Illumination from Images

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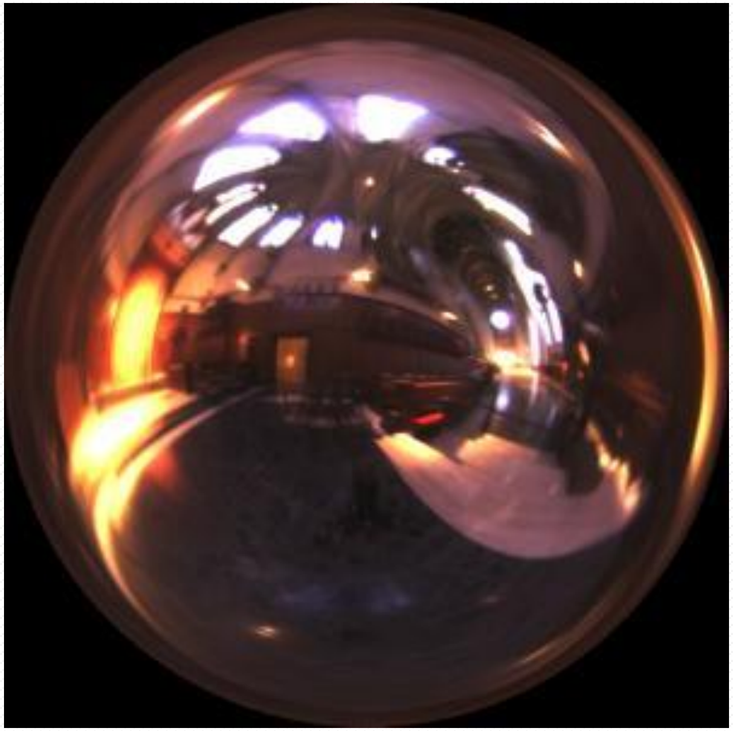
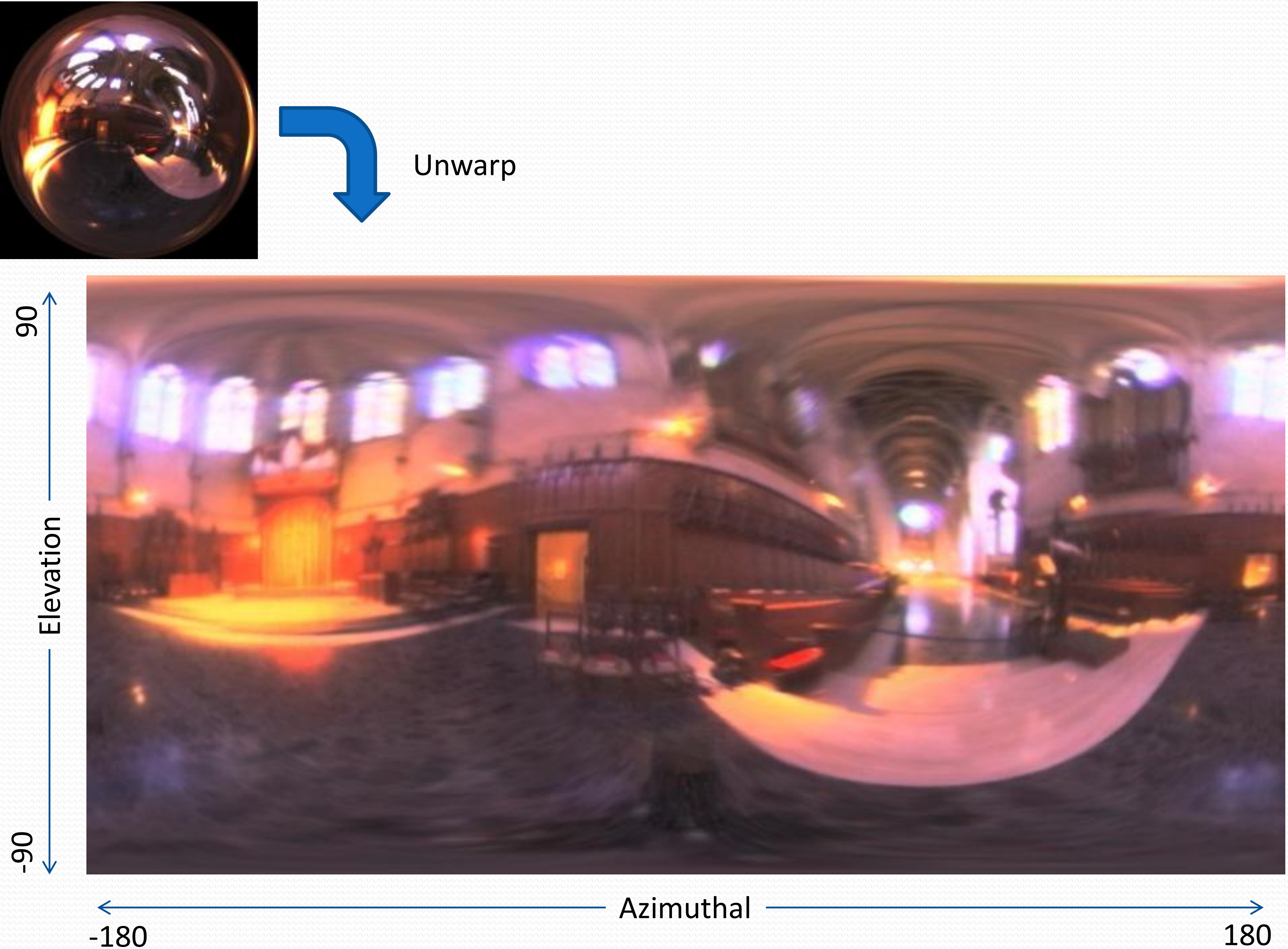
Scene Illumination

- What is it?
  - Environment map
  - A sphere **approximate** incident light from long distance
  - A 2D radiance function in sphere coordinates
- Assumptions
  - Far-field lighting
  - Independent to position



Grace Cathedral, San Francisco
Angular map format
http://ict.debevec.org/~debevec/Probes/


Unwarp
90
Elevation
-90
Azimuthal
-180
180

Applications

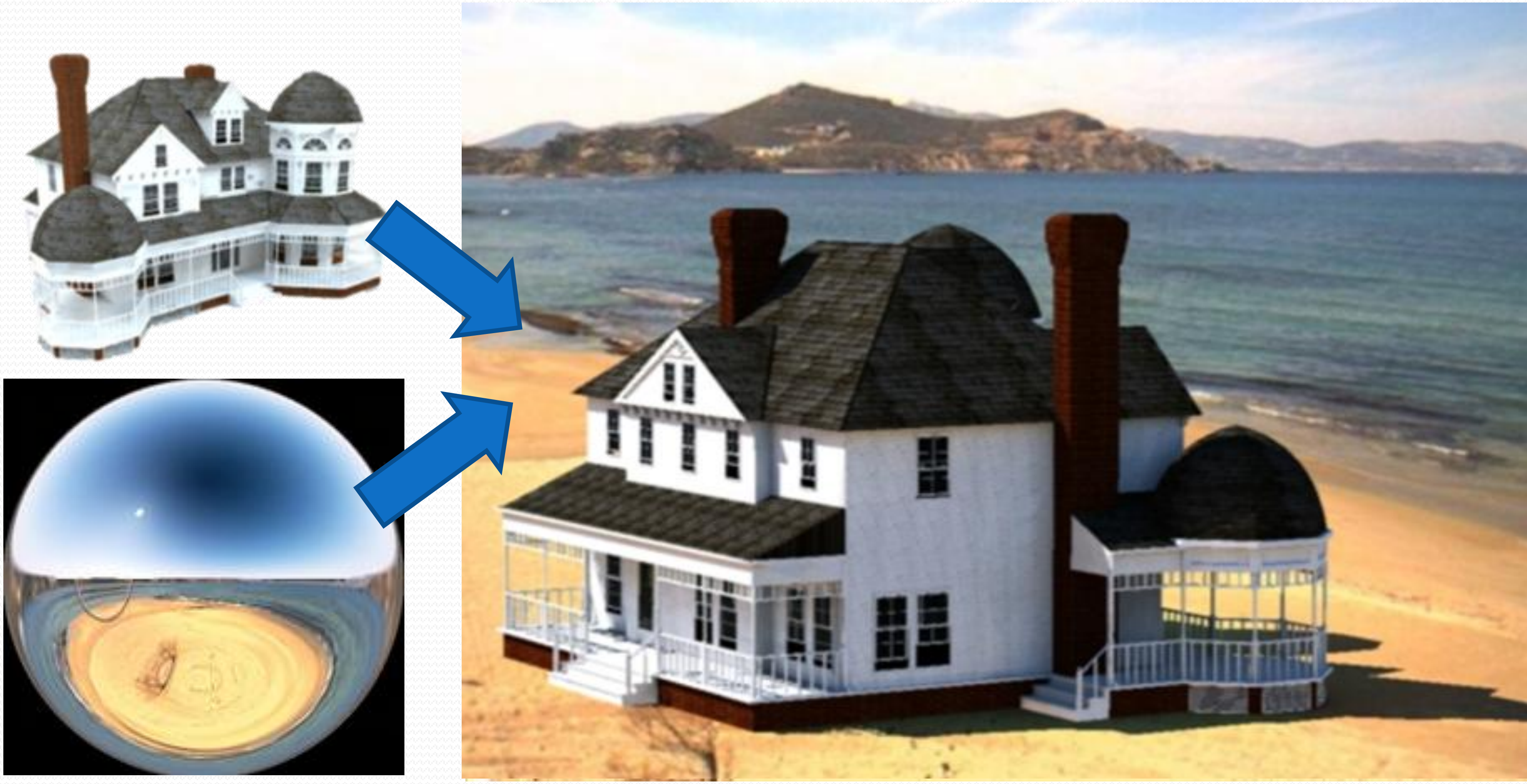
- Realistic 3D rendering/relighting

http://gl.ict.usc.edu/Research/RHL/

Applications (cont.)

- Insert 3D objects into photos

"Webcam Clipart", http://www.jflalonde.org/projects/webcamclipart/



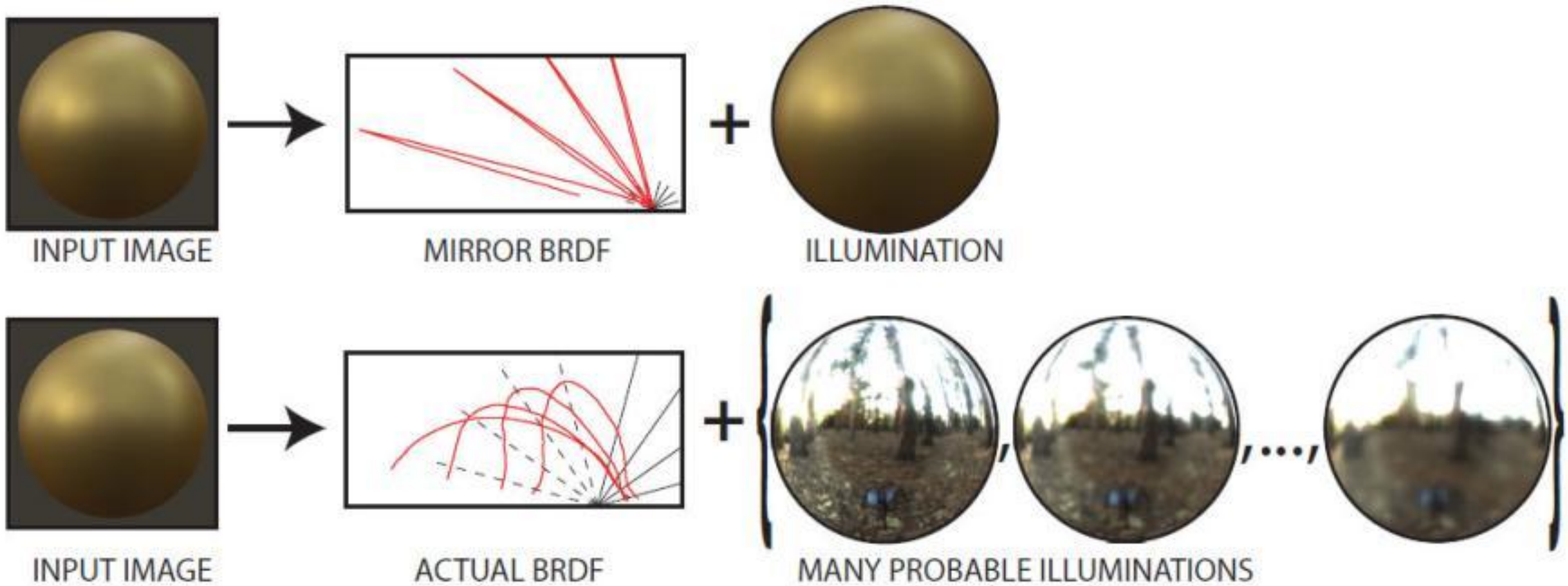
Applications (cont.)

- Help scene understanding
  - Illumination vastly changes scene appearance
  - Solution 1: use illumination invariant features (e.g., SIFT)
  - Solution 2: utilize information about scene illumination

Example: Blind Reflectometry

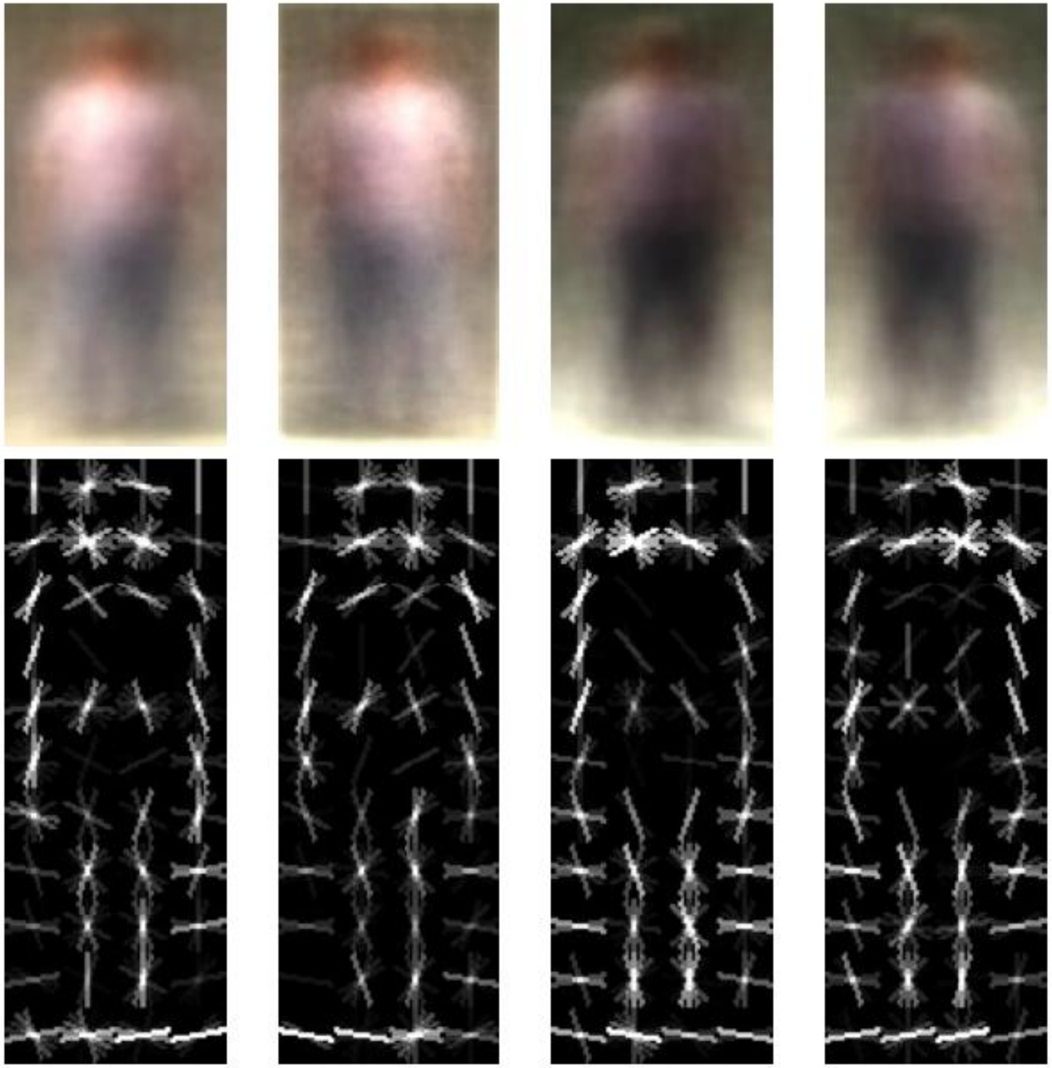
[Romeiro and Zickler, 2010]

- Ambiguity between illumination and reflectance
- Find material properties by
  - Choosing an appropriate BRDF representation
  - Find the statistics of outdoor environment maps
  - Select most likely BRDF parameters under that distribution of environment maps



Example: Illumination-Aware Pedestrian Detection

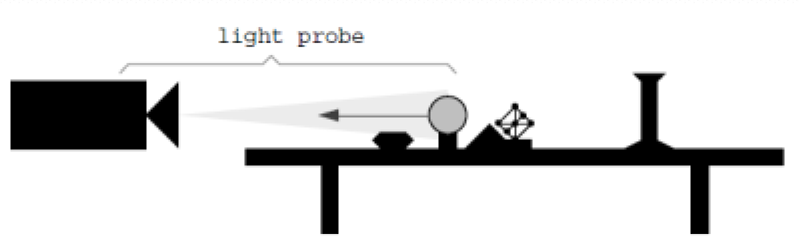
[Lalonde, PhD thesis, 2011]

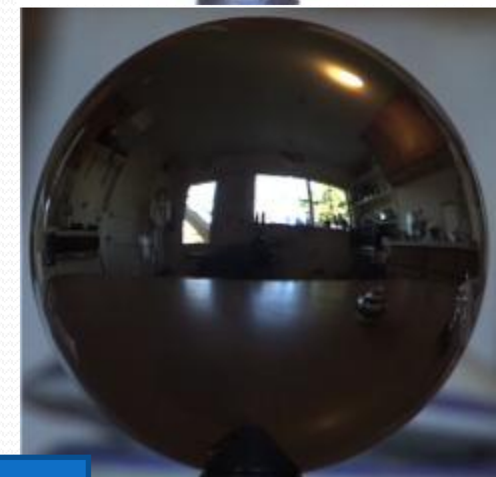


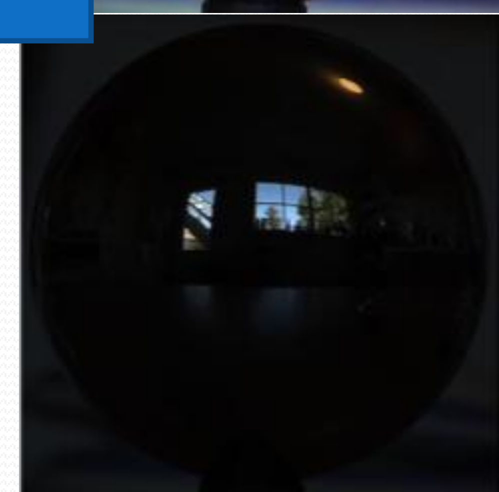
(a) Back-left (b) Back-right (c) Front-left (d) Front-right

Estimating Scene Illumination

- Light Probe [Debevec et al., 1998]



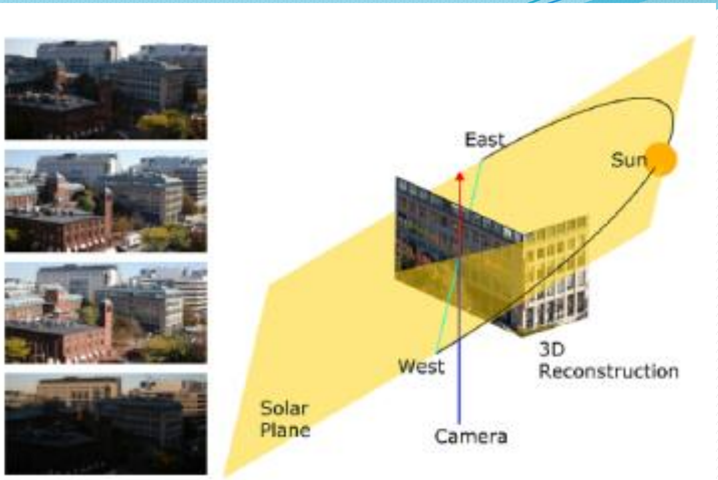




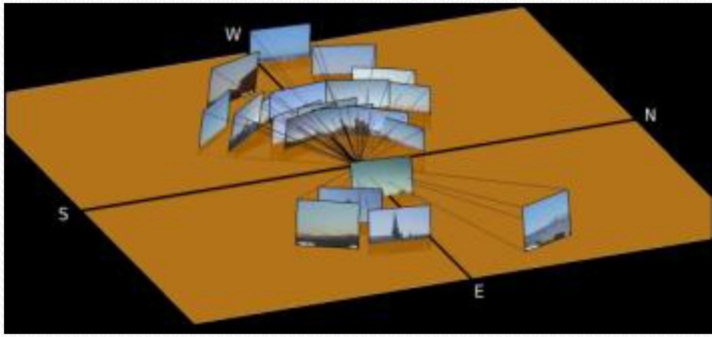
Outdoor Illumination from Image Sequence

- Webcam time lapsed video

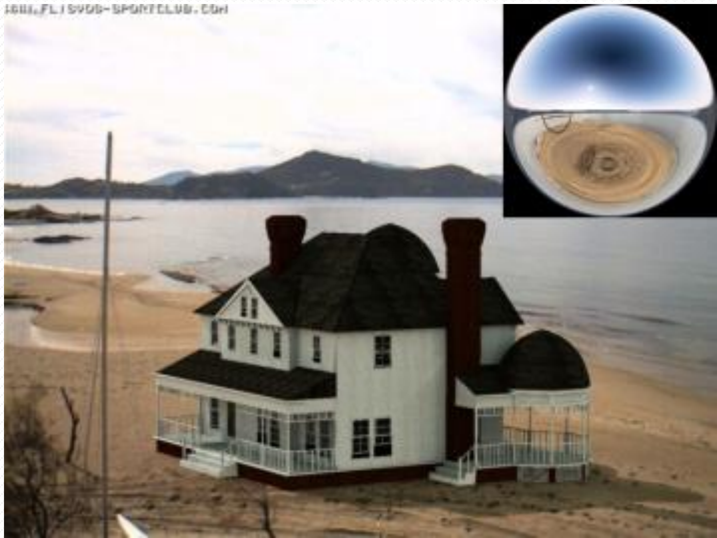
“What do color changes reveal about an outdoor scene?” [Sunkavalli et al., 2008]



“What Do the Sun and the Sky Tell Us About the Camera?” [Lalonde et al., 2008, 2010]



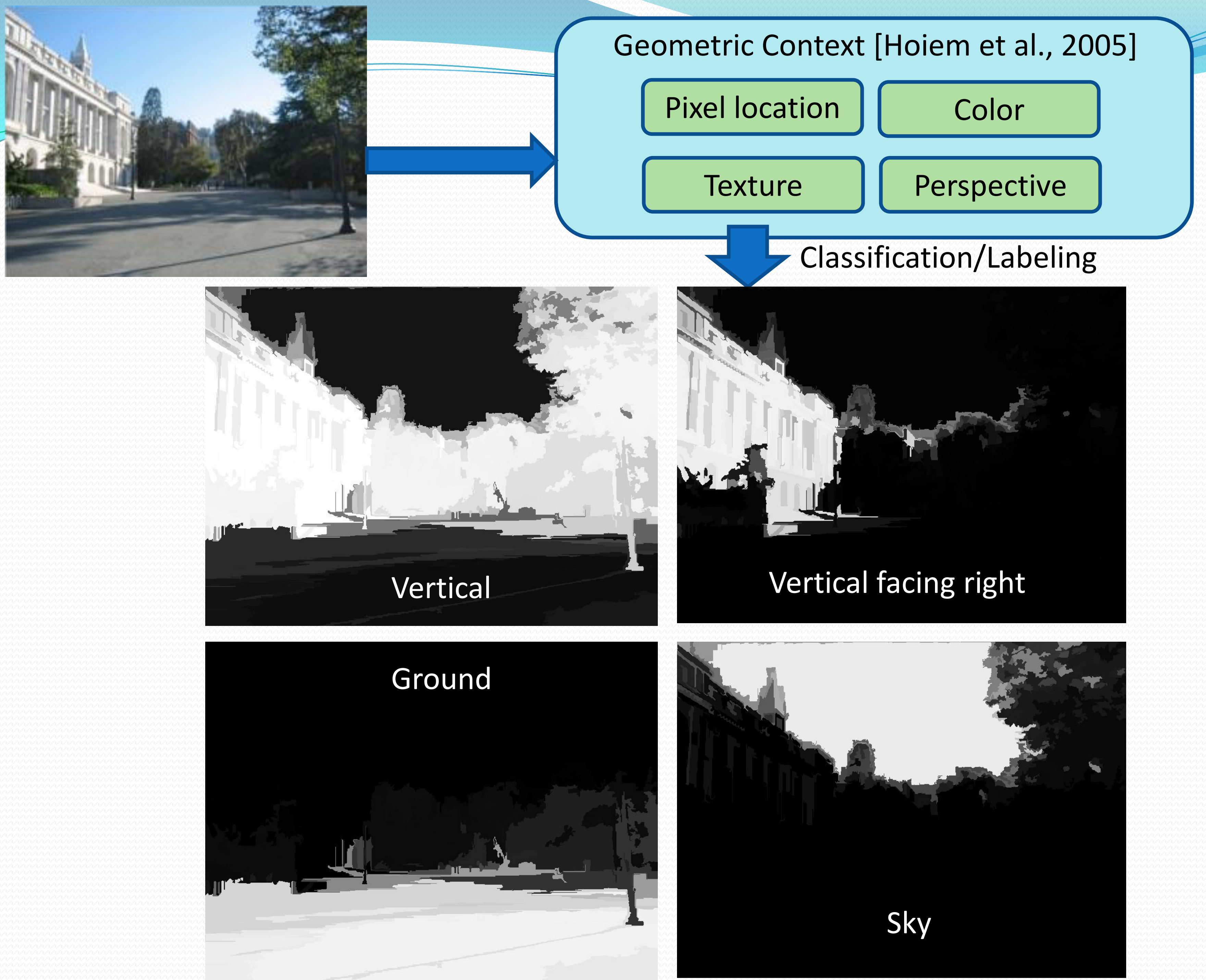
”Webcam Clip Art” [Lalonde et al., 2009]



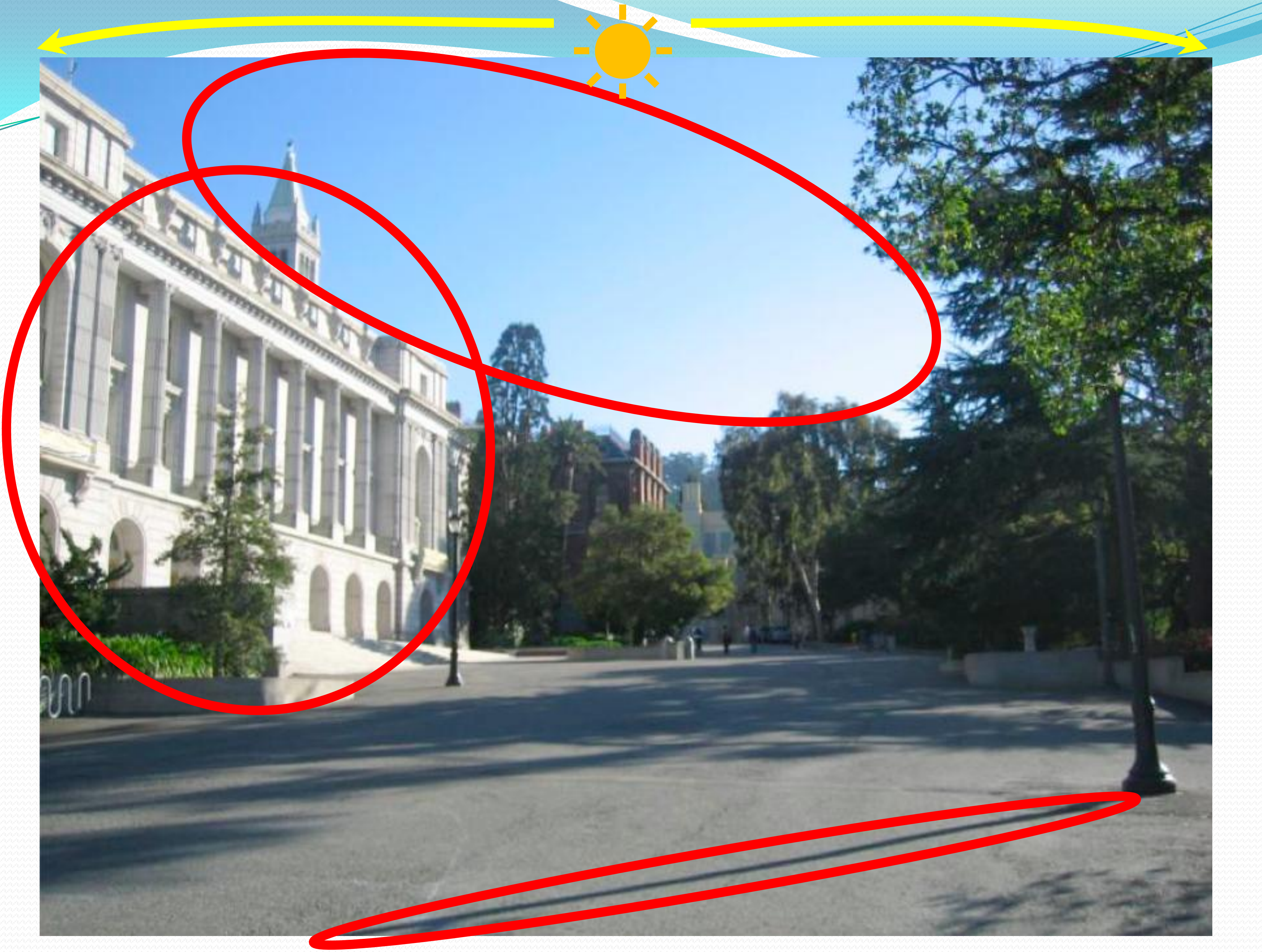
Outdoor Illumination from Single Image

- Estimating Natural Illumination from a Single Outdoor Image [Lalonde et al., 2009]
  - Estimating sun position and sky color
  - Using image cues:
    - Sky color
    - Shadow lines
    - Shading of vertical surfaces

[Lalonde et al., ICCV 2009]

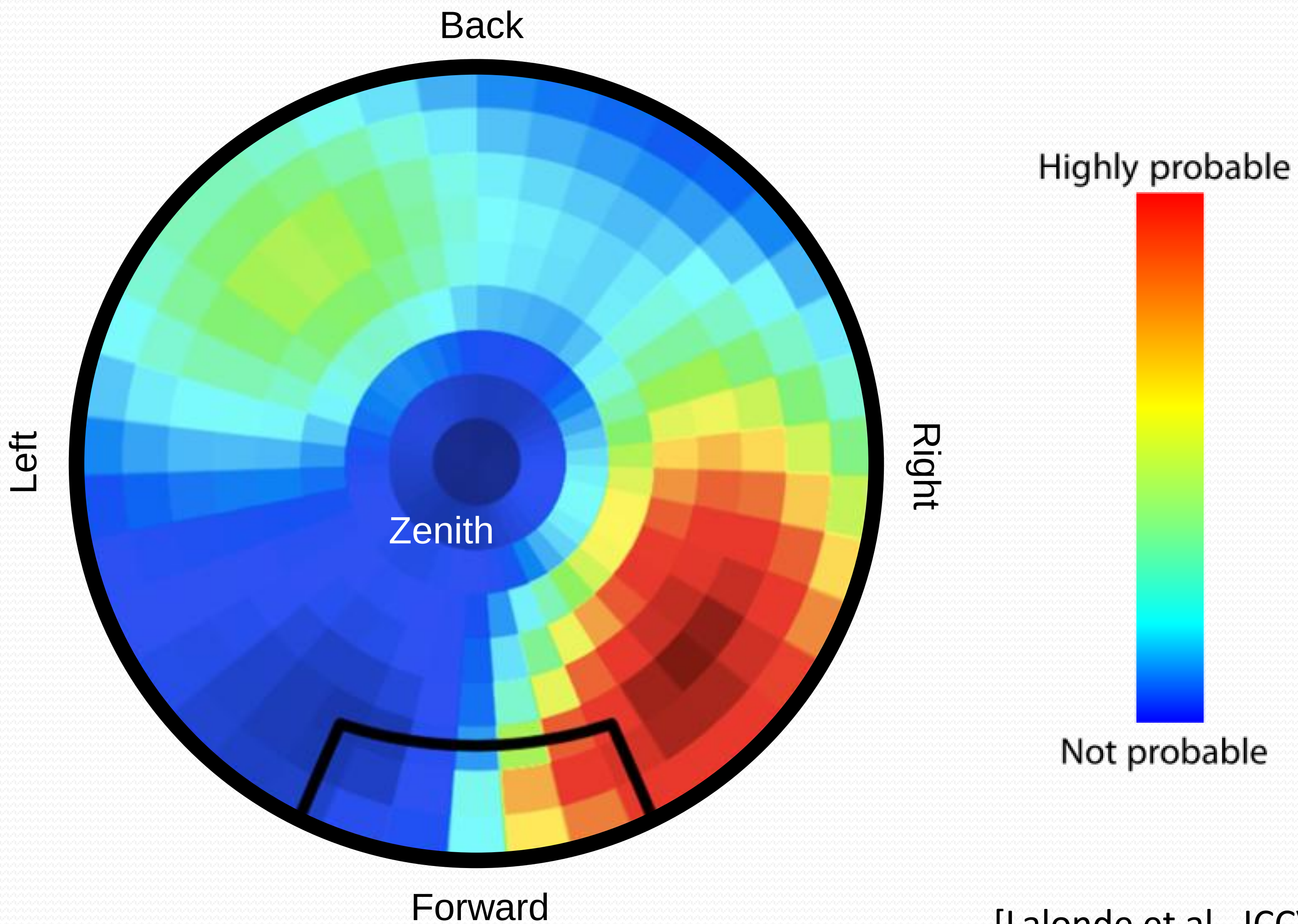


Geometric Context [Hoiem et al., 2005]
Pixel location
Color
Texture
Perspective
Classification/Labeling
Vertical
Vertical facing right
Ground
Sky



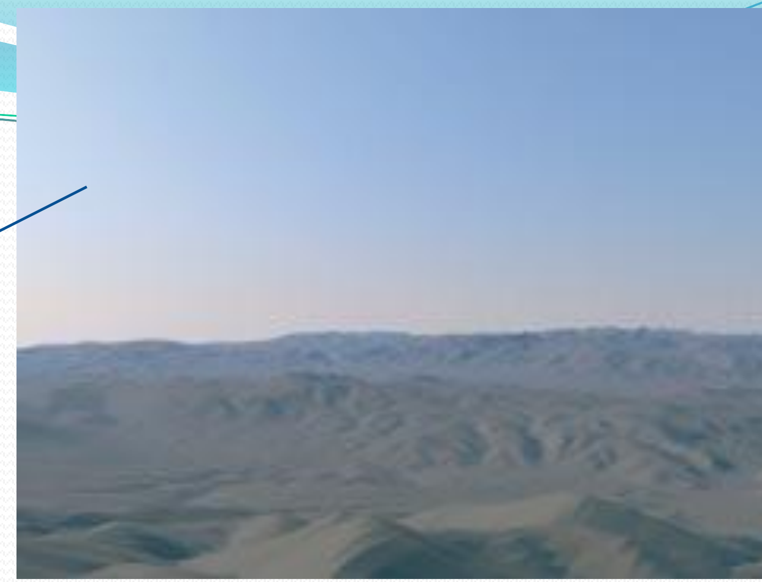
[Lalonde et al., ICCV 2009]

Sun probability distribution map



[Lalonde et al., ICCV 2009]

Sky Model



Sky luminance

$$l_p = f(\theta_p, \gamma_p) = [1 + a \exp(b / \cos\theta_p)] \times [1 + c \exp(d\gamma_p) + e \cos^2 \gamma_p]$$

zenith angle

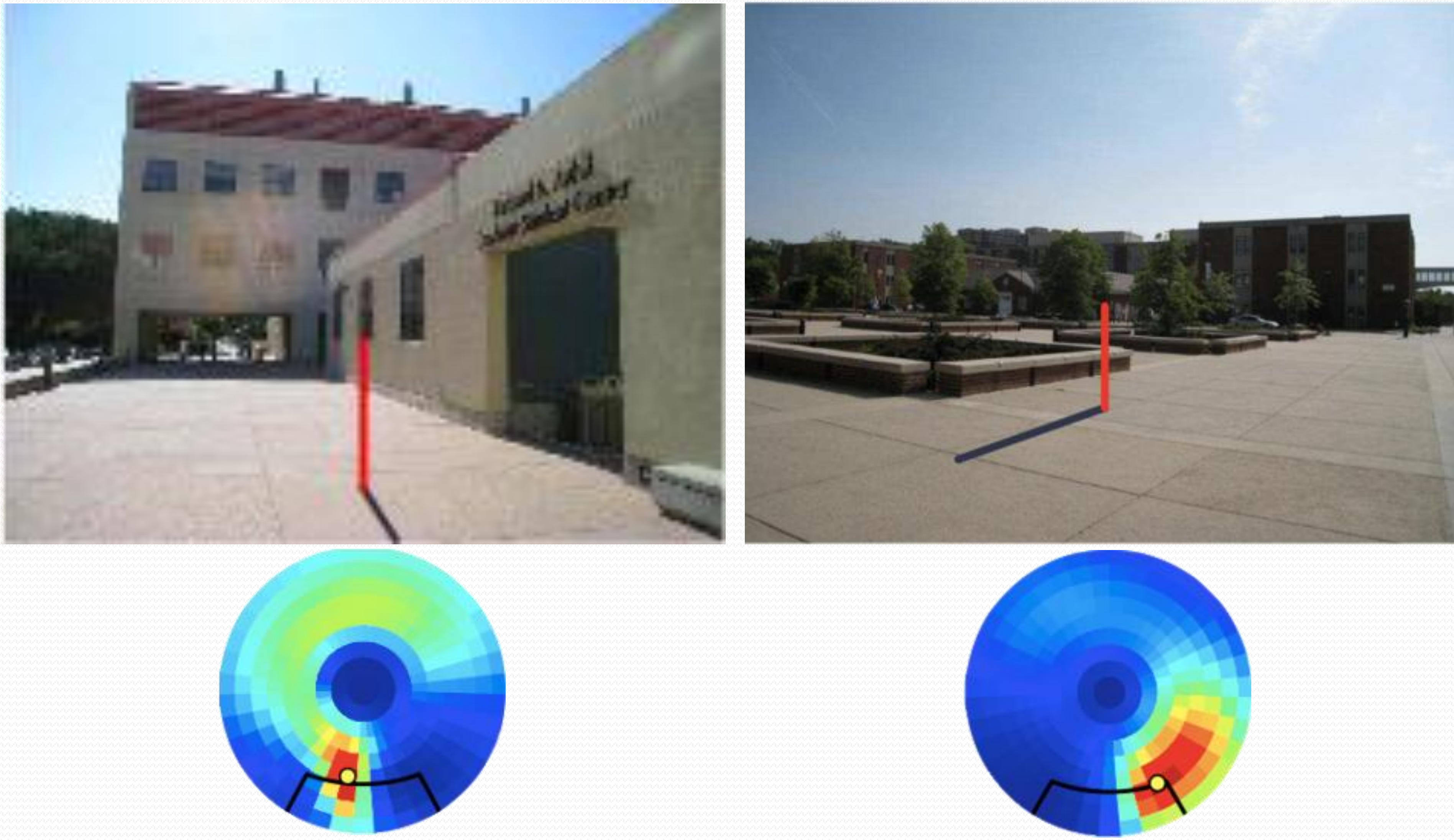
angle with the sun

- [Perez et al., 1993] and [Preetham et al., 1999]
- a,b,c,d,e can be approximated with a linear function of a single parameter, **t (turbidity)**
- In this work, sky is assumed to be clear (t = 2.17)
- Cloud is segmented by clustering based on color

Predicted sky at current sun position

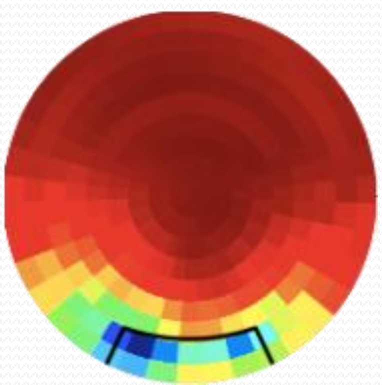
Original sky

[Lalonde et al., ICCV 2009]

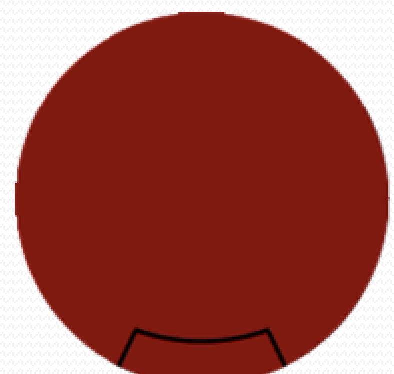


[Lalonde et al., ICCV 2009]

Sun behind camera

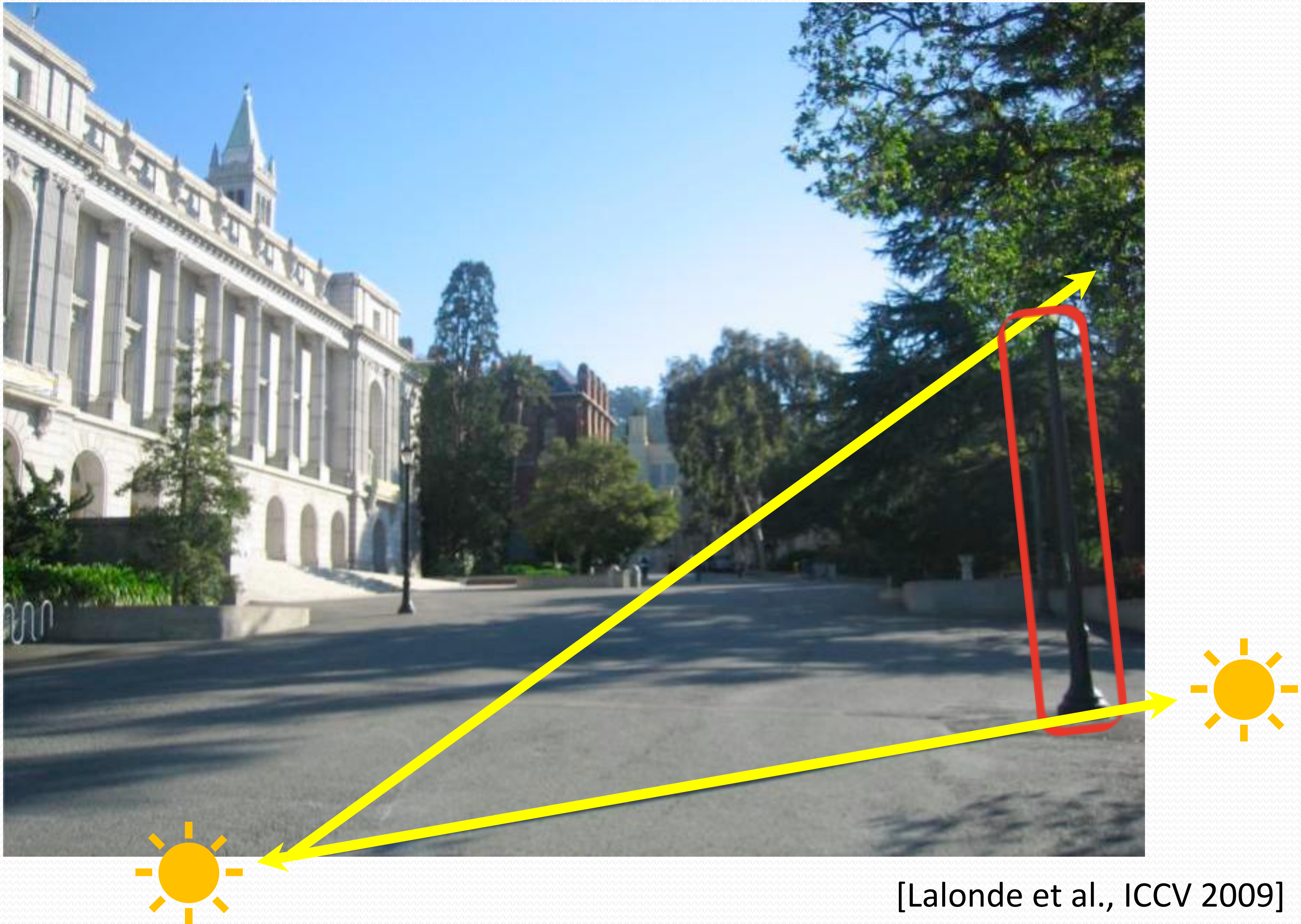


Sky not visible



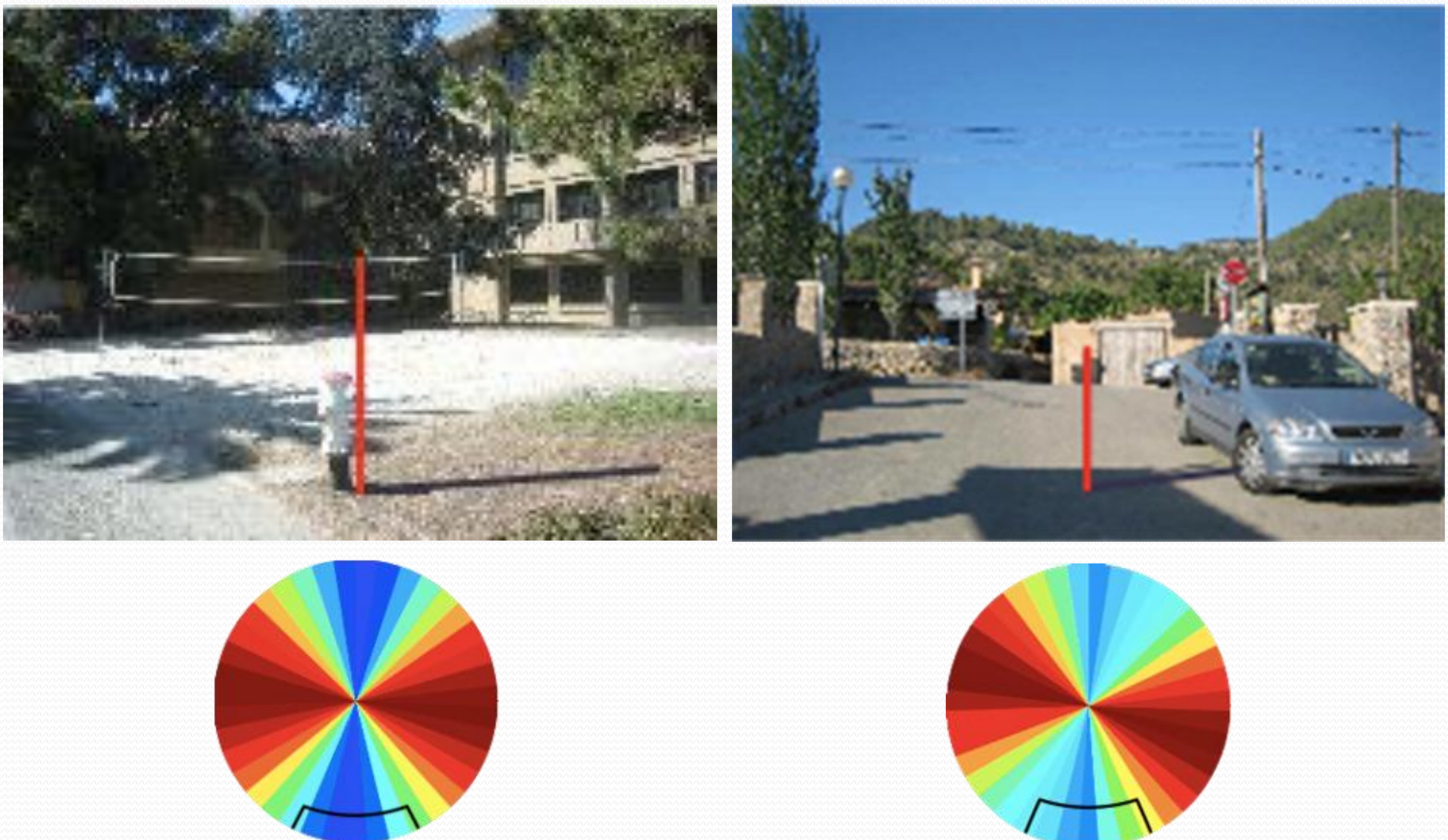
[Lalonde et al., ICCV 2009]

Ground shadows



[Lalonde et al., ICCV 2009]

[Lalonde et al., ICCV 2009]



[Lalonde et al., ICCV 2009]

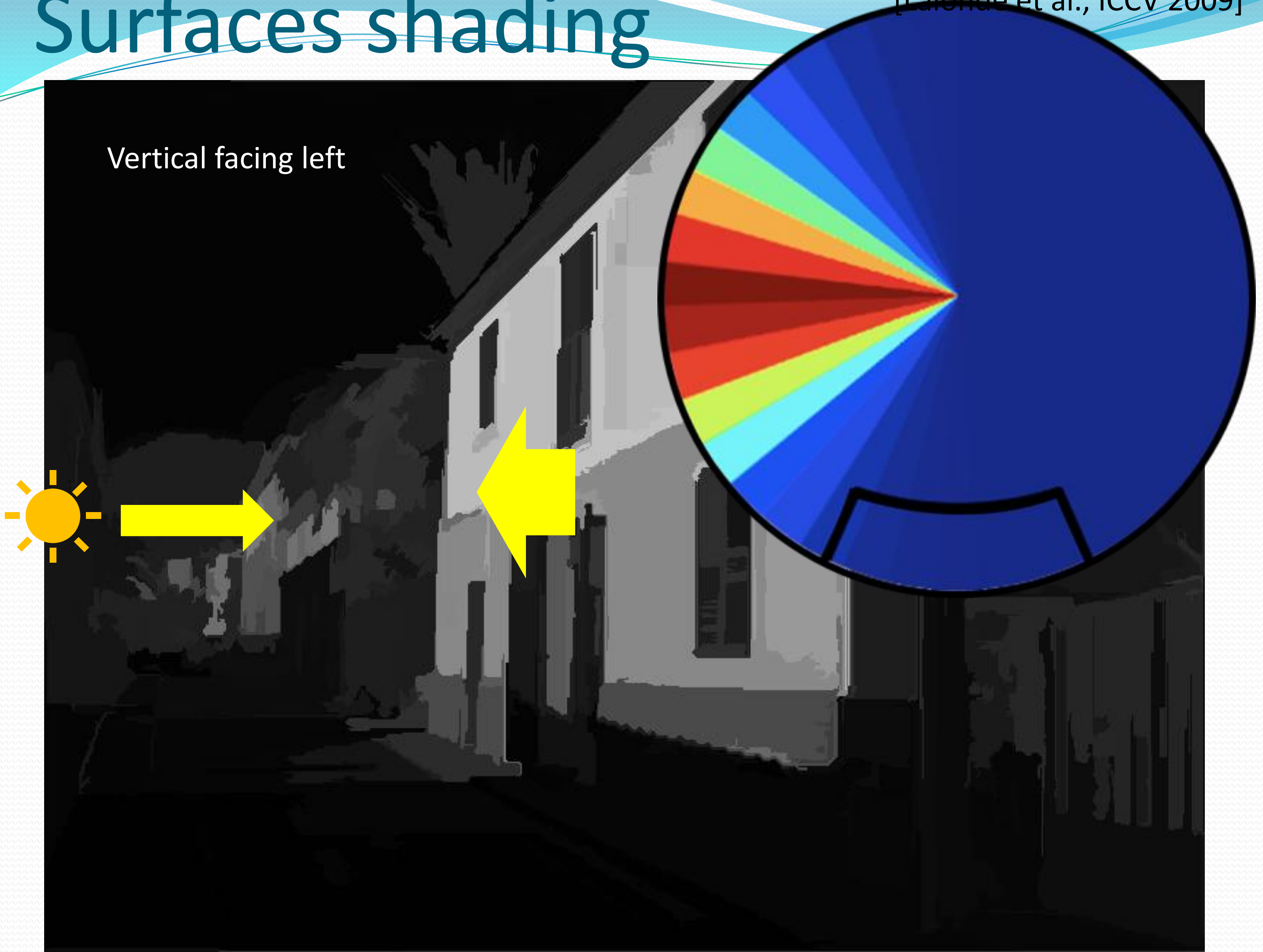
Shadow detection

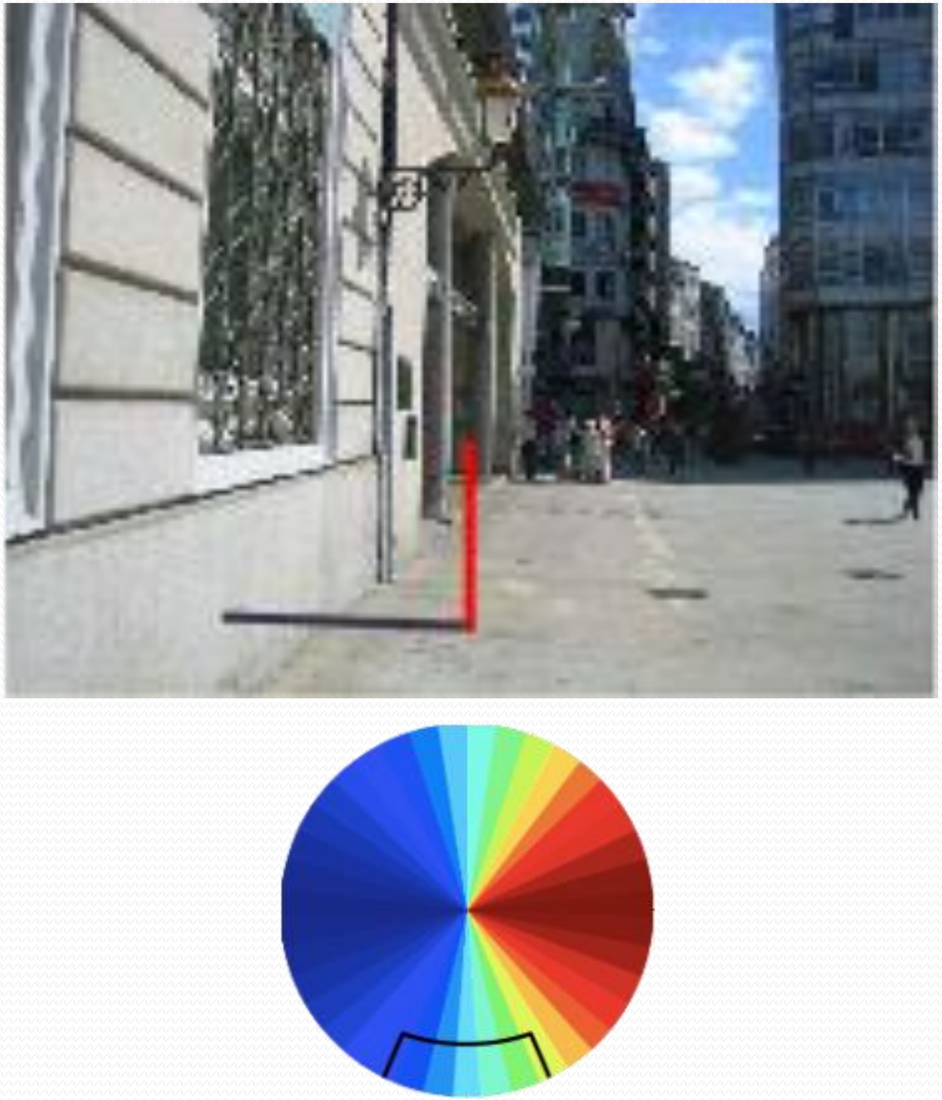
Non-vertical objects

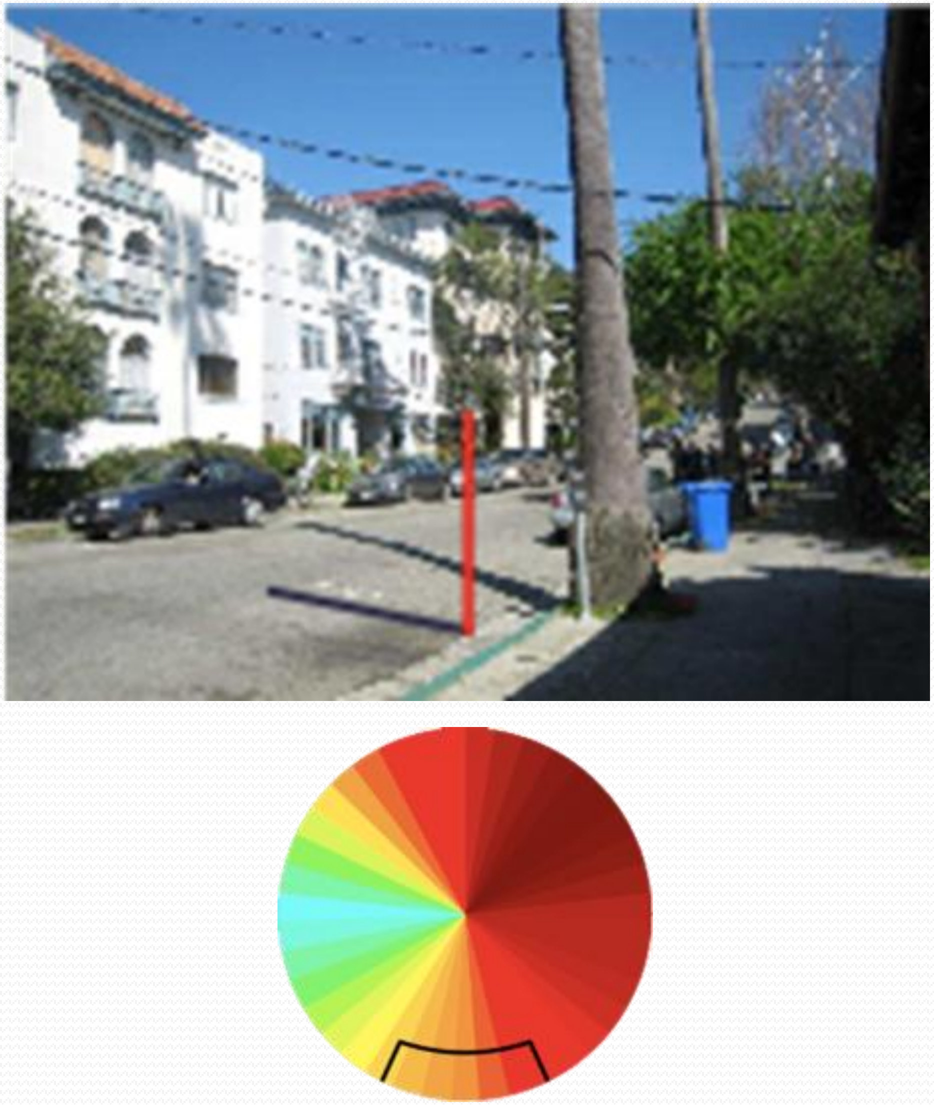
[Lalonde et al., ICCV 2009]

Surfaces shading

[Lalonde et al., ICCV 2009]

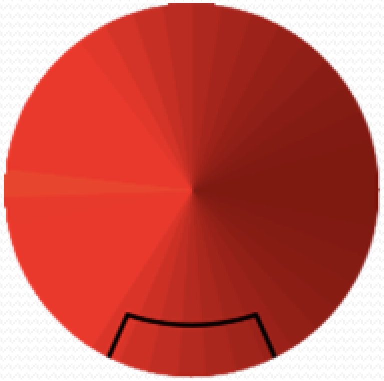






[Lalonde et al., ICCV 2009]

No flat surface



[Lalonde et al., ICCV 2009]

Cue Combination

Sun position

Sky pixels

Ground pixels

Vertical surface pixels

$$P(I \mid \mathcal{S}, \mathcal{G}, \mathcal{V})$$

Bayes rule

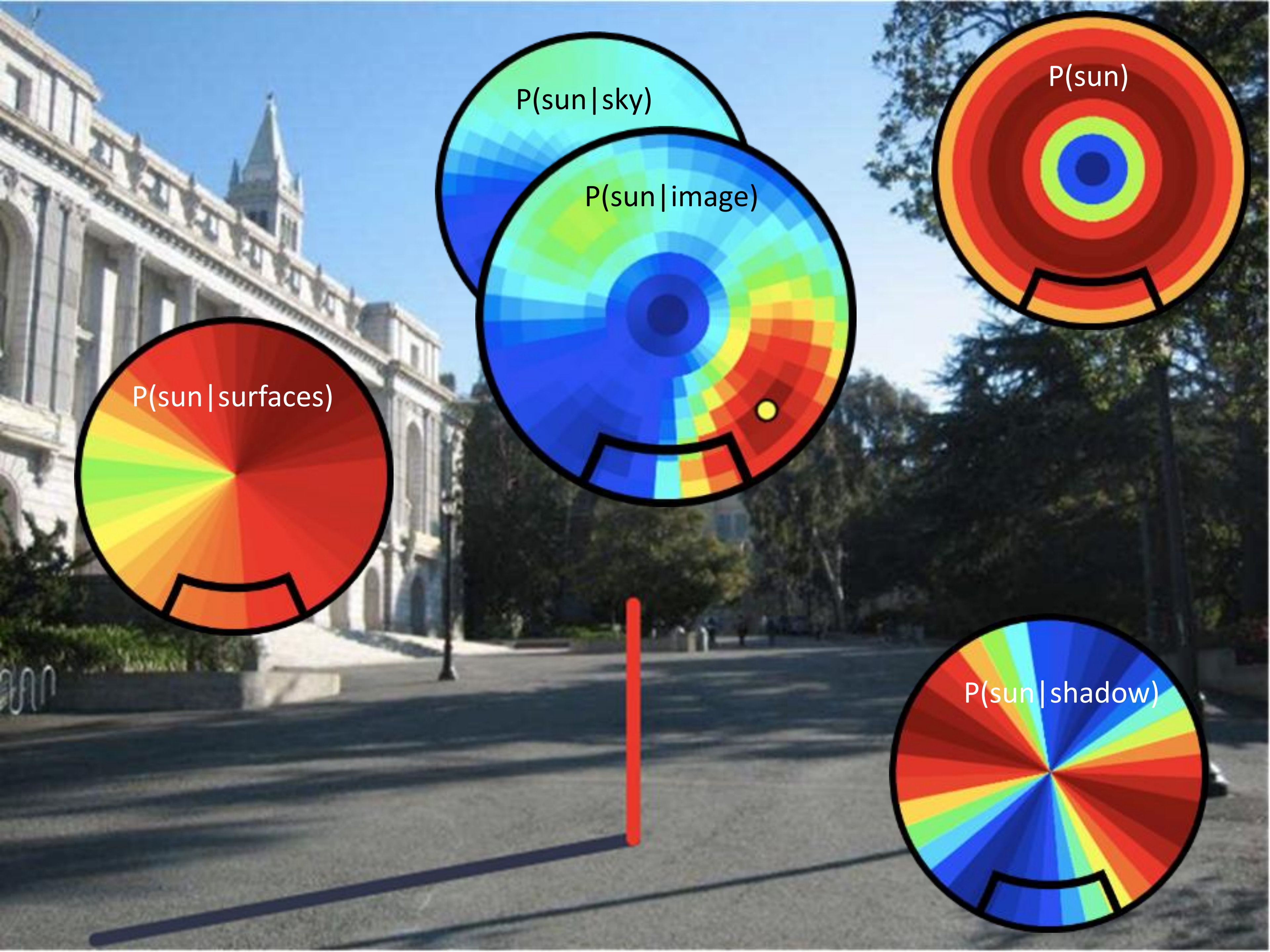
$$P(I \mid \mathcal{S}, \mathcal{G}, \mathcal{V}) \propto P(I \mid \mathcal{S})\, P(I \mid \mathcal{G})\, P(I \mid \mathcal{V})\, P(I)$$

Sky color

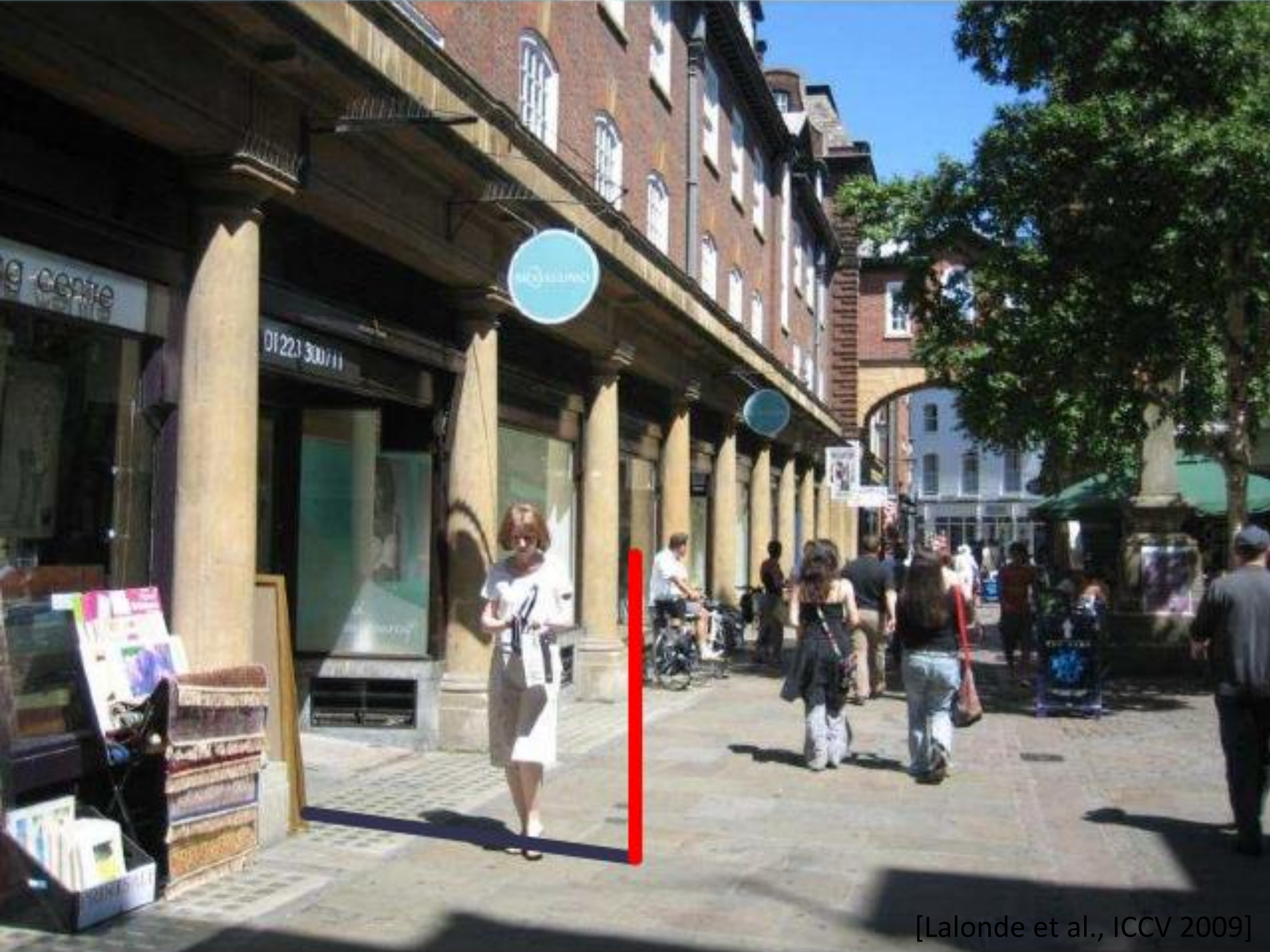
Ground shadow

Vertical surface

Sun position prior


P(sun|sky)
P(sun|image)
P(sun)
P(sun|surfaces)
P(sun|shadow)

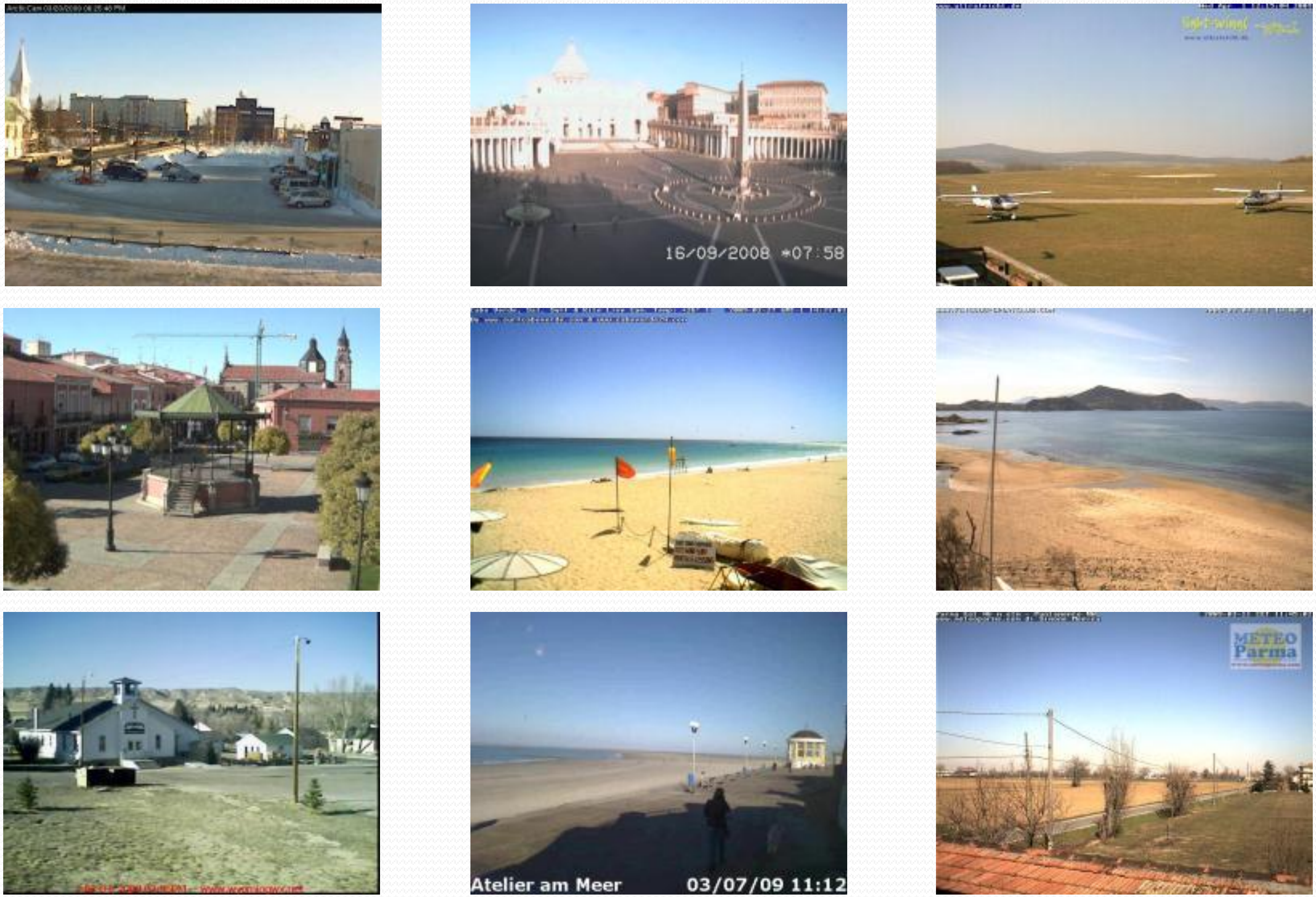
[Lalonde et al., ICCV 2009]



[Lalonde et al., ICCV 2009]

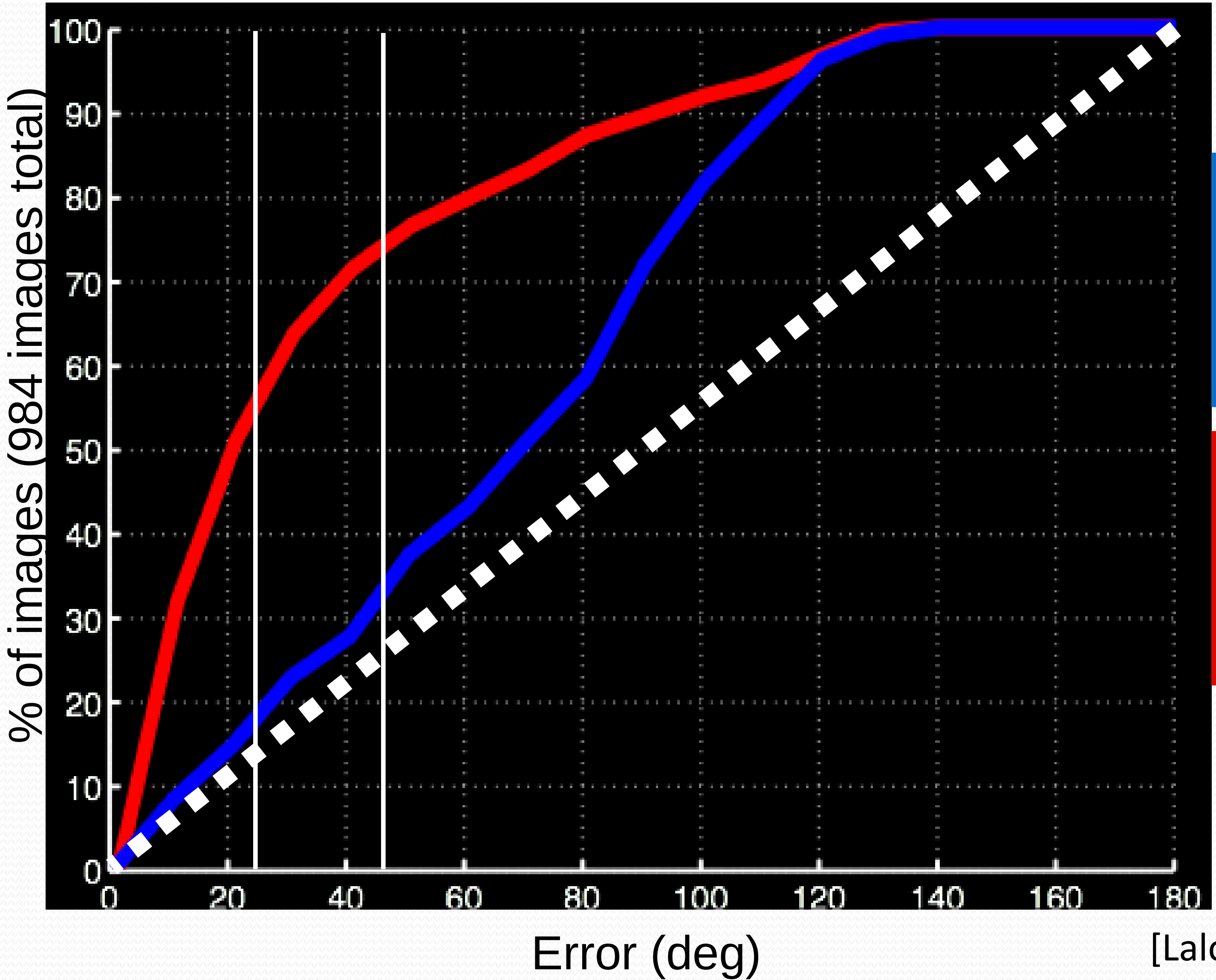
[Lalonde et al., ICCV 2009]

Quantitative evaluation



[Lalonde et al., ICCV 2009]

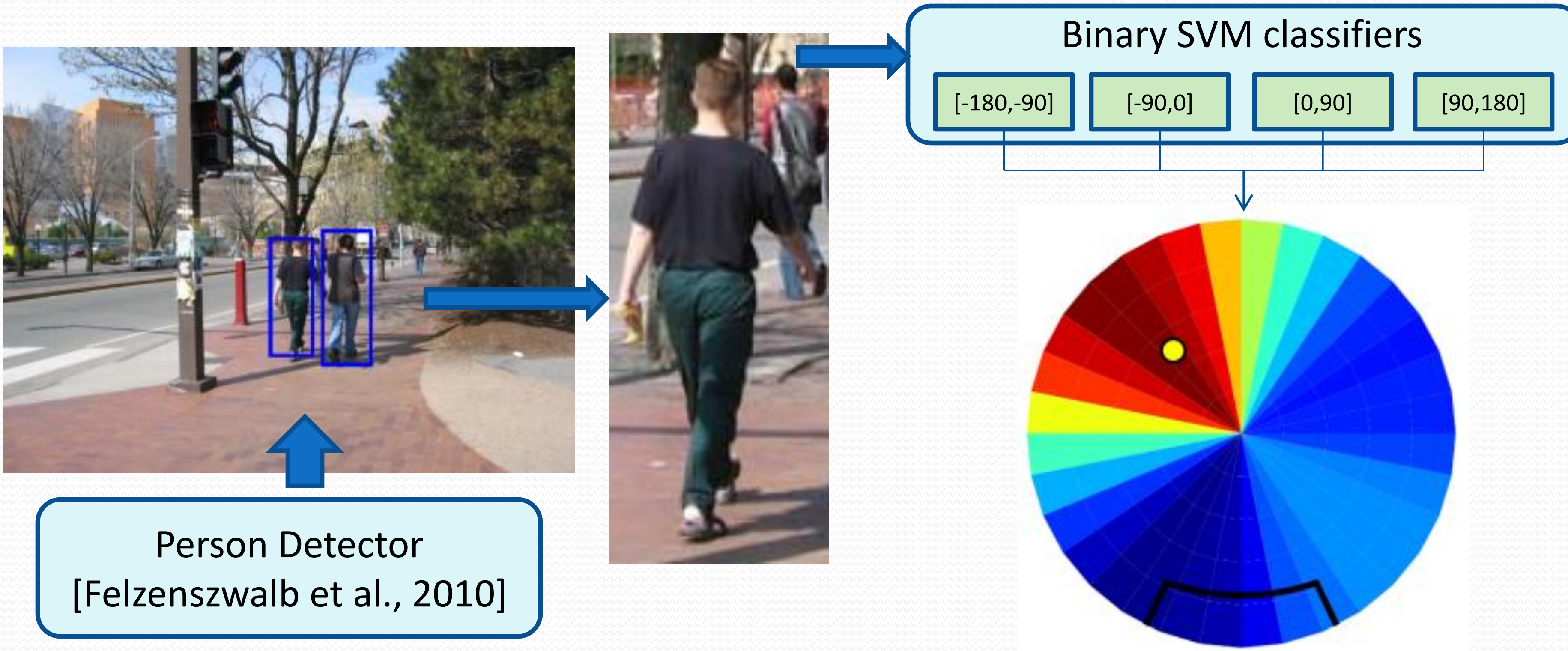
Quantitative evaluation



[Lalonde et al., ICCV 2009]

[Lalonde et al., ICCV 2009]

- Code and Dataset
  - http://www.jflalonde.org/projects/outdoorIllumination/
  - Currently only the code for the Sky model is available
- Extension in Lalonde’s PhD thesis [2011]
  - Find sun direction by person appearance



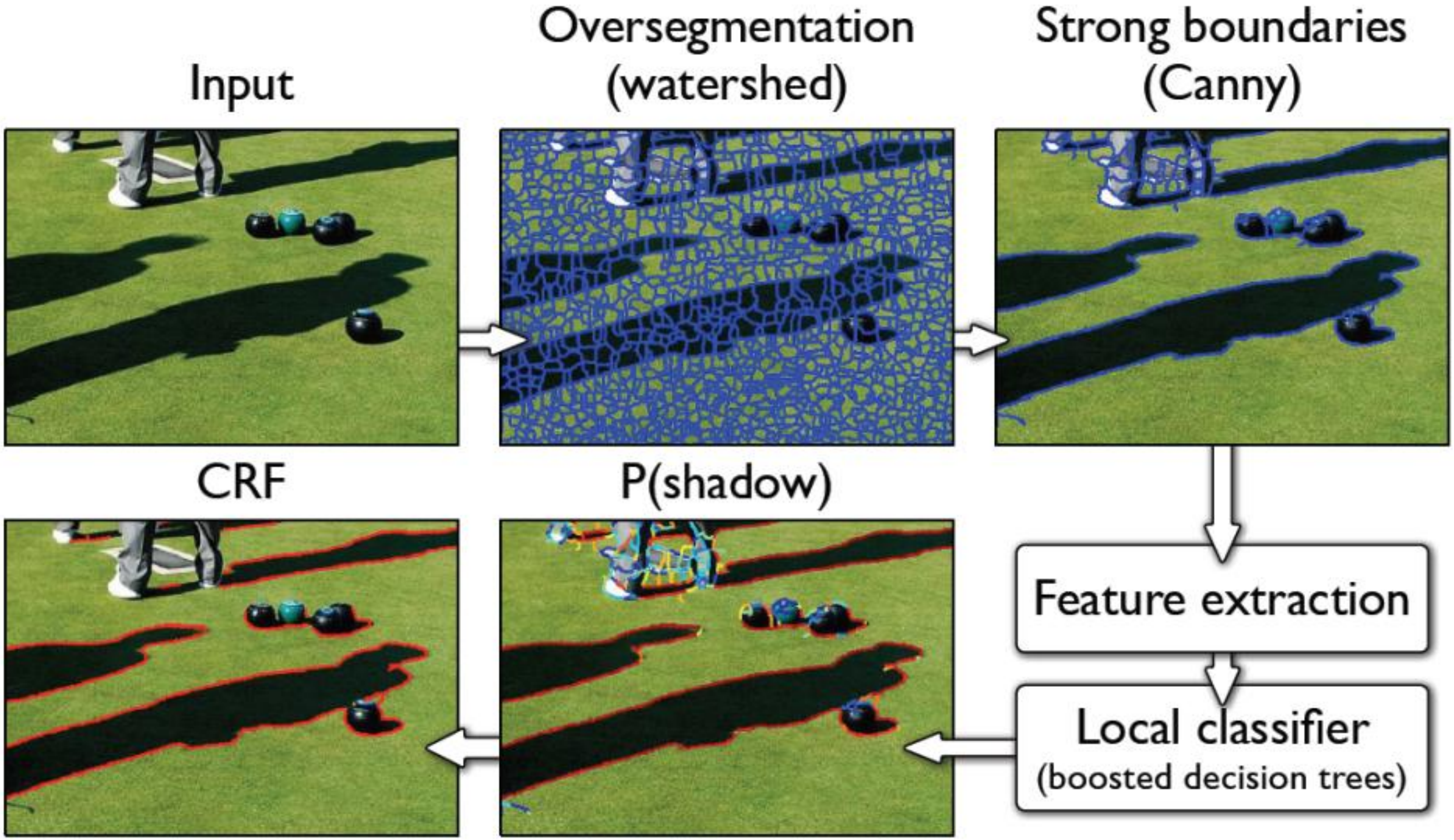
Shadow Detection

- Application
  - Estimating outdoor illumination
  - Shadow removal
  - Detecting Ground Shadowsin Outdoor Consumer Photographs [Lalonde et al., ECCV 2010]
  - Single-Image Shadow Detection and Removal using Paired Regions [Guo et al., CVPR 2011]

Detecting Ground Shadows in Outdoor Consumer Photographs

- [Lalonde et al., ECCV 2010]
- **Observation:** photometric methods do not work well on consumer images (not linear, lossy compression)
- **Hypothesis:** appearances of shadows *on the ground* are less varied than shadows in general, and *can be learned* from labeled images.

Learning shadow appearance



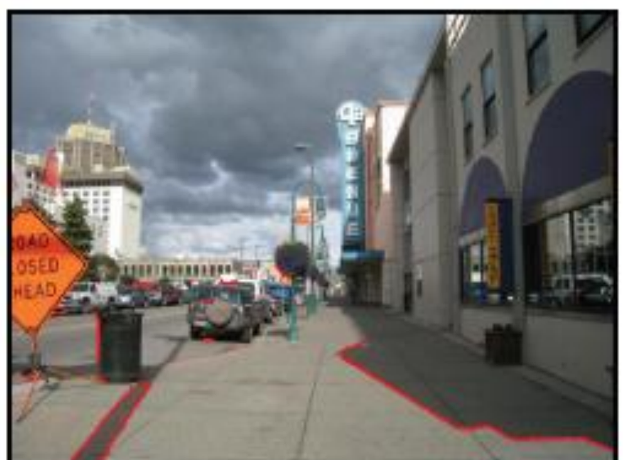
Incorporating scene layout

Input

Shadows

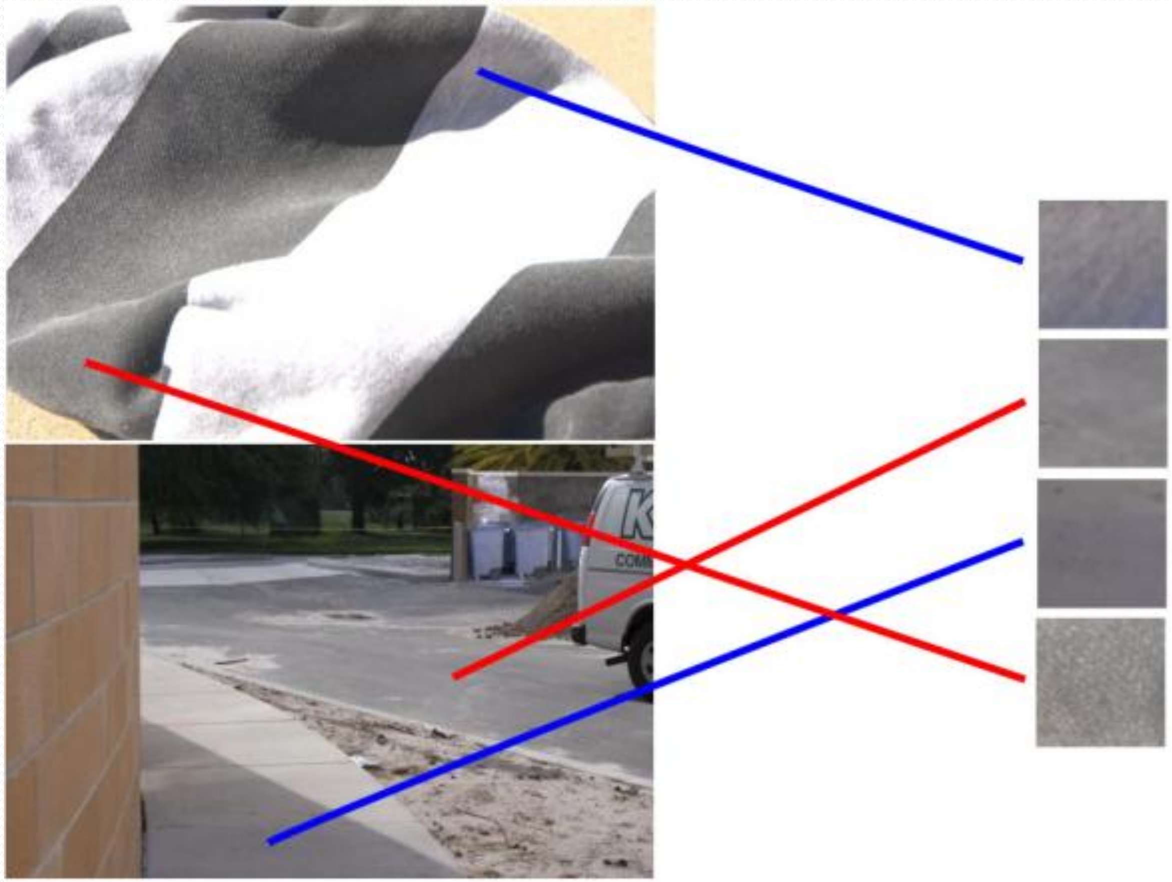
P(ground)

Ground shadows

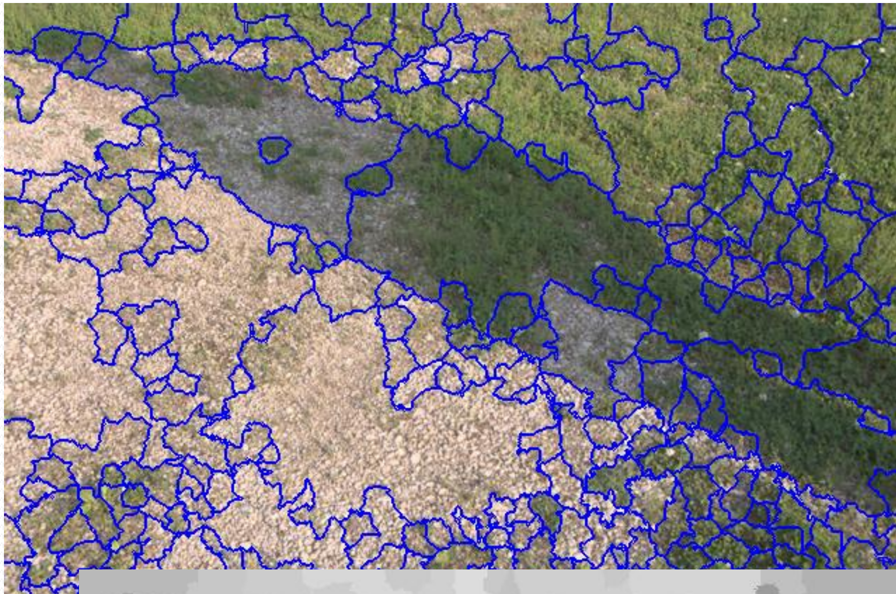


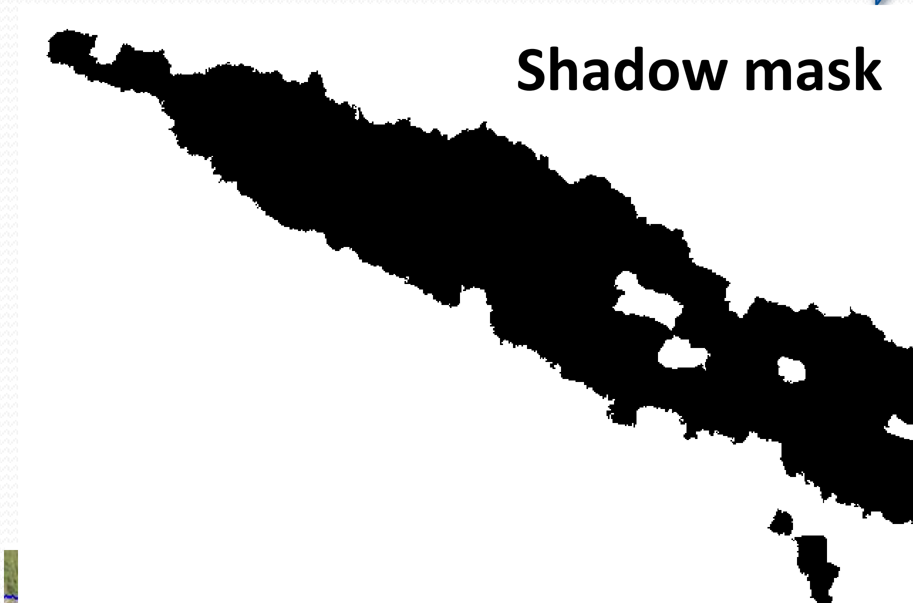
Single-Image Shadow Detection and Removal using Paired Regions

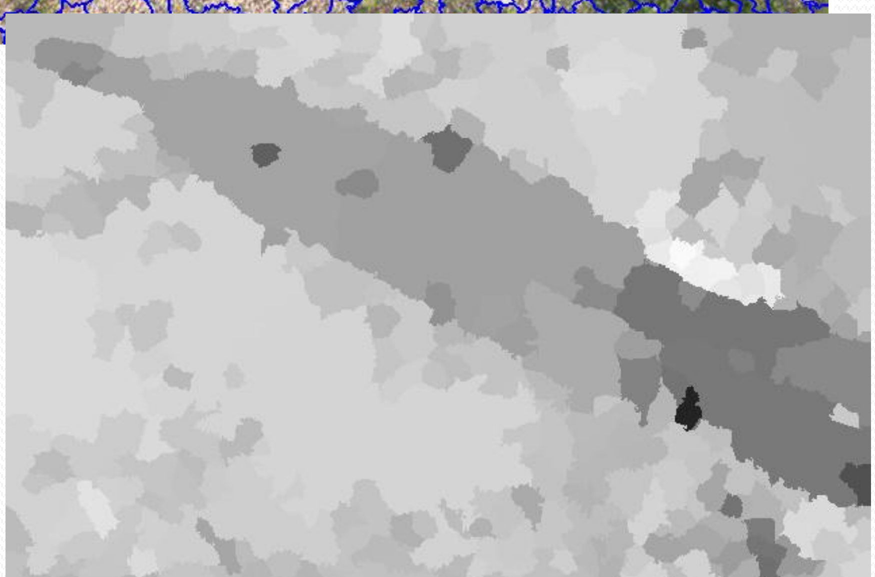
- [Guo et al., CVPR 2011]

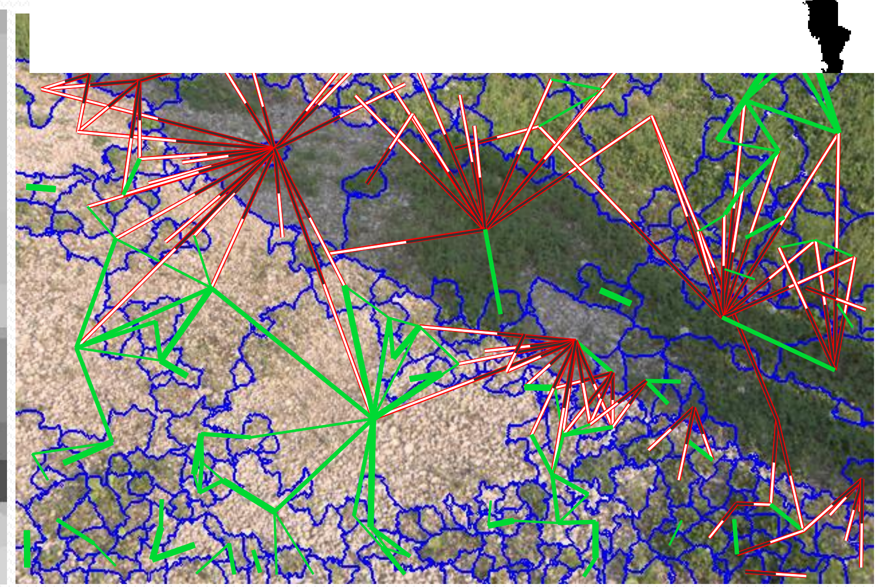


- Segmentation
- Single/Pairwise region classification
- Shadow Labeling
- Soft shadow matting
- Shadow removal










Lalonde’s method


Guo’s method

Lalonde’s method

Guo’s method

Practical Issues

- Applying to outdoor illumination estimation
  - Segmentation (region based)
    => does not work well on thin shadows

Lalonde’s method

Guo's method

Thank you

- Questions?

Question

I: illumination (sun direction)
S: sky pixels
G: ground pixels
V: vertical surface pixels
S,G,V: input image

$$P(I \mid \mathcal{S}, \mathcal{G}, \mathcal{V}) = \frac{P(\mathcal{S}, \mathcal{G}, \mathcal{V} \mid I)\, P(I)}{P(\mathcal{S}, \mathcal{G}, \mathcal{V})}$$

Bayes rule

$$\Longrightarrow \quad P(I \mid \mathcal{S}, \mathcal{G}, \mathcal{V}) \propto P(\mathcal{S}, \mathcal{G}, \mathcal{V} \mid I)\, P(I)$$

$$\Longrightarrow \quad P(I \mid \mathcal{S}, \mathcal{G}, \mathcal{V}) \propto P(\mathcal{S} \mid I)\, P(\mathcal{G} \mid I)\, P(\mathcal{V} \mid I)\, P(I)$$

Assuming conditional independence

$$P(\mathcal{S} \mid I) = \frac{P(I \mid \mathcal{S})\, P(\mathcal{S})}{P(I)}$$

Bayes rule

Can we ignore this?

$$\Longrightarrow \quad P(\mathcal{S} \mid I) \propto P(I \mid \mathcal{S})\, P(\mathcal{S})$$

$$\Longrightarrow \quad P(\mathcal{S} \mid I) \propto P(I \mid \mathcal{S})$$

$$P(I \mid \mathcal{S}, \mathcal{G}, \mathcal{V}) \propto P(I \mid \mathcal{S})\, P(I \mid \mathcal{G})\, P(I \mid \mathcal{V})\, P(I)$$