Today

- Photometric Stereo
- Early vision on a single image

Midterm Exam

Thursday, March 6th

A calculator is allowed

Cover everything till the class on Tuesday, March 4

Open book and open notes

Potential Issues in Project #1

What is the goal of camera calibration?

Estimate the intrinsic parameters, which do not depend on camera position

1. $f_u = f k_u$
2. $f_v = f k_v$
3. u_0
4. v_0

The projection matrix P is not the answer!

Potential Issues in Project #1

In addition to projection error, you should check if the calibration result does make sense

Meanings and reasonable range for intrinsic parameters

$$f_u = f * k_u \quad f_v = f * k_v$$

k_u and k_v are spatial sampling rate (pixels/mm)

u_0 and v_0 are the x-y coordinates of the principal point, which is almost at the image center

Potential Issues in Project #1

Grading is primarily based on your report.

Your report should be complete and contain all the required information:

- a brief introduction on the addressed problem,
- a succinct description on the methods you implemented with the major steps, e.g., the equations to calculate those intrinsic parameters
- **the experimental results and analysis,**
- conclusion, and
- reference.

Photometric Stereo

Assume:

- A set of point sources that are infinitely distant
- A set of pictures of an object, obtained in exactly the same camera/object configuration but using different illumination sources
- Pictures taken based on an orthographic camera model
- A Lambertian object (or the specular component has been identified and removed)

What do we want

- Reconstruct a patch of surface in 3D space

Example

$\rho(x, y) = |\mathbf{g}(x, y)|$ $\mathbf{N}(x, y) = \mathbf{g}(x, y)/|\mathbf{g}(x, y)|$ Reconstructed surface

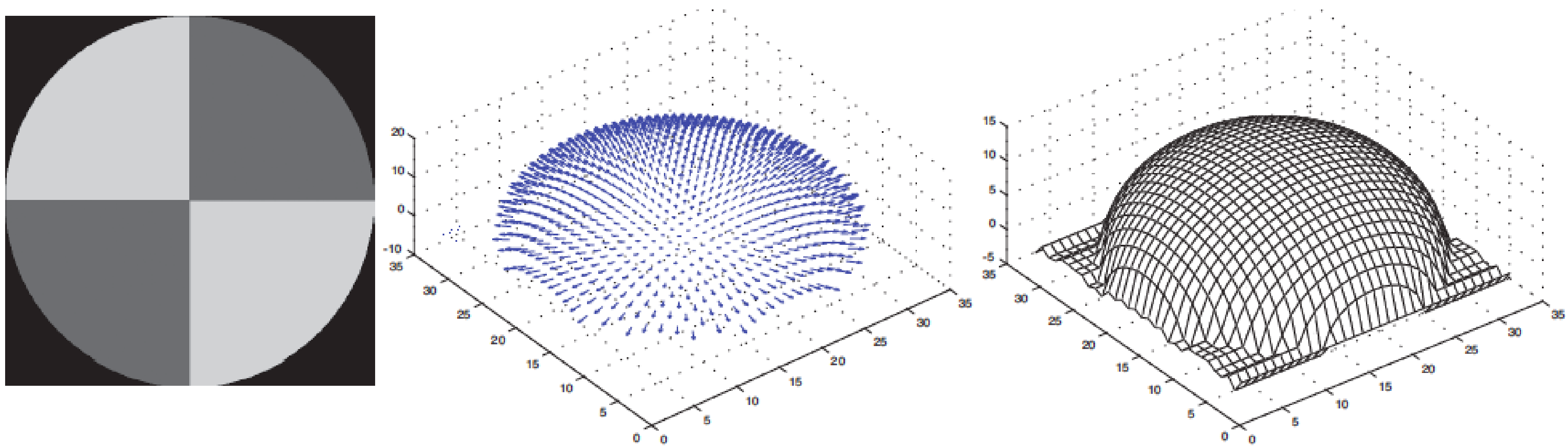


FIGURE 2.12: The image on the **left** shows the magnitude of the vector field $\boldsymbol{g}(x, y)$ recovered from the input data of Figure 2.11 represented as an image—this is the reflectance of the surface. The **center** figure shows the normal field, and the **right** figure shows the height field.

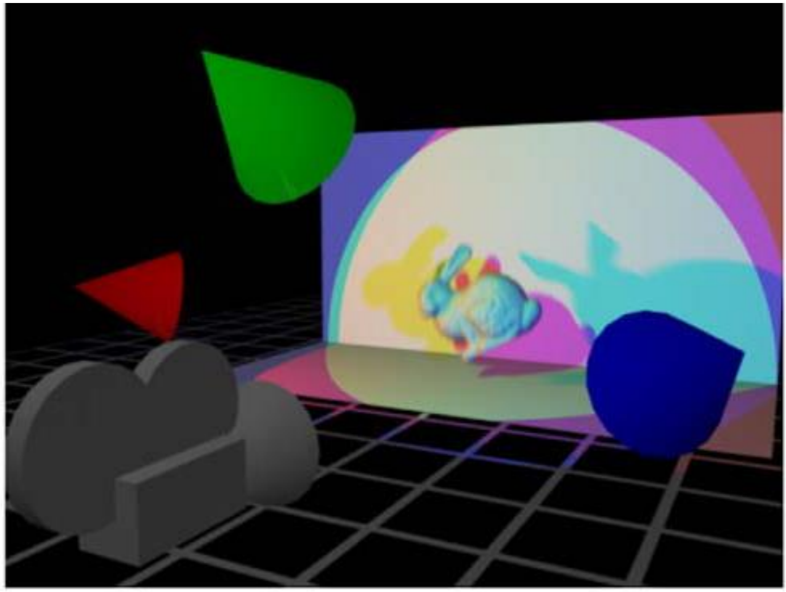
Notes

Limitation on applying different illuminations

- Cannot capture moving objects

In practice, we take multiple pictures using different camera or from different view points.

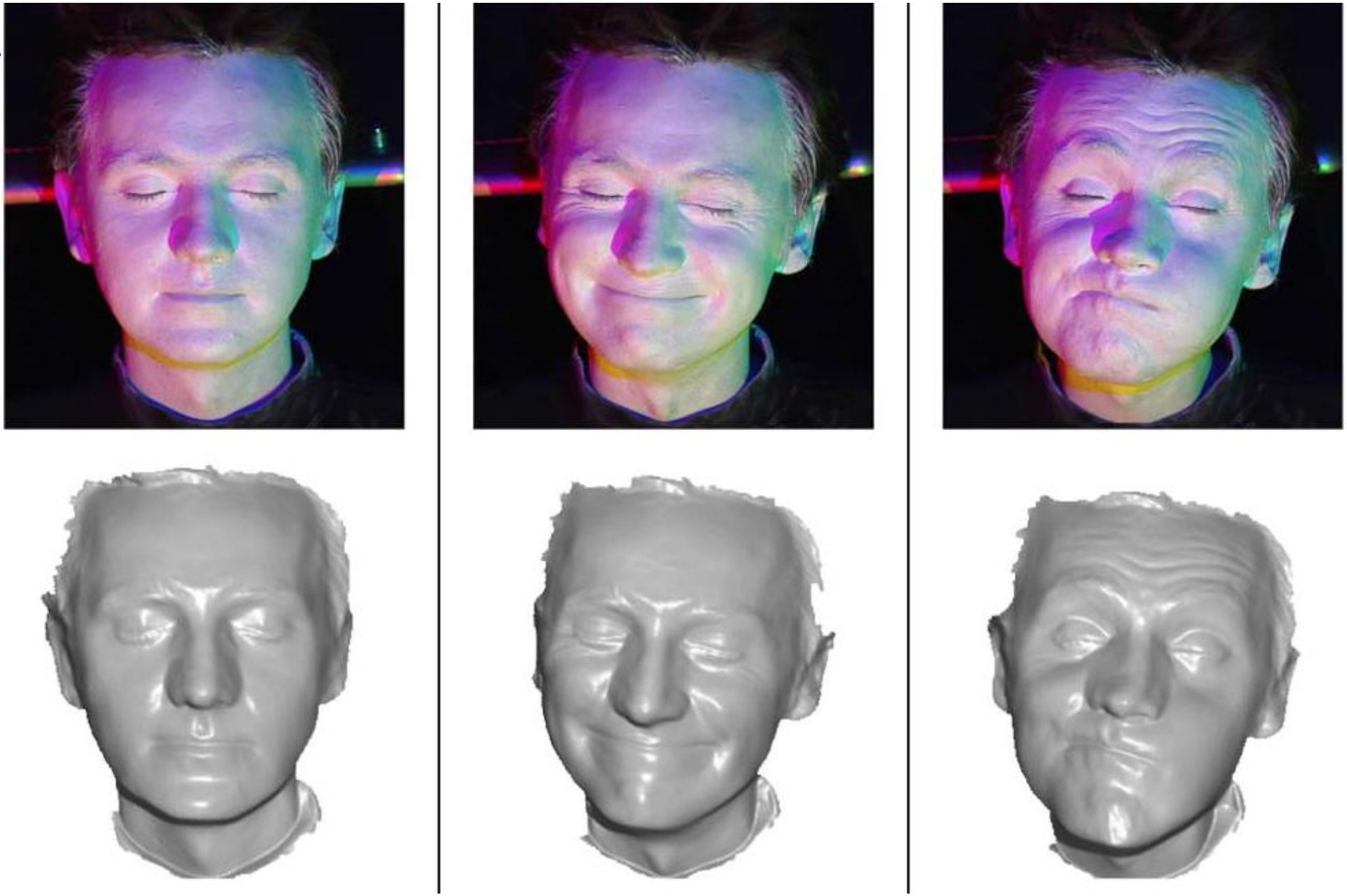
- A problem of feature matching to build correspondences across different pictures
- Low resolution of reconstruction



Take a single color image using multispectral lighting

- “Video normals from colored lights”, G. J. Brostow, C. Hernández, G. Vogiatzis,, B. Stenger, and R. Cipolla, IEEE PAMI, 2011.

FIGURE 2.13: Photometric stereo could become the method of choice to capture complex deformable surfaces. On the **top**, three images of a garment, lit from different directions, which produce the reconstruction shown on the **top right**. A natural way to obtain three different images at the same time is to use a color camera; if one has a red light, a green light, and a blue light, then a single color image frame can be treated as three images under three separate lights. On the **bottom**, an image of the garment captured in this way, which results in the photometric stereo reconstruction on the **bottom right**. *This figure was originally published as Figure 6 of "Video Normals from Colored Lights," G. J. Brostow, C. Hernández, G. Vogiatzis, B. Stenger, and R. Cipolla, IEEE Transactions on Pattern Analysis and Machine Intelligence, 2011 © IEEE, 2011.*



Reading Assignments

Chapter 2.3 – 2.5 (Forsyth and Ponce) for more related information

Early Vision on One Image

So far, we talked about image formation. Next, we will discuss early vision on one image

- **Linear and nonlinear filters**
  - Linear and nonlinear filters for noise reduction
  - Linear filters for differentiation
- **Edge detection**
- **Features**
  - Edges, lines, curves, corners etc.

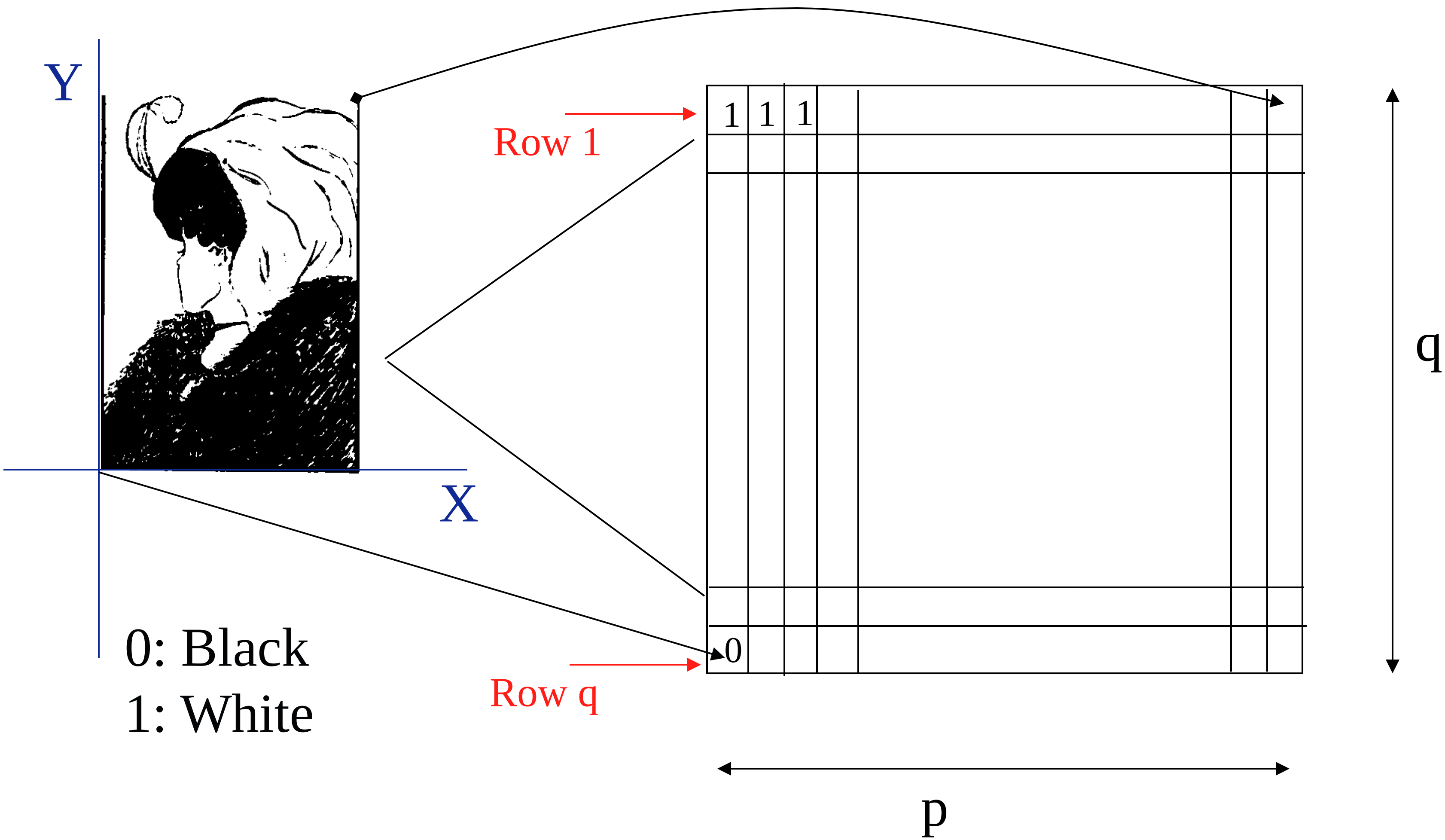
Early Vision on One Image

Binary

Gray level

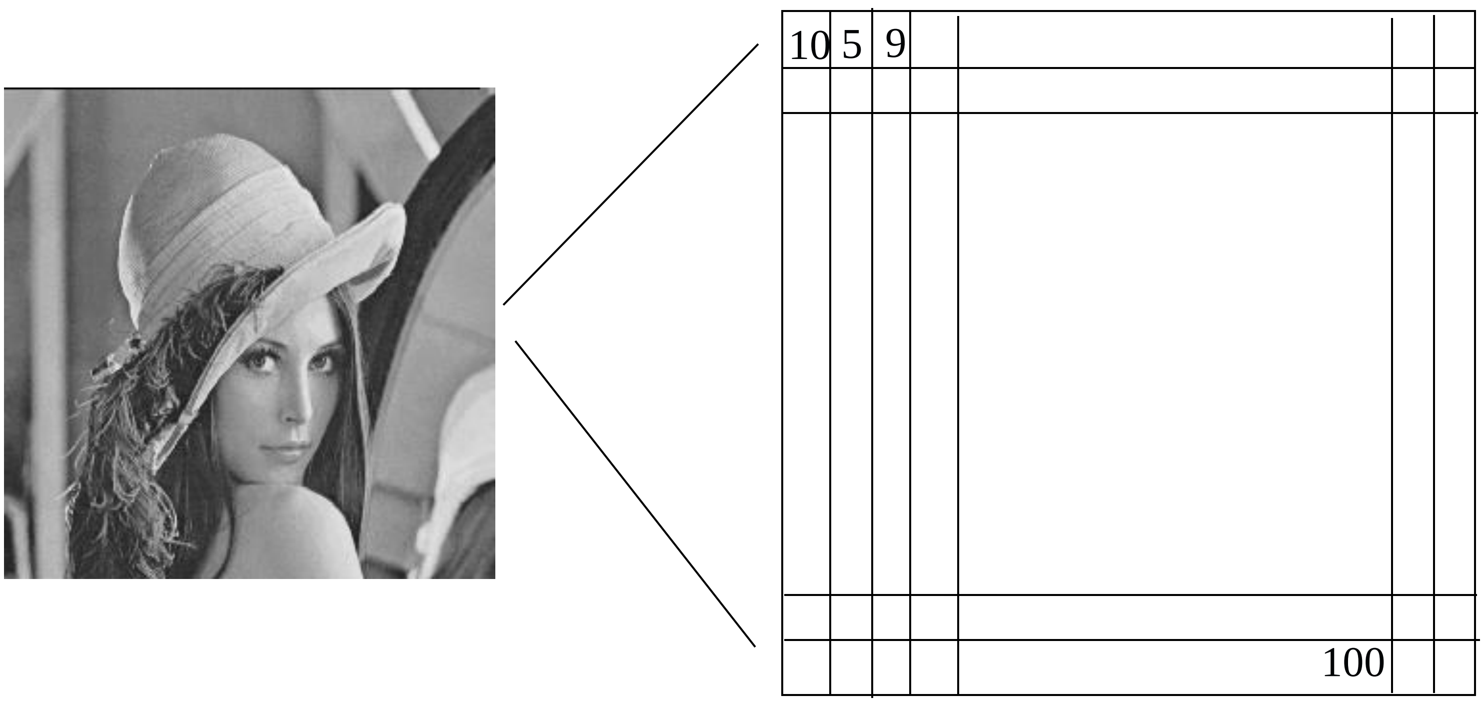
Color

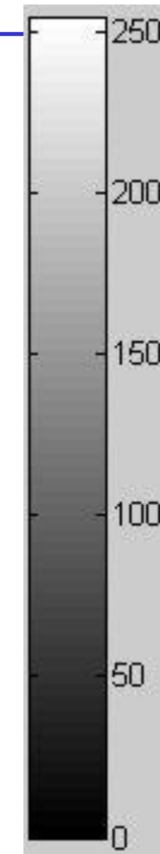
Binary Image



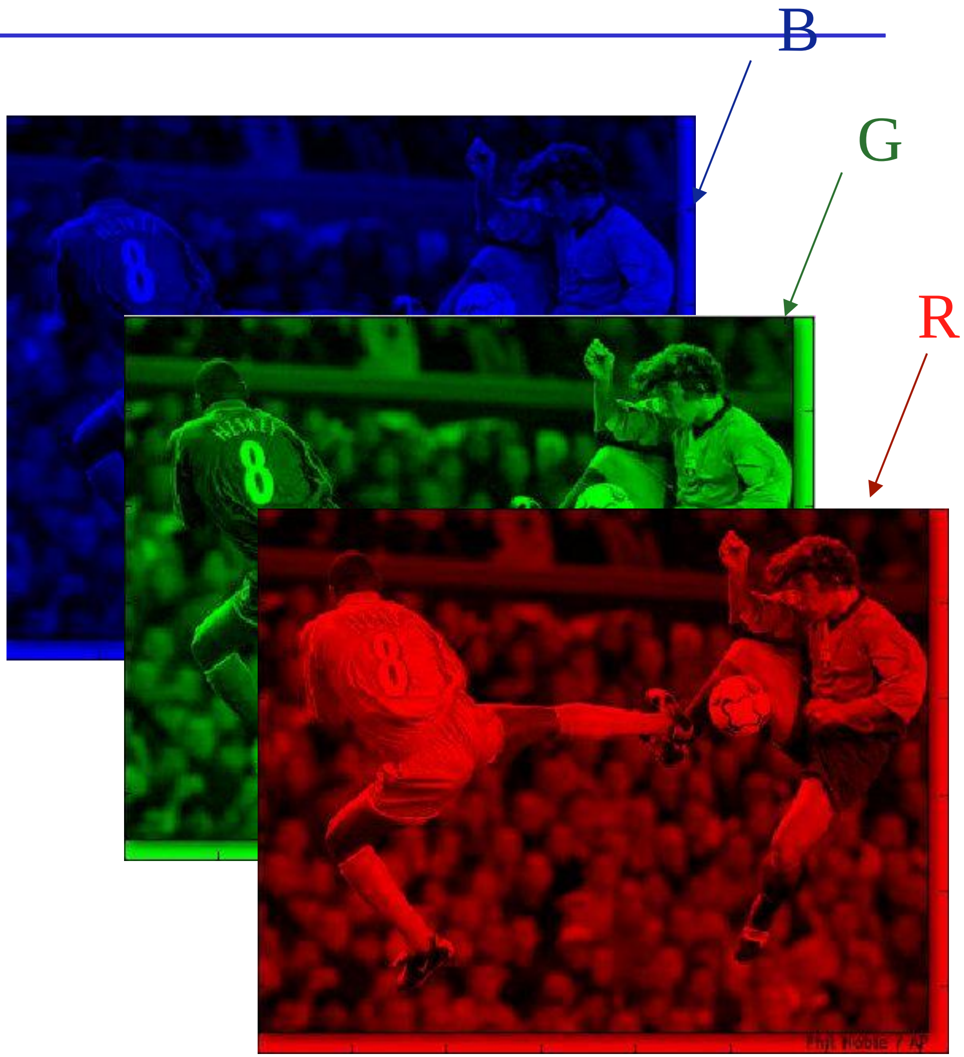
0: Black
1: White

Gray Scale Image





Color Image (RGB)



Early Vision on One Image: Two Important Topics

- **Image noise: intrinsic property of the sensor (CCD) and independent of scene**
  - Intensity noise – quantization and sensor
  - Positional noise – spatial sampling

Early Vision on One Image: Two Important Topics

- **Features: characterizing the shape/appearance of the objects in the image**
  - Edges, lines, curves, corners etc.
  - Image statistics: mean, variance, histogram etc.
  - Complex features
  - Widely used in many problems of computer vision including camera calibration, stereo, object detection/tracking/recognition, etc.

Image Noise

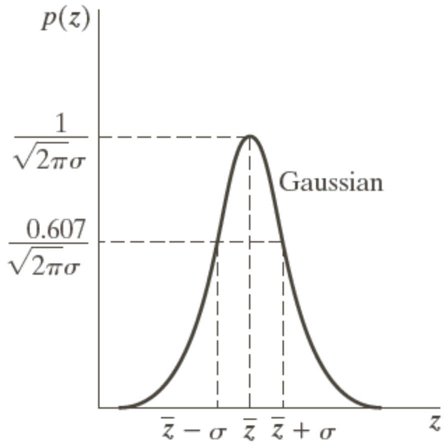
Observed image intensity   Ideal image intensity

$$\hat{I}(x, y) = I(x, y) + \eta(x, y)$$

Image noise

Some Important Noise Model

Assumption: the image noise is identically and independently.



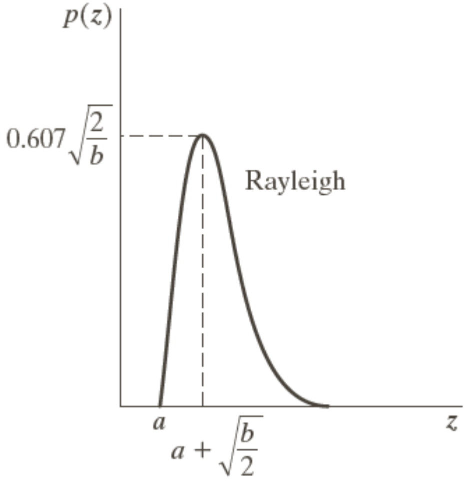
$$p(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(z-\bar{z})^2}{2\sigma^2}}$$

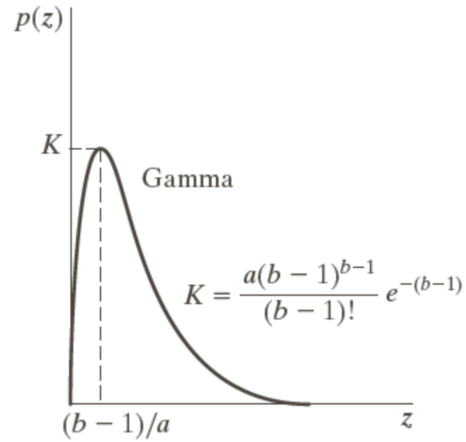
Gaussian noise model

- Due to electronic circuit
- Due to the image sensor
    - poor illumination
    - high temperature

Most popular noise model

Some Important Noise Model





$$p(z) = \begin{cases} \frac{2}{b}(z-a)e^{-\frac{(z-a)^2}{b}} & z \geq a \\ 0 & z < a \end{cases}$$

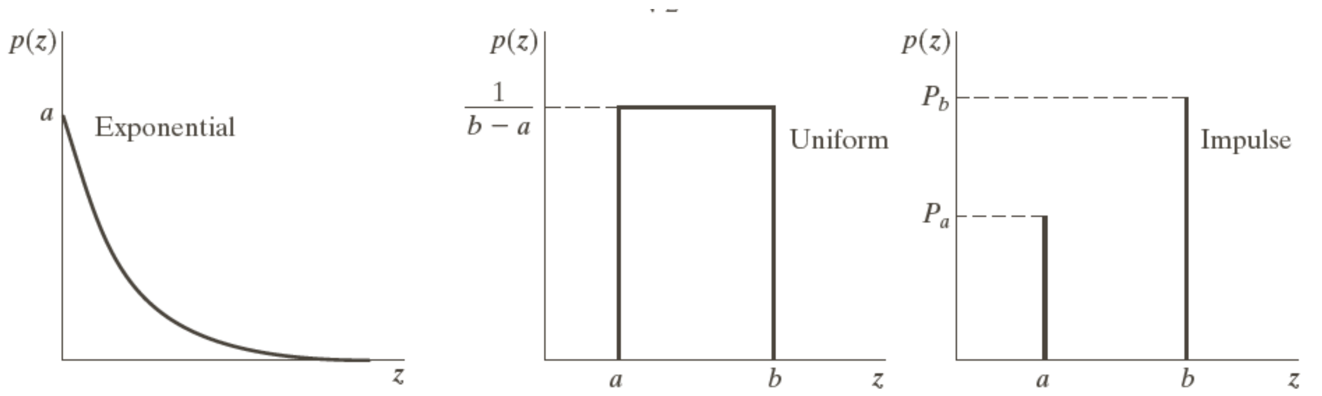
Rayleigh noise
- range imaging
- Background model for Magnetic Resonance Imaging (MRI) images

$$p(z) = \begin{cases} \frac{a^b z^{b-1}}{(b-1)!} e^{-az} & z \geq 0 \\ 0 & z < 0 \end{cases}$$

Gamma noise
- laser imaging

Figure from "Digital Image Processing", Gonzalez and Woods

Some Important Noise Model



$$P(z) = \begin{cases} ae^{-az} & z \geq 0 \\ 0 & z < 0 \end{cases}$$

$$P(z) = \begin{cases} \dfrac{1}{b-a} & a \leq z \leq b \\ 0 & otherwise \end{cases}$$

$$P(z) = \begin{cases} P_a & \text{for } z = a \\ P_b & \text{for } z = b \\ 0 & \text{Otherwise} \end{cases}$$

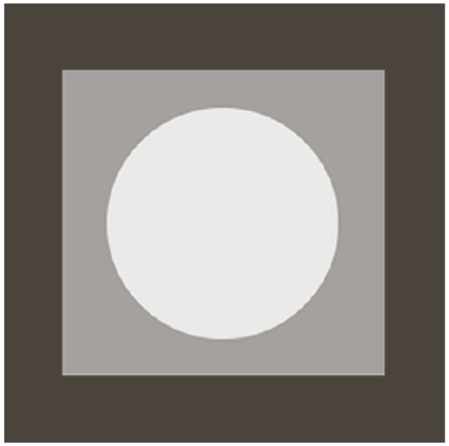
Exponential noise
- laser imaging

Uniform noise

Impulse noise
- salt and pepper noise
- A/D converter error
- bit error in transmission

Figure from "Digital Image Processing", Gonzalez and Woods

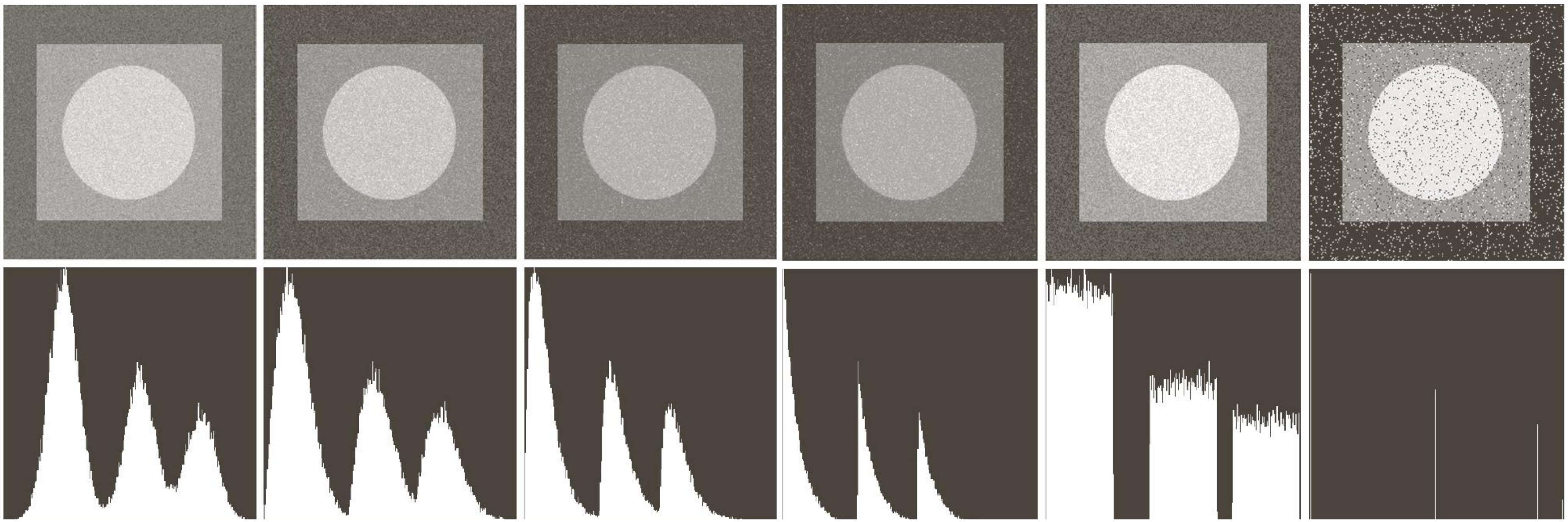
An Example



What is its histogram?

Figure from “Digital Image Processing”, Gonzalez and Woods

An Example (cont.)



Gaussian Rayleigh Gamma Exponential Uniform Salt & Pepper

Figure from "Digital Image Processing", Gonzalez and Woods

Another Example

Sigma =1

Sigma =16