

Course Review

CS/ECE 181b
Spring 2004

Topics since Midterm

- Stereo vision
- Shape from shading
- Optical flow
- Face recognition project

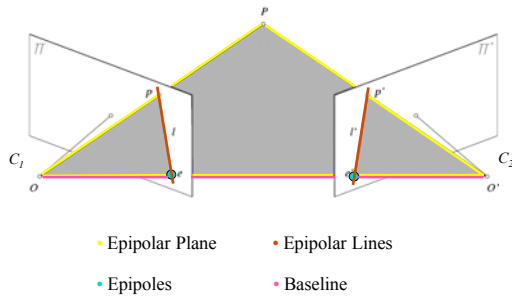
Multiview Geometry and Stereo Vision

Reading: slides, handout#6, and Chapter 8 from
H&Z

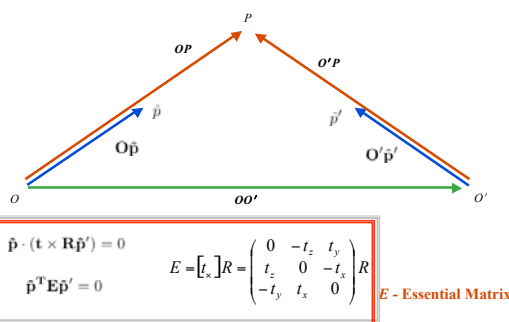
Questions

- **Correspondence geometry:** Given an image point x in the first view, how does this constrain the position of the corresponding point x' in the second image?
- **Camera geometry (motion):** Given a set of corresponding image points $\{x_i, x'_i\}$, $i=1, \dots, n$, what are the cameras P and P' for the two views?
- **Scene geometry (structure):** Given corresponding image points x_i, x'_i and cameras P, P' , what is the position of (their pre-image) X in space?

Epipolar geometry



Essential Matrix



Case 2: Uncalibrated camera

- Intrinsic parameters not known

$$\begin{aligned} p &= K_1 \hat{p} \\ p' &= K_2 \hat{p}' \end{aligned} \quad \begin{array}{l} \text{Points in the normalized image plane} \\ \nearrow \end{array} \quad K = \begin{bmatrix} \alpha & -\alpha \cot \theta & u_0 \\ 0 & \frac{\beta}{\sin \theta} & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\hat{p}^T E \hat{p}' = 0$$

$$(K_1^{-1} p)^T E (K_2^{-1} p') = 0$$

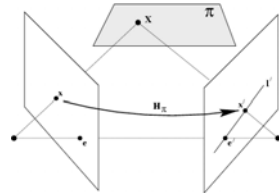
$$(p^T K_1^{-T}) E (K_2^{-1} p') = 0$$

$$p^T F p' = 0$$

$$F = K_1^{-T} E K_2^{-1} \quad \text{Fundamental Matrix}$$

Fundamental Matrix F

geometric derivation



$$x' = H_0 x$$

$$l' = c' \times x' = [c']_x H_0 x = Fx$$

mapping from 2-D to 1-D family (rank 2)

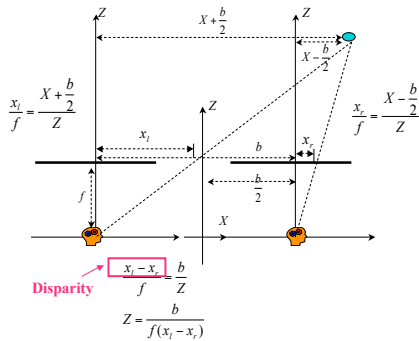
The Fundamental Matrix

- F has seven independent parameters
- A simple, linear technique to recover F from corresponding point locations is the “eight point algorithm”
- From F , we can recover the epipolar geometry of the cameras
 - Not saying how...
- This is called *weak calibration*

Stereopsis

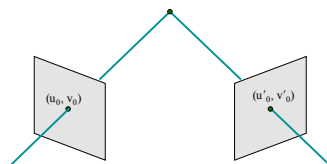


Basic Stereo Configuration: rectified images



Stereo disparity

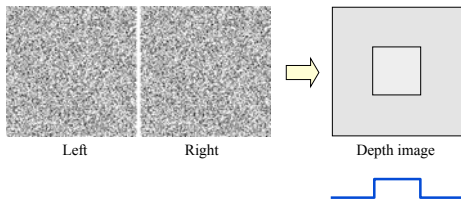
- “Stereo disparity” is the difference in position between correspondence points in two images
 - Disparity is inversely proportional to scene depth



Disparity: $(du_0, dv_0) = (u_0 - u'_0, v_0 - v'_0) = (0, 0)$

Disparity is a vector!

Random Dot Stereograms



How is this possible with completely random correspondence?

Stereo: Summary

- Multiview geometry
 - Epipolar geometry
- Correspondence problem
- Essential Matrix and Fundamental Matrix
- Stereopsis: stereo matching, disparity and depth
- Random dot stereograms

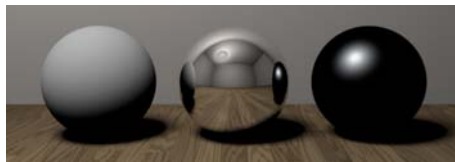
Shape from shading

Reading: handout #7 and slides

Shape from shading

- Radiance and Irradiance
- Lambertian and Specular surfaces
- Bidirectional reflectance distribution function (BRDF)
- Fundamental Radiometric Relation
- Gradient Space
- Reflectance Map
- Photometric Stereo

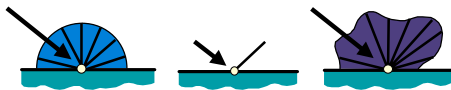
Three surface reflectance functions/models

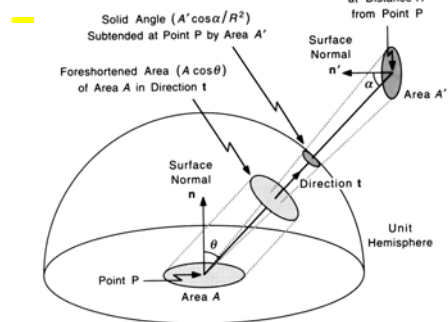


Ideal diffuse
(Lambertian)

Ideal
specular

Directional
diffuse

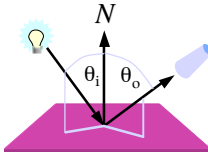




Bidirectional Reflectance Distribution Function

- The BRDF tells us how bright a surface appears when viewed from one direction while light falls on it from another one
 - General model of local reflection
- More precisely, it is the ratio of reflected radiance dL_r in the direction toward the viewer to the irradiance dE_i in the direction toward the light source

$$\text{BRDF} : \rho = \frac{\text{Reflected energy}}{\text{Incident energy}} = f(\theta_i, \phi_i, \theta_o, \phi_o)$$
$$0 \leq \rho \leq \infty$$



BRDF models

For many surfaces, a simple BRDF suffices

- Specular surface (e.g., a mirror)

$$f(\theta_i, \phi_i, \theta_o, \phi_o) = \begin{cases} \frac{1}{\cos \theta \sin \theta} & \text{if } \theta_i = \theta_o \text{ and } \phi_o = \phi_i + \pi \\ 0 & \text{otherwise} \end{cases}$$

- Lambertian (diffuse, matte) surface (e.g., white powder)
 - Independent of exit angle

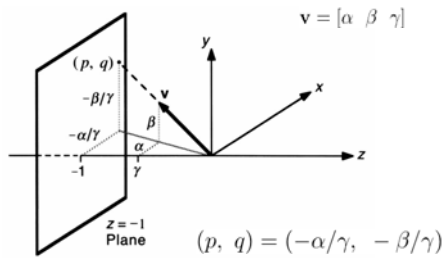
$$f(\theta_i, \phi_i, \theta_o, \phi_o) = \rho_L = \frac{1}{\pi}$$

- Combinations (Phong, Lambertian+Specular, ...)

Gradient Space Representation

- Orientation of a vector in 3-D space has two degrees of freedom.
- Suppose we are interested in representing all vectors in a particular hemisphere, say $z < 0$ hemisphere:
 - We can then represent any such vector with a negative z component as (p, q) . See next slide.

Gradient space



Gradient Space

Let the imaged surface be $z = f(x, y)$

Then its surface normal can be obtained as a cross product of the two surface vectors:

$$\begin{bmatrix} 1 & 0 & \partial f / \partial x \end{bmatrix} \quad \begin{bmatrix} 0 & 1 & \partial f / \partial y \end{bmatrix}$$

$$\begin{aligned} \text{Surface normal: } & \pm [\partial f / \partial x \ \partial f / \partial y \ -1] \\ & = [p \ q \ -1] \end{aligned}$$

Reflectance Map

- Reflectance map captures the dependence of brightness on surface orientation.
- At a particular point in the image, we measure the image irradiance $E(x, y)$.
- This irradiance is proportional to the radiance at the corresponding point on the surface imaged.
- If the surface gradient at that point is (p, q) , then the radiance there is $R(p, q)$.
 - This assumes or ignores other contributing factors such as reflectance properties of the surface or distribution of light sources
- Normalizing the proportionality constant, we get:

$$E(x, y) = R(p, q)$$

Image irradiance equation

Lambertian surface

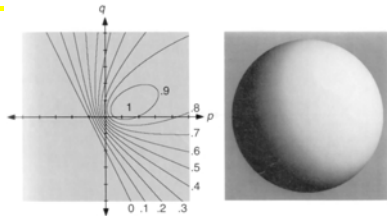
Lambertian surface: appears equally bright from all viewing angles.

Let the incident light direction be $-\begin{bmatrix} p_s & q_s & -1 \end{bmatrix}$

$$R(p, q) = \cos i = \frac{-\begin{bmatrix} p_s & q_s & -1 \end{bmatrix} \cdot \begin{bmatrix} p & q & -1 \end{bmatrix}}{\| \begin{bmatrix} p_s & q_s & -1 \end{bmatrix} \| \cdot \| \begin{bmatrix} p & q & -1 \end{bmatrix} \|}$$

$$= \frac{-(p_s p + q_s q + 1)}{\sqrt{p_s^2 + q_s^2 + 1} \sqrt{p^2 + q^2 + 1}}$$

Reflectance Map



- Illuminant direction: $-\begin{bmatrix} 1 & 0.5 & -1 \end{bmatrix}$
- Isobrightness contours of a reflectance map of a Lambertian surface are a set of conic sections in gradient space.

Photometric Stereo

- Two images, taken with different lighting, will yield two equations for each image point.

$$R_1(p, q) = E_1; R_2(p, q) = E_2$$

- If these equations are linear and independent, there will be a unique solution for p and q .
- For best results, the two light source directions should be far apart in gradient space.
- For Lambertian surfaces, these lead to non-linear equations; there can be two solutions, one solution, or none, depending on the particular values of the intensity.

Shape from shading

- Radiance and Irradiance
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- Bidirectional reflectance distribution function (BRDF)
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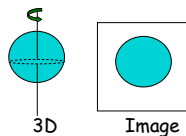
Motion field and optical flow

Reading: Handout #8 and slides

MF $\neq$ OF

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Consider a smooth, lambertian, uniform sphere rotating around a diameter, in front of a camera:



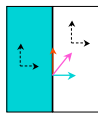
-MF $\neq 0$ since the points on the sphere are moving

-OF = 0 since there are no moving patterns in the images

Brightness Constancy Equation

- Let P be a moving point in 3D:
 - At time t, P has coords $(X(t), Y(t), Z(t))$
 - Let $p=(x(t), y(t))$ be the coords. of its image at time t.
 - Let $I(x(t), y(t), t)$ be the brightness at p at time t.
- Brightness Constancy Assumption:
 - As P moves over time, $I(x(t), y(t), t)$ remains constant.

Optical Flow Constraint



$$I_x u + I_y v = -I_t$$



no spatial change in brightness induce no temporal change in brightness no discernible motion



motion perpendicular to local gradient induce no temporal change in brightness no discernible motion

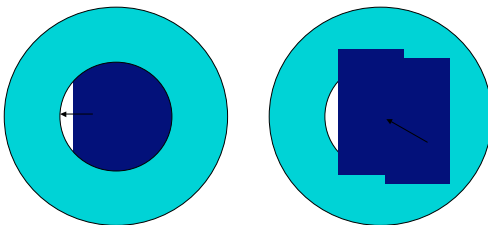


motion in the direction of local gradient induce temporal change in brightness discernible motion



only the motion component in the direction of local gradient induce temporal change in brightness discernible motion

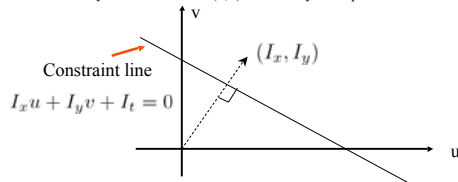
The aperture problem



The Image Brightness Constancy Assumption only provides the OF component in the direction of the spatial image gradient

Difficulty

- One equation with two unknowns
- Aperture problem
 - spatial derivatives use only a few adjacent pixels (limited aperture and visibility)
 - many combinations of (u, v) will satisfy the equation



MF & OF Summary

- Motion field
- Optical flow
- MF not the same as OF
- Optical flow constraint equation
- Aperture problem

Summary

- Projective Geometry
- Edge detection
- Stereo
- Shape from shading
- Optical flow
- Face recognition project

Final Project report and exam

- Report due today (June 4, 2004) by 5PM
- Exam
 - Comprehensive
 - Emphasis on topics covered after midterm
 - Closed book; no calculator or other electronic devices
 - Two pages of notes allowed (either one sheet with two sides of notes, or two separate pages, one sided. 8.5 in x 11 in, 12 pt, ...)
- Solutions for the S'2001 exam distributed.

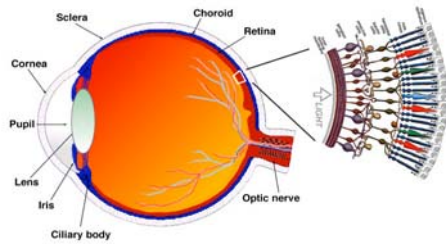
Computer Vision Research at UCSB

Many groups
Computer Science: Wang, Turk
Psychology: Loomis, Eckstein, ...
ECE: Manjunath

Manjunath's lab

- Image and Video Databases
 - Several ongoing projects
 - Several contributions to the MPEG-7 standard
- Image Registration
- Data Hiding
- Bio-image Informatics
 - Center for Bioimage Informatics (NSF supported)
 - <http://www.bioimage.ucsb.edu>
- IGERT Fellowships in multimedia
 - <http://media.igert.ucsb.edu>
 - ♦ \$30K/year + tuition/fee covered
 - ♦ Highly competitive
- More info: <http://vision.ece.ucsb.edu>

Bio-image: an example--study of retinal detachment



Concluding remarks

- Vision and information processing
 - Many opportunities
 - ♦ Understanding human/biological vision
 - ♦ Developing practical computational methods
 - An active research area
 - Opportunities for graduate students
 - ♦ IGERT
 - ♦ ITR (Bioinformatics)
 - ♦ Contact me if you are interested in knowing more about these programs.

Thank You!!

Please take a few minutes to fill out the evaluation forms!
