Classifying Under Uncertainty

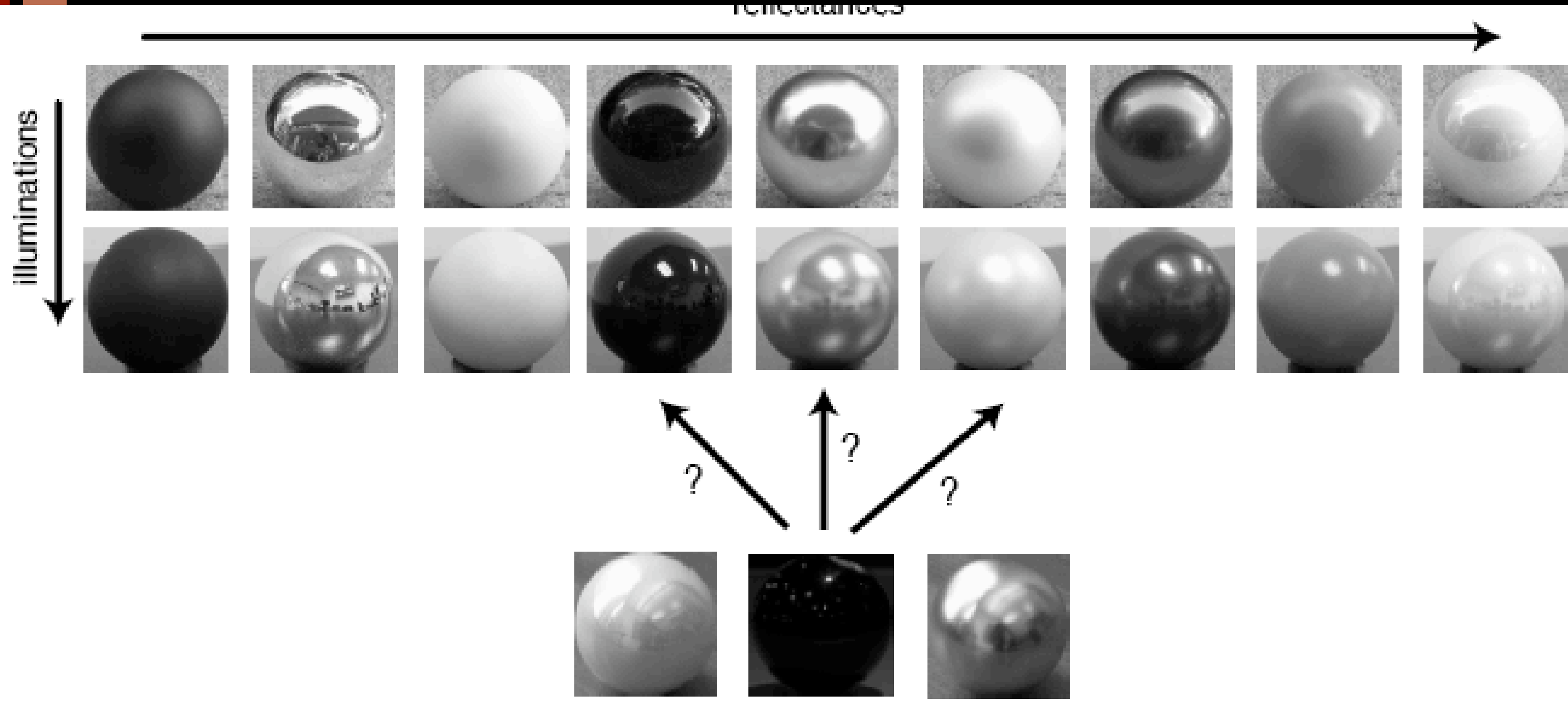
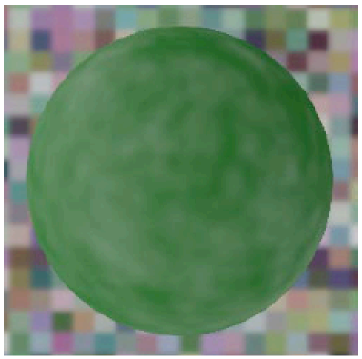


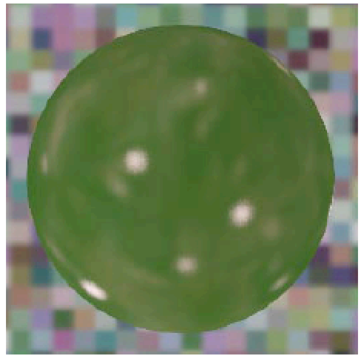
Figure 3.7. The problem addressed by a classifier of Chapter 6, illustrated using a database of photographs. Each of nine spheres was photographed under seven different illuminations. We trained a nine-way classifier using the images corresponding to several illuminations, and then used it to classify individual images under novel illuminations.

More Fake Light

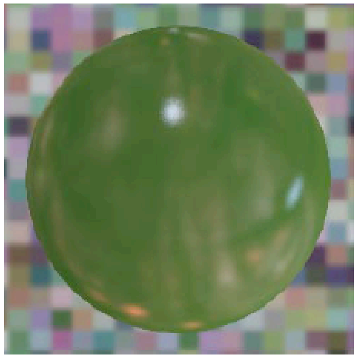
(a) Original



(b) $1/f^2$ power spectrum



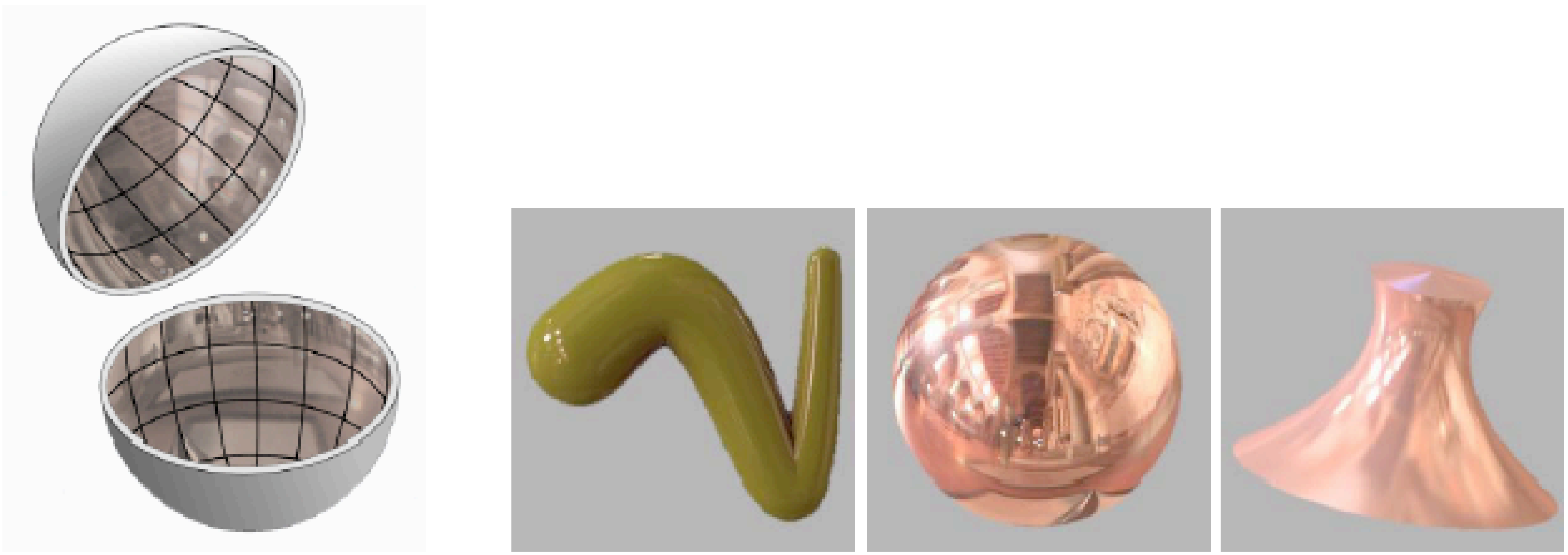
(c) Heeger and Bergen texture



(d) Portilla and Simoncelli texture

Figure 4.14. Spheres of identical reflectance properties rendered under a photographically-acquired illumination map (a) and three synthetic illumination maps (b-d). The illumination in (b) is Gaussian noise with a $1/f^2$ power spectrum. The illumination in (c) was synthesized with the procedure of Heeger and Bergen [43] to match the pixel histogram and marginal wavelet histograms of the illumination in (a). The illumination in (d) was synthesized using the technique of Portilla and Simoncelli, which also enforces conditions on the joint wavelet histograms. The illumination map of (a) is due to Debevec [24].

Illumination Maps



(a) (b) (c) (d)

Figure 5.2. (a) A photographically-acquired illumination map, illustrated on the inside of a spherical shell. The illumination map is identical to that of Figure 4.1d. (b-d) Three surfaces of different geometry and reflectance rendered under this illumination map using the methods of Appendix B.

Classification

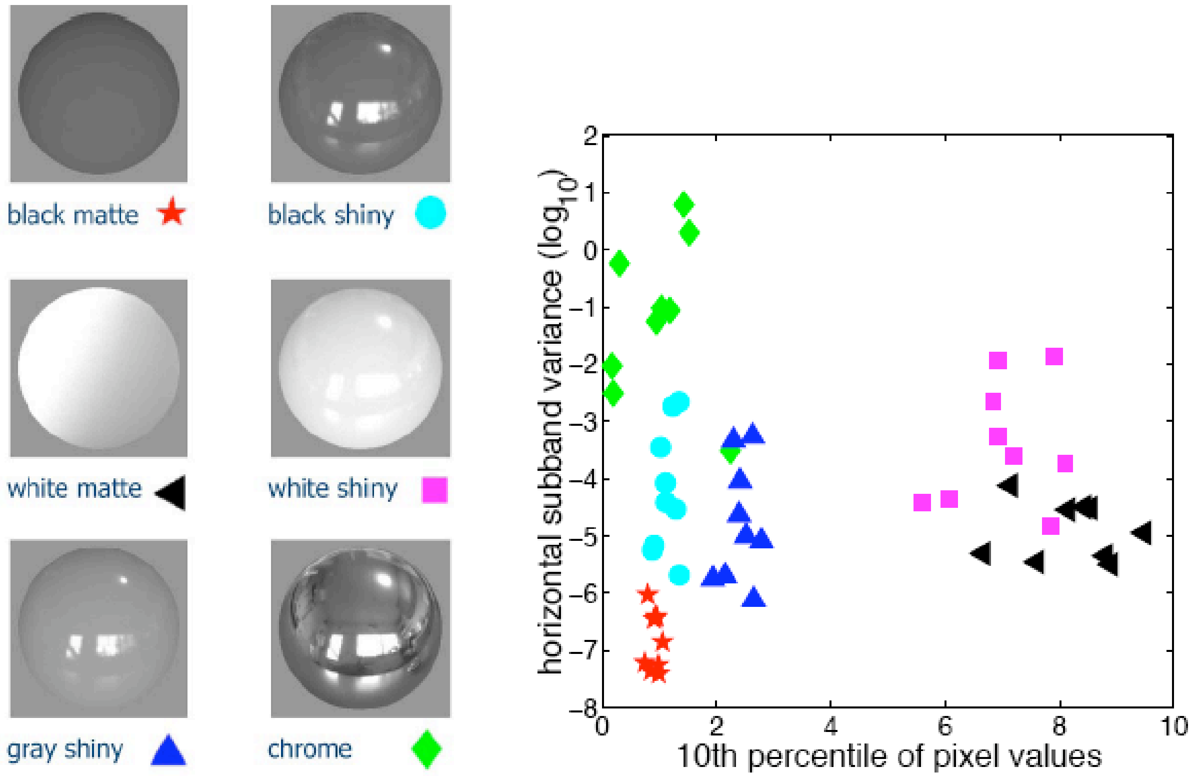


Figure 5.11. At left, synthetic spheres of 6 different reflectances, each rendered under one of Debevec's illumination maps. Ward model parameters are as follows: black matte, $\rho_d = .1$, $\rho_s = 0$; black shiny, $\rho_d = .1$, $\rho_s = .1$, $\alpha = .01$; white matte, $\rho_d = .9$, $\rho_s = 0$; white shiny, $\rho_d = .7$, $\rho_s = .25$, $\alpha = .01$; chrome, $\rho_d = 0$, $\rho_s = .75$, $\alpha = 0$; gray shiny, $\rho_d = .25$, $\rho_s = .05$, $\alpha = .01$. We rendered each sphere under the nine photographically-acquired illuminations depicted in Figure 2.7 and plotted a symbol corresponding to each in the two-dimensional feature space at right. The horizontal axis represents the 10th percentile of pixel intensity, while the vertical axis is the log variance of horizontally-oriented QMF wavelet coefficients at the second-finest scale, computed after geometrically distorting the original image as described in Section 6.1.2.

Classification Continued

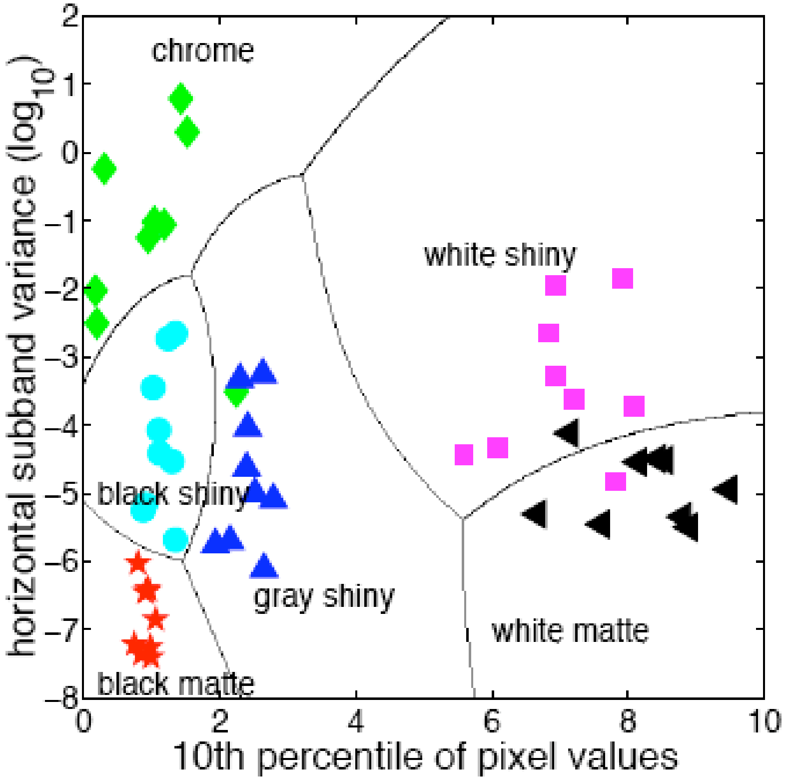


Figure 5.12. The curved lines separate regions assigned to different reflectances by a simple classifier based on two image features. The training examples are the images described in Figure 5.11. The classifier is a one-versus-all support vector machine, described in Section 6.1.1. Using additional image features improves classifier performance.

Lighting direction vs. Viewer direction

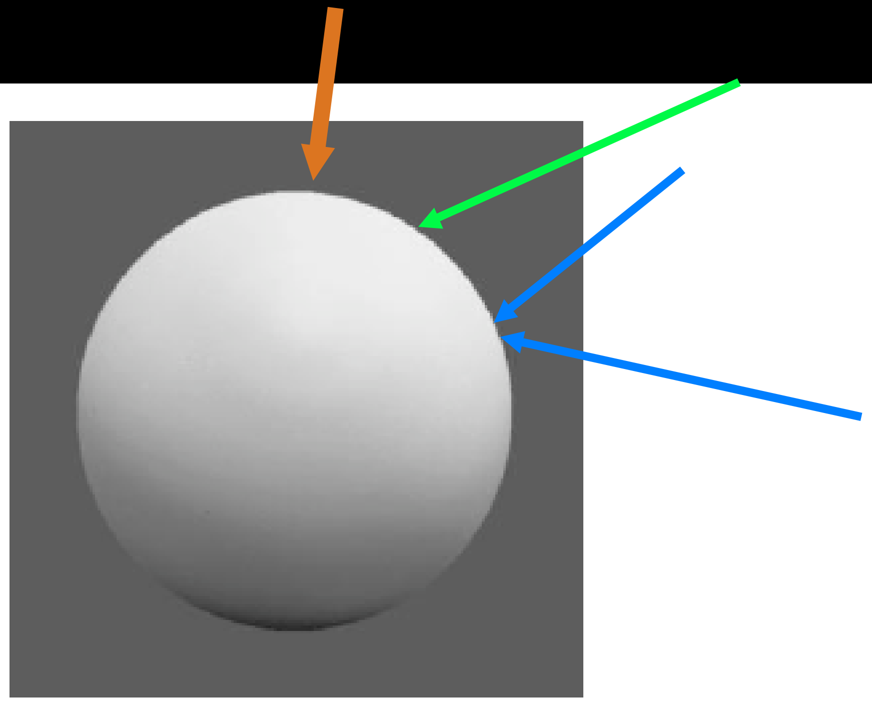
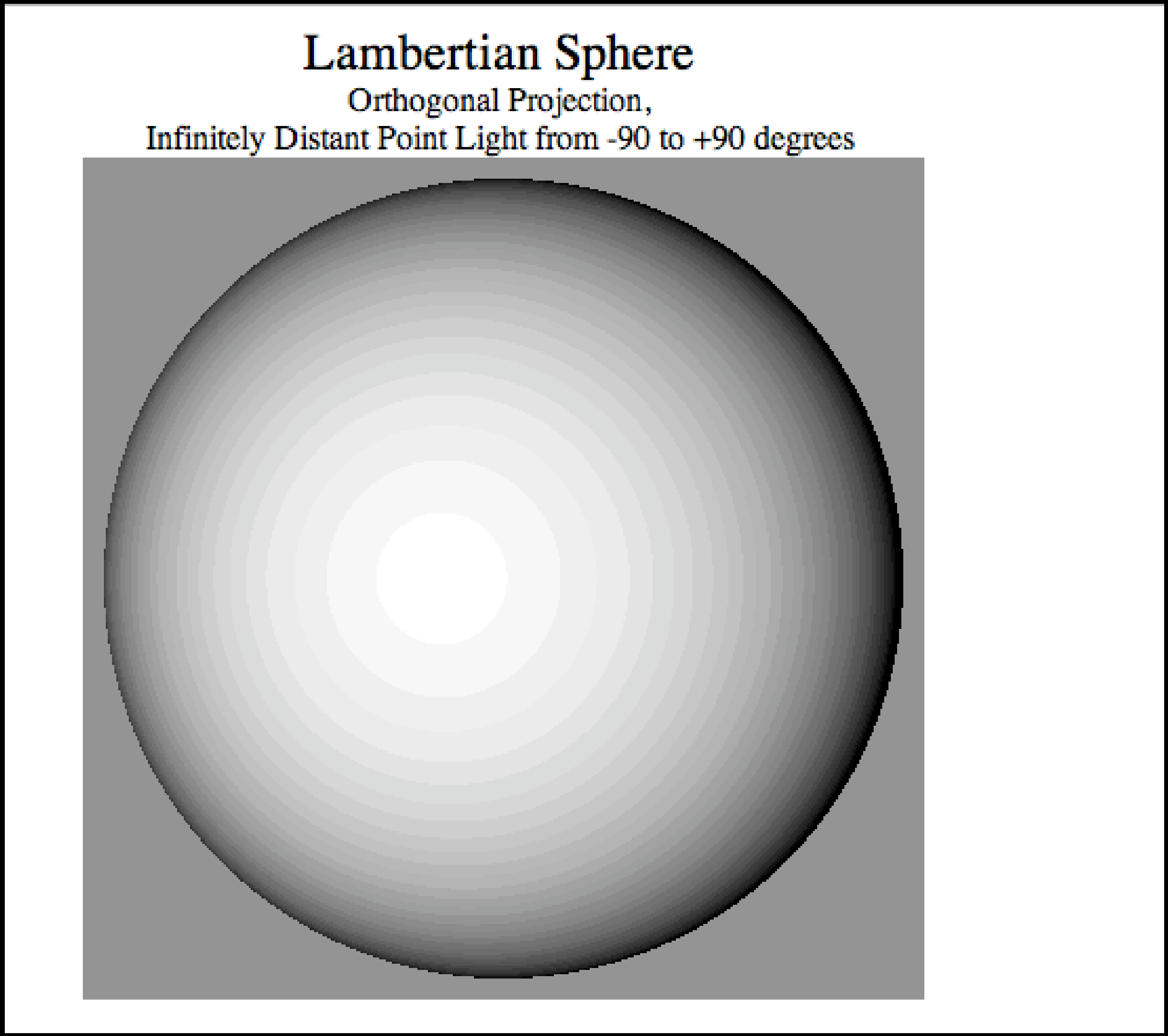


Figure 3.6. A photograph of a matte sphere, shown against a uniform gray background.

For Lambertian surface:

Viewer direction is irrelevant

Lighting direction is *very relevant*


Lambertian Sphere
Orthogonal Projection,
Infinitely Distant Point Light from -90 to +90 degrees

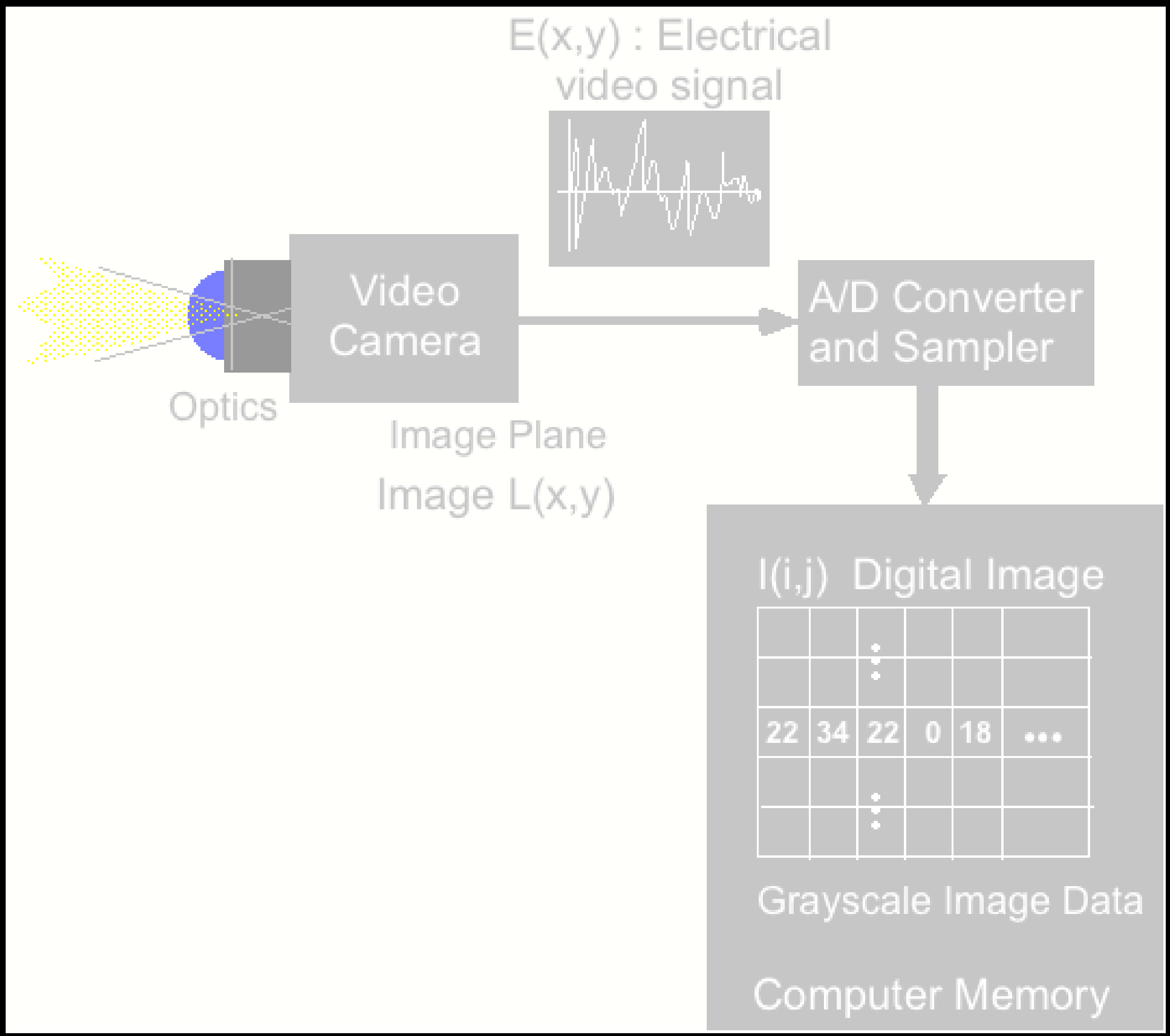
Photometry

- Photometry:

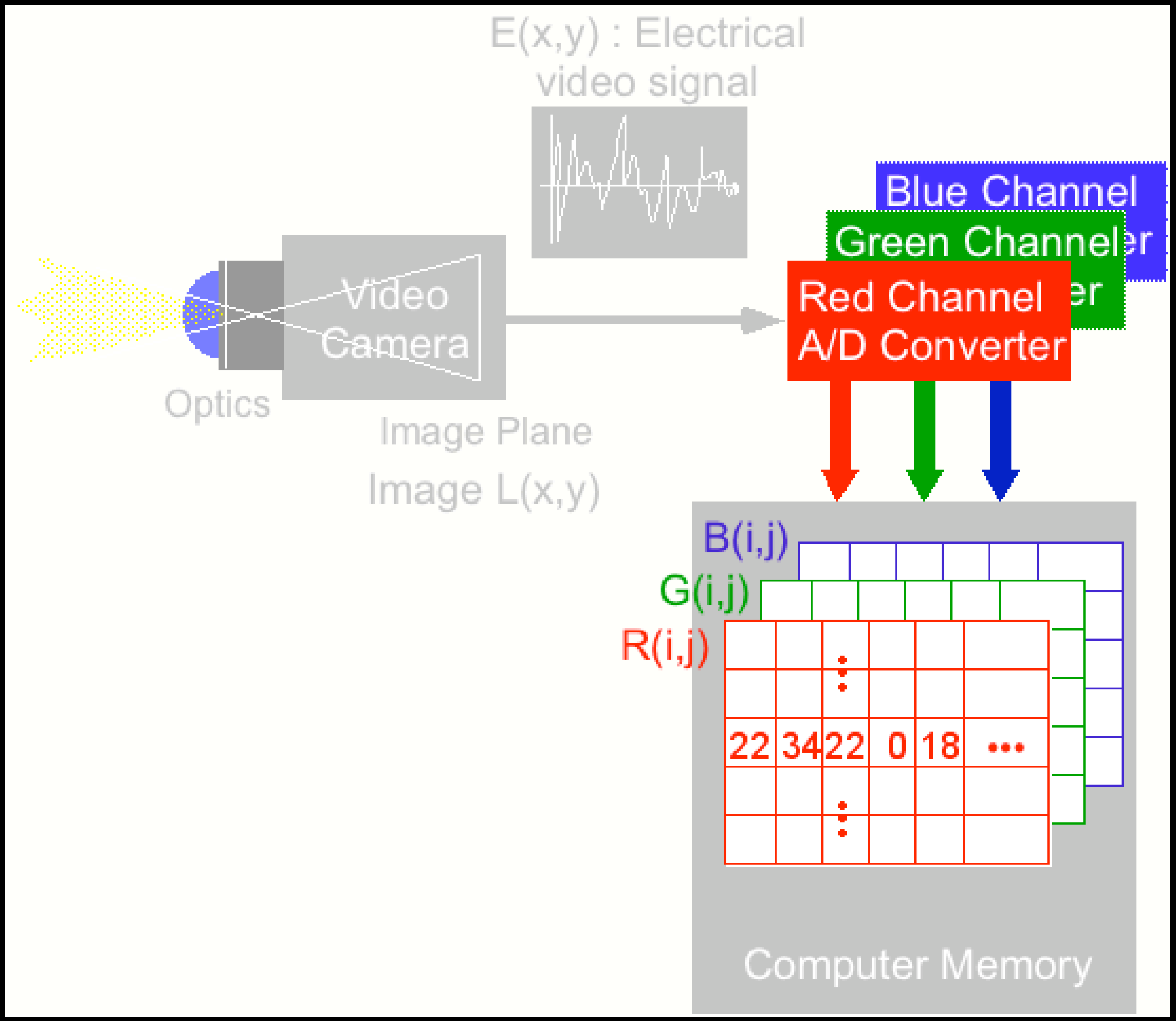
  Concerned with mechanisms for converting light energy into electrical energy.

World → Optics → Sensor →
Signal → Digitizer →
Digital Representation

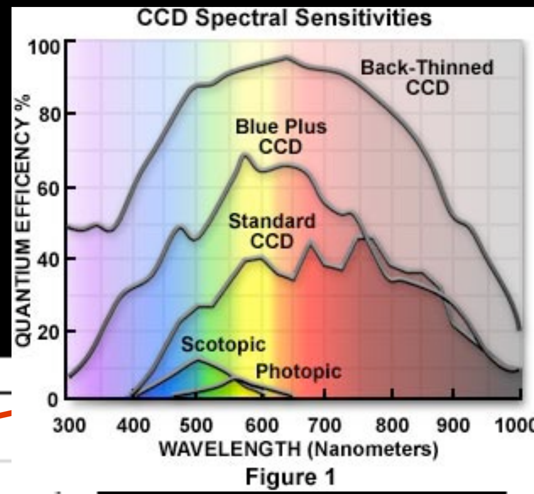
B&W Video System



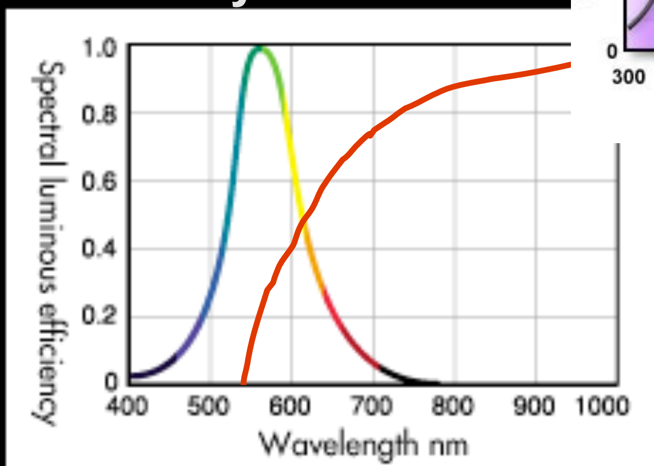
Color Video System



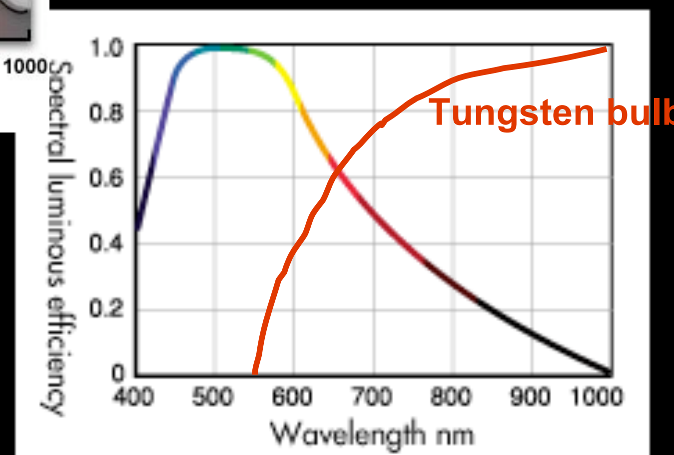
Spectral Sensitivity



Human Eye



CCD Camera



- Figure 1 shows relative efficiency of conversion for the eye (scotopic and photopic curves) and several types of CCD cameras. Note the CCD cameras are much more sensitive than the eye.
- Note the enhanced sensitivity of the CCD in the Infrared and Ultraviolet (bottom two figures)
- Both figures also show a handrawn sketch of the spectrum of a tungsten light bulb

Characteristics

- In general, $V(x,y) = k\,E(x,y)^{\gamma}$ where
  - k is a constant
  - **γ is a parameter of the type of sensor**
    - **$\gamma=1$ (approximately) for a CCD camera**
    - **$\gamma=.65$ for an old type vidicon camera**
- Factors influencing performance:
  - Optical distortion: pincushion, barrel, non-linearities
  - Sensor dynamic range (30:1 CCD, 200:1 vidicon)
  - Sensor Shading (nonuniform responses from different locations)
- **TV Camera pros: cheap, portable, small size**
- **TV Camera cons: poor signal to noise, limited dynamic range, fixed array size with small image (getting better)**

Sensor Performance

- Optical Distortion: pincushion, barrel, non-linearities
- Sensor Dynamic Range: (30:1 for a CCD, 200:1 Vidicon)
- Sensor Blooming: spot size proportional to input intensity
- Sensor Shading: (non-uniform response at outer edges of image)
- Dead CCD cells

There is no “universal sensor”. Sensors must be selected/tuned for a particular domain and application.

Lens Aberrations

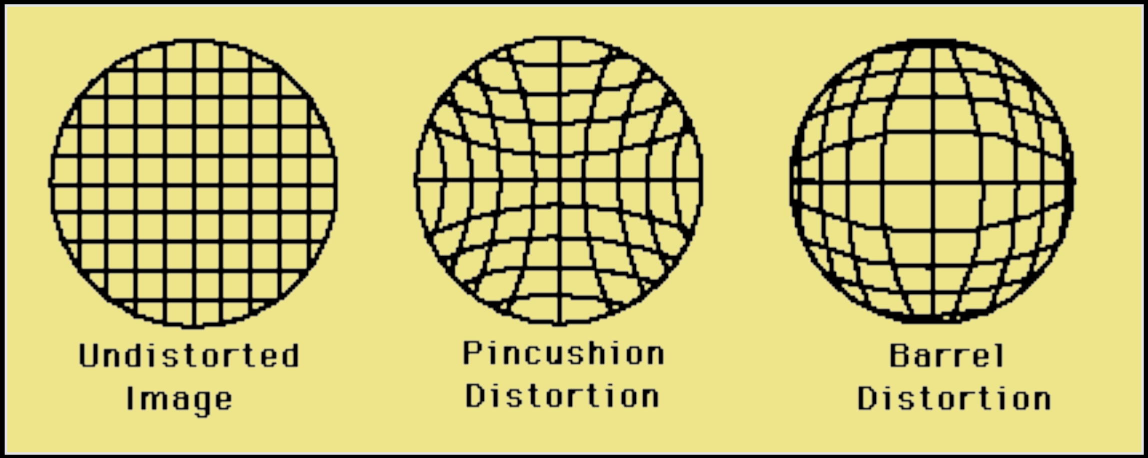
- In an ideal optical system, all rays of light from a point in the object plane would converge to the same point in the image plane, forming a clear image.
- The lens defects which cause different rays to converge to different points are called aberrations.

  - Distortion: barrel, pincushion
  - Curvature of field
  - Chromatic aberration
  - Spherical aberration
  - Coma
  - Astigmatism

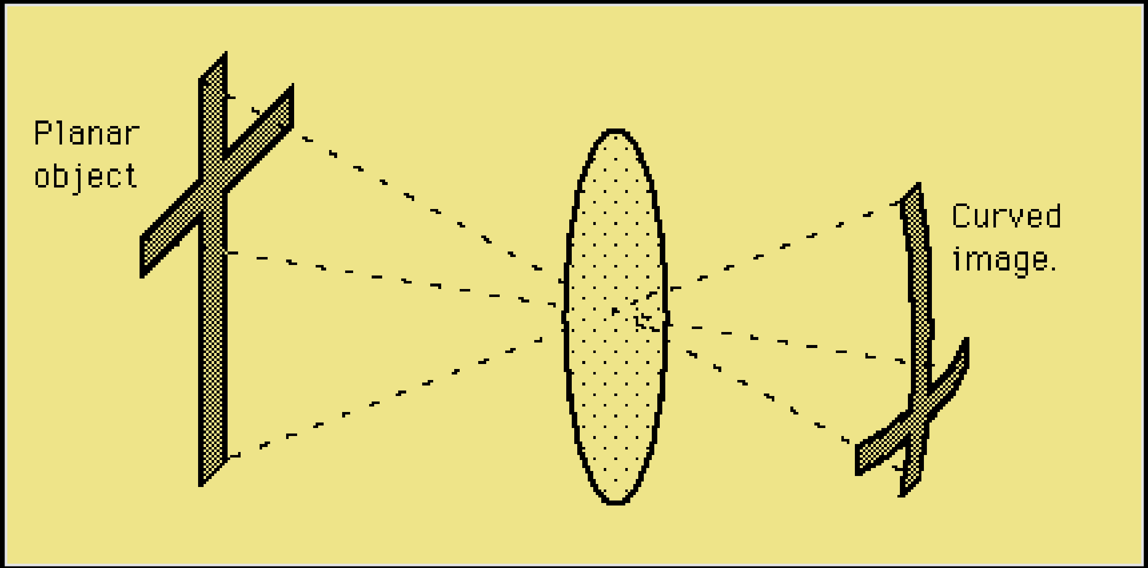
Aberration slides after http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/aberrcon.html#c1

Lens Aberrations

- Distortion

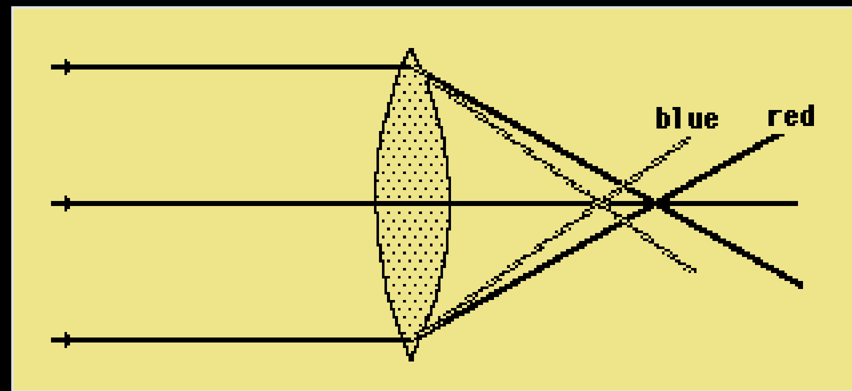


- Curved Field



Lens Aberrations

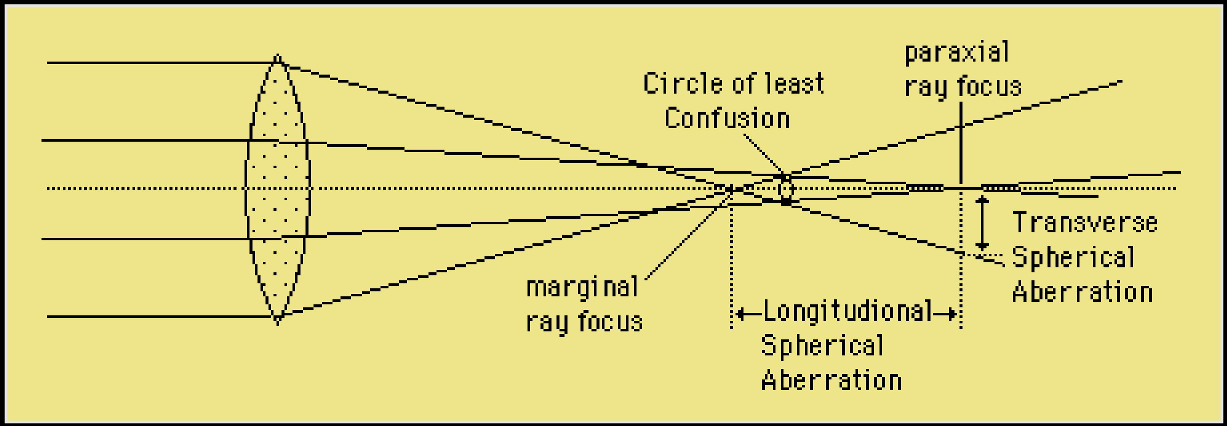
- Chromatic Aberration



- Focal Length of lens depends on refraction and
- The index of refraction for blue light (short wavelengths) is larger than that of red light (long wavelengths).
- Therefore, a lens will not focus different colors in exactly the same place
- The amount of chromatic aberration depends on the dispersion (change of index of refraction with wavelength) of the glass.

Lens Aberration

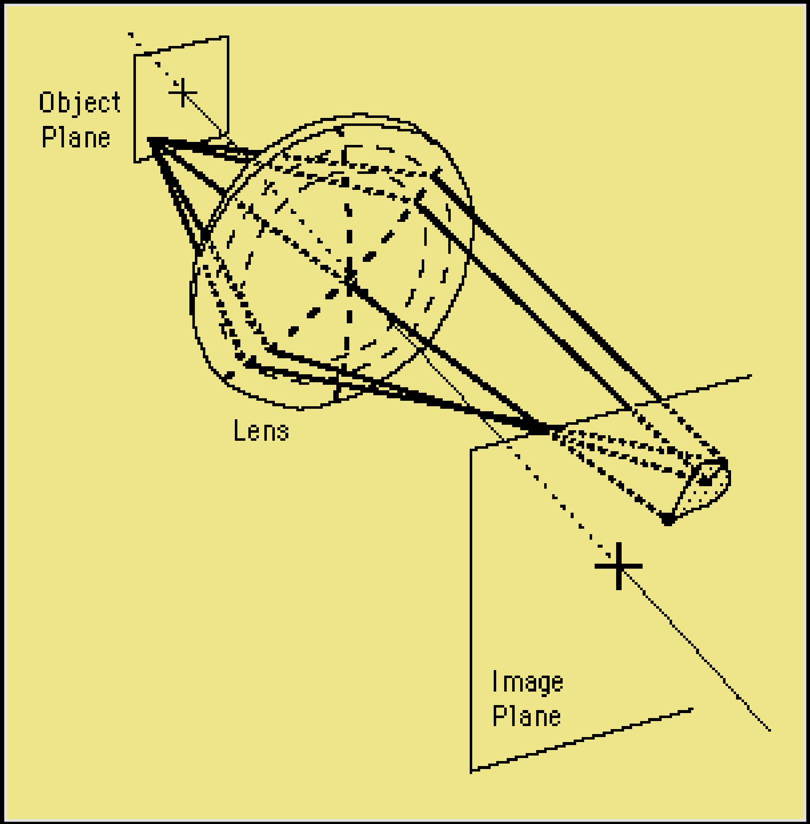
- Spherical Aberration



- Rays which are parallel to the optic axis but at different distances from the optic axis fail to converge to the same point.

Lens Aberrations

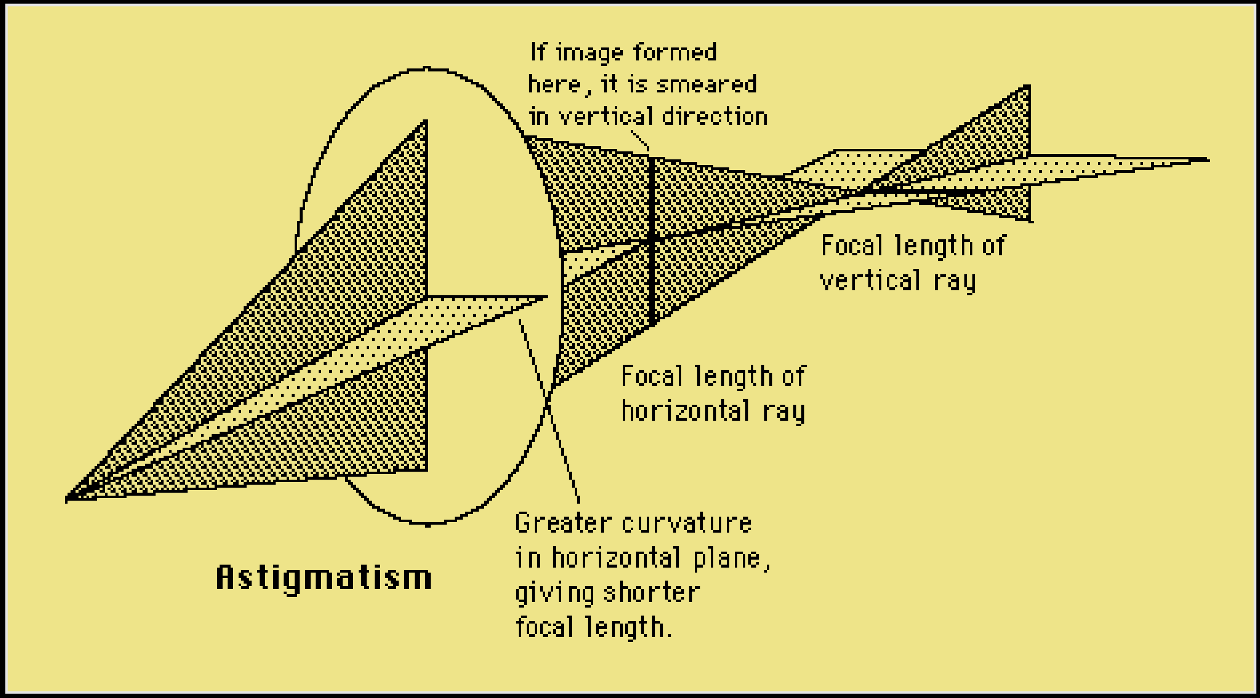
- Coma



- Rays from an off-axis point of light in the object plane create a trailing "comet-like" blur directed away from the optic axis
- Becomes worse the further away from the central axis the point is

Lens Aberrations

- Astigmatism

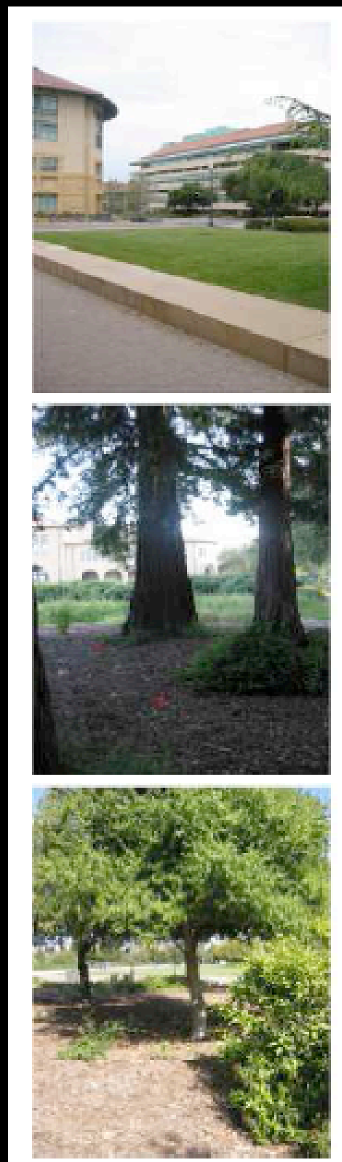


- Results from different lens curvatures in different planes.

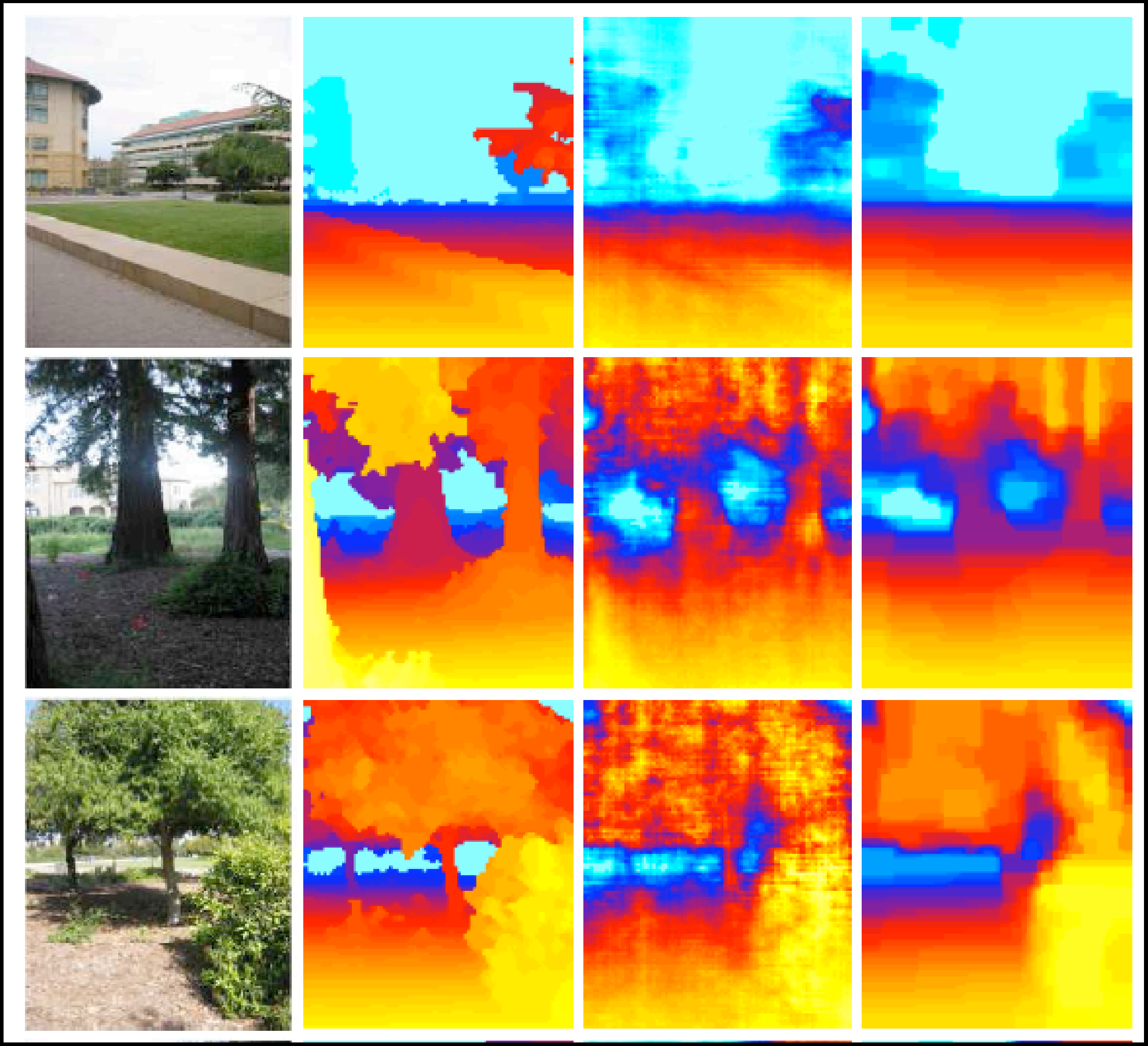
Sensor Summary

- Visible Light/Heat
  - Camera/Film combination
  - Digital Camera
  - Video Cameras
  - FLIR (Forward Looking Infrared)
- Range Sensors
  - Radar (active sensing)
    - sonar
    - laser
  - Triangulation
    - stereo
    - structured light
      - – striped, patterned
    - Moire
    - Holographic Interferometry
    - Lens Focus
    - Fresnel Diffraction
- Others
- Almost anything which produces a 2d signal that is related to the scene can be used as a sensor

Depth Images (Stanford)



Depth Images

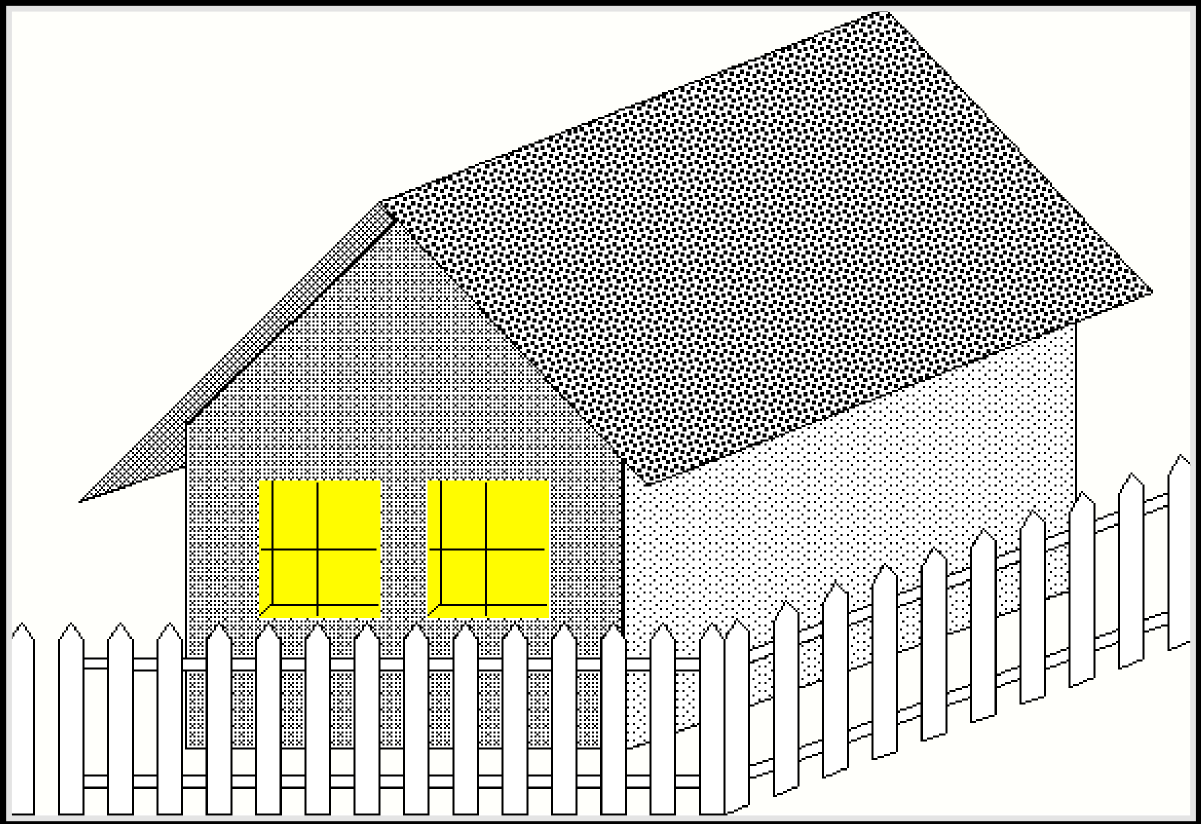


Digitization

World → Optics → Sensor → Signal → Digitizer → Digital Representation

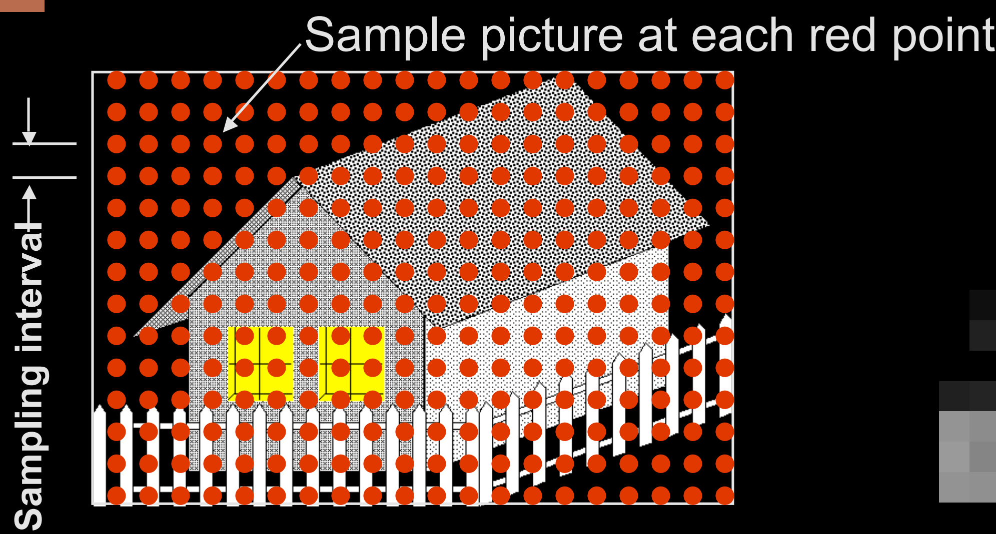
- Digitization: conversion of the continuous (in space and value) electrical signal into a digital signal (digital image)
- Three decisions must be made:
  - Spatial resolution (how many samples to take)
  - Signal resolution (dynamic range of values)
  - Tessellation pattern (how to 'cover' the image with sample points)

Digitization: Spatial Resolution

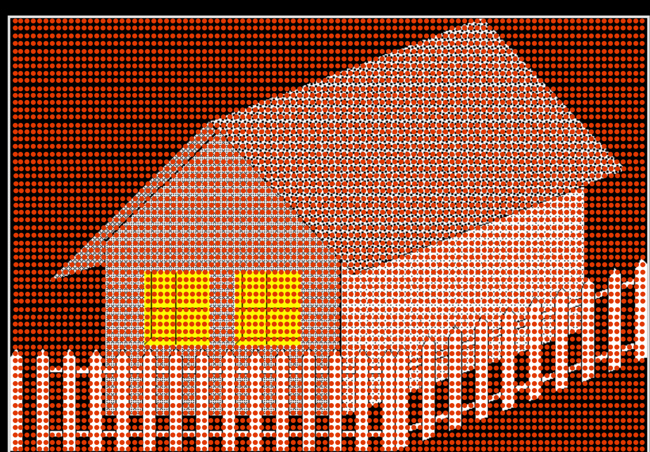


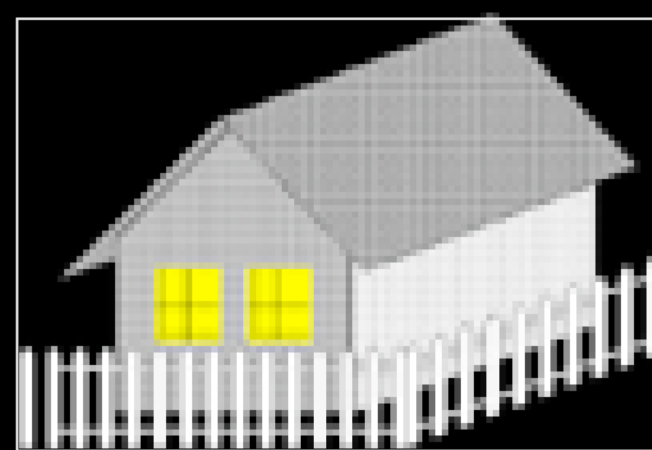
- Let's digitize this image
  - Assume a square sampling pattern
  - Vary density of sampling grid

Spatial Resolution



Coarse Sampling: 20 points per row by 14 rows



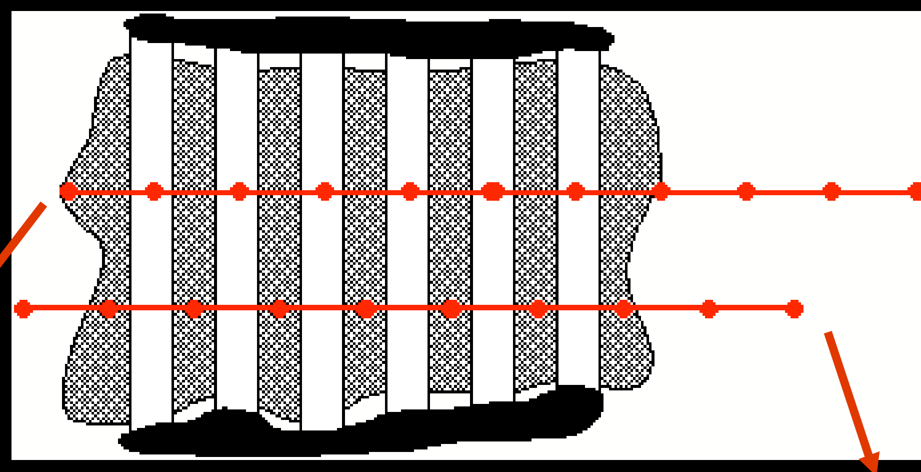


Finer Sampling: 100 points per row by 68 rows

Effect of Sampling Interval - 1

- Look in vicinity of the picket fence:

Sampling Interval: 



100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100

White Image!

NO EVIDENCE OF THE FENCE!

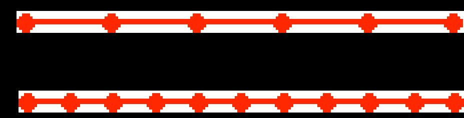
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40

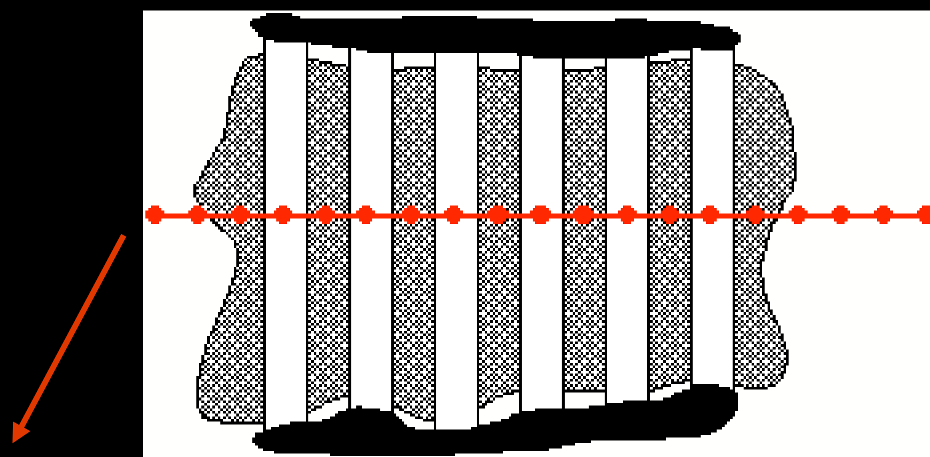
Dark Gray Image!

Effect of Sampling Interval - 2

- Look in vicinity of picket fence:

Sampling Interval:





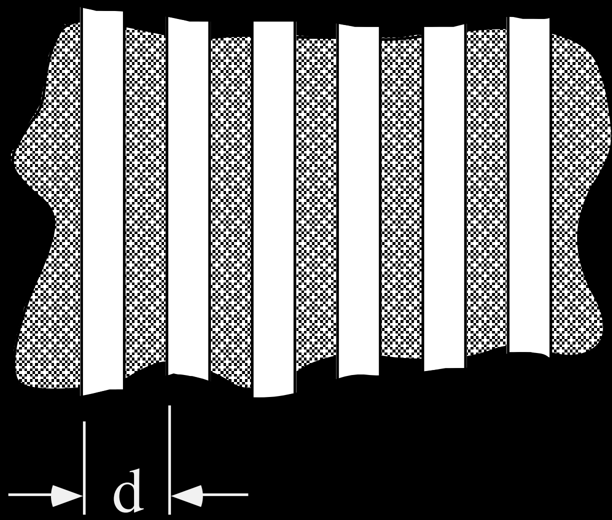
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40

Now we've got a fence!

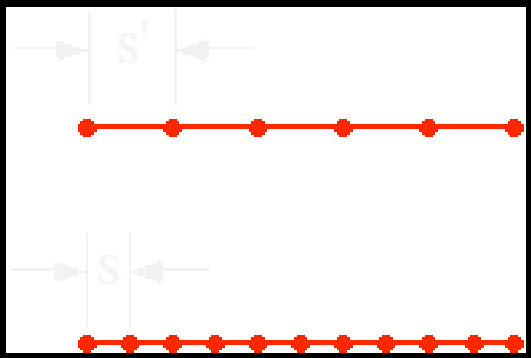
What's the difference between this attempt and the last one?

The Missing Fence Found

- Consider the repetitive structure of the fence:



Sampling Intervals



Case 1: s' = d The sampling interval is equal to the size of the repetitive structure **NO FENCE**

Case 2: s = d/2 The sampling interval is one-half the size of the repetitive structure **FENCE**

The Sampling Theorem

- IF: the size of the smallest structure to be preserved is d
- THEN: the sampling interval must be smaller than d/2

- Can be shown to be true mathematically
- Repetitive structure has a certain frequency ('pickets/foot')
  - To preserve structure must sample at twice the frequency
  - Holds for images, audio CDs, digital television….
- Leads naturally to Fourier Analysis

Human Eye Sampling

- Fine near the center of the retina (fovea)
- Coarse at the edges

- Strategy:
  - Detect points of interest with low resolution sampling
  - “Foveate” to point of interest and use high resolution sampling.