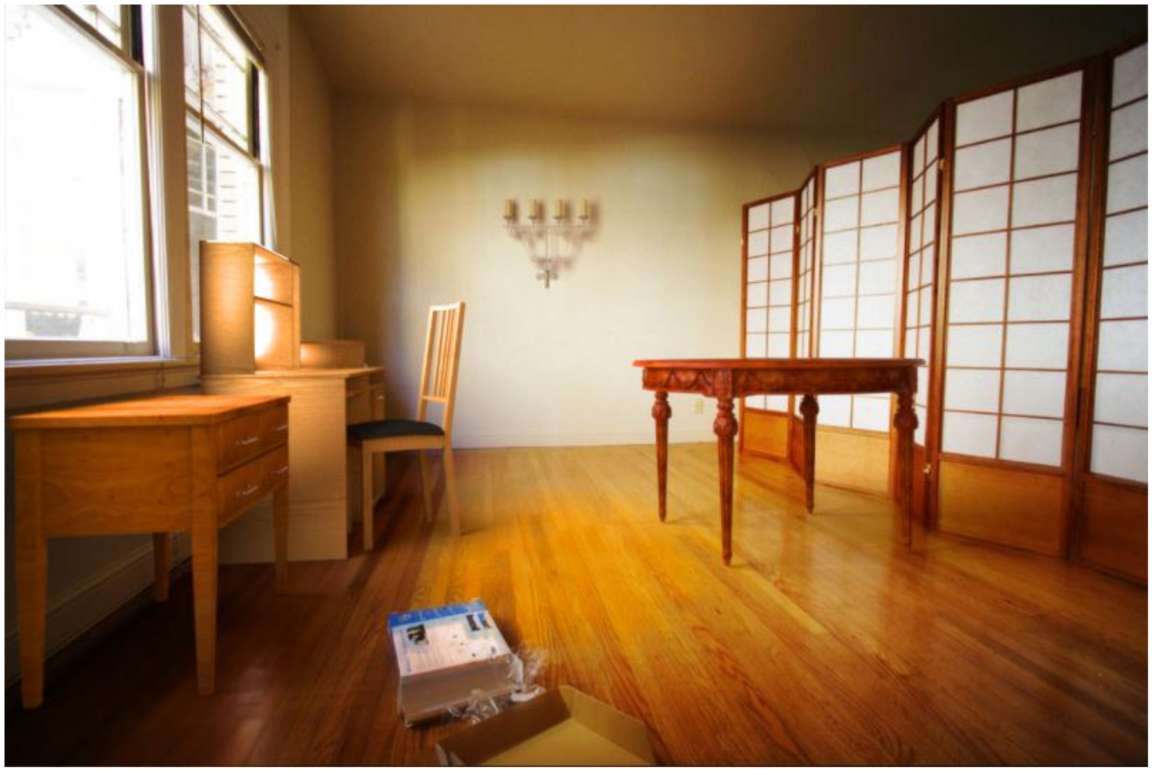
The image as a virtual stage



Computational Photography

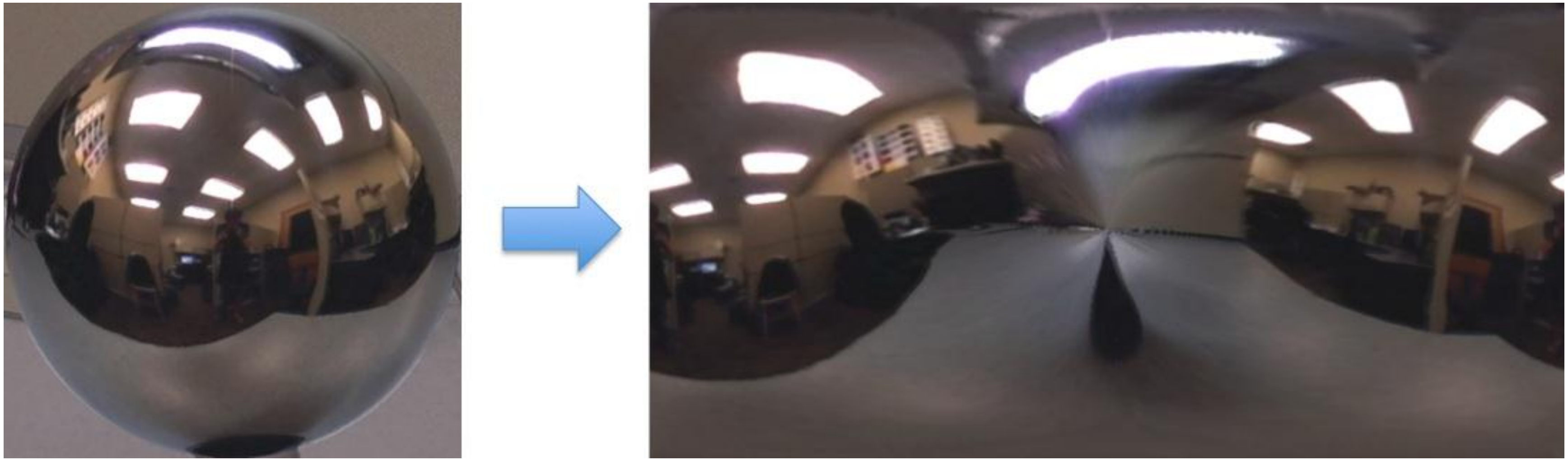
Fall 2013

Kevin Karsch

Today

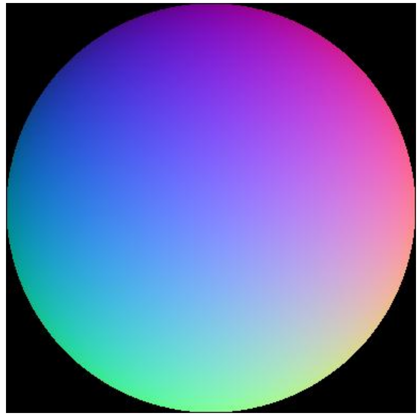
- Brief review of last class
- Inserting objects into *legacy* photos
- Using Blender

Mirror ball -> equirectangular

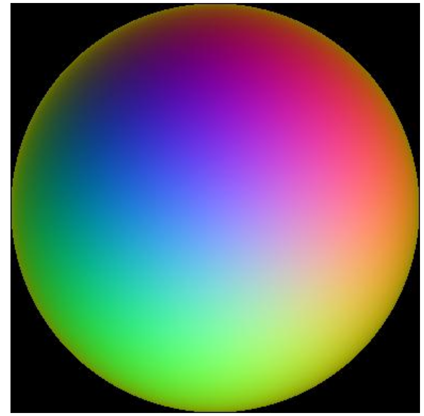


Mirror ball -> equirectangular

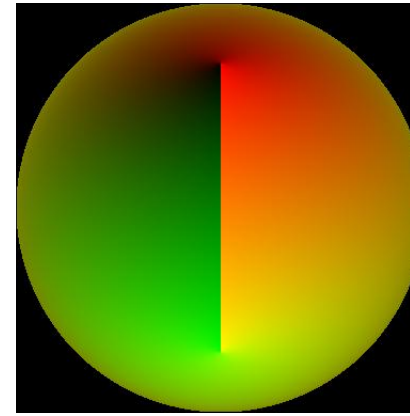
Mirror ball



Normals



Reflection vectors



Phi/theta of reflection vecs

Equirectangular

Phi/theta equirectangular domain

Mirror ball -> equirectangular

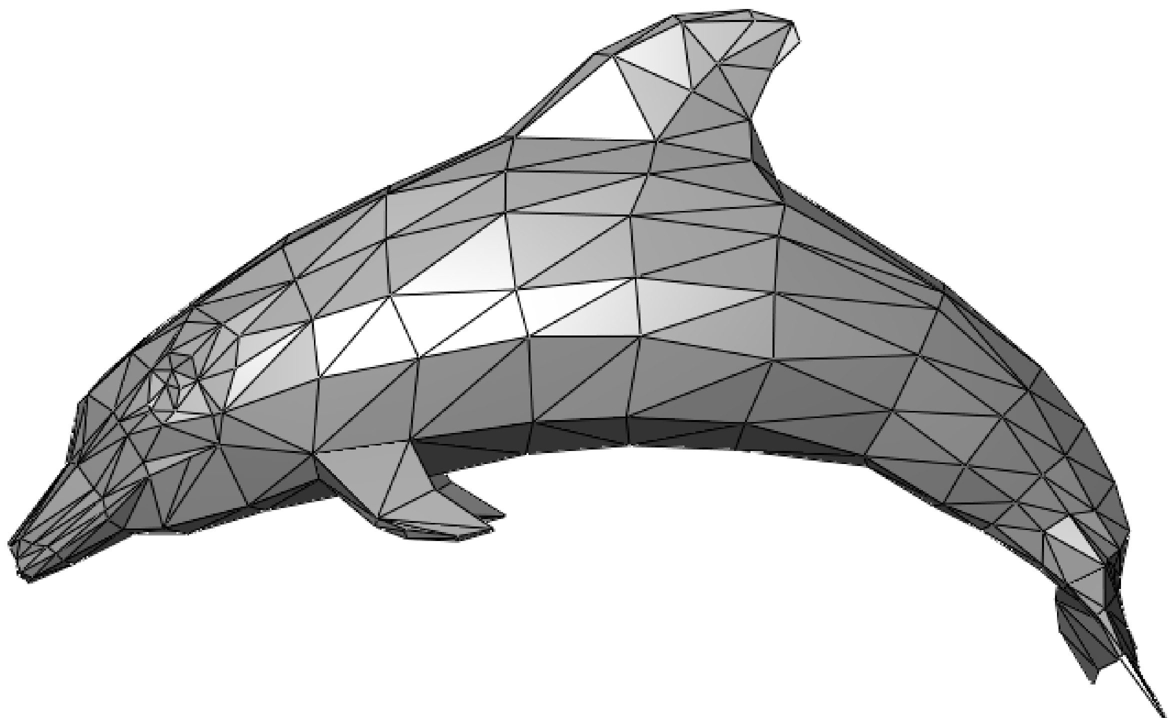
- Domain transformation in matlab
  - Create an interpolation function F with TriScatteredInterp
  - Compute values for each pixel in new domain

Pseudocode:

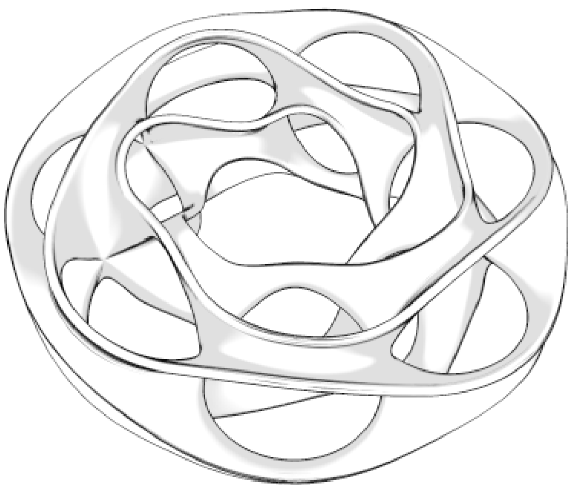
```
for i=1:d
    F = TriScatteredInterp(phi_ball, theta_ball, mirrorball(:,:,i));
    latlon(:,:,i) = F(phi_latlon, theta_latlon);
end
```

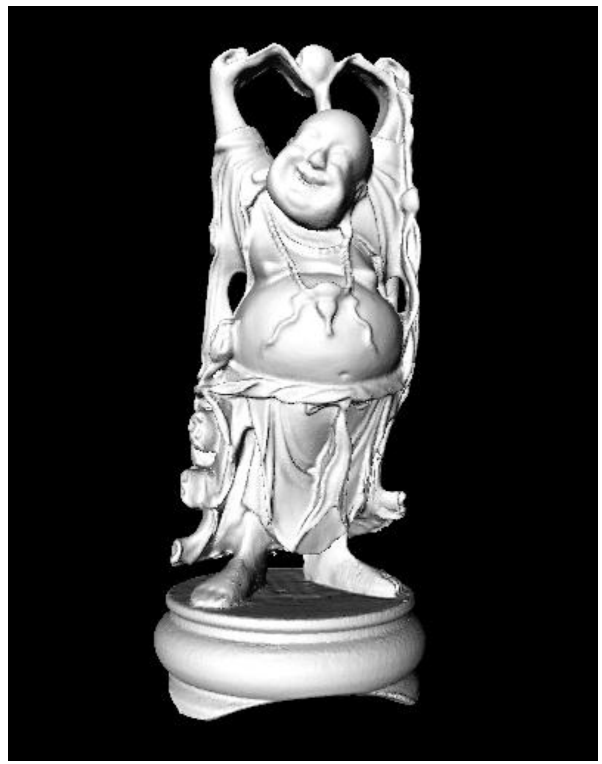
The polygonal mesh

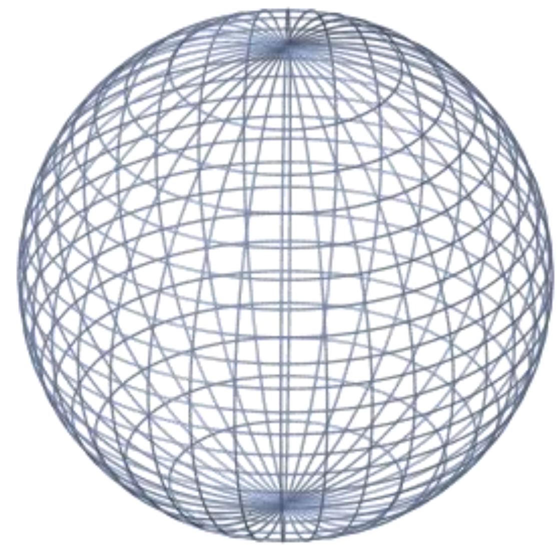
- Discrete representation of a surface
  - Represented by vertices -> edges -> polygons (faces)



Insert these…







…into this

…into this

Or, remove this

Or, remove this

Problem statement

- From a single image, we want to seamlessly insert objects into and delete objects from an image while automatically handling perspective, occlusion, collision, and lighting.

Useful for…

- Home planning/redecoration
- Movies (visual effects)
- Video games

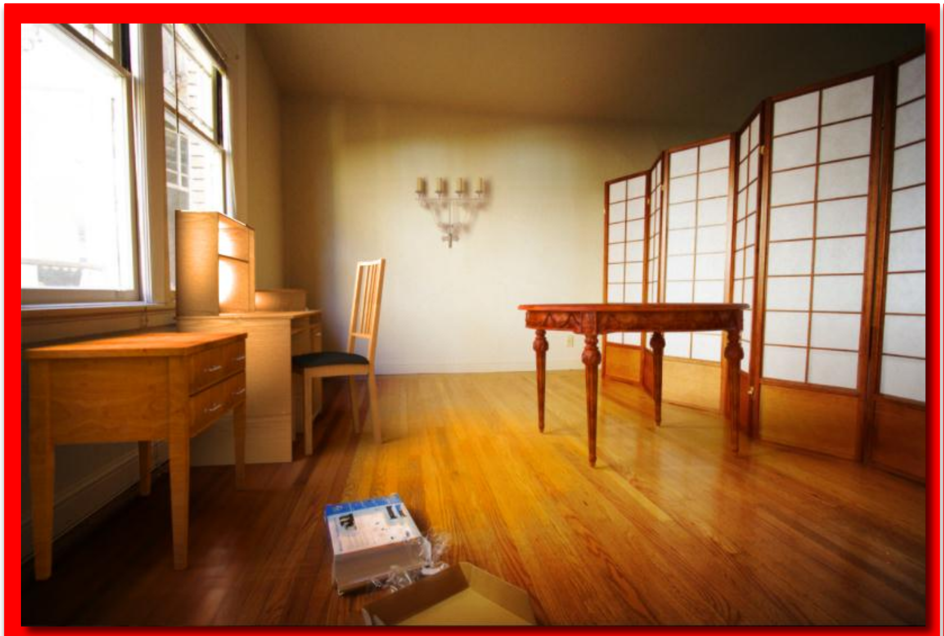
However…

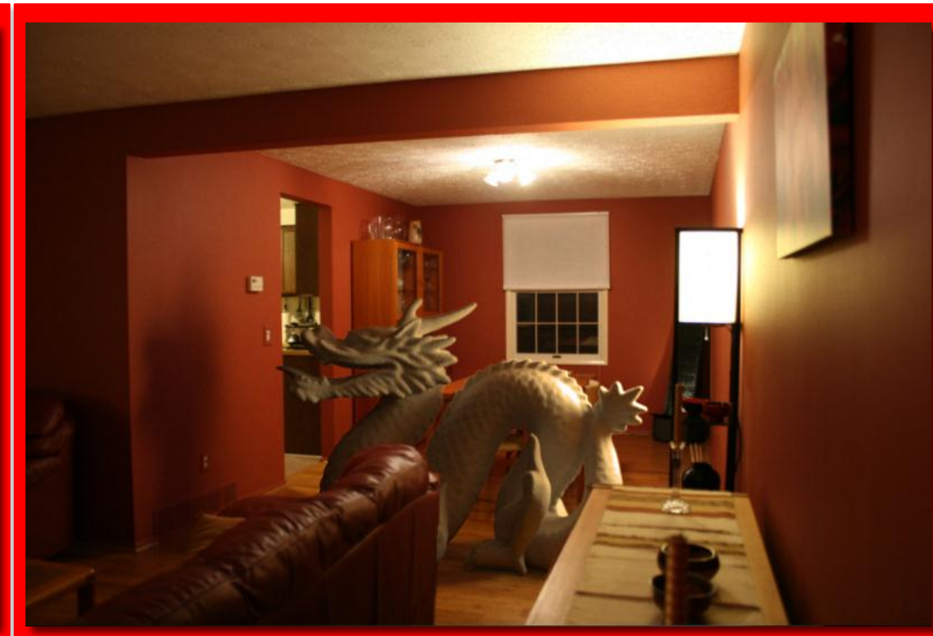
- Tedious with current modeling tools
  - Blender, Photoshop, etc

- Alternatives require scene measurements and/or multiple photographs

What do we need?

- A 3D representation of the scene
  - Camera parameters (focal length, positioning, etc)
  - Scene geometry
  - Light positions and intensities
- Which requires
  - Projective geometry (vanishing pts, homographies, etc) [Camera, geometry]
  - Segmentation [Geometry]
  - Numerical optimization [Lights]






→ let's do
→ we can have
and send them
→ we can put all
and they will be
→ Donating not


GOLFER

Overview

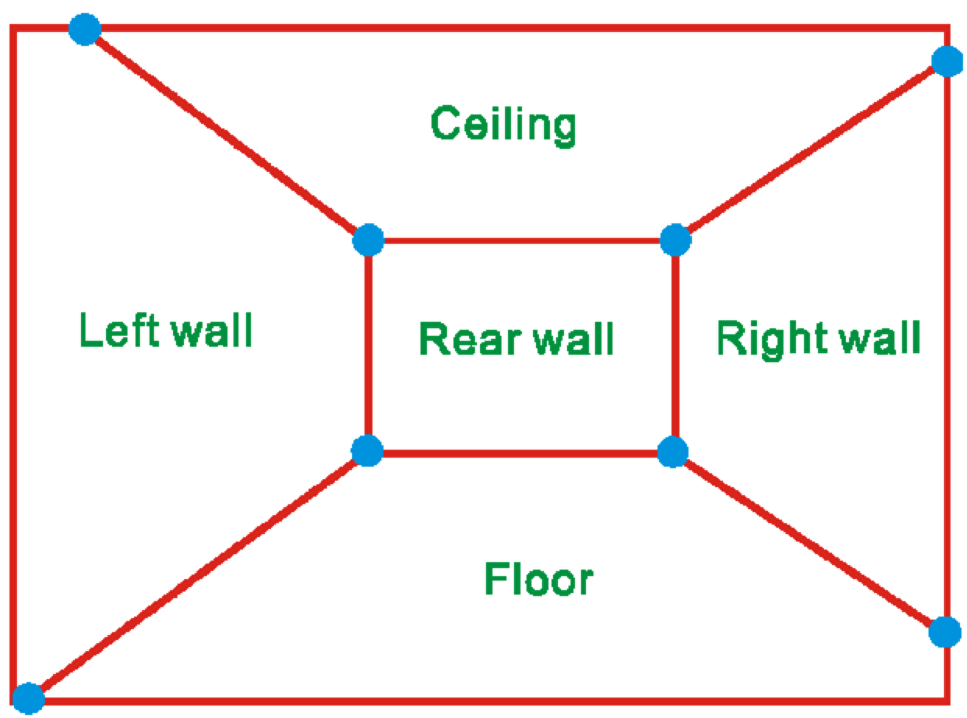
- Inserting objects
  - Perspective
  - Occlusion
  - Relighting
- Recap
- Unsolved problems

What’s wrong here?

That’s better, sort of…

Single view reconstruction

Many scenes can be represented as an axis-aligned box volume



Single view reconstruction

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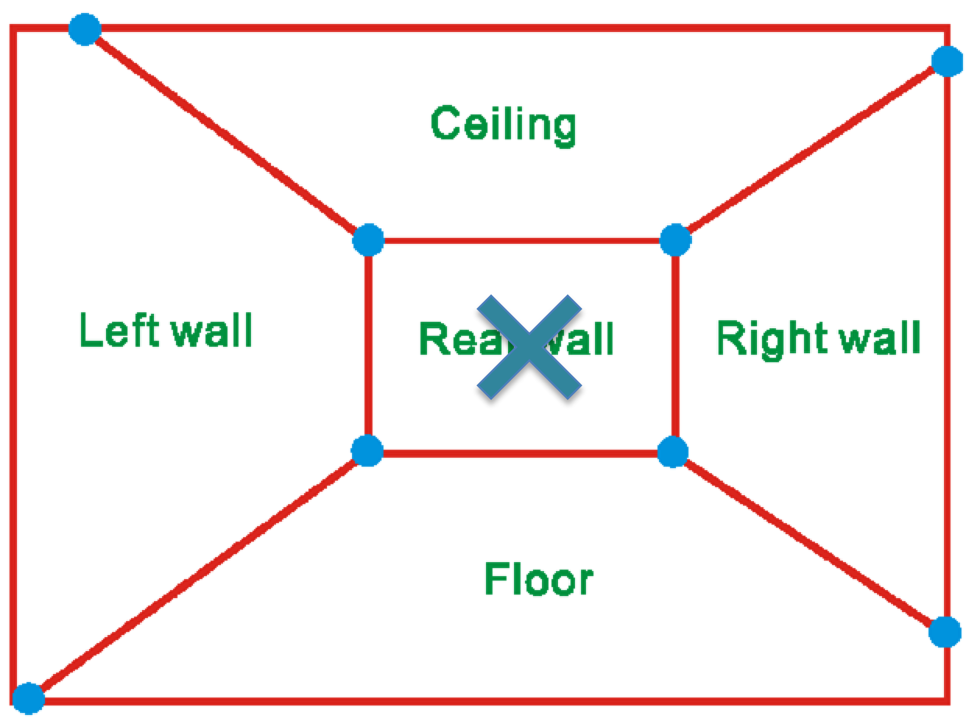

Ideal example

Ideal example

Computing a projection

- Given 3 orthogonal VPs (at least two finite), can compute projection operator

$$K = \begin{bmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

Computing a projection

- Given 3 orthogonal VPs (at least two finite), can compute projection operator

$$e_i = (1,0,0)^T, e_j = (0,1,0)^T, e_k = (0,0,1)^T$$
$$v_i = KRe_i, v_j = KRe_j, v_k = KRe_k$$
$$(KR)^{-1}v_i = e^i, (KR)^{-1}v_j = e^j, (KR)^{-1}v_k = e^k$$

$$e_i^T e_j = e_j^T e_k = e_i^T e_k = 0$$
$$v_i^T K^{-T} R R^{-1} K^{-1} v_j = v_j^T K^{-T} R R^{-1} K^{-1} v_k = v_i^T K^{-T} R R^{-1} K^{-1} v_k = 0$$
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$$\boxed{\begin{aligned} &v_i^T K^{-T} R R^{-1} K^{-1} v_j = v_j^T K^{-T} R R^{-1} K^{-1} v_k = v_i^T K^{-T} R R^{-1} K^{-1} v_k = 0 \\ &v_i^T K^{-T} K^{-1} v_j = v_j^T K^{-T} K^{-1} v_k = v_i^T K^{-T} K^{-1} v_k = 0 \end{aligned}}$$

Computing a projection

- Given 3 orthogonal VPs (at least two finite), can compute projection operator

$$R = \begin{bmatrix} R_{1c} & R_{2c} & R_{3c} \end{bmatrix}$$

$$\lambda v_i = K R e_i \qquad\qquad e_i = [1, 0, 0]^T$$

$$R_{ic} = \lambda K^{-1} v_i$$

Projecting to image space

- Given K, R, and a position in 3D (v_object), we can find its corresponding 2D image location:

$$v_{image} = KRv_{object}$$

What about the reverse?

- Given K, R, and a 2D position on the image (v_image), what do we know about its 3D location?

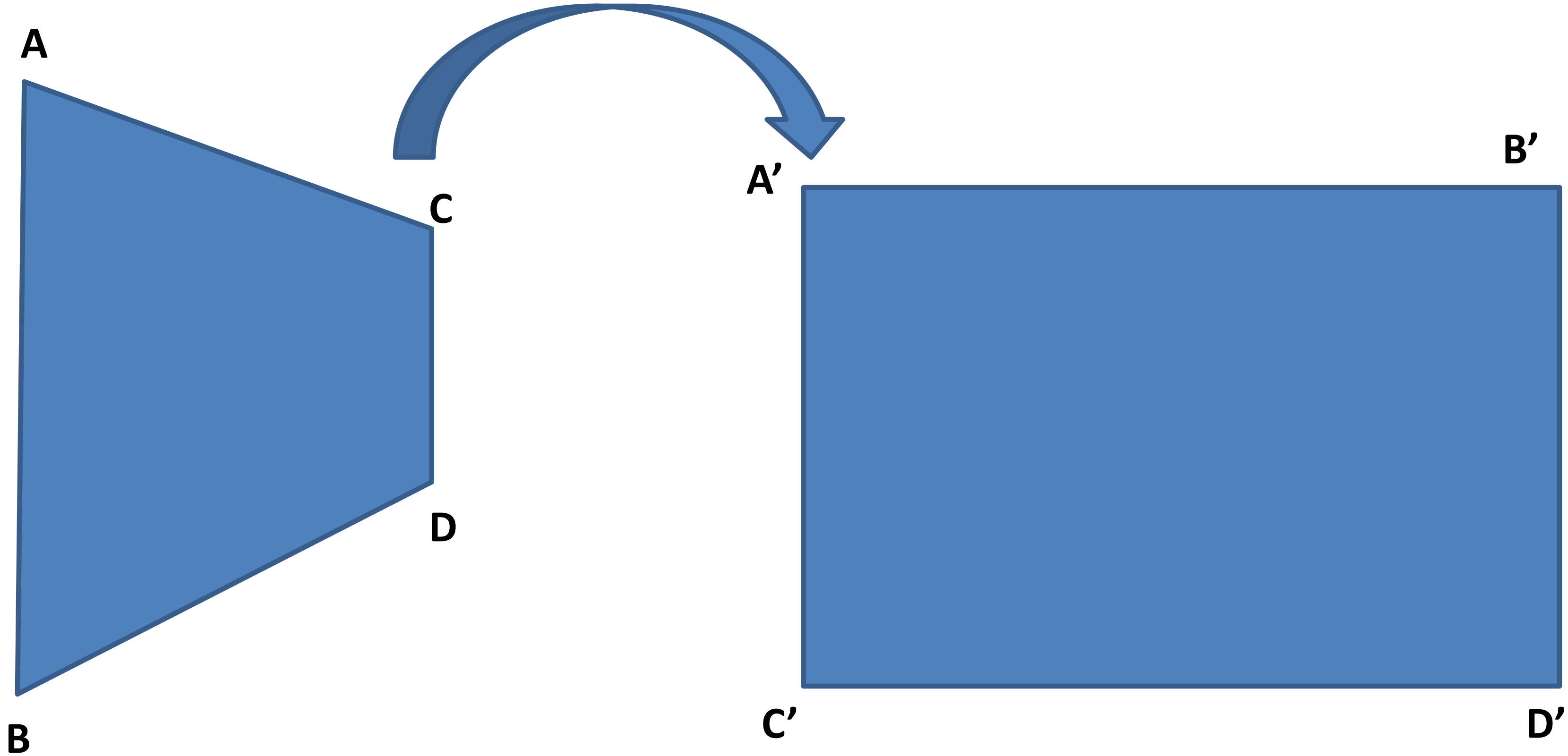
What about the reverse?

- Given K, R, and a 2D position on the image (v_image), what do we know about its 3D location?

$$\lambda v_{object} = (KR)^{-1} v_{image}$$

- Implies a line along which the 3D point lies
- Allows for image space interactions to be localized in 3D!

Homographies



(Projective warping from one domain to another)

Image Rectification

Overview

- Inserting objects
  - Perspective & collision
  - Occlusion
  - Relighting
  - Animation
- Removing objects
- Recap + Unsolved problems

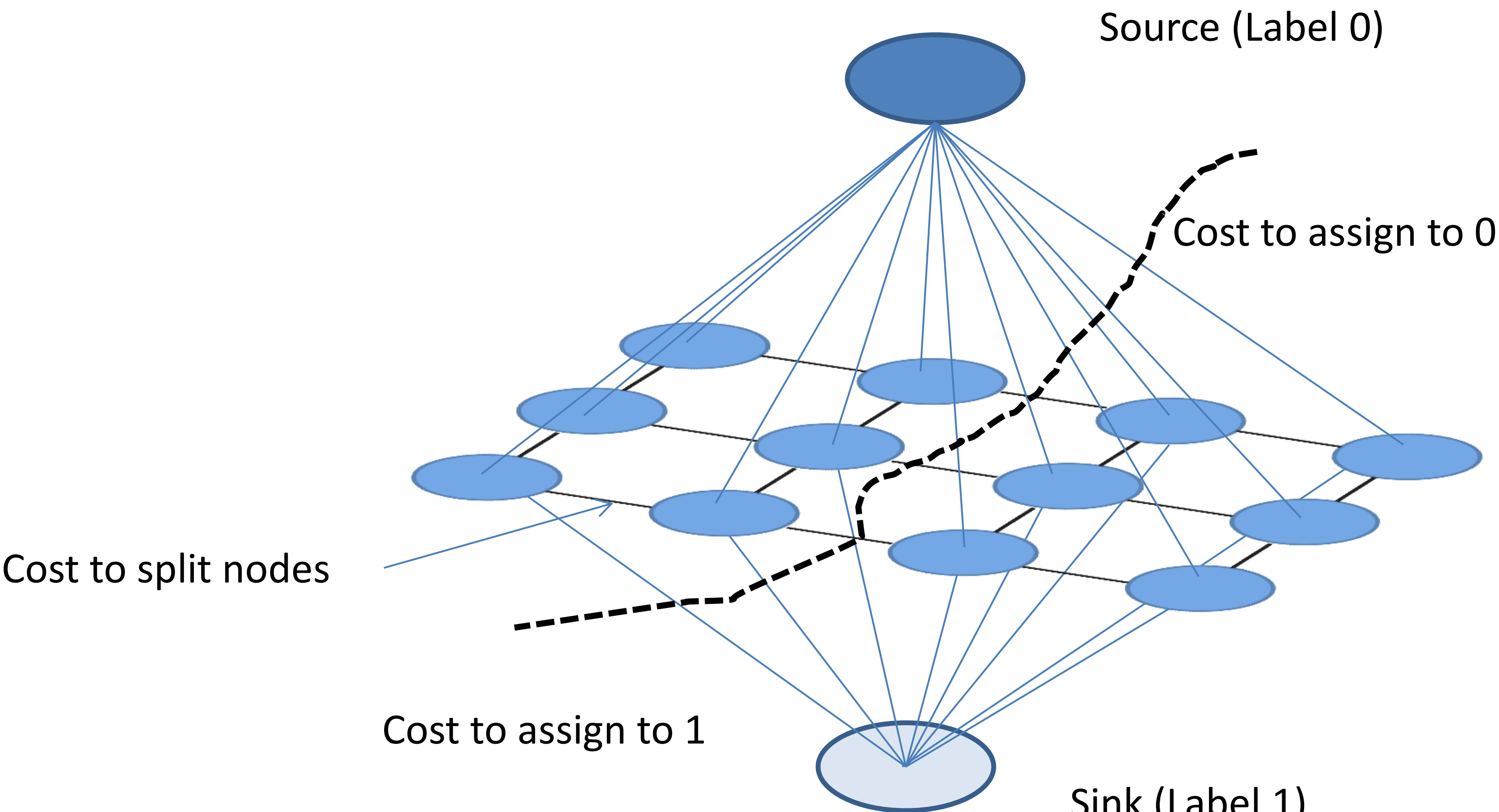
Modeling occlusions

User-defined boundary

- Tedious/inaccurate
- How can we make this better?

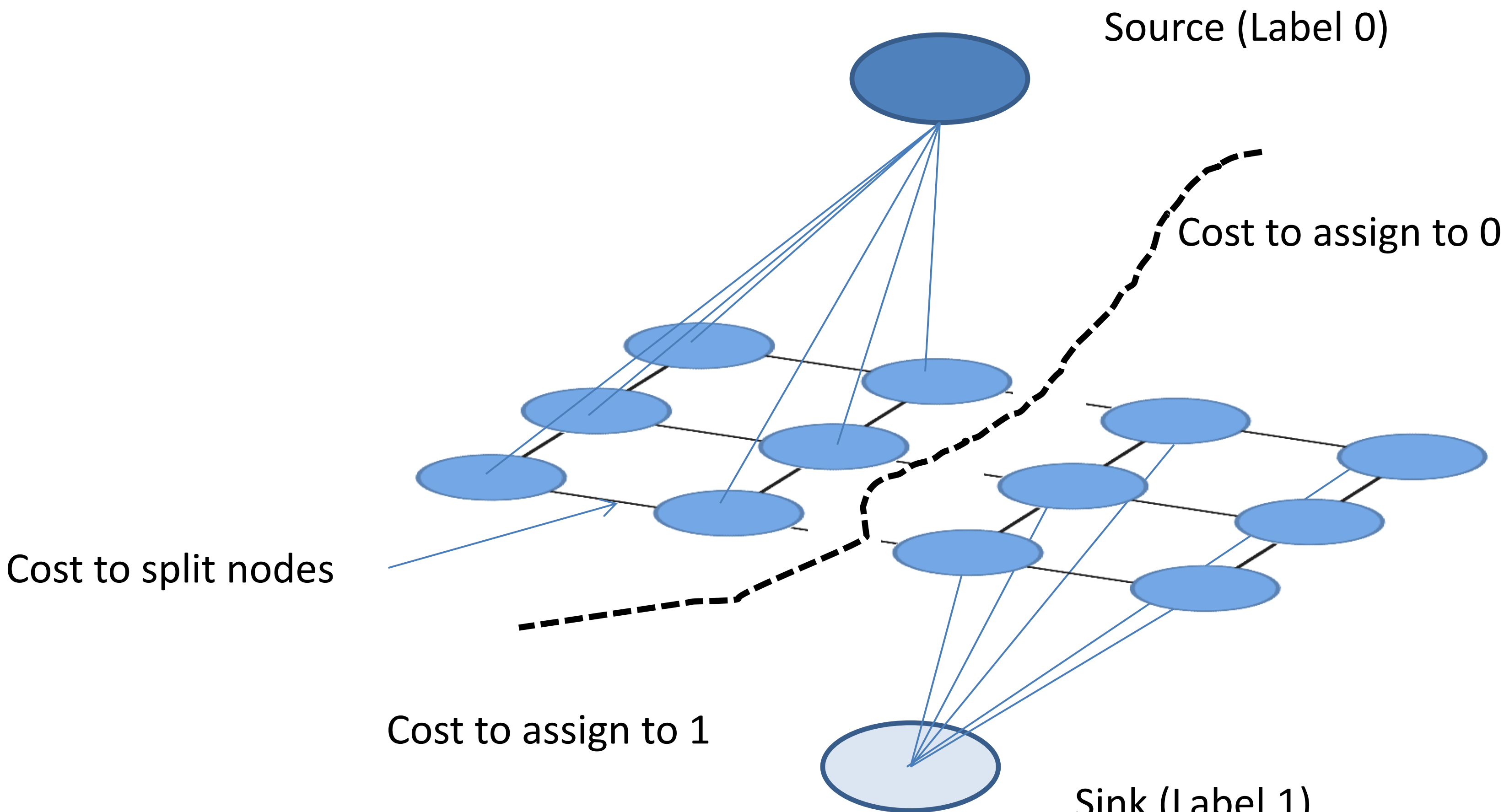
Refined segmentation

Segmentation with graph cuts



$$Energy(\mathbf{y};\theta,data)=\sum_{i}\psi_{1}(y_{i};\theta,data)\ \sum_{i,j\in edges}\psi_{2}(y_{i},y_{j};\theta,data)$$

Segmentation with graph cuts



$$Energy(\mathbf{y};\theta,data)=\sum_{i}\psi_1(y_i;\theta,data)\ \sum_{i,j\in edges}\psi_2(y_i,y_j;\theta,data)$$

A spectral approach

A spectral approach

A spectral approach

- Create NxN matrix describing neighboring pixel similarity (Laplacian matrix, L)
- Extract “smallest” eigenvectors of L
- Segmentation defined by linear combination of eigenvectors
  - Scribbles as constraints

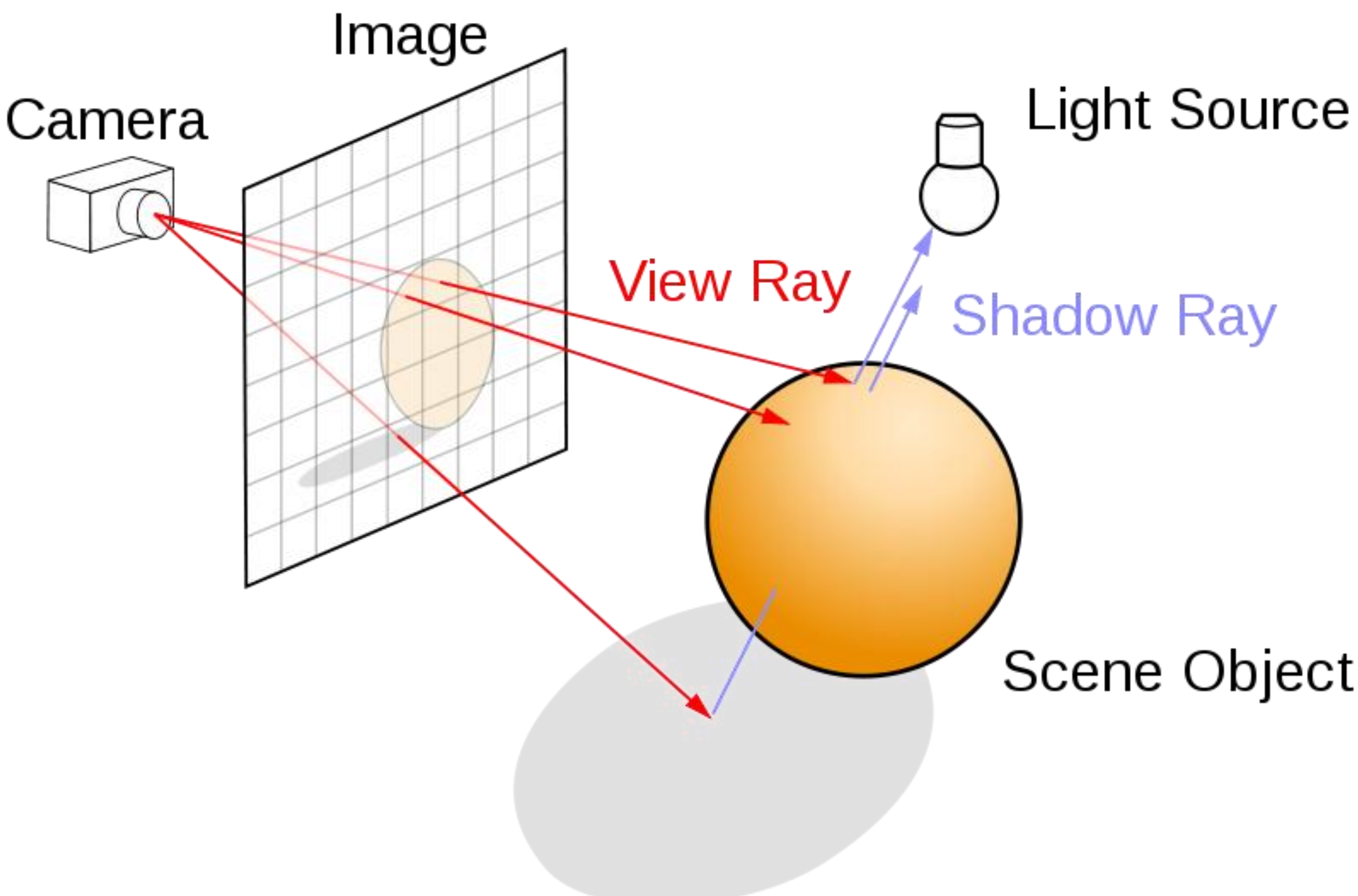
A spectral approach

A spectral approach

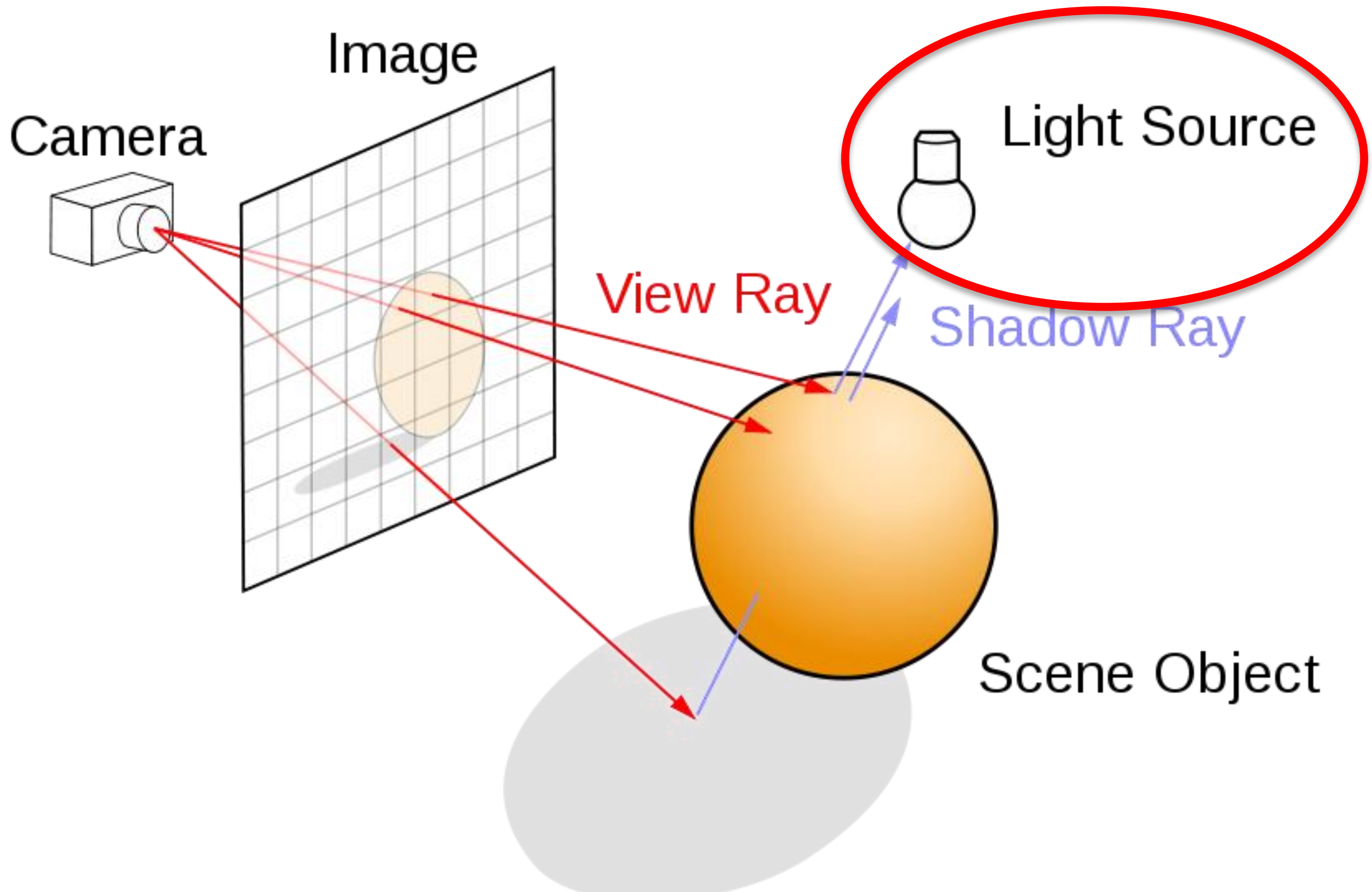
Segmentations as “billboards”

Segmentations as “billboards”

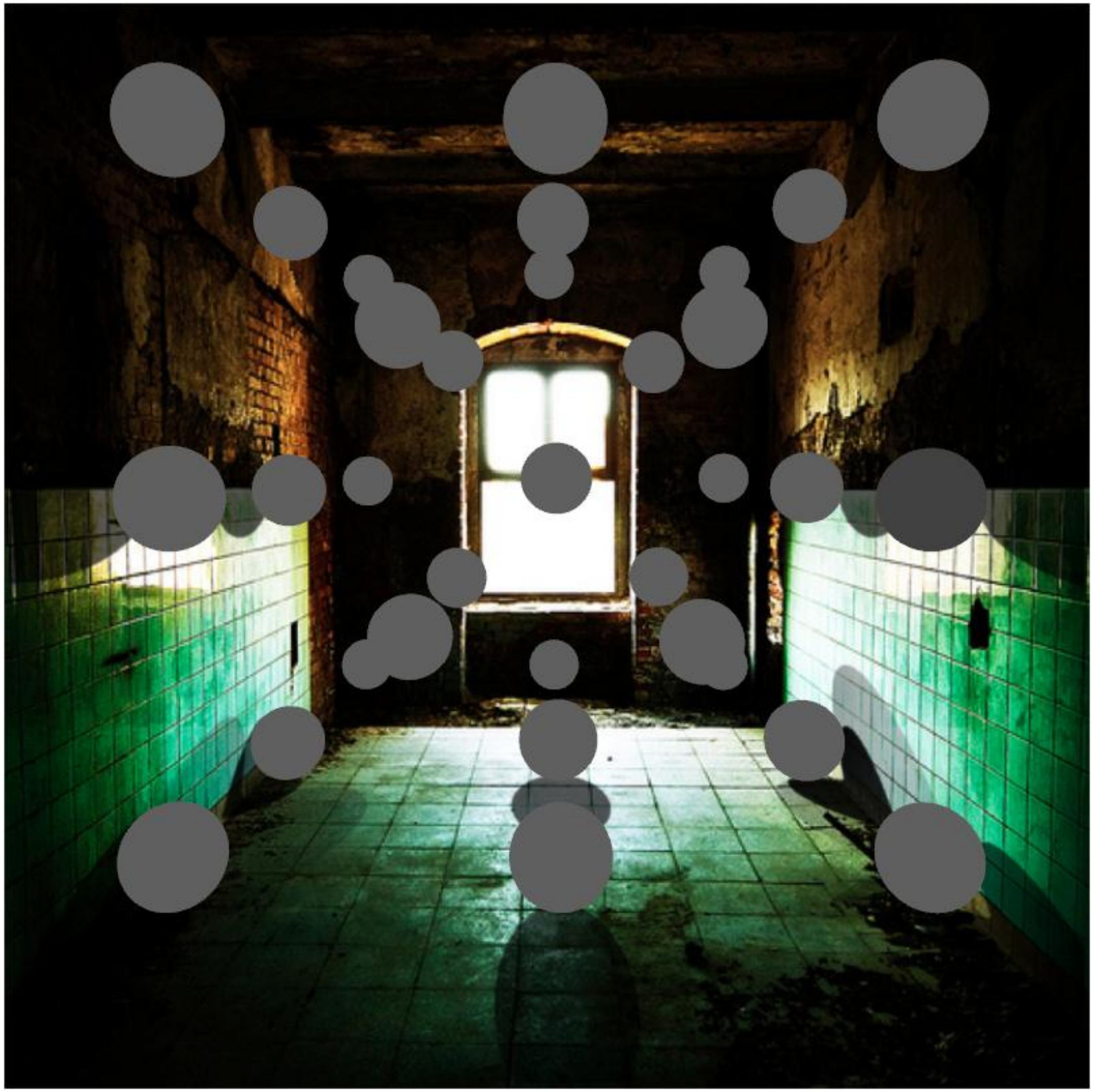
Rendering via ray tracing



Rendering via ray tracing



Insertion without relighting



…with relighting

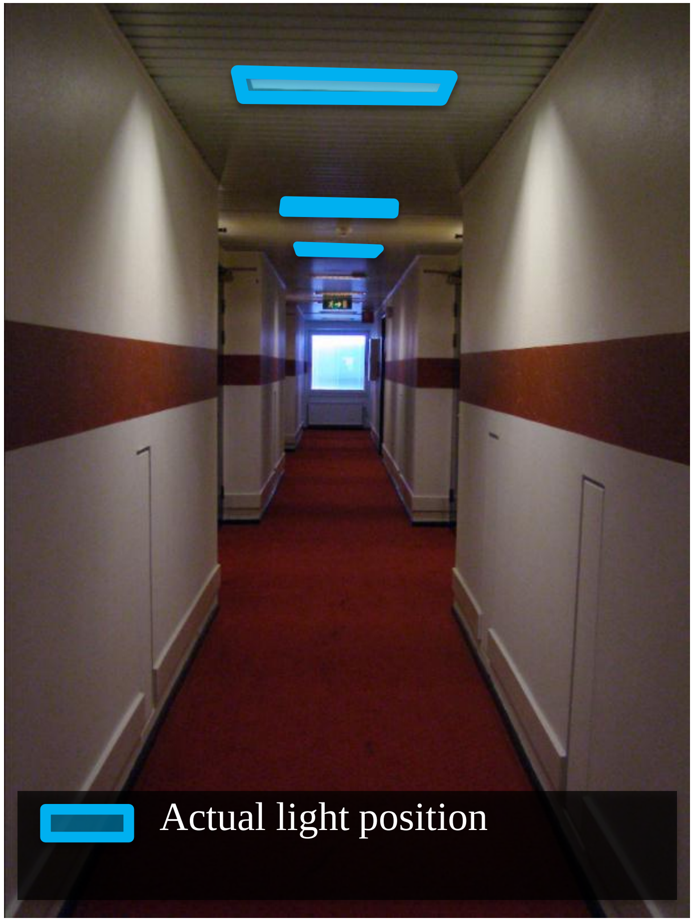
Understanding light: our approach

- Hypothesize physical light sources in the scene
  - Physical → CG representations of light sources found in the real world (area lights, etc)

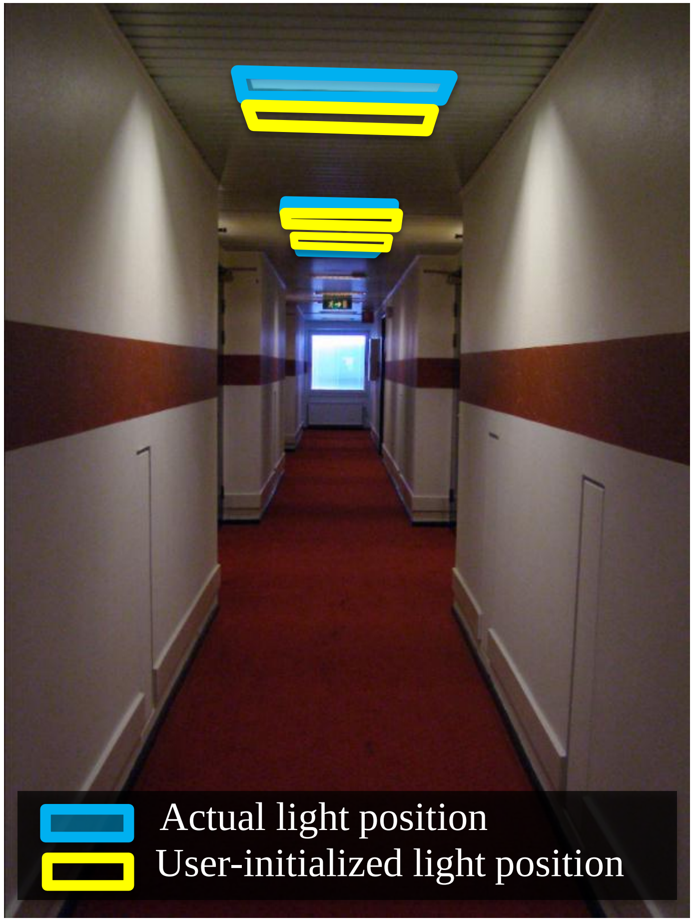
- Visible sources in image marked by user
  - Refined to best match geometry and materials
- User annotates light shafts; direction vector
  - Shafts automatically matted and refined

Lighting estimation

Lighting estimation

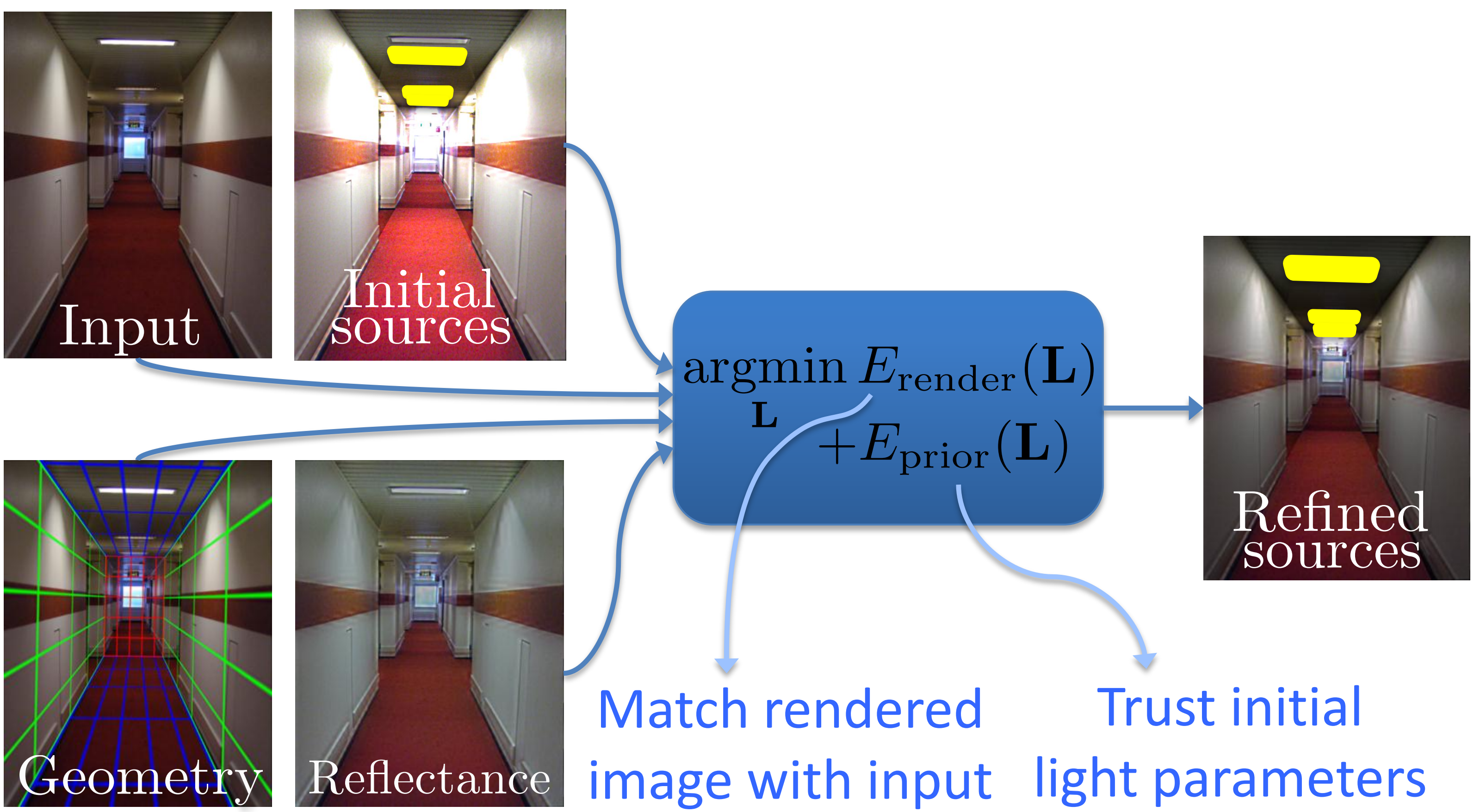


Lighting estimation

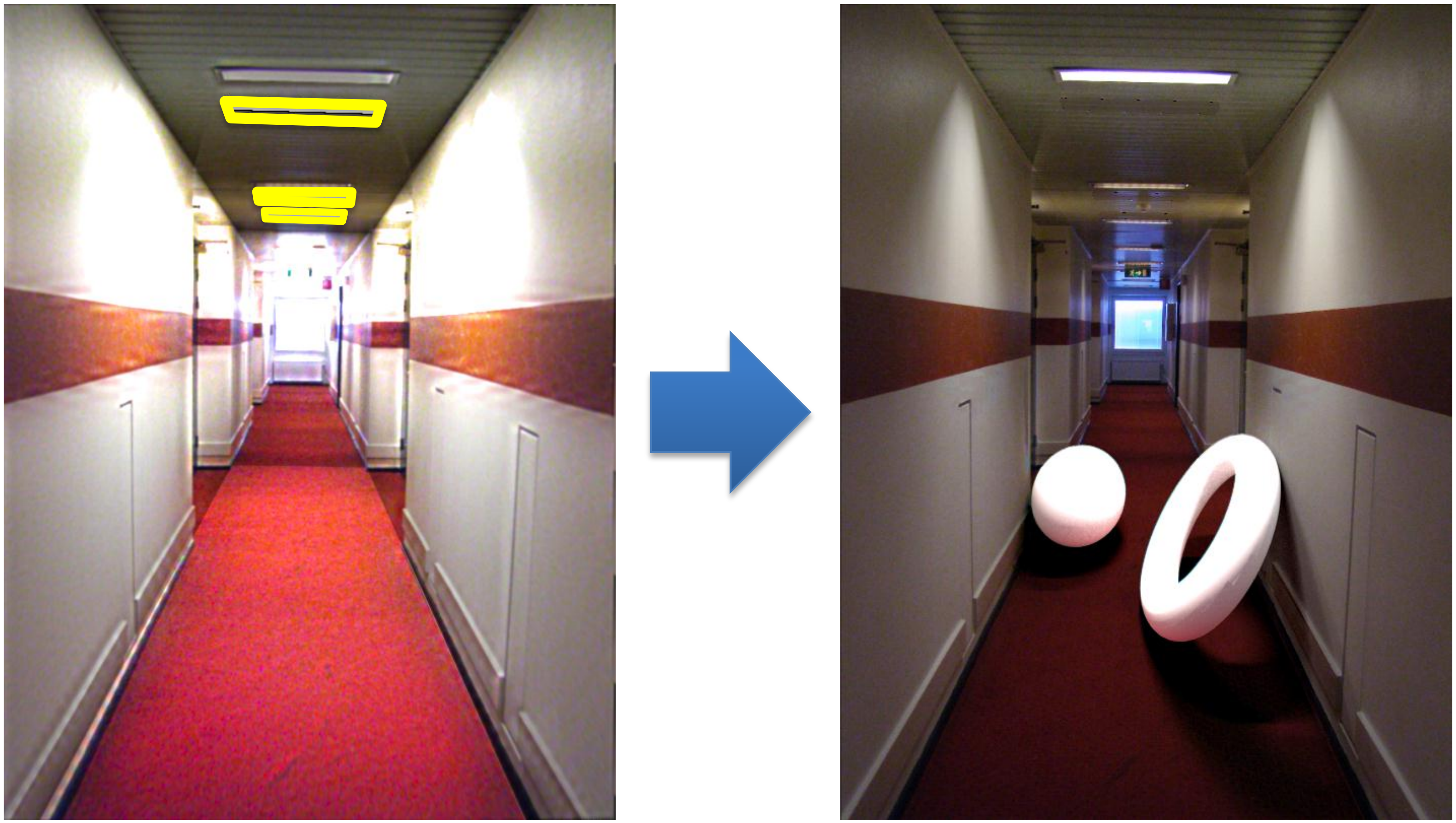


Light refinement

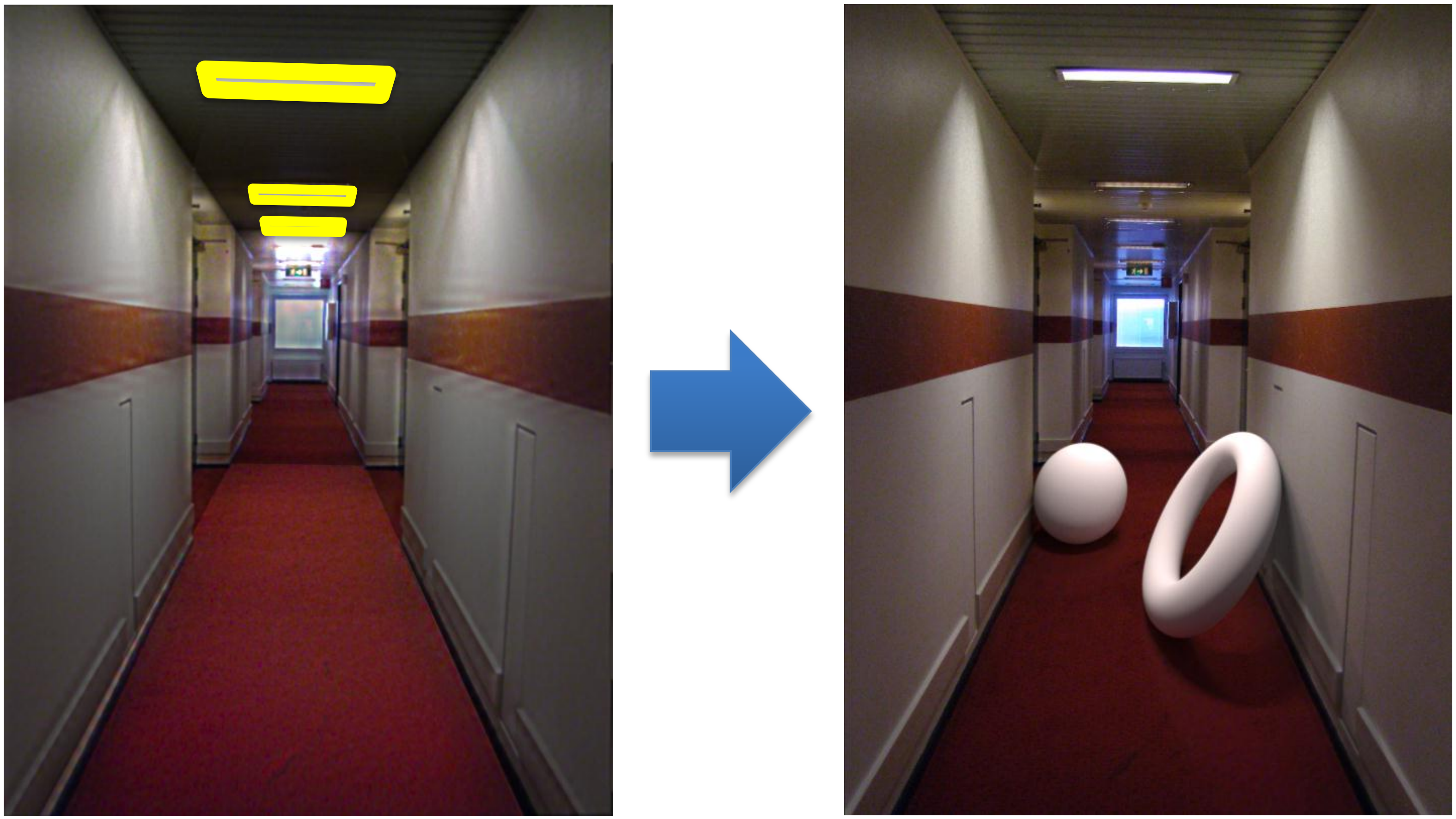
- Match original image to rendered image



Initial light parameters

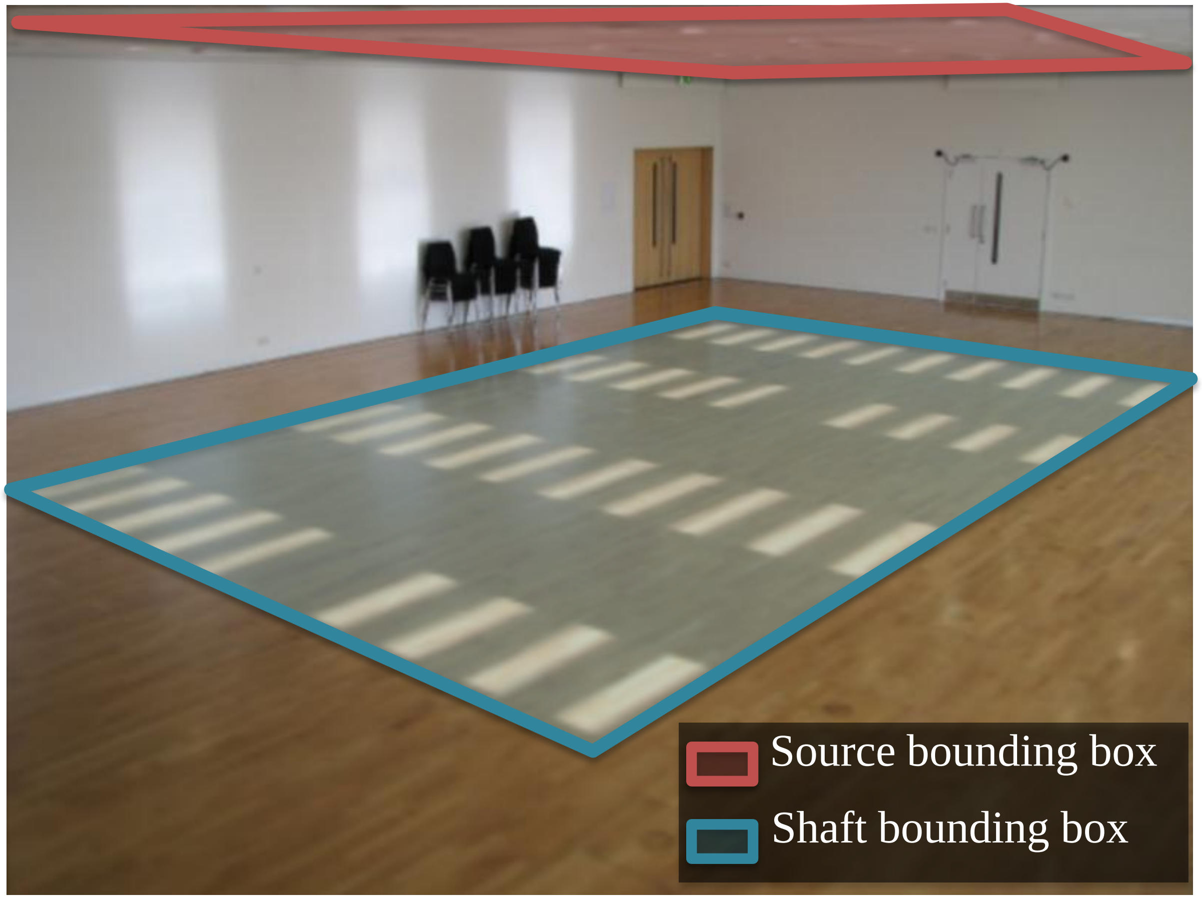


Refined light parameters



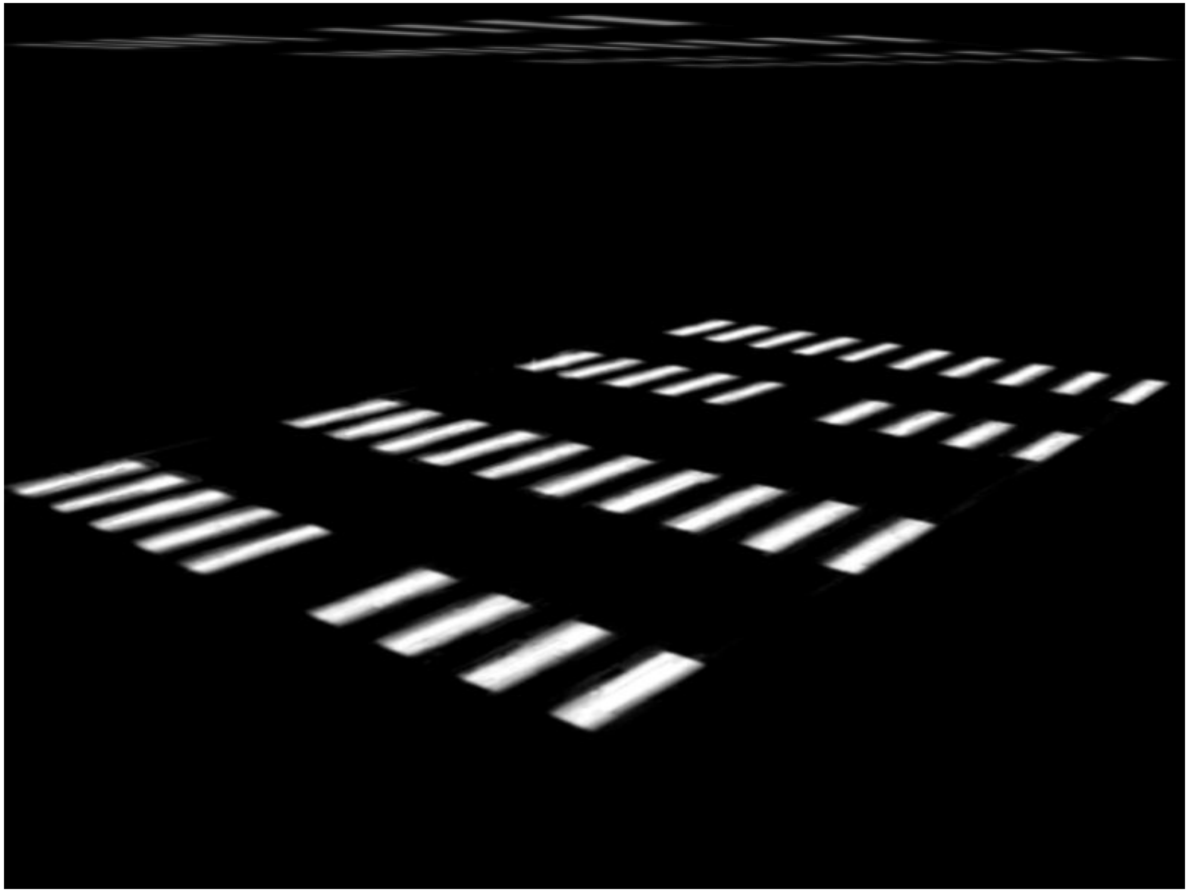
External light shafts

External light shafts



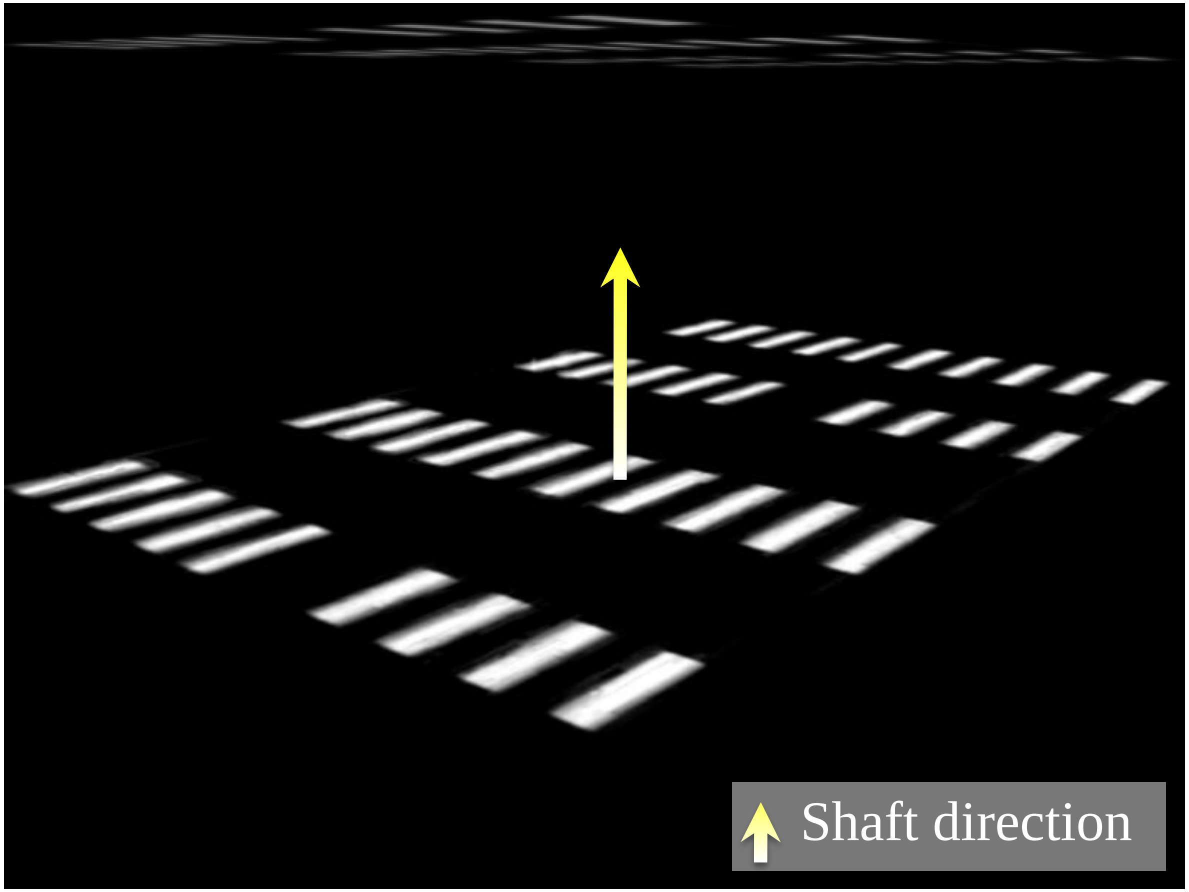
External light shafts

Shadow matting via Guo et al. [2011]

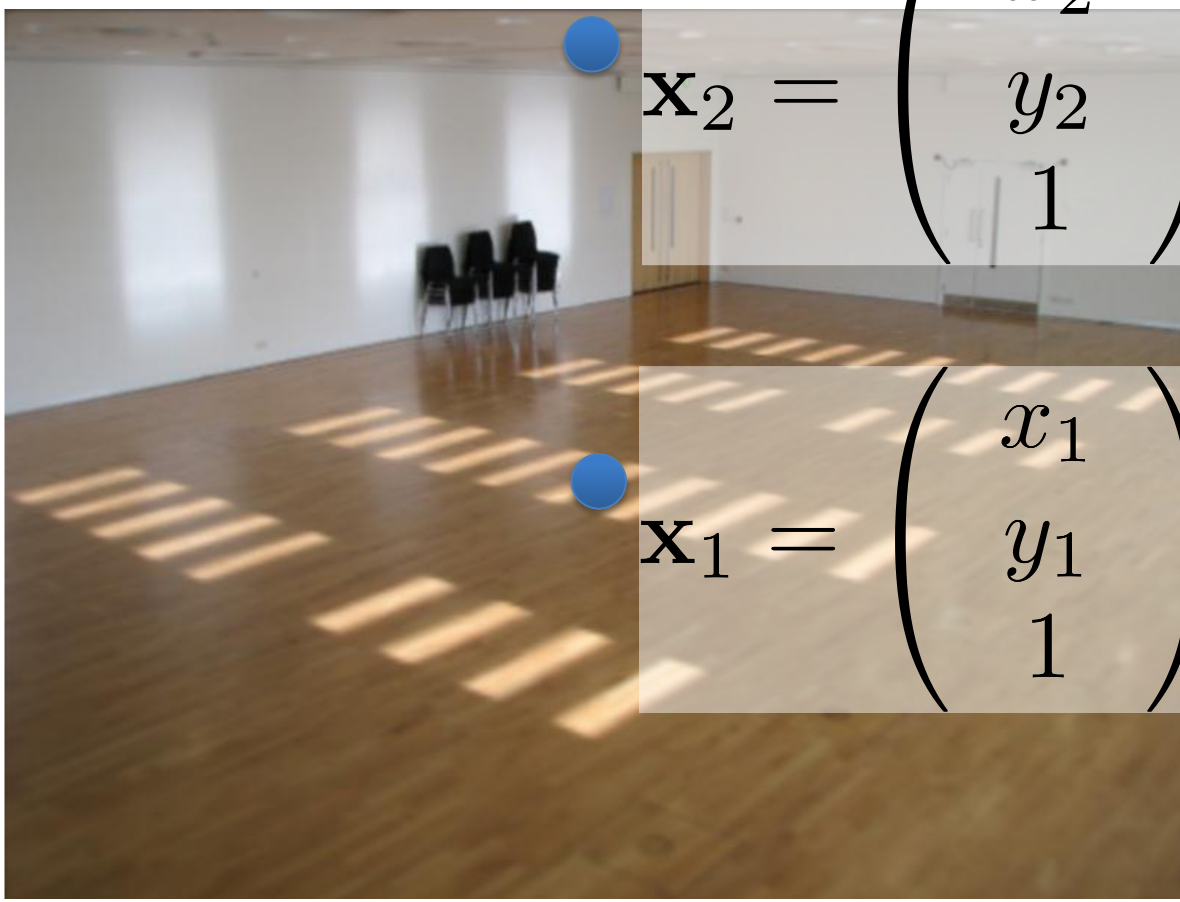


External light shafts

- Can we find the direction of the shaft in 3D?



Example on board



$$\mathbf{x}_2 = \begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix}$$

$$\mathbf{x}_1 = \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix}$$

Light shaft result

Light shaft result

Inserting objects

- Representation of geometry, materials and lights compatible with 3D modeling software
- Two methods of insertion/interaction
  - Novice: image space editing
  - Professional: 3D modeling tools (e.g. Maya)
- Scene rendered with physically based renderer (e.g. LuxRender, Blender's Cycles)

Final composite

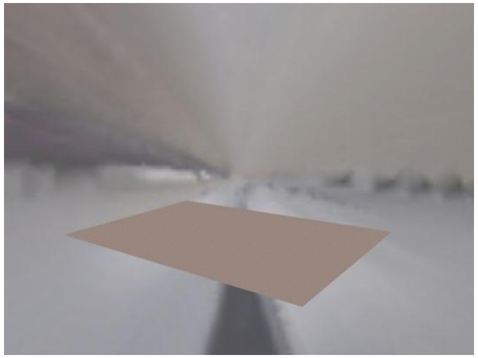
- Additive differential technique [Debevec 1998]

composite = M.*R + (1-M).*I + (1-M).*(R-E).*c

I (background)

composite

R (rendered)



E (empty)

M (mask)

Blender demos

Putting it all together

Video

Unsolved problems

- Can we “do better” with
  - Multiple images?
  - Videos?
  - Depth?
- Better scene understanding?
- How to insert image fragments (Poisson Blending style)?