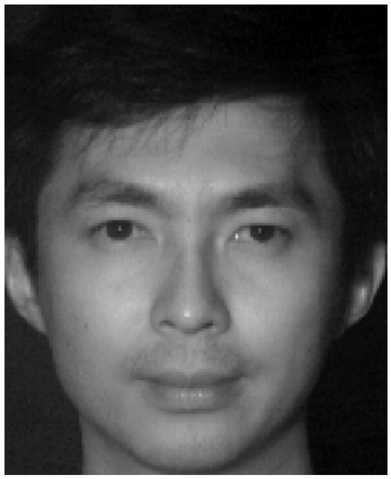
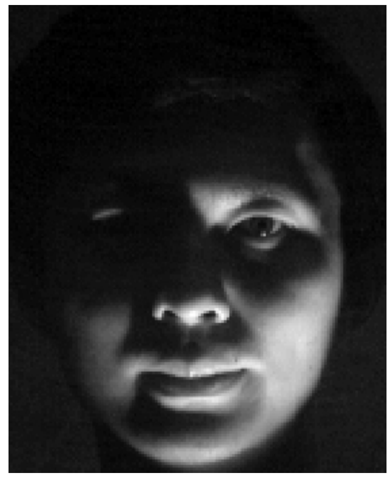
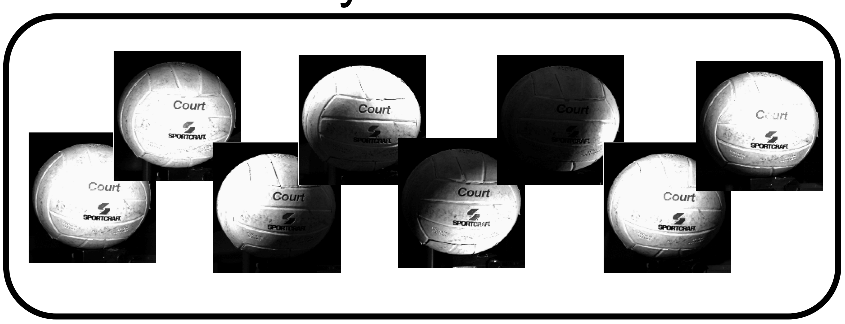
Lighting affects appearance



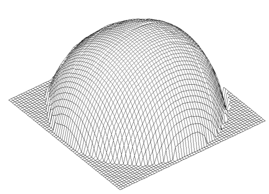


Photometric Stereo: using this variability to reconstruct

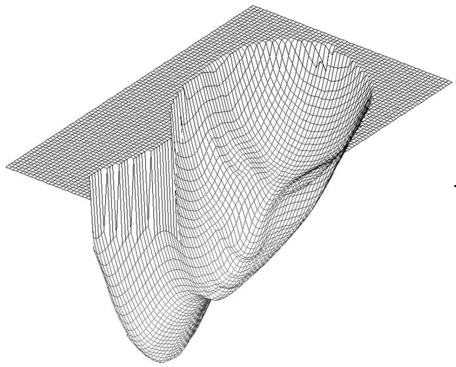


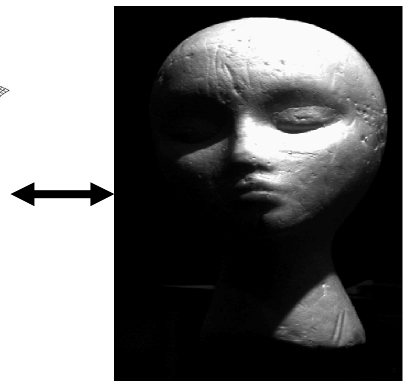
Albedos

Shape (normals only)



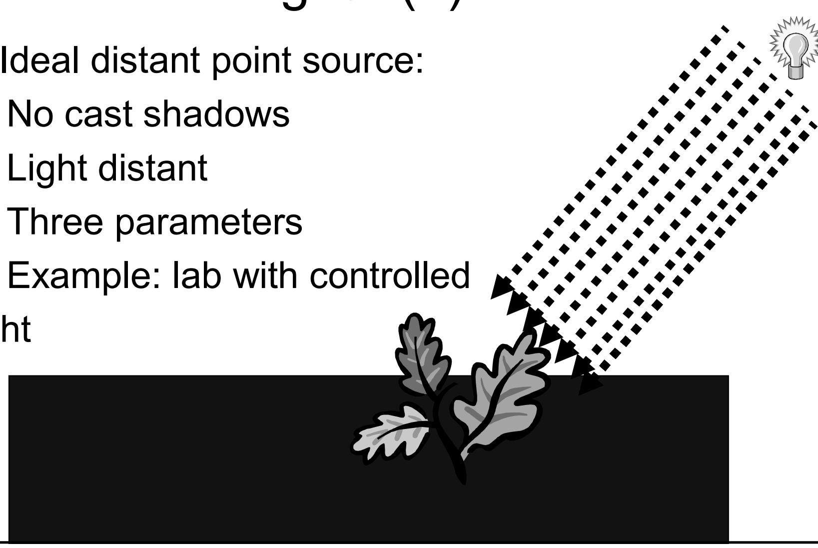
Recognition: Accounting for this variability in matching



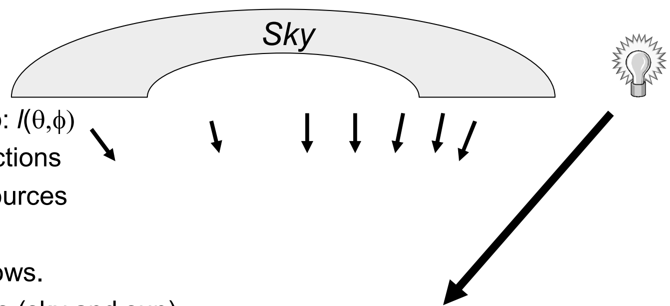


Basics: How do we represent light? (1)

- Ideal distant point source:
  - No cast shadows
  - Light distant
  - Three parameters
  - Example: lab with controlled light

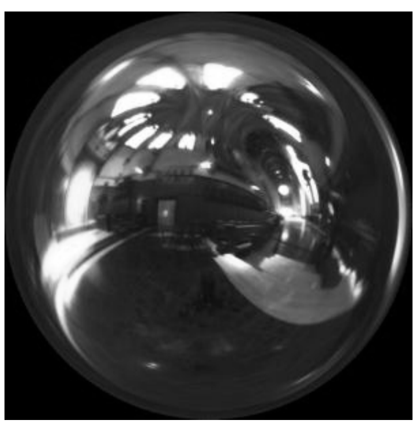


Basics: How do we represent light? (2)



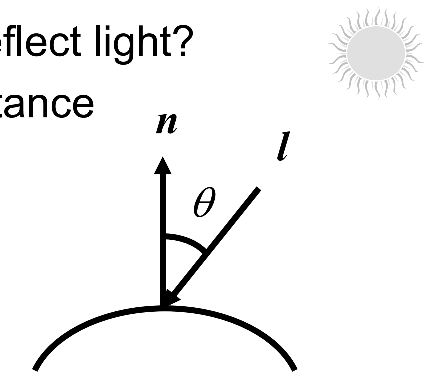
- Environment map: $I(\theta,\phi)$
  - Light from all directions
  - Diffuse or point sources
  - Still distant
  - Still no cast shadows.
  - Example: outdoors (sky and sun)

`



Basics

- How do objects reflect light?
- Lambertian reflectance



$l\lambda \max(\cos\theta, 0)$

Reflectance map

- Reflected light is function of surface normal: $i = f(\theta,\phi)$
- Suitable for environment map.
- Can be measured with calibration object.

Photometric stereo

- Given reflectance map:

i = f(θ,ϕ) each image constrains normal to one degree of freedom.

- Given multiple images, solve at each point.

Lambertian + Point Source

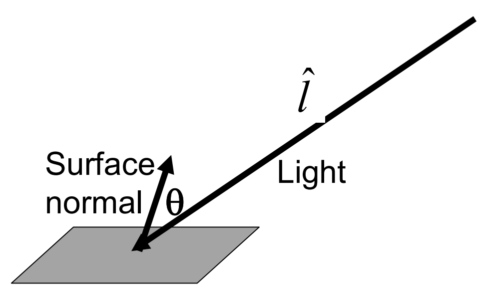
$$\vec{l} = l \bullet \vec{l} \quad \begin{cases} \vec{l} \text{ is direction of light} \\ l \text{ is intensity of light} \end{cases}$$

$i = \max(0, \lambda(\vec{l} \bullet \hat{n})$

i is radiance

λ is *albedo*

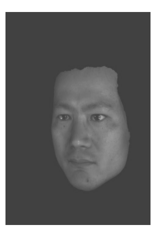
$\hat{n}$ is surface normal



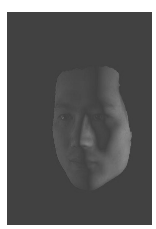
Lambertian, point sources, no shadows. (Shashua, Moses)

- *Whiteboard*
- Solution linear
- Linear ambiguity in recovering scaled normals
- Lighting, reflectance map not known.
- Recognition by linear combinations.

Linear basis for lighting



λZ



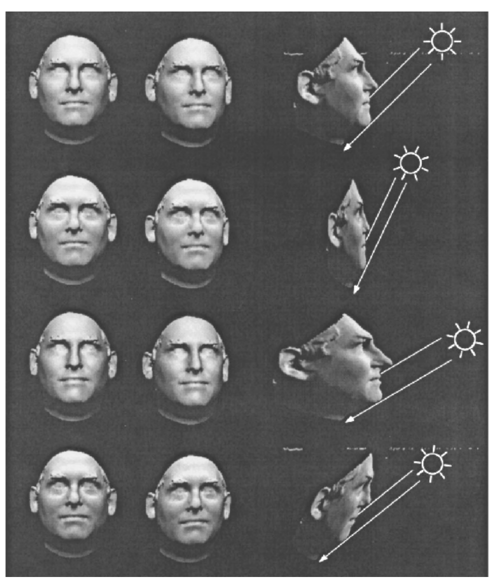
λX

λY

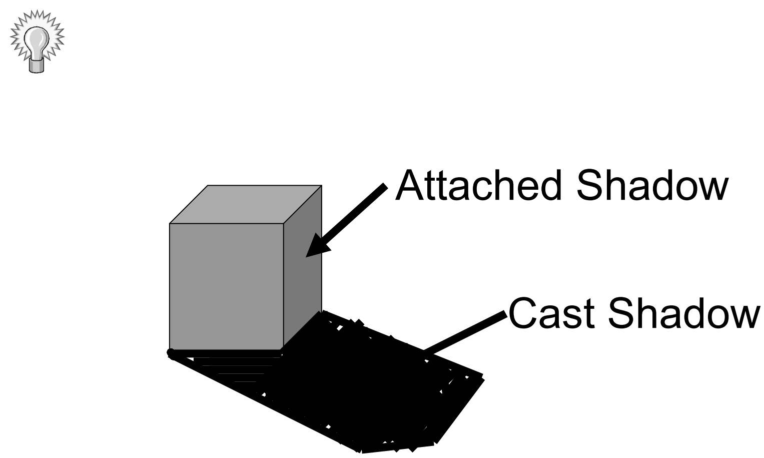
Integrability

- Means we can write height: z=f(x,y).
- *Whiteboard*
- Reduces ambiguity to bas-relief ambiguity.
- Also useful in shape-from-shading and other photometric stereo.

Bas-relief Ambiguity



Shadows



With Shadows: Empirical Study

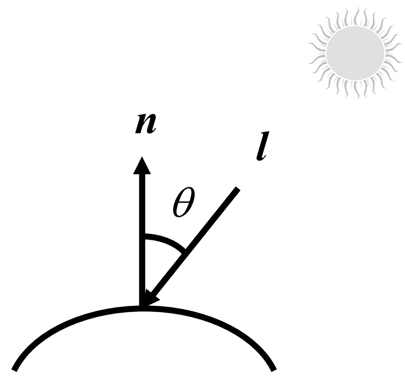
(Epstein, Hallinan and Yuille;
see also Hallinan; Belhumeur and Kriegman)

	Ball	Face	Phone	Parrot
#1	48.2	53.7	67.9	42.8
#3	94.4	90.2	88.2	76.3
#5	97.9	93.5	94.1	84.7
#7	99.1	95.3	96.3	88.5
#9	99.5	96.3	97.2	90.7

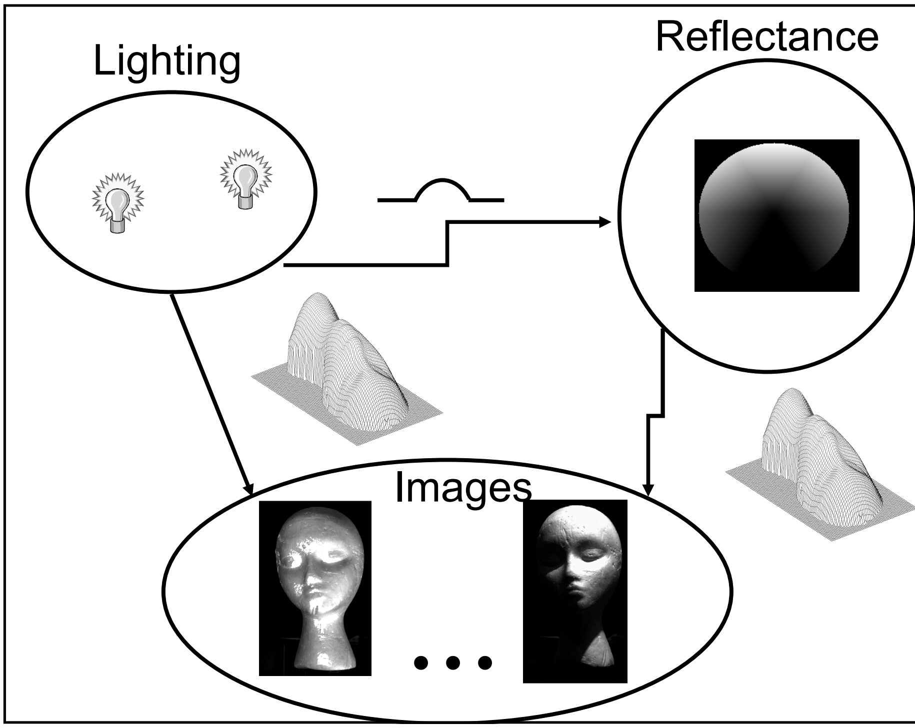
Dimension: $5 \pm 2D$

Attached Shadows

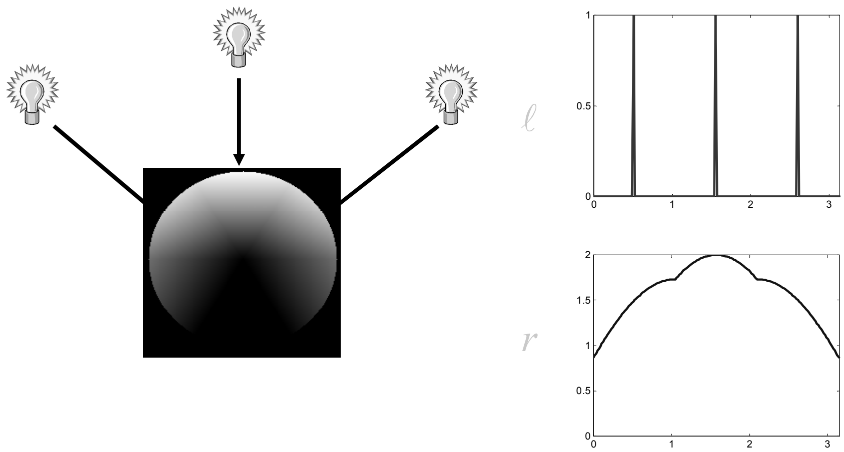
- Lambertian
- Environment map

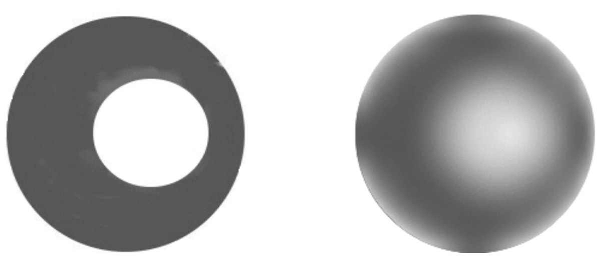


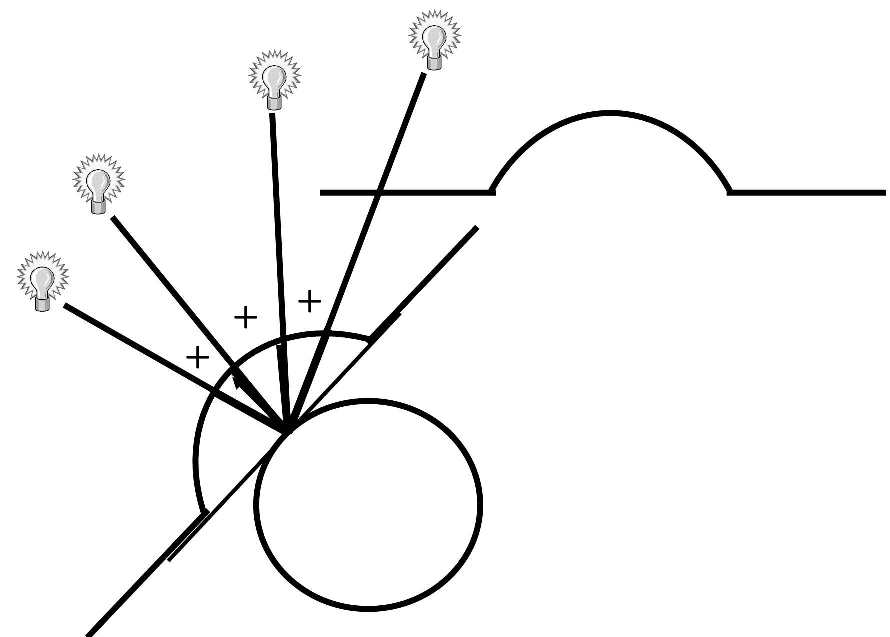
$l\lambda\max\,(\cos\theta, 0)$



Lighting to Reflectance: Intuition



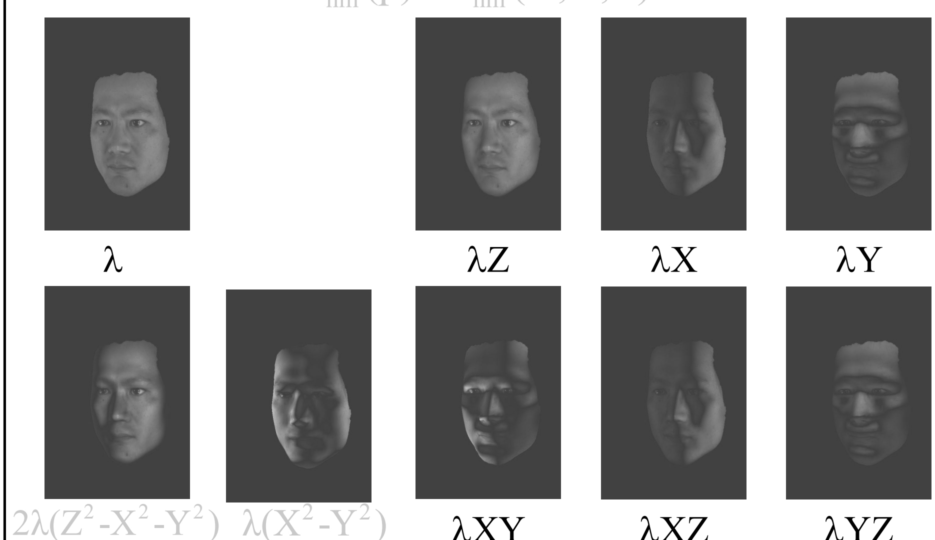


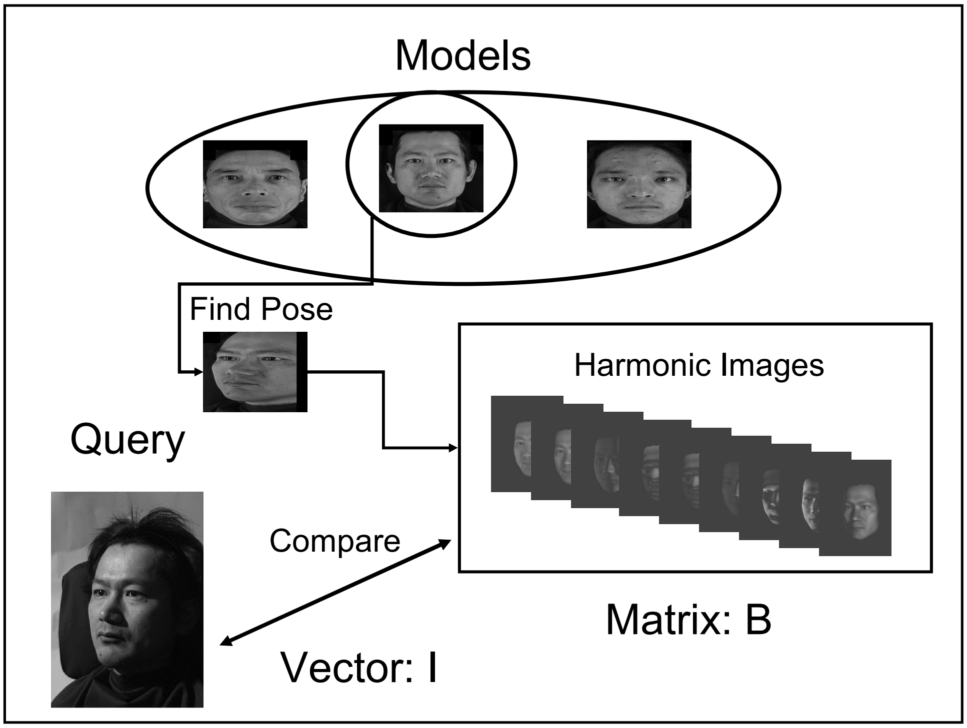


(See D’Zmura, ‘91; Ramamoorthi and Hanrahan ‘00)

Forming Harmonic Images

$$b_{nm}(p)=\lambda r_{nm}(X,Y,Z)$$





Experiments

- 3-D Models of 42 faces acquired with scanner.
- 30 query images for each of 10 faces (300 images).
- Pose automatically computed using manually selected features (Blicher and Roy).
- Best lighting found for each model; best fitting model wins.

Results

- 9D Linear Method: 90% correct.
- 9D Non-negative light: 88% correct.
- Ongoing work: Most errors seem due to pose problems. With better poses, results seem near 97%.

Summary

- Linear solutions are good.
- For pose variation with points, each image is linear combination of 2 others.
- For Lambertian lighting no shadows, each image is linear combination of 3.
- With attached shadows, linear combination of 9.
- Only diffuse lighting affects images, unless there are shadows or specularities.