Joint Estimation of Multiple Light Sources and Reflectance from Images

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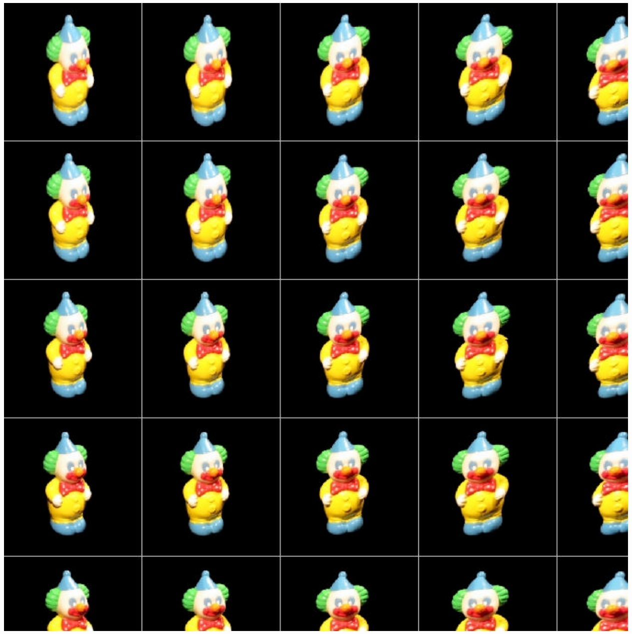
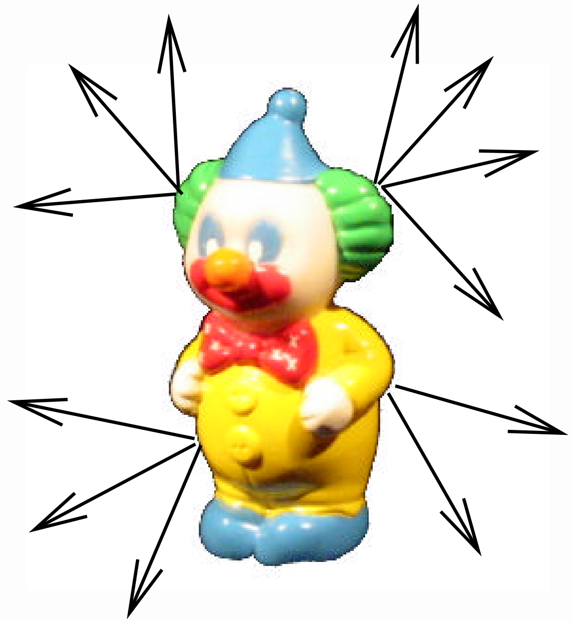
Goals

- From a set of images



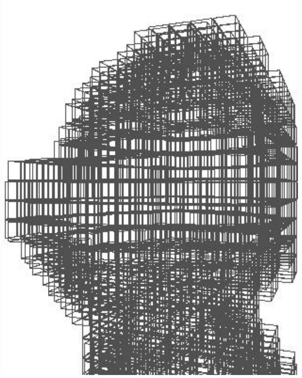


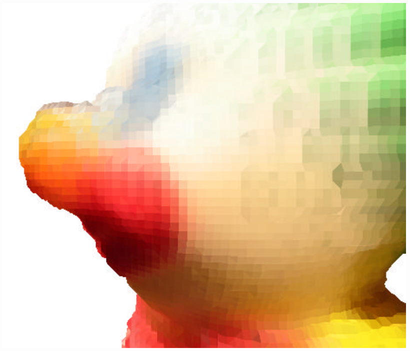
- Search for light sources
  - object geometry
  - joint estimation

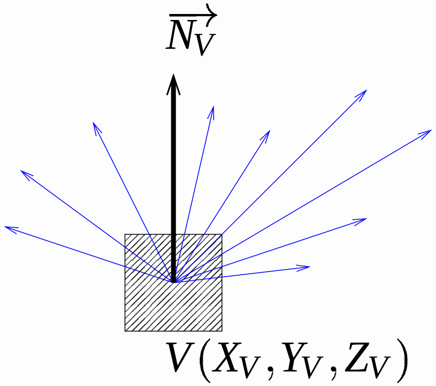
  $\Longrightarrow$ light sources & surface properties

Assumptions

- Geometry estimation [Sze93, LC87, MMF03]







octree — shape from silhouette | polygonal surface — marching cubes | voxel : normal — radiance samples

- Modified Phong-model [Lew94]

$$L_r = \frac{L_s K_d}{\pi r^2} \cos\theta + \frac{(n+2) L_s K_s}{2\pi r^2} \cos\theta \cos^n \phi$$

Work Overview

- Data organization
  - voxels classification
  - type of surface estimation
- Light source detection
  - point light source
  - directional light source
  - choose between point and directional
- Joint estimation
  - light sources
  - surface properties

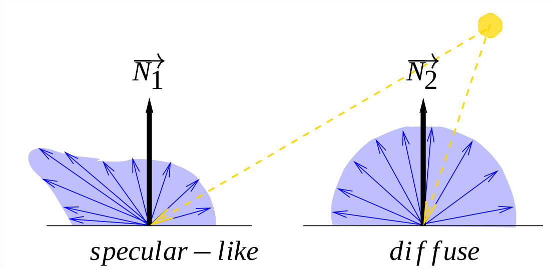
Classification

- 2 passes classification

hue + saturation ⇒ classes

- Type of surface : diffuse/specular

$$VC = \sqrt{\frac{\sum_{i=1}^{\#Vox} \sum_{j=1}^{\#Rad(V_i)} \left(\frac{L_j(V_i) - L^{average}(V_i)}{L^{average}(V_i)} \right)^2}{\#Radiances}}$$



- Light sources detection

Classification

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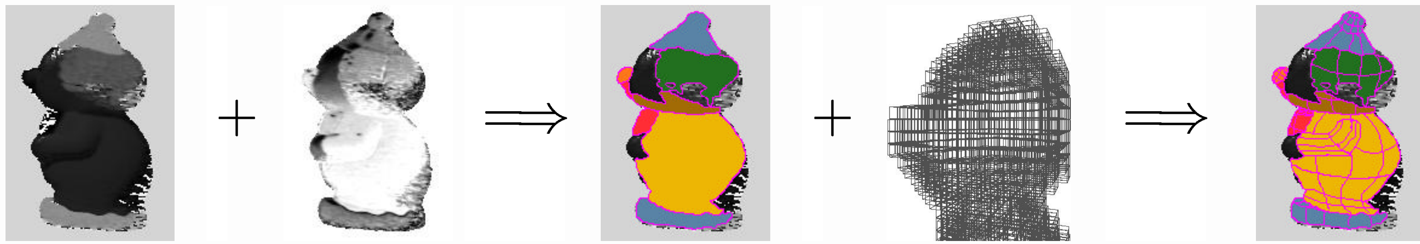

hue + saturation ⟹ classes + normals ⟹ subclasses

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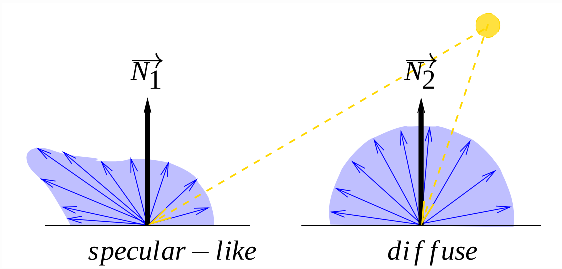
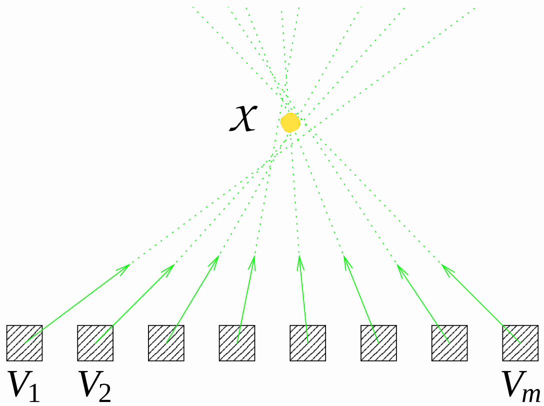


- Light sources detection

Algorithm

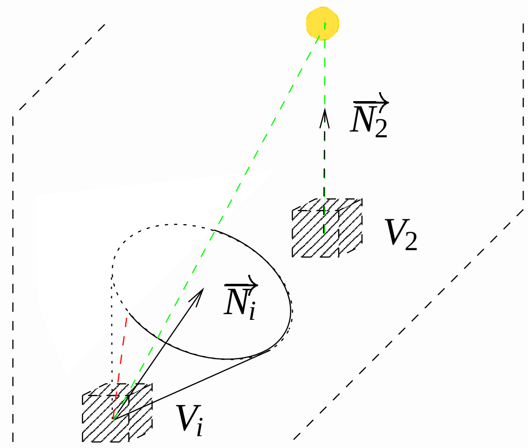
- Introduction
- Overview
- **Classification**
- Point Source
- Direct. Source
- Identification
- Results
- Conclusion

- For each subclass
  - for each voxel
    $\Longrightarrow$ estimation of the incident light direction
  - detecting a point light source
    $\Longrightarrow$ intersection
    - m incident light directions
    - 1 direction = 2 orthogonal planes
    - matrix system $\mathcal{M}\mathcal{X} = \mathcal{D}$
    - pseudo-inverse $\mathcal{X} = \mathcal{M}_{pi}\mathcal{D}$
    - Error $E_d = \sum_{i=1}^{2m} (\mathcal{M}_i\mathcal{X} - \mathcal{D}_i)^2$
  - detecting a directional light source
    $\Longrightarrow$ average



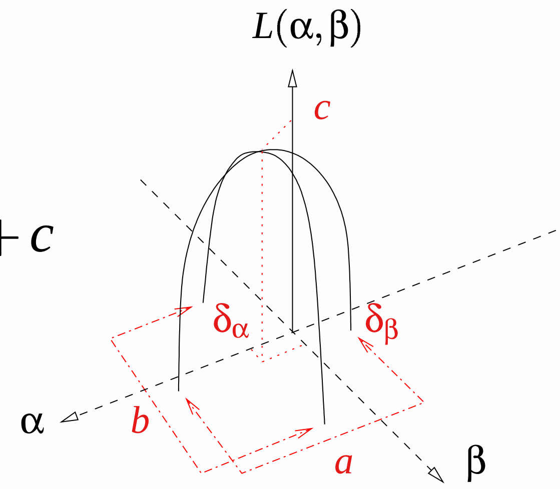
Point Light Source Detection

- Diffuse surface
  - radiance $L(V_i) = L_s K_d \cos(\theta_i)$
  - maximal radiance $L(V_2) = L_s K_d$
    $\theta_i = \cos^{-1}(L(V_i)/L(V_2))$
  - intersection



$\Longrightarrow$ light source position $\mathcal{X}$

- Specular-like surface
  - specular lobe : parabolic surface
    $L(\alpha,\beta) = a(\alpha - \delta_\alpha)^2 + b(\beta - \delta_\beta)^2 + c$
  - mirror direction $(\delta_\alpha, \delta_\beta)$
    gradient descent method
  - intersection



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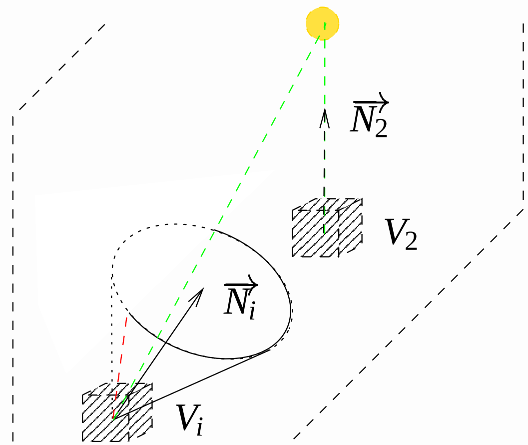

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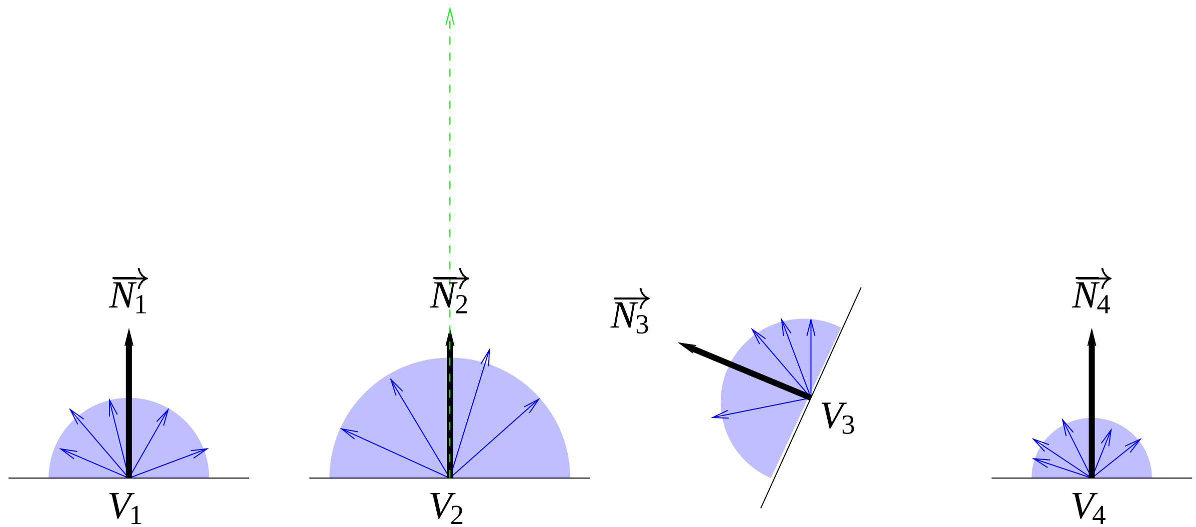

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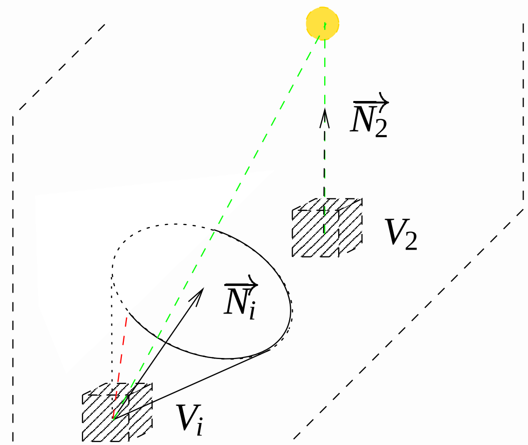

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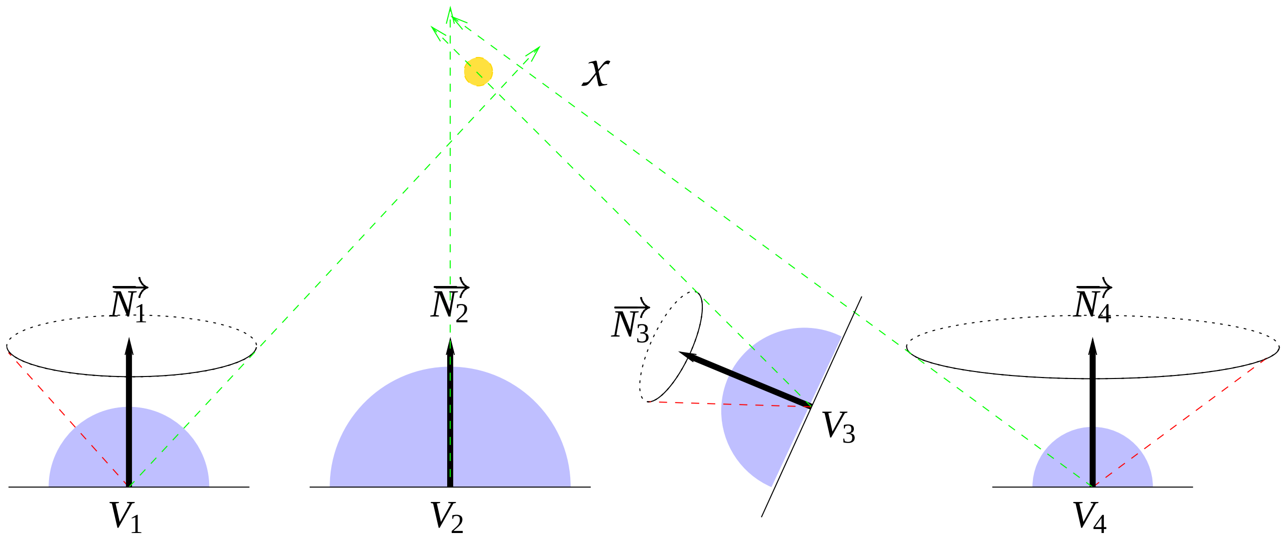

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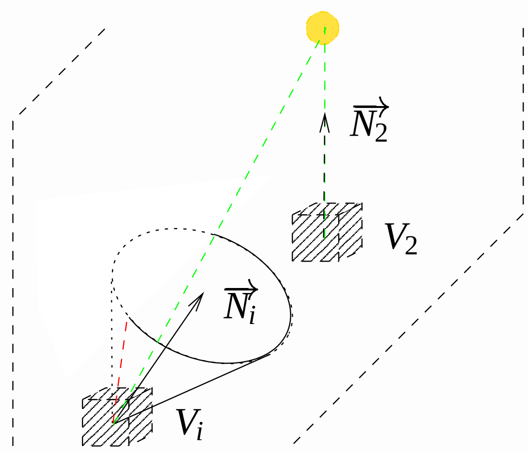

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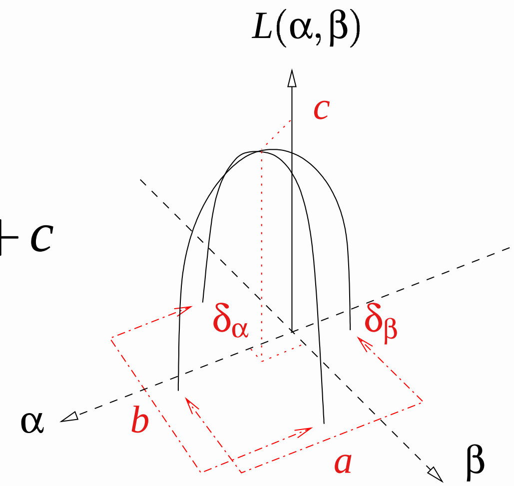
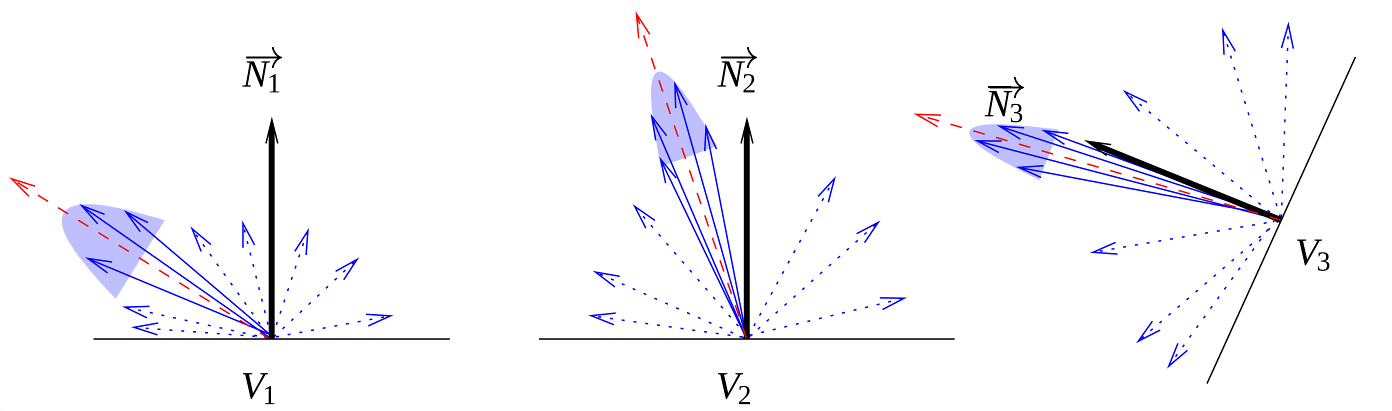


Point Light Source Detection



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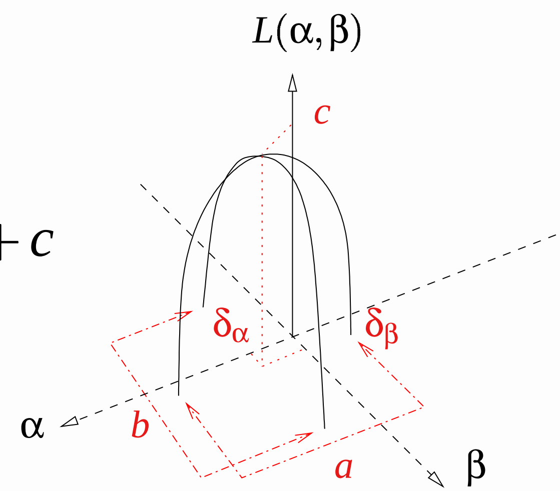

Point Light Source Detection

Introduction
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Classification
Point Source
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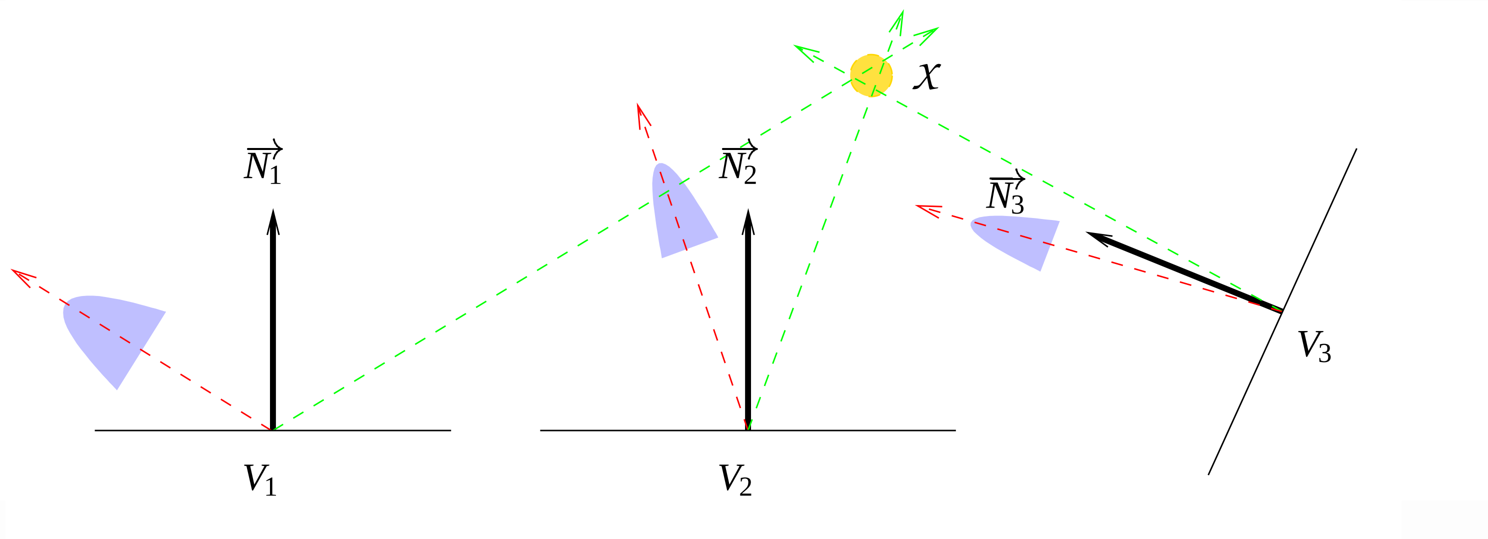

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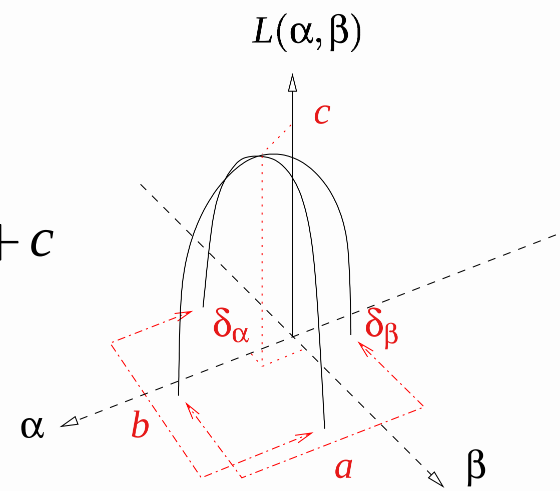


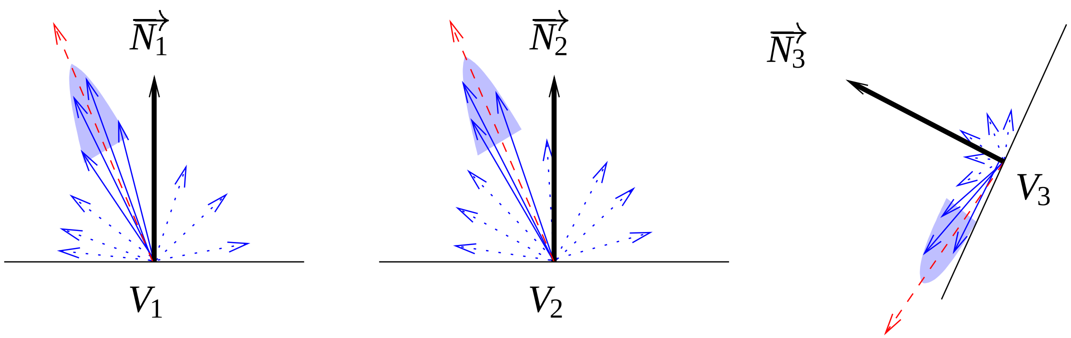
Directional Light Source Detection

- Diffuse surface
  - $L_V = L_s K_d \cos(\theta_V) = L_s K_d (\overrightarrow{I}.\overrightarrow{N_V})$
  - matrix system $\mathcal{M}\mathcal{X} = \mathcal{D}$

$$\begin{pmatrix} N_{V_1,x} & N_{V_1,y} & N_{V_1,z} \\ N_{V_2,x} & N_{V_2,y} & N_{V_2,z} \\ \vdots & \vdots & \vdots \\ N_{V_n,x} & N_{V_n,y} & N_{V_n,z} \end{pmatrix} \begin{pmatrix} L_s K_d I_x \\ L_s K_d I_y \\ L_s K_d I_z \end{pmatrix} = \begin{pmatrix} L_{V_1} \\ L_{V_2} \\ \vdots \\ L_{V_n} \end{pmatrix}$$

  - pseudo-inverse $\Longrightarrow$ light source direction $\mathcal{X}$
- Specular-like surface
  - specular lobe
  - mirror direction
  - average of incident light directions

Directional Light Source Detection



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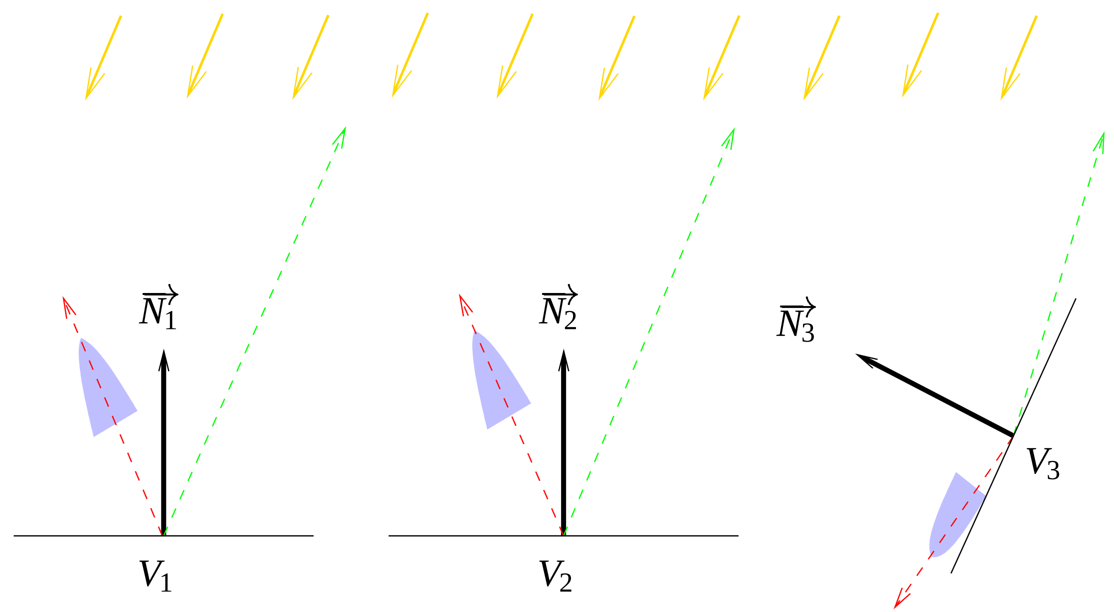
Directional Light Source Detection



- Specular-like surface
  - specular lobe
  - mirror direction
  - average of incident light directions

Joint Identification

- For each voxels subclass
  - detection of 2 light sources (point and directional)
  - improving light source detection

$$E_a = \sum_{i=1}^{\#Vox} \sum_{j=1}^{\#Rad(V_i)} [(\frac{L_s K_d}{\pi r^2} \cos\theta_i + \frac{(n+2) L_s K_s}{2\pi r^2} \cos\theta_i \cos^n \phi_{i,j}) - L_{i,j}]^2$$

  - identification algorithm for $L_s K_d$, $L_s K_s$ and n
- Grouping identical light sources
  - ignoring some light sources
  - reflexion coefficients for each surface
  - power ratio between different light sources

Results

- Randomly-generated samples
(1-meter diameter surface)

Surface type	*Object-source distance*	*Final estimation*	*inaccuracy on* source pos/dir	$L_s K_d$ $L_s K_s$	n
diffuse	$0-9m$	point	$< 1cm$	1%	$\times$
	$> 9m$	directional	$< 1°$		
specular-like	$0-2m$	point	$< 15cm$	1%	5%
	$6m$	none	$1m$		
	$> 6m$	directional	$< 1°$		

- From images
  - virtual objects lit by 3 directional light sources
    average precision : 6°
  - real objects lit by 2 directional light sources
    average precision : 35°

Conclusion

- Presented method
  - multiple light sources detection
  - modified Phong-BRDF model
  - estimation of reflectance properties
- Light sources detection
  - depends on geometric reconstruction accuracy
  - more precise for directional light sources
  - more precise for diffuse surfaces
- Future works
  - using specular spots
  - using various brdf models
  - relighting objects

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