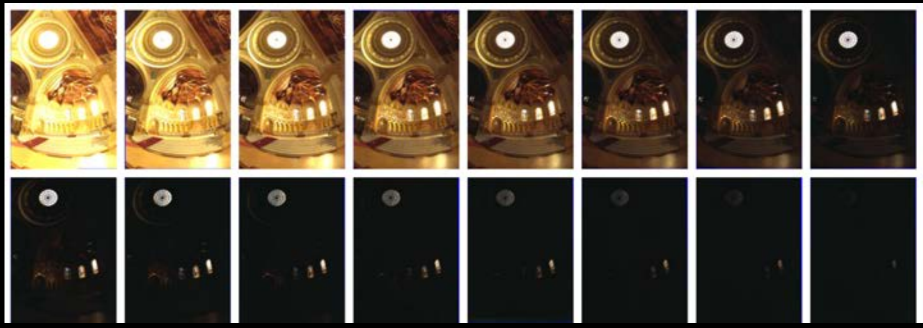
Output #1: Depth map

Output #2: All-focused image

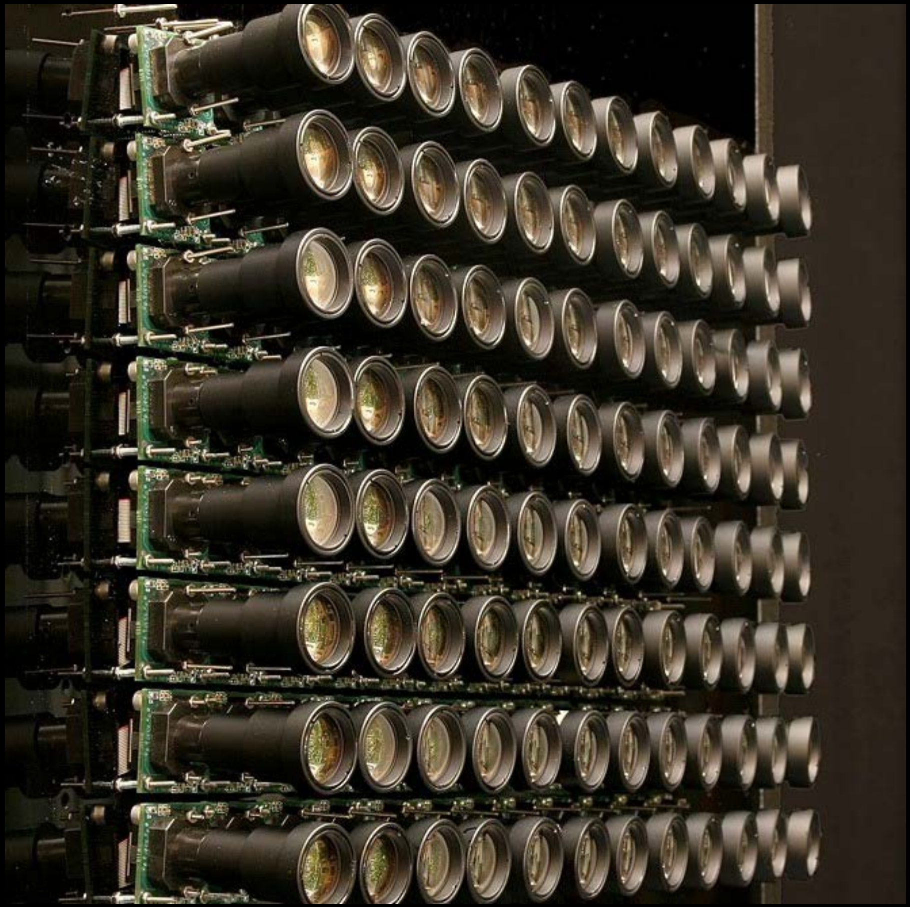


# Burst Photography

- high dynamic range
- super-resolution
- noisy / blurry
- Focal stack

# Light Fields and The Plenoptic Function



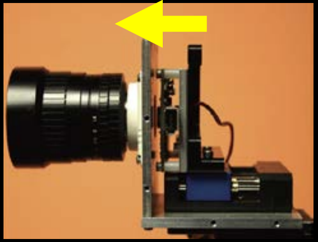
- camera arrays
- integral imaging
- coded masks
- refocus
- fourier slice photography

# The Computational Camera Zoo

**Goal: a unified mathematical framework**

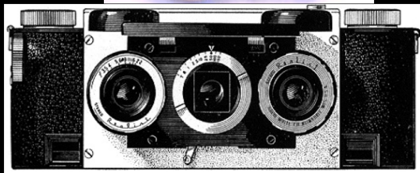
- Evaluate and compare computational cameras
- Systematically design new cameras

Conventional single-lens cameras



Focus sweep

Stereo and trinocular cameras

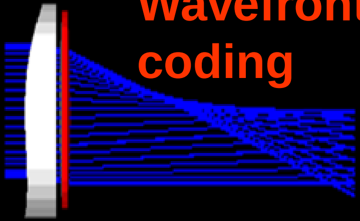


Coded aperture

Plenoptic cameras

Lattice-focal lens

Multi-aperture



Wavefront coding

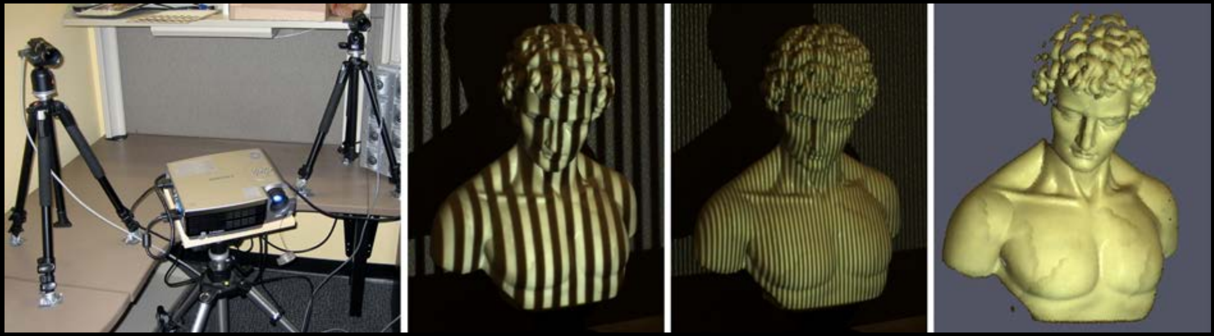
# Computational illumination

**Infer on the interaction between scene and light**

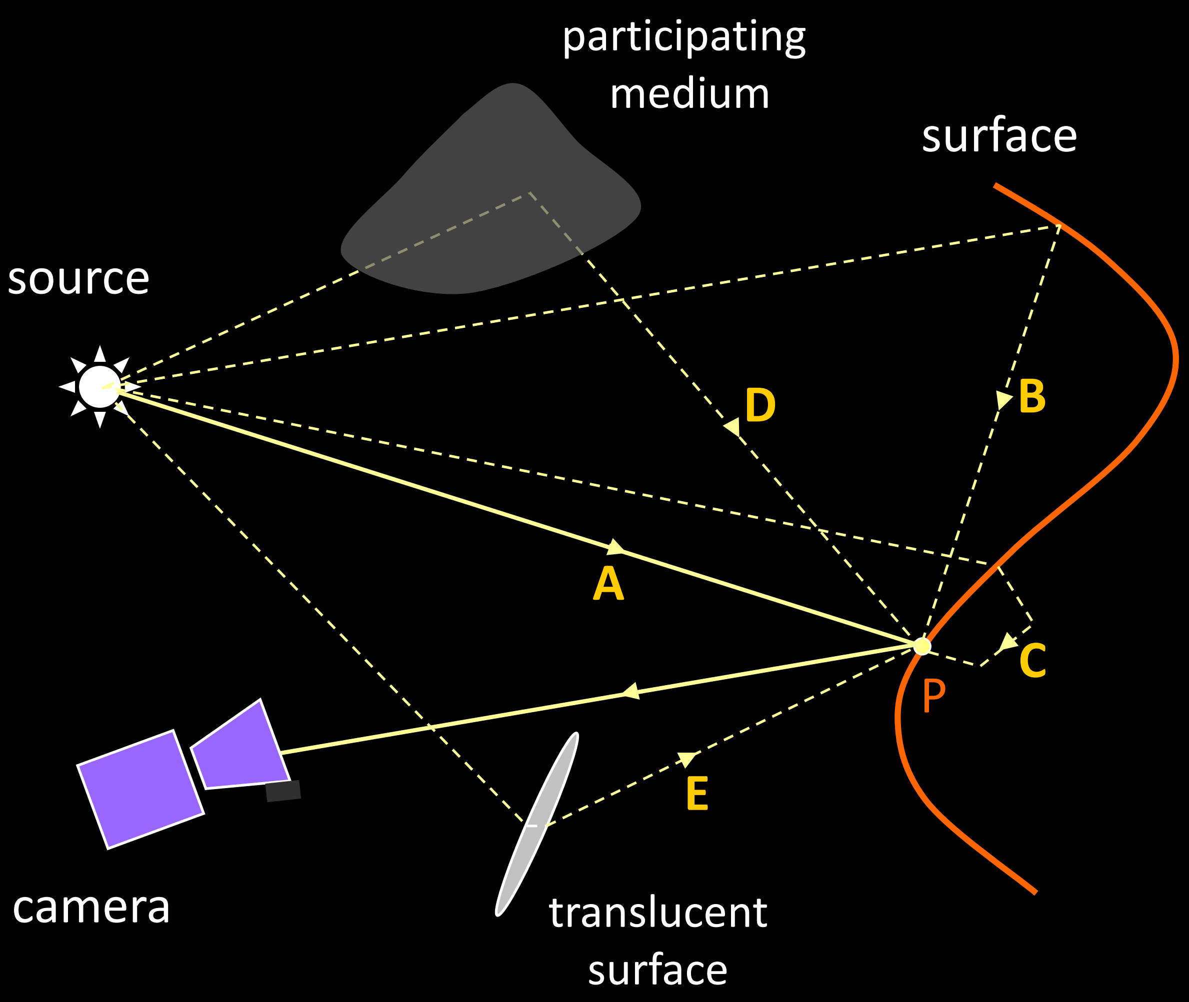
# Computational illumination

- time of flight
- structured illumination
- photometric stereo
- multi-flash photography
- microsoft kinect
- leap motion

MS Kinect One



# Direct and Global Illumination




A : Direct

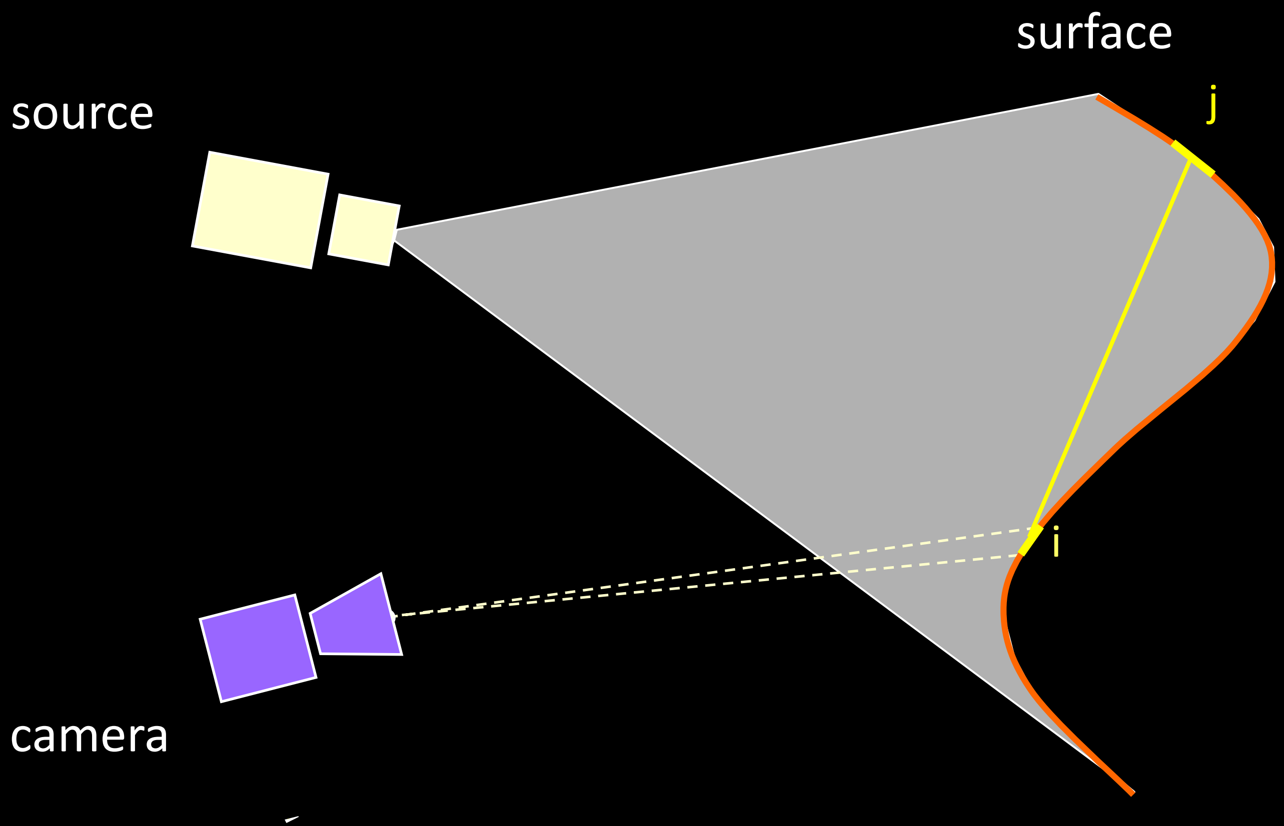
B : Interrelection

C : Subsurface

D : Volumetric

E : Diffusion

# Direct and Global Components: Interreflections




$$L[c,i] = L_d[c,i] + L_g[c,i]$$

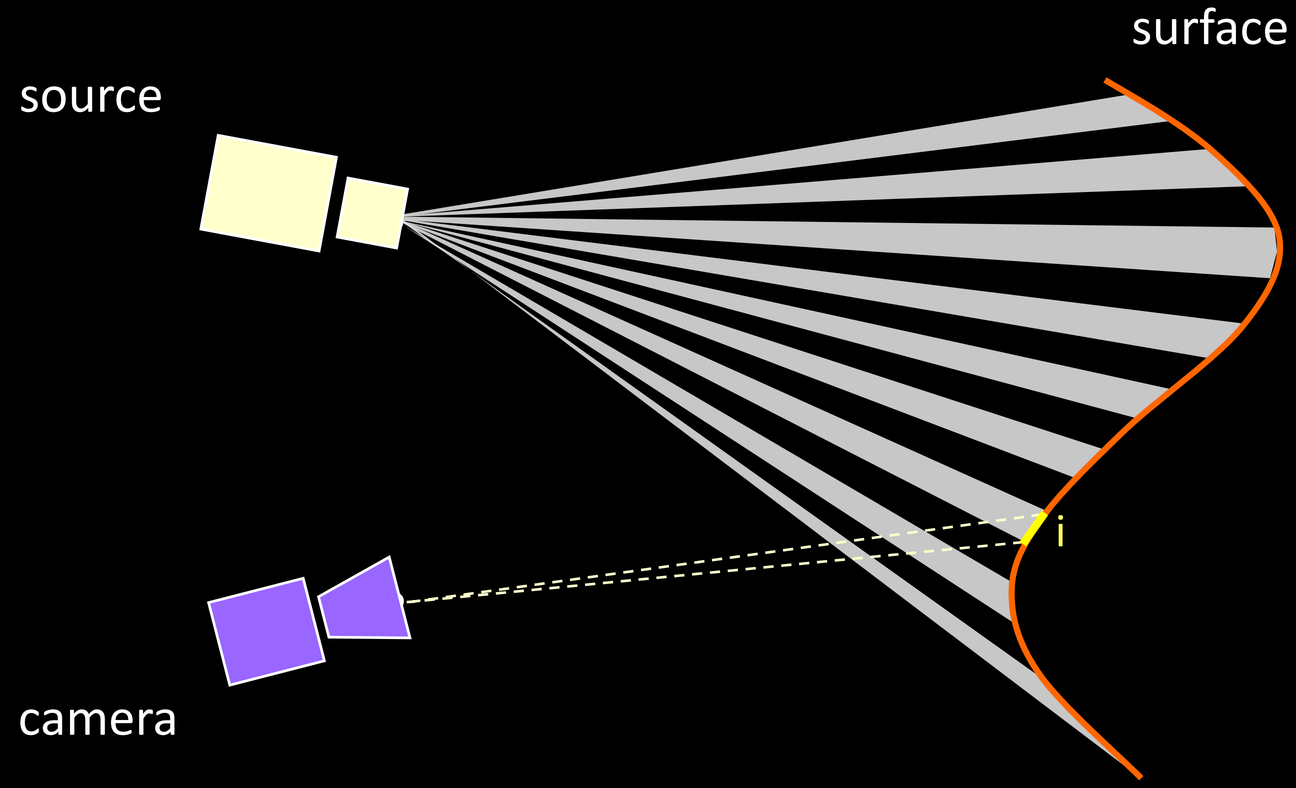
radiance direct global

$$L_g[c,i] = \sum_P A[i,j]\, L[i,j]$$

BRDF and geometry

# Direct-global separation using high-frequency illumination

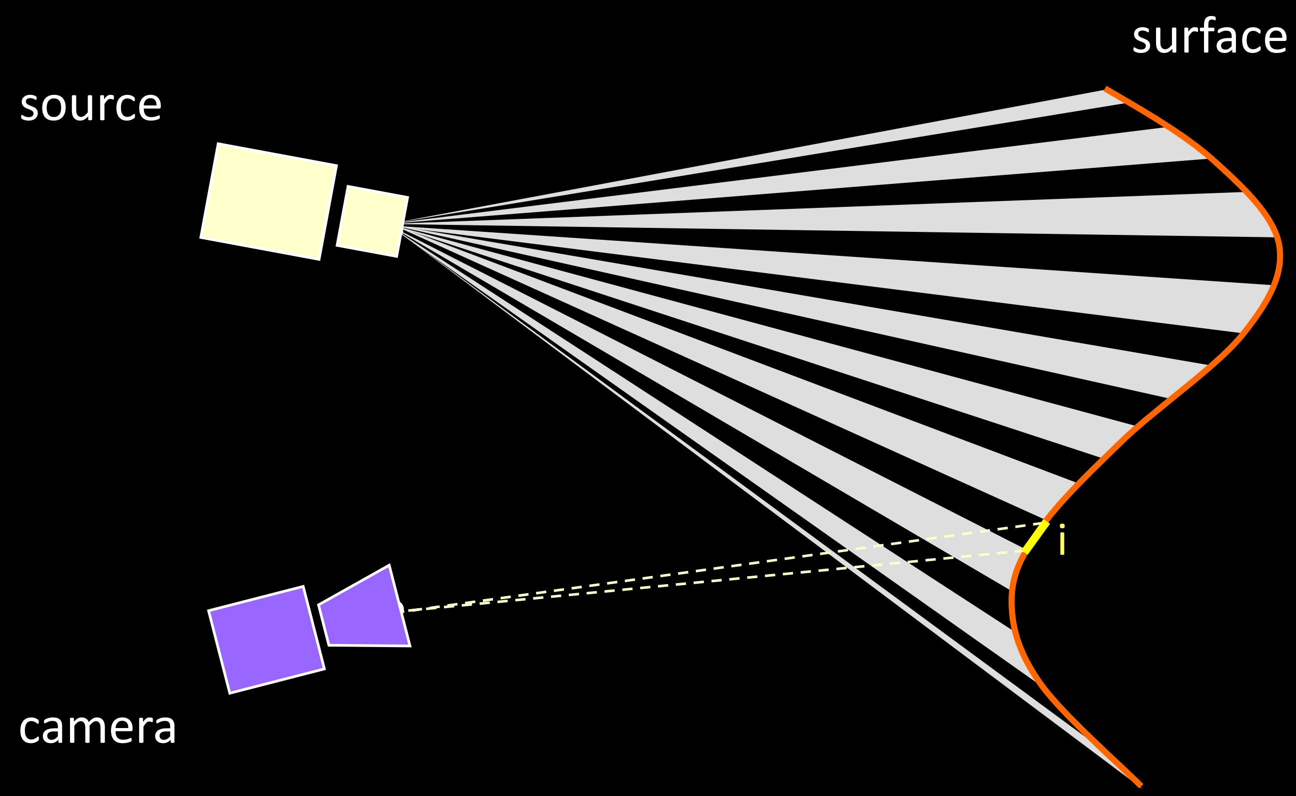
# High Frequency Illumination Pattern




$$L^{+}[c,i] = L_d[c,i] + \alpha L_g[c,i]$$

fraction of activated source elements

# High Frequency Illumination Pattern




$$L^{+}[c,i] = L_d[c,i] + \alpha\, L_g[c,i]$$

$$L^{-}[c,i] = (1-\alpha)\, L_g[c,i]$$

fraction of activated source elements

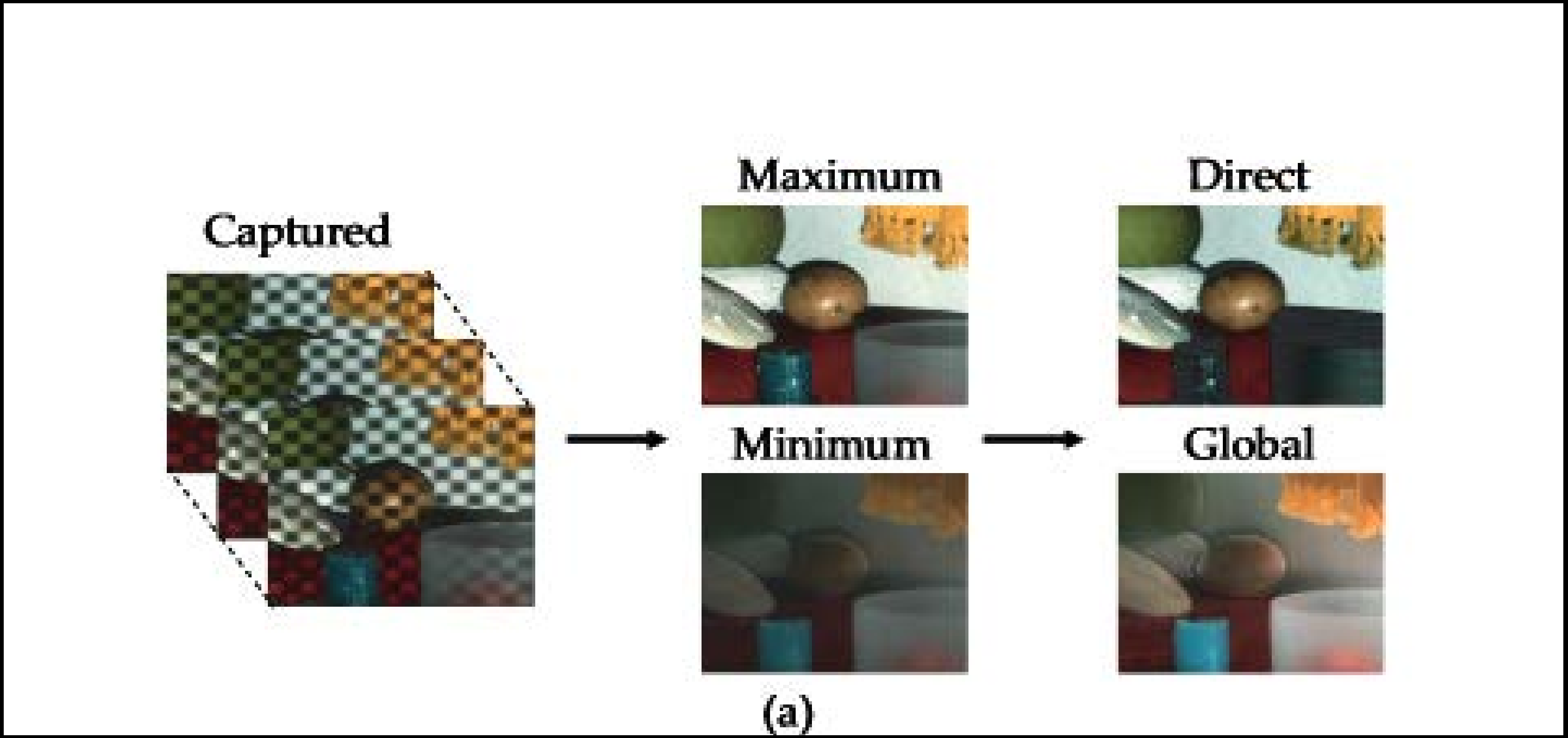
# Separation from Two Images

$$\alpha = \frac{1}{2}: \quad \boxed{L_d = L_{\max} - L_{\min} \,, \quad L_g = 2L_{\min}}$$

direct

global

# Separation of Direct and Global Images




Diffuse
Interreflections
Specular
Interreflections
Diffusion
Volumetric
Scattering
Subsurface
Scattering

Scene

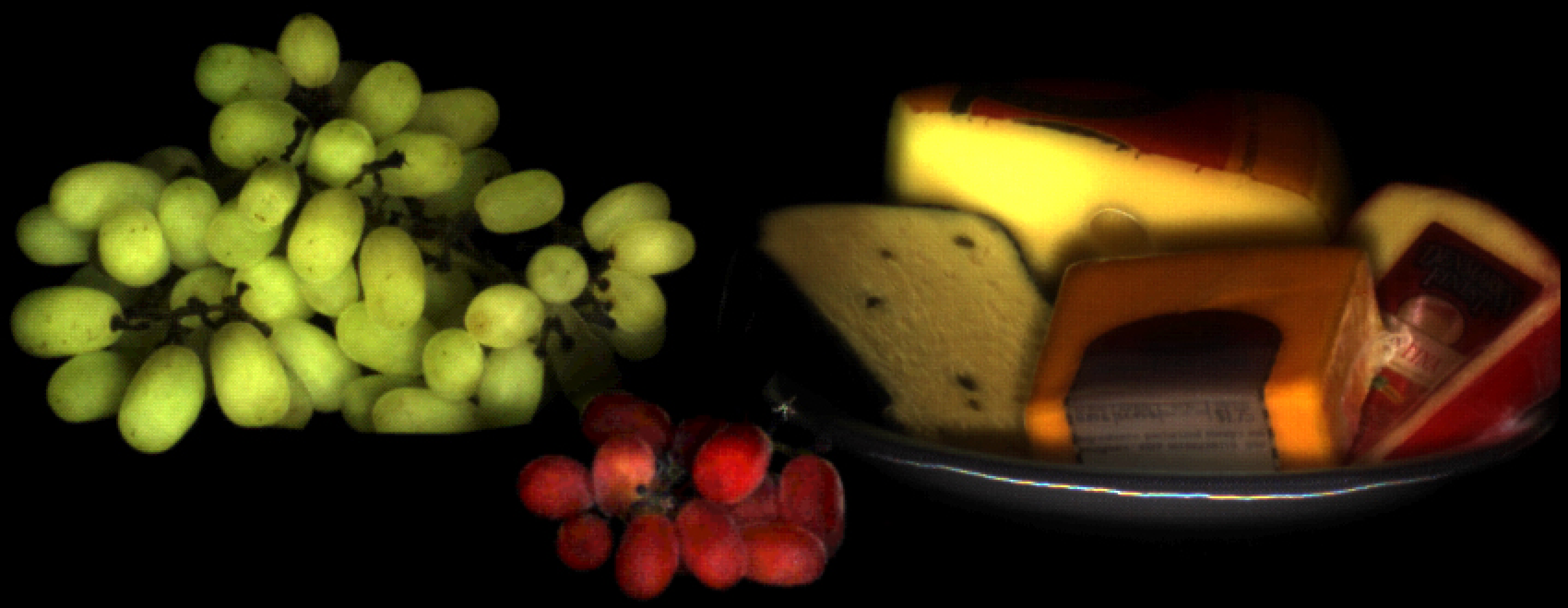
Direct

Global

# Separation of Direct and Global Images

# Separation of Direct and Global Images

# Separation of Direct and Global Images



# Peppers: Subsurface Scattering

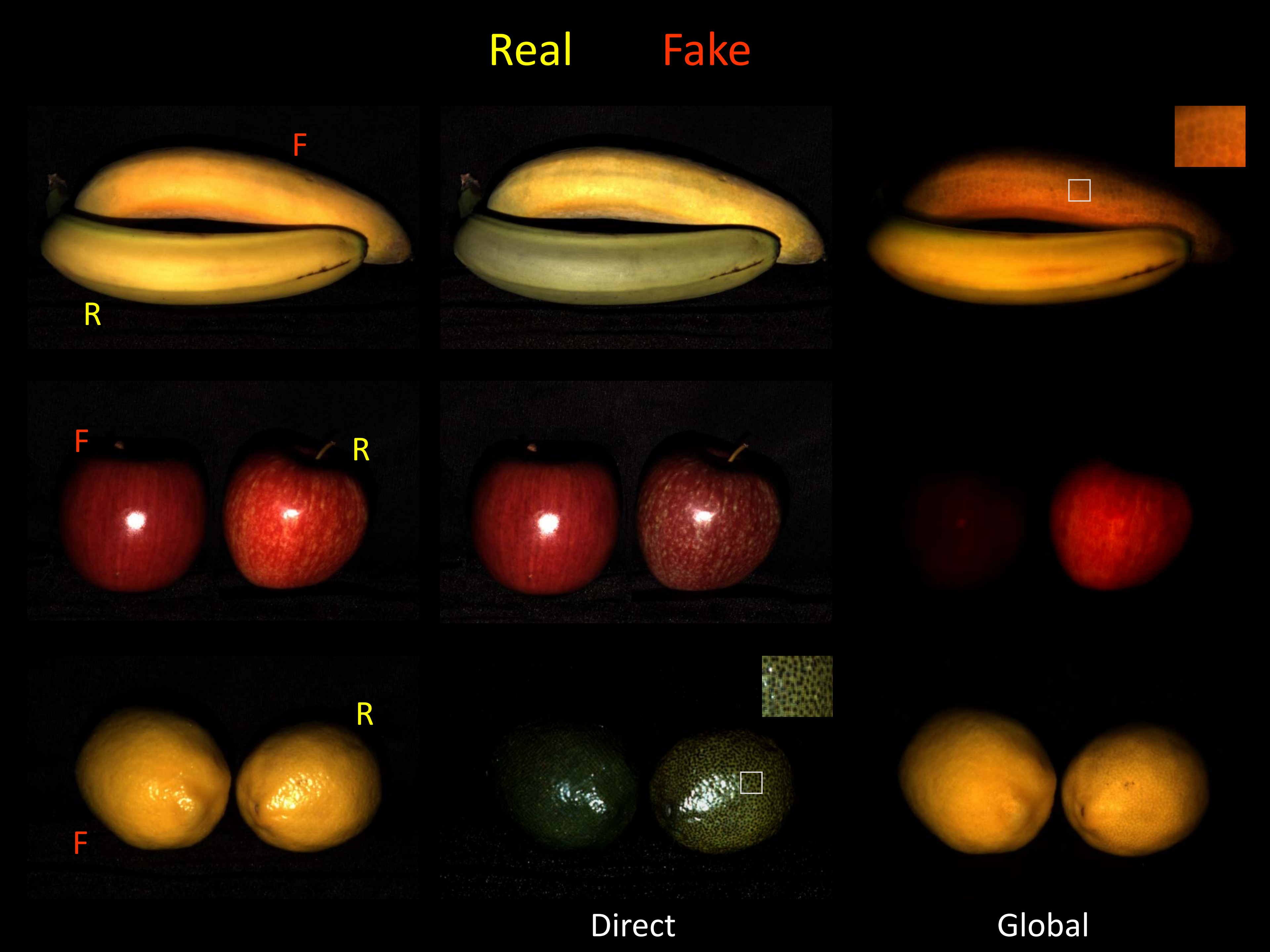
Direct

Global

# Eggs: Diffuse Interreflections

Direct

Global


Real
Fake
F
R
F
R
R
F
Direct
Global

# Pink Carnation

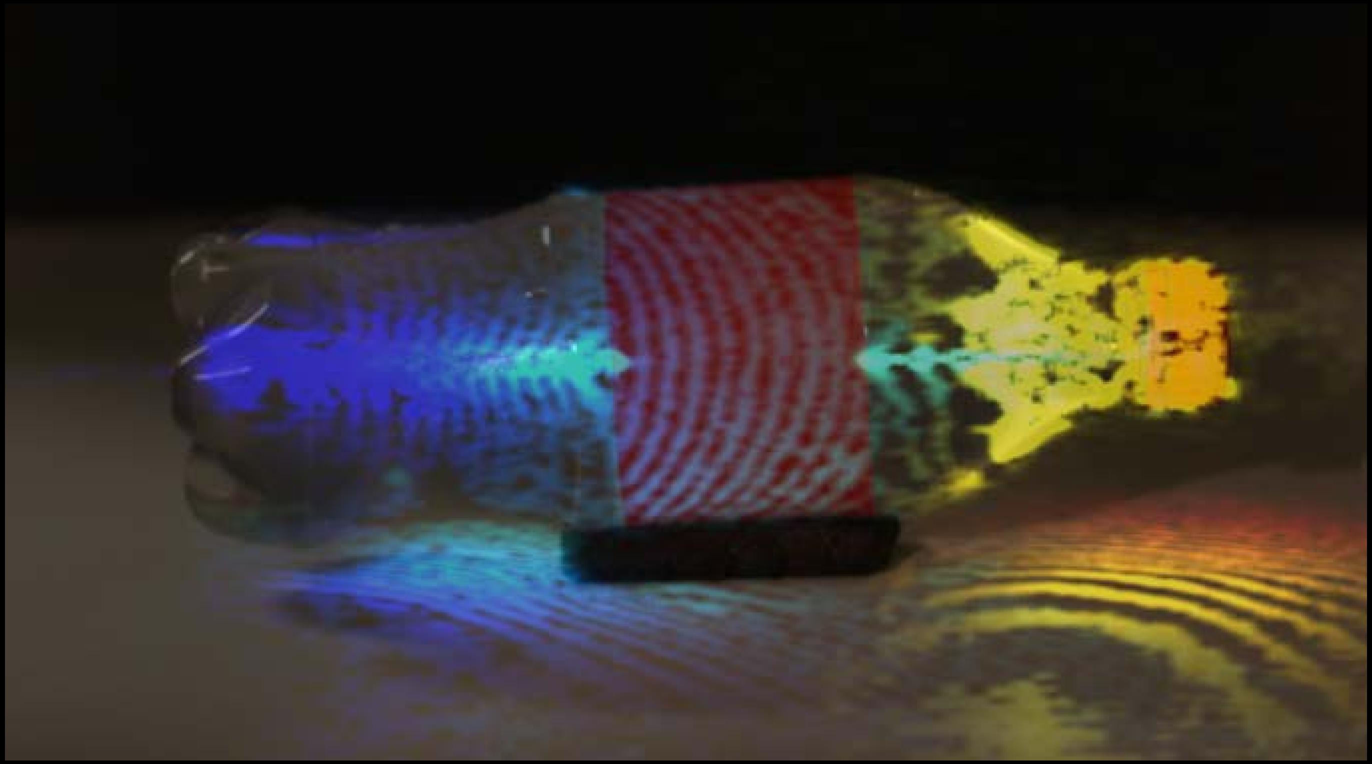
Spectral Bleeding: Funt et al. 91

Direct

Global

# Transient imaging: visualizing photons in motion

http://web.media.mit.edu/~raskar//trillionfps/



# Transient imaging: visualizing photons in motion