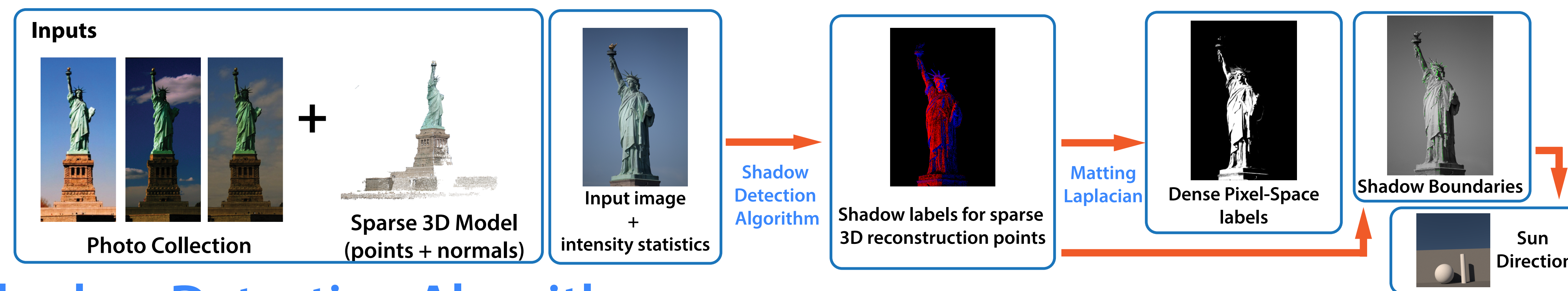


Shadow Detection and Sun Direction in Photo Collections

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<http://www.cs.cornell.edu/projects/shadows>

System Overview



Motivation

- Appearance modeling in outdoor photo collections is challenging because many factors affect image intensity.
- Existing approaches tend to model many elements at once, using complex algorithms and unstable nonlinear optimization.
- **Shadow detection** is a simpler, more tractable problem that can nonetheless reveal a lot about the illumination in a scene.
- **Sun direction** is an important illumination property linked to capture time and applicable to more detailed lighting estimation, relighting, and other applications.

Contributions

- Introduction and analysis of the *Illumination Ratio*, a quantity that captures the relative illumination of two scene points in an image, invariant to albedo and camera exposure.
- An algorithm using the illumination ratio to estimate binary shadow labels for points in a large Internet photo collection.
- A method for using sparse shadow labels to estimate the direction of the sun.

The Illumination Ratio

Image Formation Model:

$$I_i(x) = \rho_x E_i [C_{x,i} L_d \cos(\phi_{x,i}) + L_a]$$

The Illumination Ratio:

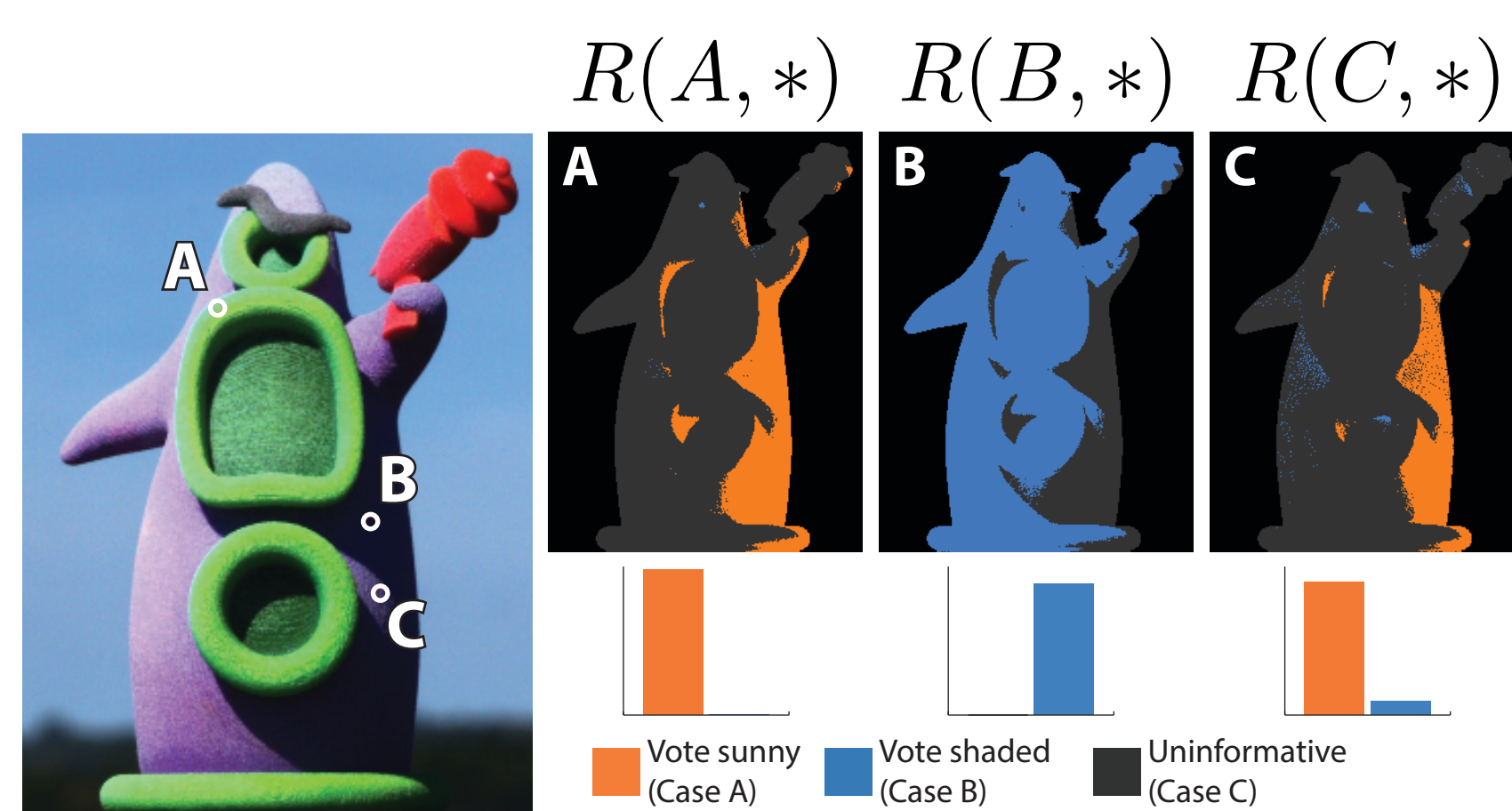
$$R(x, y) = \frac{I_i(x)}{\mathcal{E}_i[I_i(x)]} = \frac{\text{Intensity of } x}{\text{Average intensity of } x}$$

$$= \frac{I_i(y)}{\mathcal{E}_i[I_i(y)]} = \frac{\text{Intensity of } y}{\text{Average intensity of } y}$$

$$= \frac{\rho_x E_i L_{i,x}}{\rho_x \mathcal{E}_i [E_i L_{i,x}]} = \frac{C_x \cos(\phi_x) + f}{C_y \cos(\phi_y) + f} \quad f = \frac{L_a}{L_d}$$

Key Properties:

- Invariant to albedo and exposure
- Captures relative illumination of x and y.



Shadow Detection Algorithm

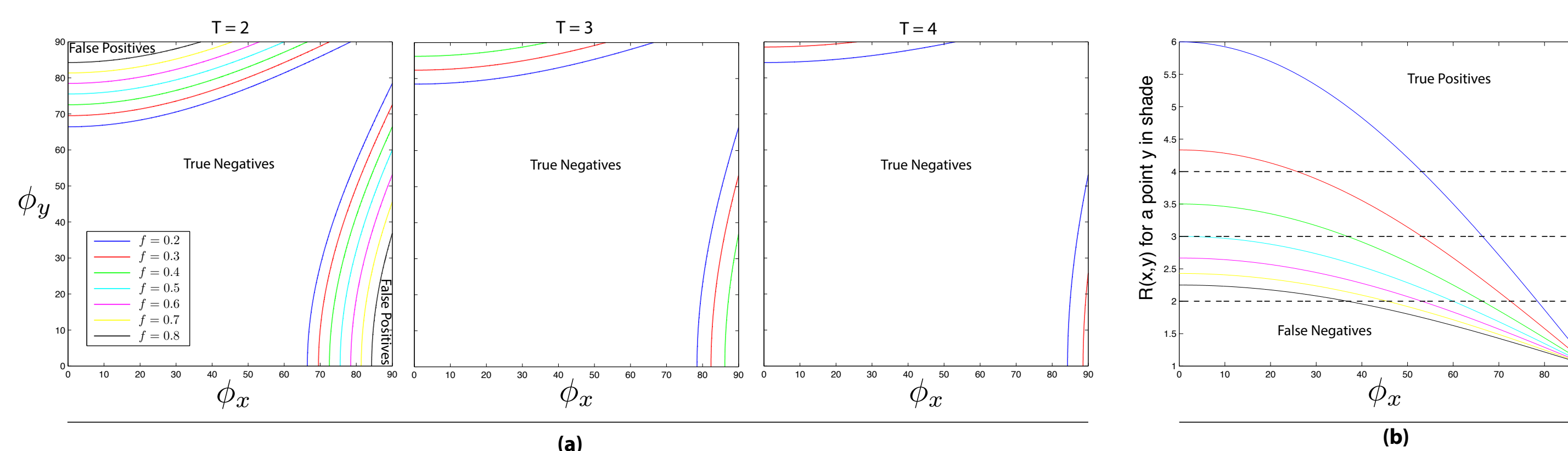
Key Idea: Compute illumination ratio among many pairs of points, and aggregate information by voting.

For each point x :

1. Pick K other points $y_1 \dots y_K$
2. For each y_j :
 - If $R(x, y_j) > T$: cast a vote for x being sunlit.
 - If $R(x, y_j) < 1/T$: cast a vote for x being shaded.
 - Otherwise: cast no vote
3. Assign x 's label according to majority vote.
4. Use the Matting Laplacian [Levin et al. 2006] to estimate dense pixel-space labels from projected 3D point labels

How do we choose T ?

No ideal value, because $\cos(\phi)$ and L_a/L_d both vary and are unknown *a priori*. Because of voting, the threshold needs to be correct a majority of the time. $T=3$ works empirically and is supported by our analysis based on possible values of $\cos(\phi)$ and L_a/L_d .

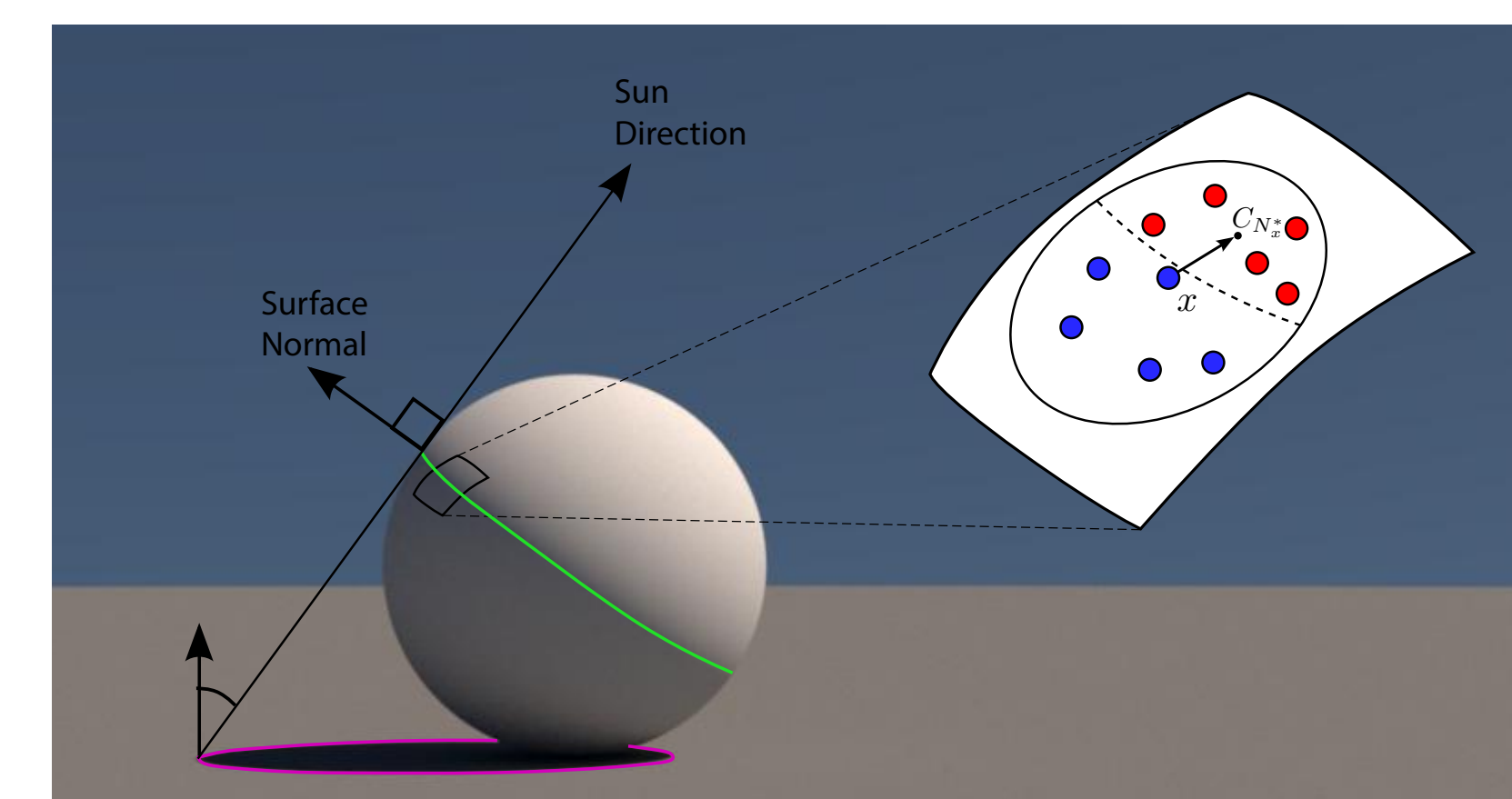


Results: Shadow Detection



Application: Sun Direction Estimation

Key Idea: Surface normals at attached shadow boundaries are orthogonal to the sun direction.



Algorithm:

1. Find shadow boundaries: $B_i(x) = c_{sign} \frac{|N_x^*|}{|N_x|} (C_{N_x^*} - x)$
 2. Use RANSAC to find consensus sun direction, discarding cast shadow boundaries and outliers.
- OR
2. If scene is georegistered and date is known, test only hypotheses along the 1D sun path for that place and date.

Results: Sun Direction

