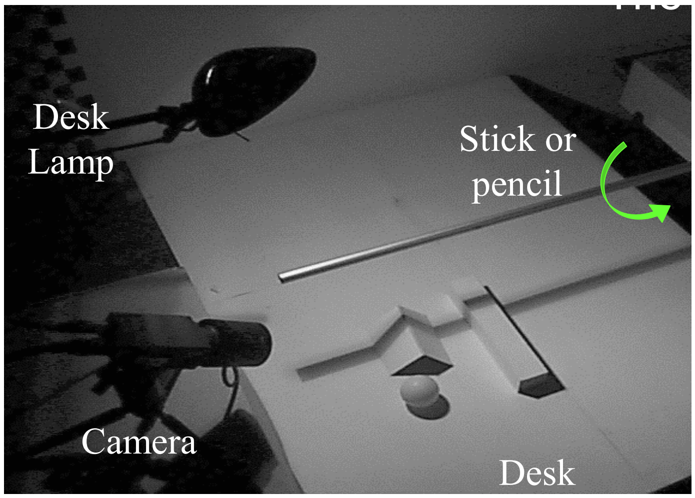
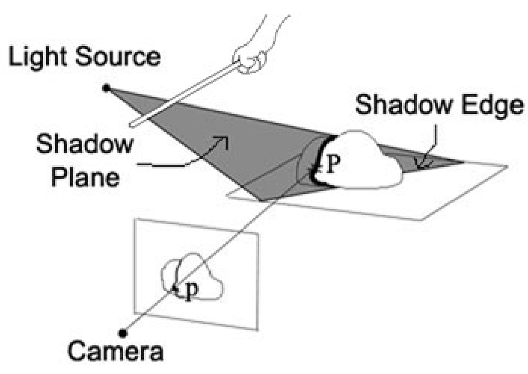
Shadow Scanning [Bouguet 1999]



J.-Y. Bouguet and P. Perona, "3D Photography on your desk", ICCV'98, pages 43-50, January 1998
available at: http://www.vision.caltech.edu/bouguetj/ICCV98/

Basic Idea

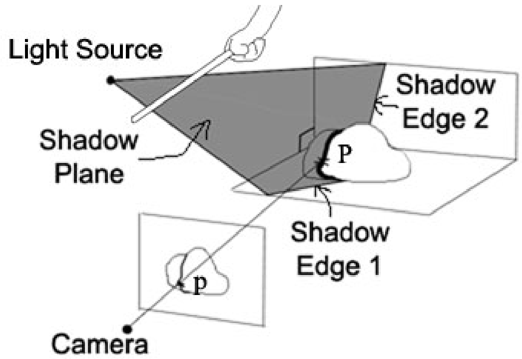


(from Jiwon Kim and Jia-chi Wu)

Calibration issues:

- where's the camera wrt. ground plane?
- where's the shadow plane?
  - depends on light source position, shadow edge

Two Plane Version



(from Jiwon Kim and Jia-chi Wu)

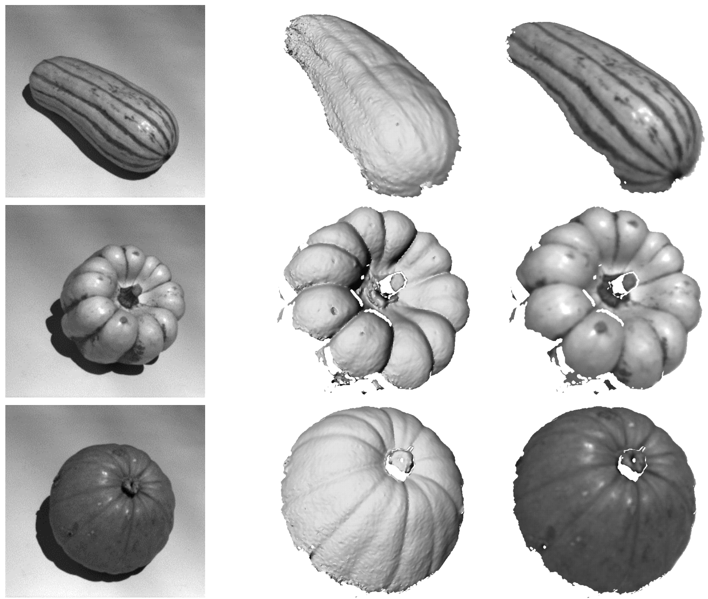
Advantage

- don't need to pre-calibrate the light source
- shadow plane determined from two shadow edges

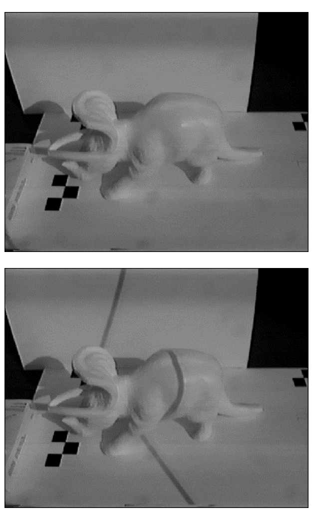
Angel experiment

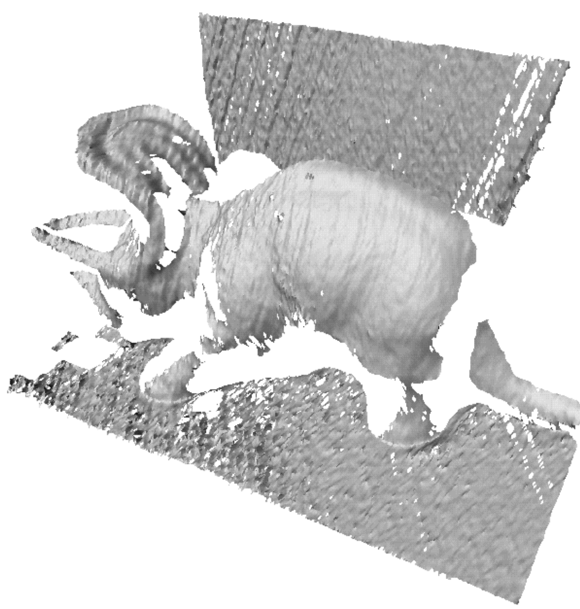
Accuracy: 0.1mm over 10cm → ~ 0.1% error

Textured objects



Scanning with the sun

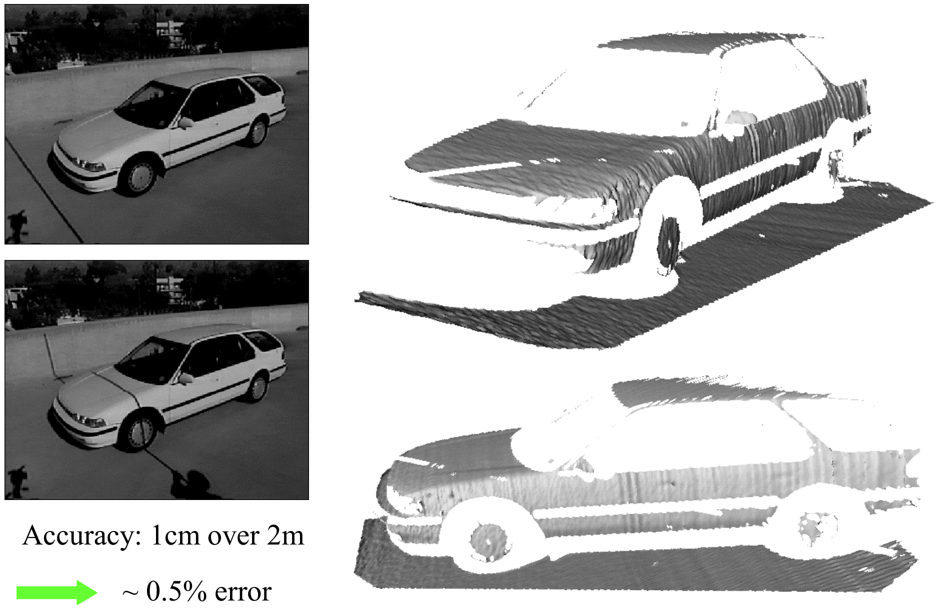




Accuracy: 1mm over 50cm

→ ~ 0.5% error

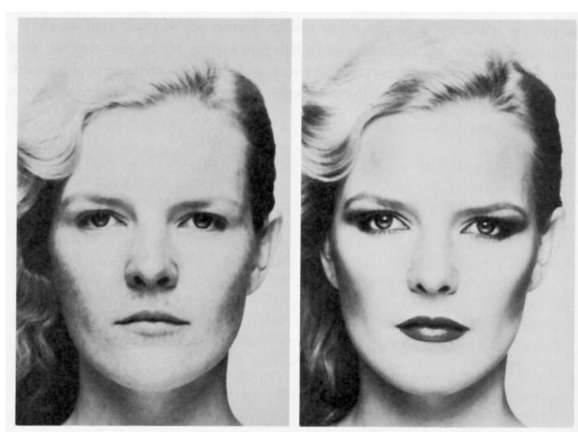
Scanning with the sun



Accuracy: 1cm over 2m

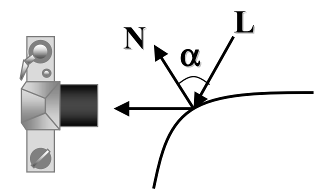
→ ~ 0.5% error

Shading as a 3D Cue



Merle Norman Cosmetics, Los Angeles

Shape from Shading [Horn, 1970]

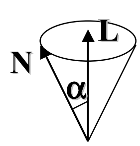


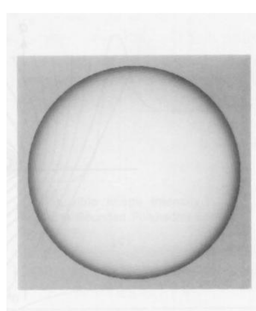
Classical Approach

- Suppose reflected light depends only on α

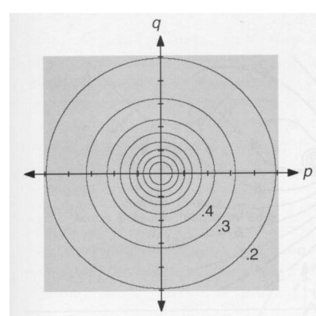
$$radiance = k\, cos\, \alpha$$

The Reflectance Map





Image



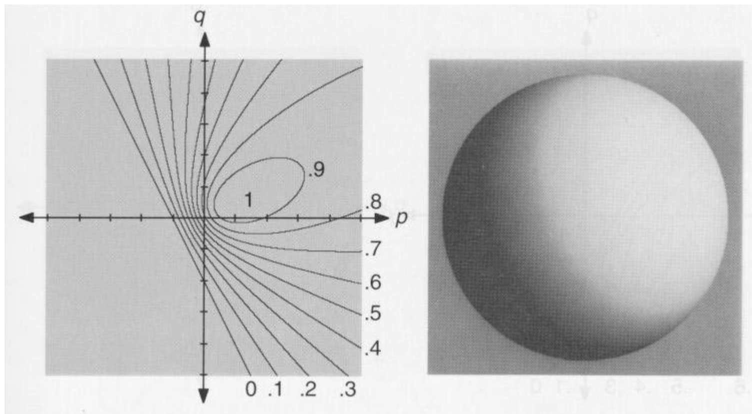
Reflectance Map:
R(p,q) = cos α

Suppose

- image intensity = cos α
- **L** is known

$$\mathbf{N} = \left[\frac{\partial z}{\partial x} \quad \frac{\partial z}{\partial y} \quad -1 \right] = \left[p \quad q \quad -1 \right]$$

The Reflectance Map



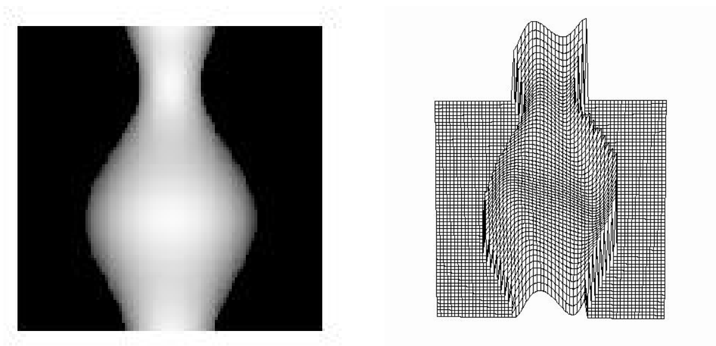
Reflectance Map **Image**

Finding a Unique Solution

Three Approaches

- Characteristic Strip Method [Horn, 77]
  - select a few points where normal is known
  - grow solution by moving direction of **∇R**
- Variational Method [Ikeuchi & Horn, 81]
  - start with an initial guess of surface shape
  - define energy function
  - refine to minimize energy function
- Photometric Stereo [Woodham 80]
  - use more images

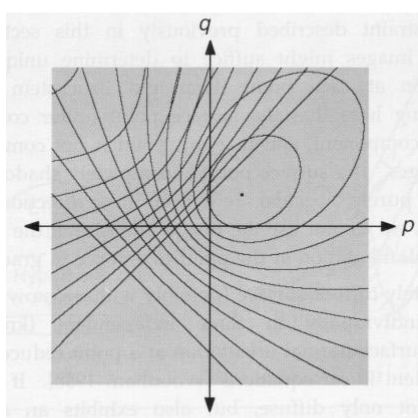
Shape from Shading



Lee & Kau 91 (from survey by Zhang et al., 1999)

Photometric Stereo

Two Images Under Different Lighting



Need Three Images for Unique Solution

Photometric Stereo: Matrix Formulation

Write Equations in Matrix Form

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{L}}_1^{\mathbf{T}} \\ \hat{\mathbf{L}}_2^{\mathbf{T}} \\ \hat{\mathbf{L}}_3^{\mathbf{T}} \end{bmatrix} \bullet \begin{bmatrix} k\hat{\mathbf{N}} \\ k\hat{\mathbf{N}} \\ k\hat{\mathbf{N}} \end{bmatrix}$$

$$\mathbf{I}_{3\times 1} \quad \mathbf{L}_{3\times 3} \quad \tilde{\mathbf{N}}_{3\times 1}$$

$$\Rightarrow \quad \tilde{\mathbf{N}} = \mathbf{L}_1^{-1}\,\mathbf{I} \qquad k = \left\|\tilde{\mathbf{N}}\right\|$$

Advantage:

- Can solve for reflectance *k* that varies over the surface

Depth from Normals

- Solve for z(i,j) from (p,q)
- This is an integration problem—can be solved by minimizing an energy function:

$$\begin{aligned} E &= E_{data} + E_{smooth} + E_{constraint} \\ &= \sum_{i,j} w_{data} * \left[\left(\frac{\partial z(i,j)}{\partial x} - p_{ij} \right)^2 + \left(\frac{\partial z(i,j)}{\partial y} - q_{ij} \right)^2 \right] \\ &+ \sum_{i,j} w_{smooth} * \left[\left(\frac{\partial^2 z(i,j)}{\partial x^2} \right)^2 + 2\left(\frac{\partial^2 z(i,j)}{\partial x \partial y} \right)^2 + \left(\frac{\partial^2 z(i,j)}{\partial y^2} \right)^2 \right] \\ &+ \sum_{(i,j) \in Constraints} w_{constraint} * \left(z(i,j) - c_{ij} \right)^2 \end{aligned}$$

(from Yung-Yu Chuang and David Ely)

Issues

Limitations?

- Lambertian assumption
- No interreflections
  - work by Shree Nayar & colleagues addresses this issue
- No transparency
- No discontinuities
- Requires known light source

Strengths (compared to stereo)?

- No correspondence problem
- Recovers reflectance parameter
- Easier to implement

Bibliography

Shape from Shading/Photometric Stereo

- **B. Horn and M. Brooks, "Shape from Shading", 1989, MIT Press.**
- **L. Wolff, S. Shafer, and G. E. Healey, "Physics-Based Vision: Shape Recovery", 1992, Jones and Bartlett.**
- **R. J. Woodham, "Photometric Method for Determining Surface Orientation from Multiple Images", Optical Engineering, 1980, pp. 139-144.**

Shadow Scanning

- **J.-Y. Bouguet and P. Perona, "3D Photography on your desk", ICCV'98, pages 43-50, January 1998.**
- **J.-Y. Bouguet and P. Perona, "3D photography using shadows in dual-space geometry", to appear in the International Journal of Computer Vision.**
- **For papers, images, models, talks, and more, see: http://www.vision.caltech.edu/bouguetj/ICCV98/**