

Image Formation and Cameras

Introduction to Computer Vision
CSE 152
Lecture 5

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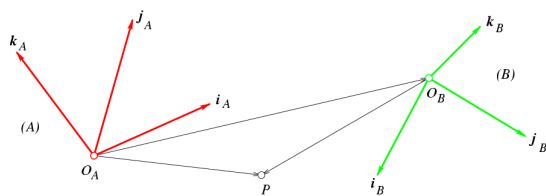
Announcements

- Reading
 - Trucco & Verri, Chapter 2, pp. 16-26,
 - Szeliski pp.60-72
- Assignment 1: To be assigned later today.

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Coordinate Changes: Rigid Transformations
Rotation + Translation



$${}^B P = {}^B R {}^A P + {}^B O_A$$

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More about rotations matrices

A rotation matrix R has the following properties:

- Its inverse is equal to its transpose $R^{-1} = R^T$ or $R^T R = I$

- Its determinant is equal to 1: $\det(R) = 1$.

Or equivalently:

- Rows (or columns) of R form a right-handed orthonormal coordinate system.

Even though a rotation matrix is 3x3 with nine numbers, it only has three degrees of freedom can be parameterized with three numbers. There are many parameterizations:

- Roll-Pitch Yaw
- Euler angles
- Axis Angle

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Camera parameters

- Issue
 - camera may not be at the origin, looking down the z-axis
 - extrinsic parameters (Rigid Transformation)
 - one unit in camera coordinates may not be the same as one unit in world coordinates
 - intrinsic parameters - focal length, principal point, aspect ratio, angle between axes, etc.

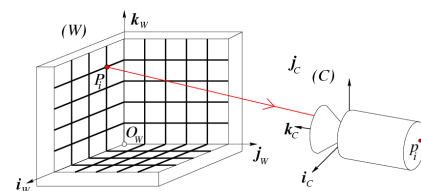
$$\begin{pmatrix} U \\ V \\ W \end{pmatrix} = \begin{pmatrix} \text{Transformation} \\ \text{representing} \\ \text{intrinsic parameters} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \text{Transformation} \\ \text{representing} \\ \text{extrinsic parameters} \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ T \end{pmatrix}$$

3 x 3 4 x 4

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Camera Calibration



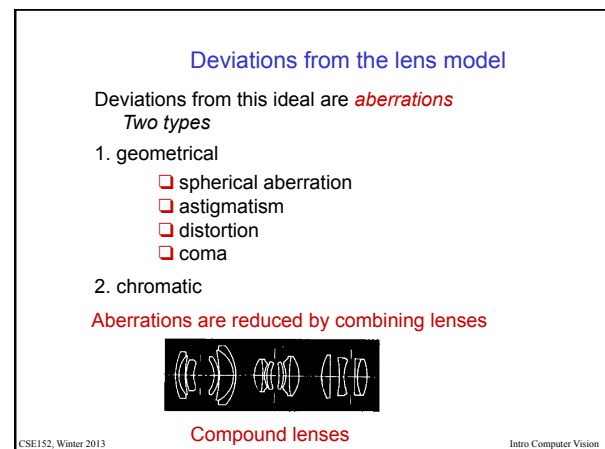
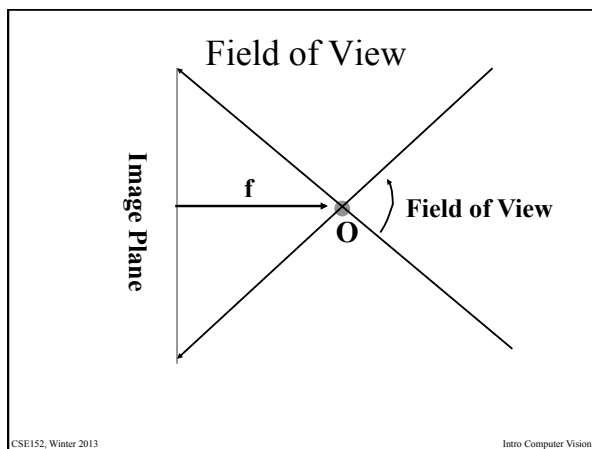
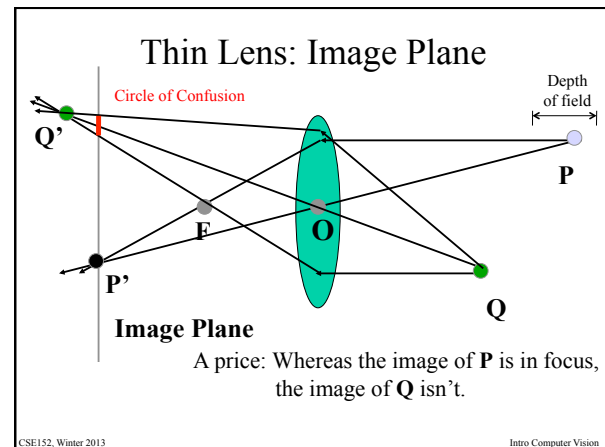
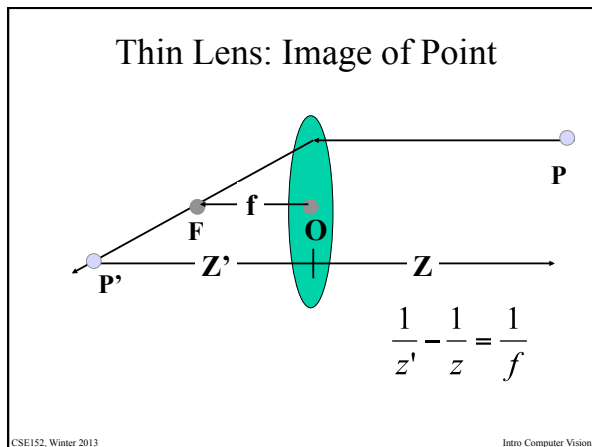
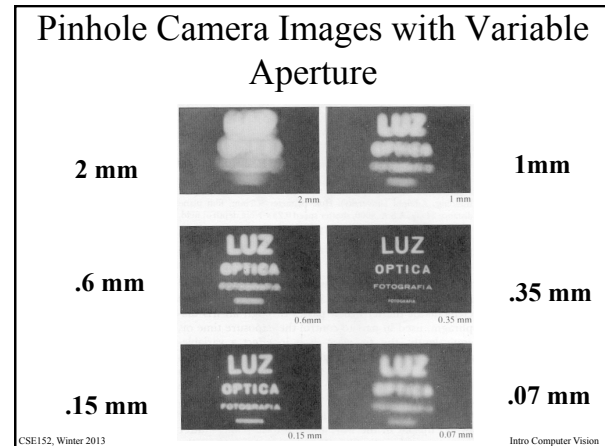
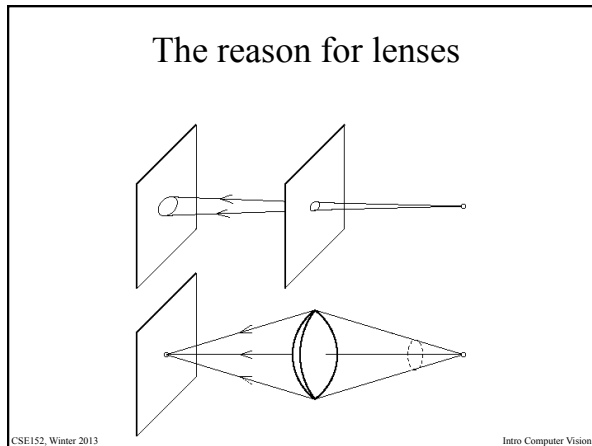
Given n points $P_1, \dots, P_n$ with known positions and their images $p_1, \dots, p_n$, estimate the camera matrix which includes the intrinsic and extrinsic camera parameters

- See Text book for how to do it.
- Camera Calibration Toolbox for Matlab (Bouguet)

<http://www.vision.caltech.edu/bouguetj/calib/doc/>

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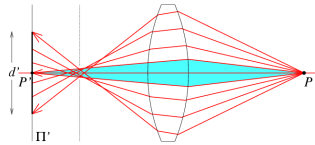
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Spherical aberration

Rays parallel to the axis do not converge

Outer portions of the lens yield smaller focal lengths

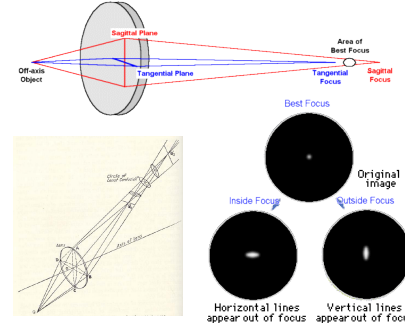


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Astigmatism

Different focal length for inclined rays

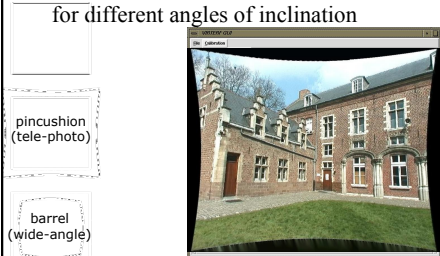


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Horizontal lines appear out of focus. Vertical lines appear out of focus.

Distortion

magnification/focal length different for different angles of inclination



Can be corrected! (if parameters are known)

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Chromatic aberration

Index of refraction of lens depends on wavelength of light

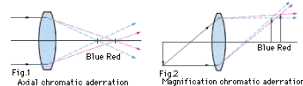


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Chromatic aberration

Rays of different wavelengths focus in different planes

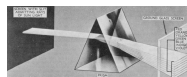


Cannot be removed completely

Sometimes **achromatization** is achieved for more than 2 wavelengths



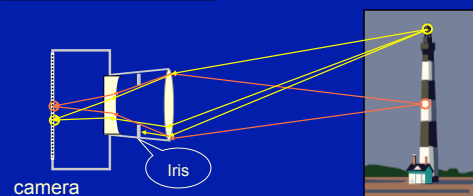
The image is blurred and appears colored at the fringe.



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Spatial Non-Uniformity



Litvinov & Schechner, radiometric nonidealities

Vignetting



Only part of the light reaches the sensor
Periphery of the image is dimmer

Radiometry, Lighting, Intensity

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Lighting

- Special light sources
 - Point sources
 - Distant point sources
 - Strip sources
 - Area sources
- Common to think of lighting at infinity (a function on the sphere, a 2-D space)
- Most generally, applied lighting can be represented as a function on the 4-D ray space (radiances)

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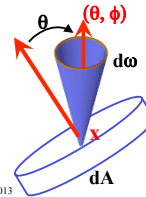
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Radiance

- Power traveling at some point in a specified direction, per unit area perpendicular to the direction of travel, per unit solid angle

$$L = \frac{P}{(dA \cos \theta) d\omega}$$

- Units: watts per square meter per steradian : $w/(m^2 sr^1)$



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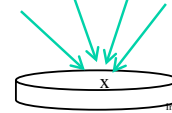
Irradiance

- How much light is arriving at a surface?
- Irradiance -- power per unit area: W/cm^2 $E(x,y)$

- Total power arriving at the surface is given by adding irradiance over all incoming angles

$$\int_{\text{hemisphere}} L(x, \theta, \phi) \cos \theta d\omega$$

$$= \int_0^{2\pi} \int_0^{\pi/2} L(x, \theta, \phi) \cos \theta \sin \theta d\theta d\phi$$



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Camera's sensor

- Measured pixel intensity is a function of irradiance integrated over
 - pixel's area
 - over a range of wavelengths
 - For some time

$$I = \iiint_{t \lambda x y} E(x, y, \lambda, t) s(x, y) q(\lambda) dy dx d\lambda dt$$

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Light at surfaces

Many effects when light strikes a surface -- could be:

- transmitted
 - Skin, glass
- reflected
 - mirror
- scattered
 - milk
- travel along the surface and leave at some other point
- absorbed
 - sweaty skin

We generally assume that

- surfaces don't fluoresce
 - e.g. scorpions, detergents
- surfaces don't emit light (i.e. are cool)
- all the light leaving a point is due to that arriving at that point

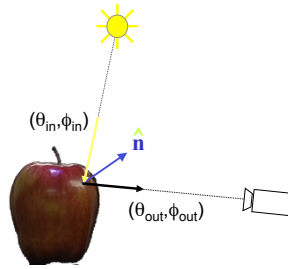
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BRDF

- Bi-directional Reflectance Distribution Function

$$\rho(\theta_{in}, \phi_{in}; \theta_{out}, \phi_{out})$$
- Function of
 - Incoming light direction:
 θ_{in}, ϕ_{in}
 - Outgoing light direction:
 θ_{out}, ϕ_{out}
- Ratio of incident irradiance to emitted radiance



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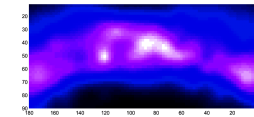
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Surface Reflectance Models

Common Models

- Lambertian
- Phong
- Physics-based
 - Specular [Blinn 1977], [Cook-Torrance 1982], [Ward 1992]
 - Diffuse [Hanrahan, Kreuger 1993]
 - Generalized Lambertian [Oren, Nayar 1995]
 - Thoroughly Pitted Surfaces [Koenderink et al 1999]
- Phenomenological [Koenderink, Van Doorn 1996]

Arbitrary Reflectance

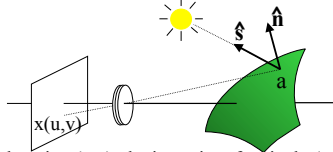


- Non-parametric model
- Anisotropic
- Non-uniform over surface
- BRDF Measurement [Dana et al., 1999], [Marschner]

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Lambertian Surface



At image location (u,v) , the intensity of a pixel $x(u,v)$ is:

$$x(u,v) = a(u,v) \hat{n}(u,v) \cdot s_0 \hat{s} = b(u,v) \cdot s$$

- $a(u,v)$ is the albedo of the surface projecting to (u,v) .
- $\hat{n}(u,v)$ is the direction of the surface normal.
- s_0 is the light source intensity.
- $\hat{s}$ is the direction to the light source.

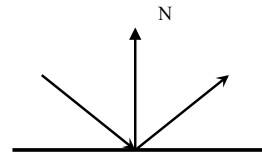
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Specular Reflection: Smooth Surface



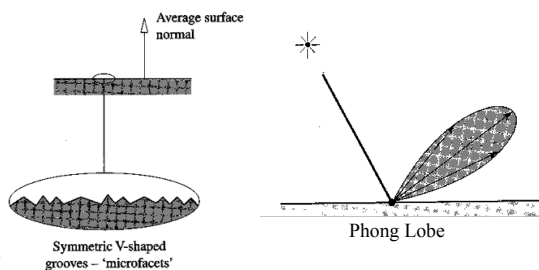
Phong – rough, specular



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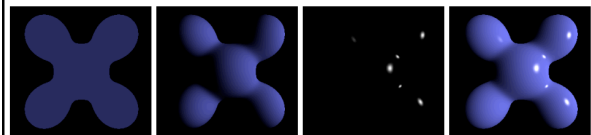
Rough Specular Surface



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Full Phong Model



Ambient + Diffuse + Specular = Phong Reflection

$$I_p = k_a i_a + \sum_{m \in \text{lights}} (k_d (\hat{L}_m \cdot \hat{N}) i_{m,d} + k_s (\hat{R}_m \cdot \hat{V})^\alpha i_{m,s}).$$

$$\hat{R}_m = 2(\hat{L}_m \cdot \hat{N})\hat{N} - \hat{L}_m$$

BRDF Parameters
 k_a, k_d, k_s, α

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