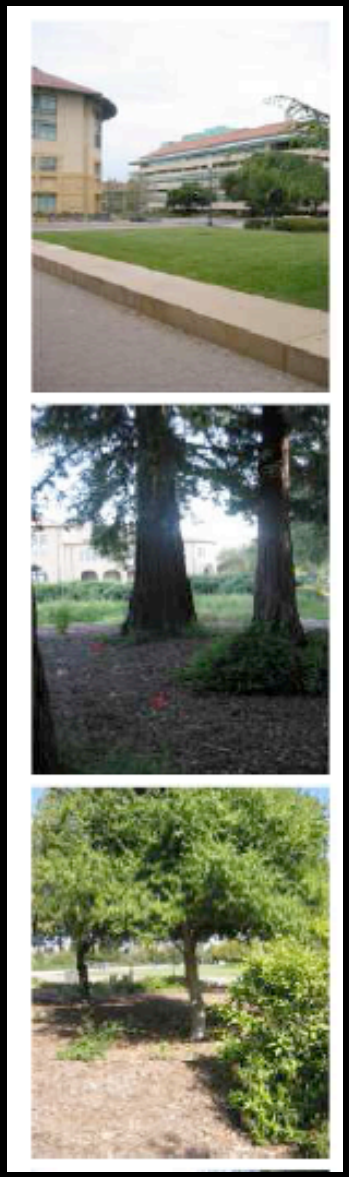
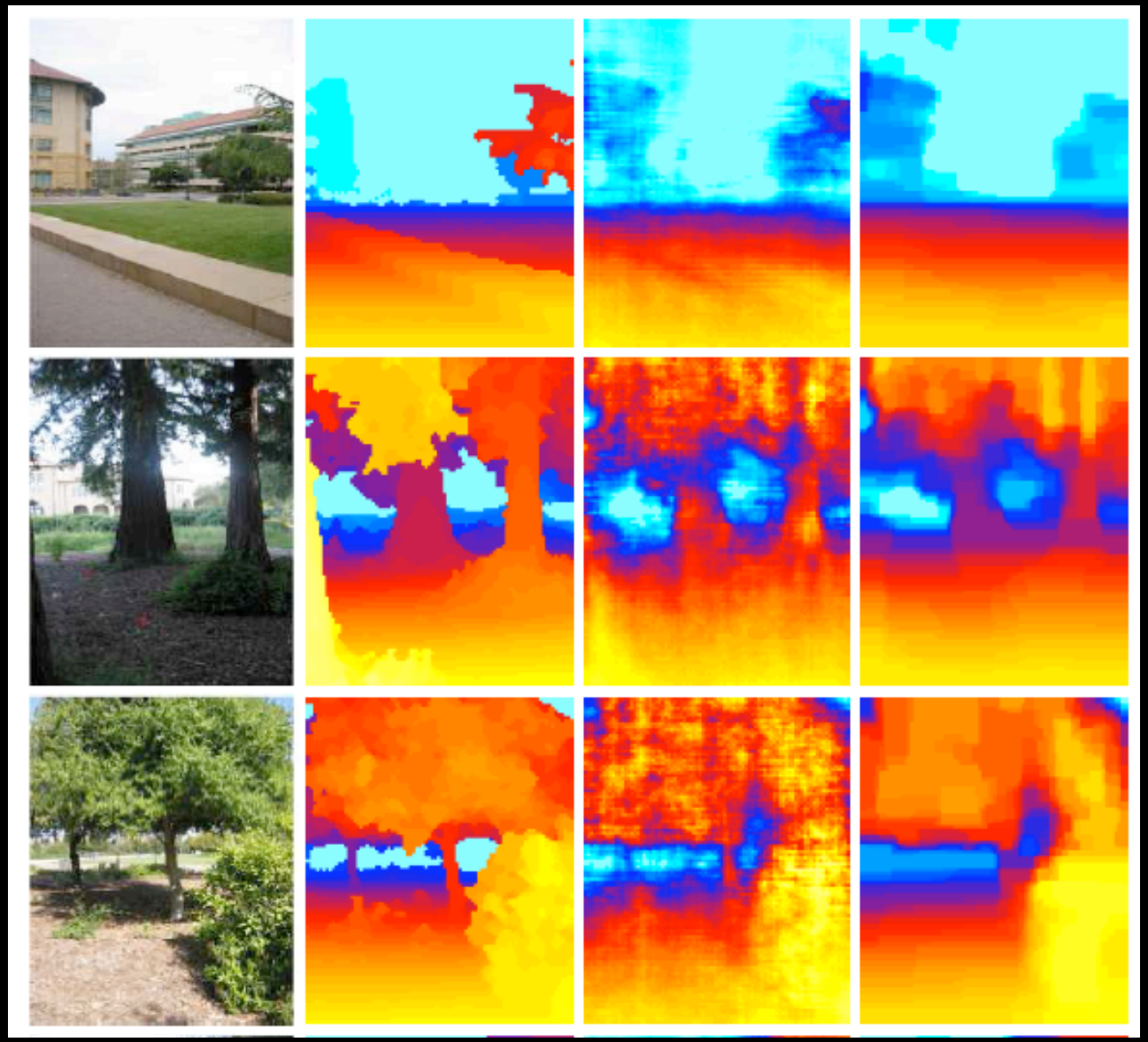
Sensor Summary

- 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

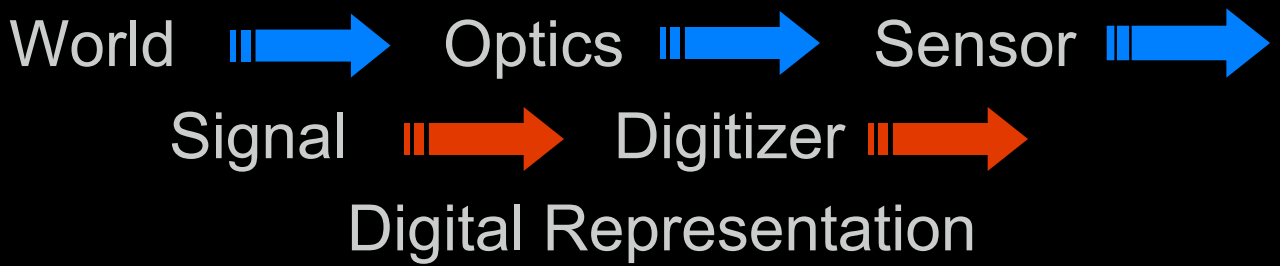
Depth Images (Stanford)



Depth Images

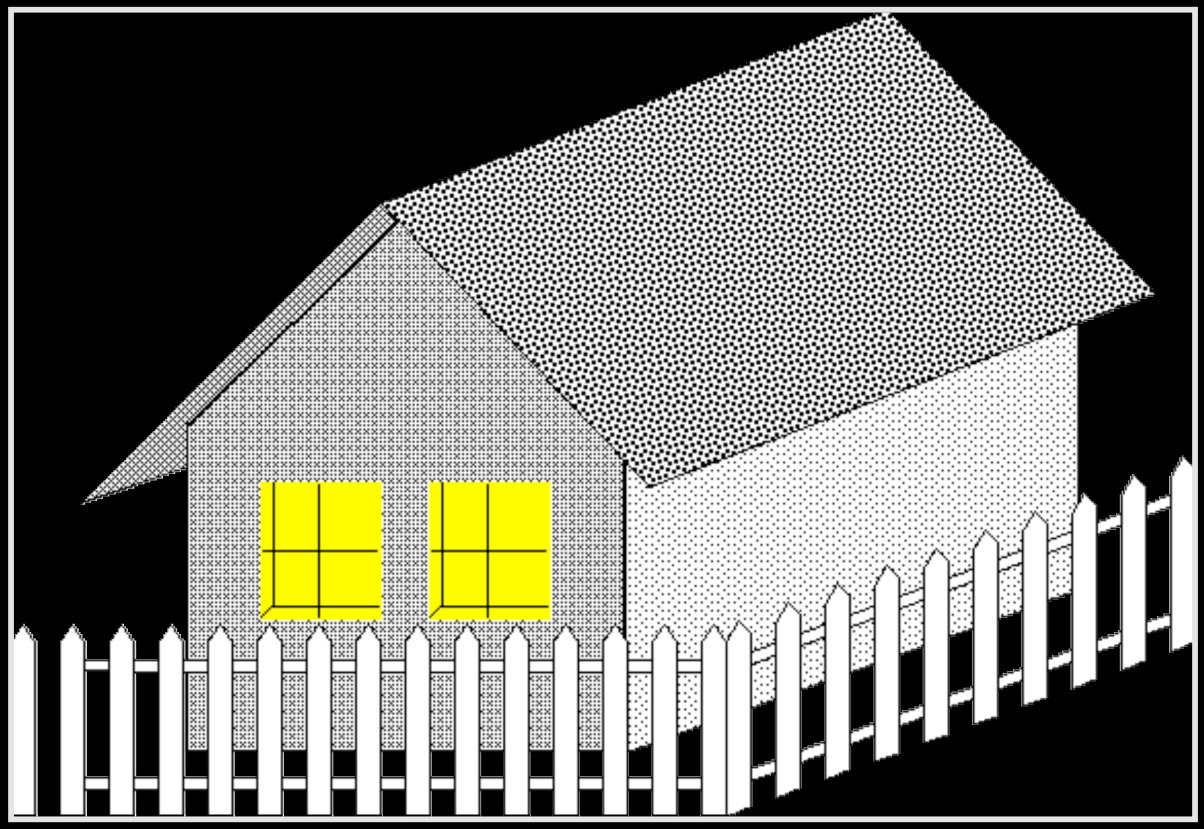


Digitization



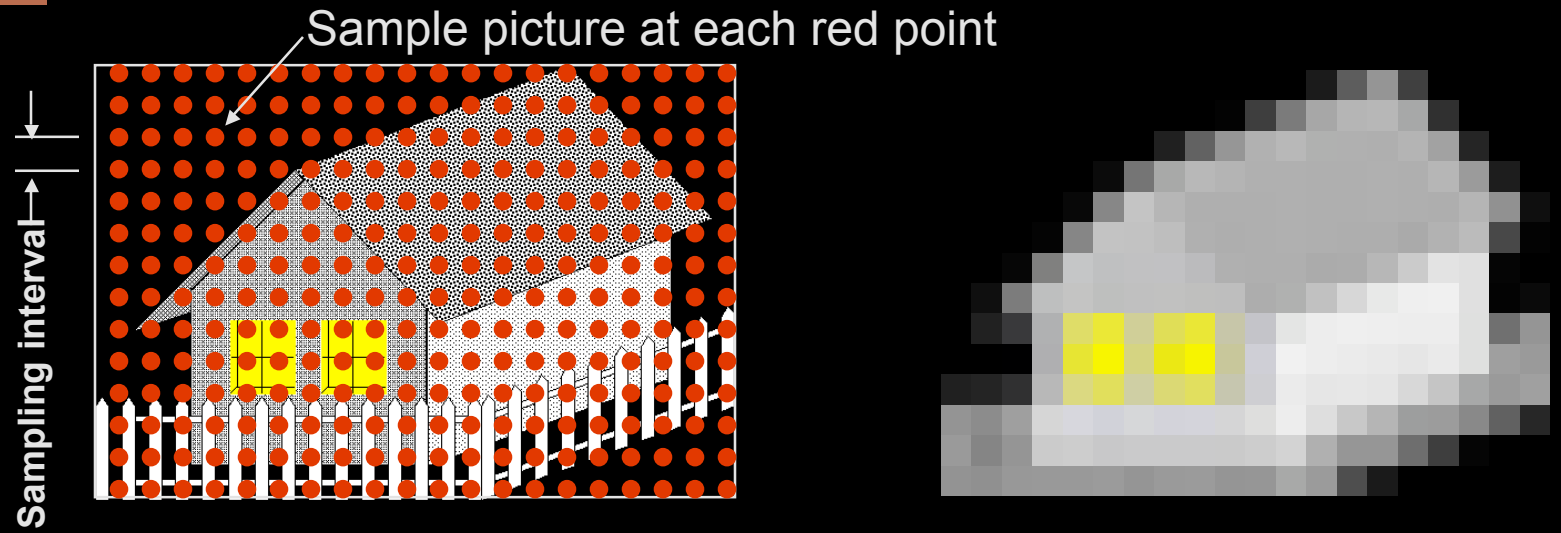
- Digitization: conversion of the continuous (in space and value) electrical signal into a digital signal (digital image)
- Three decisions must be made:
  - Spatial resolution (how many samples to take)
  - Signal resolution (dynamic range of values)
  - Tessellation pattern (how to 'cover' the image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

Digitization: Spatial Resolution

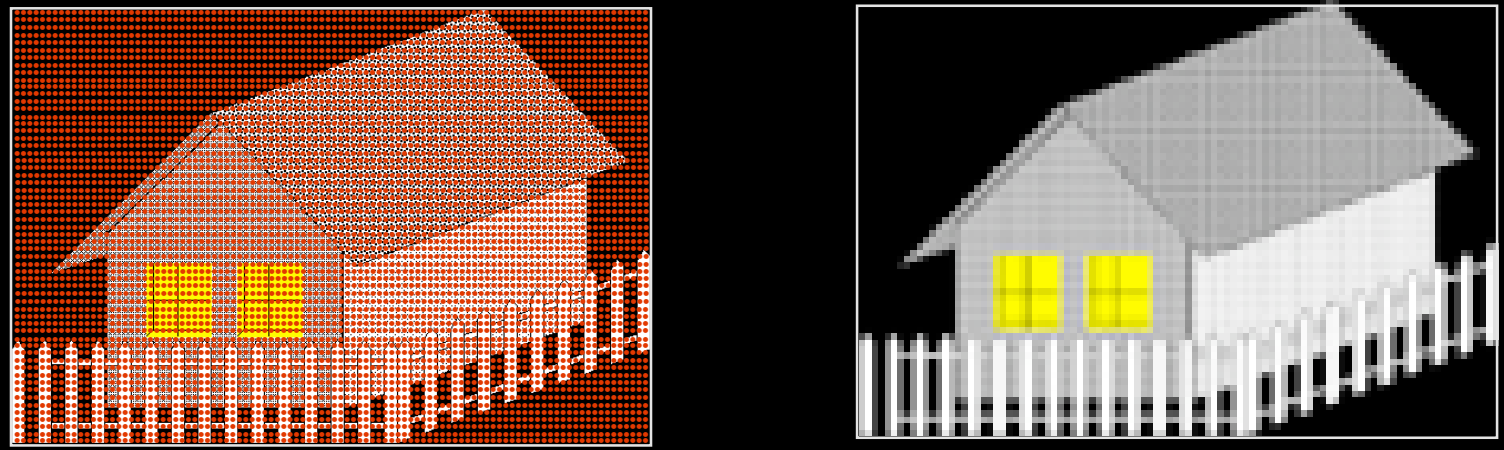


- Let's digitize this image
  - Assume a square sampling pattern
  - Vary density of sampling grid

Spatial Resolution



Coarse Sampling: 20 points per row by 14 rows

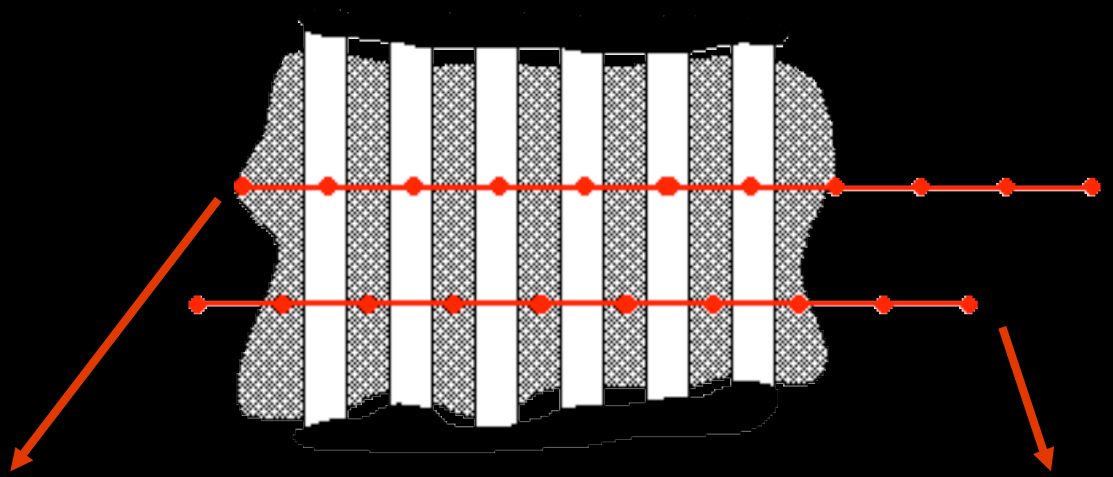


Finer Sampling: 100 points per row by 68 rows

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!

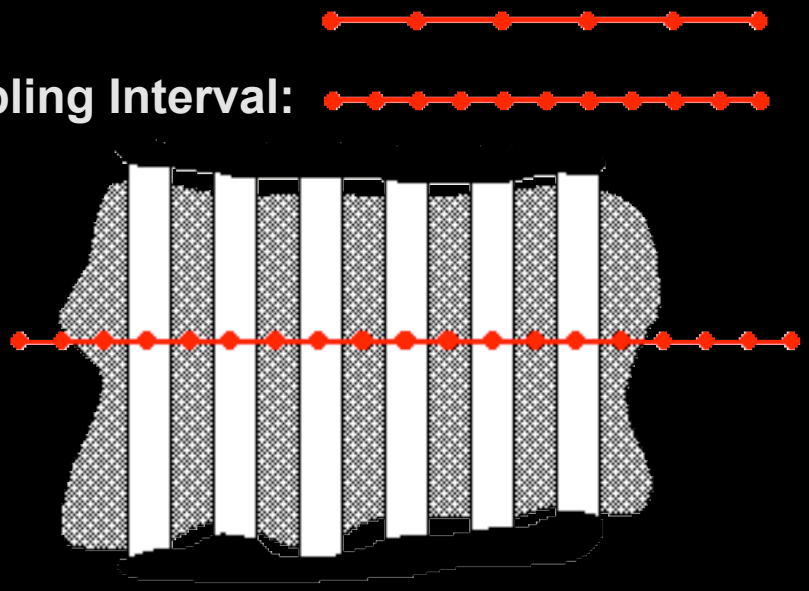
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40

Dark Gray Image!

Effect of Sampling Interval - 2

- Look in vicinity of picket fence:

Sampling Interval:



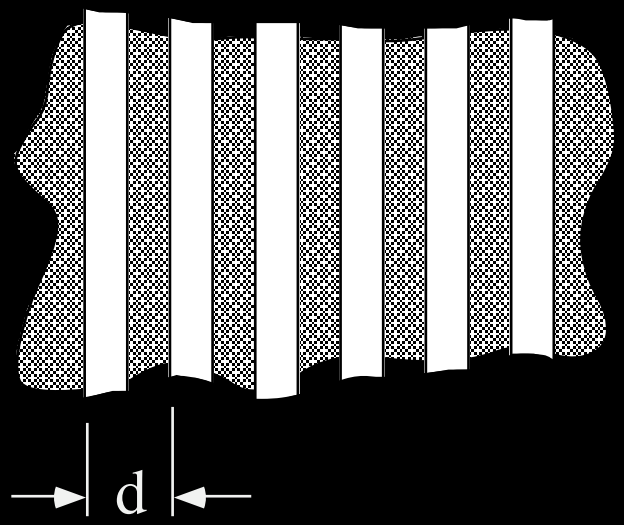
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40

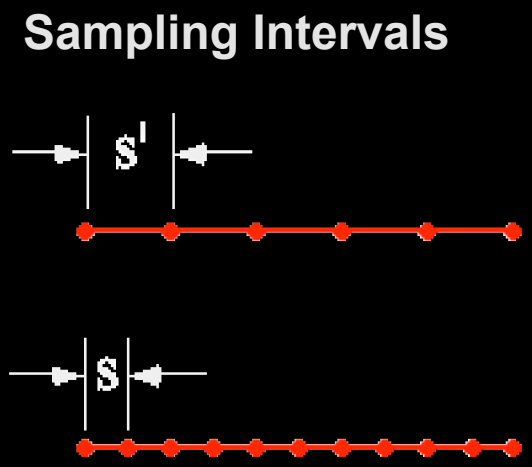
Now we've got a fence!

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

The Missing Fence Found

- Consider the repetitive structure of the fence:





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 (later in course)

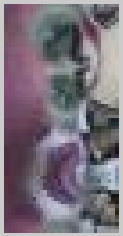
Human Eye Sampling

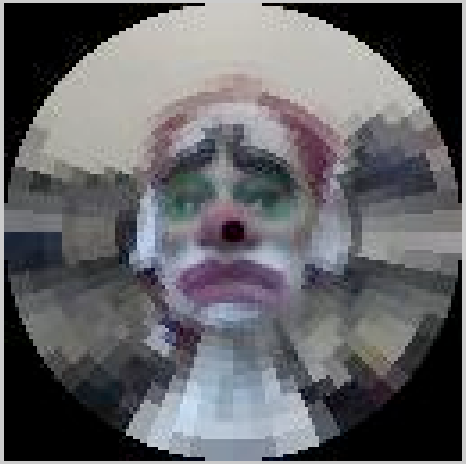
- Fine near the center of the retina (fovea)
- Coarse at the edges

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

Human Eye Sampling

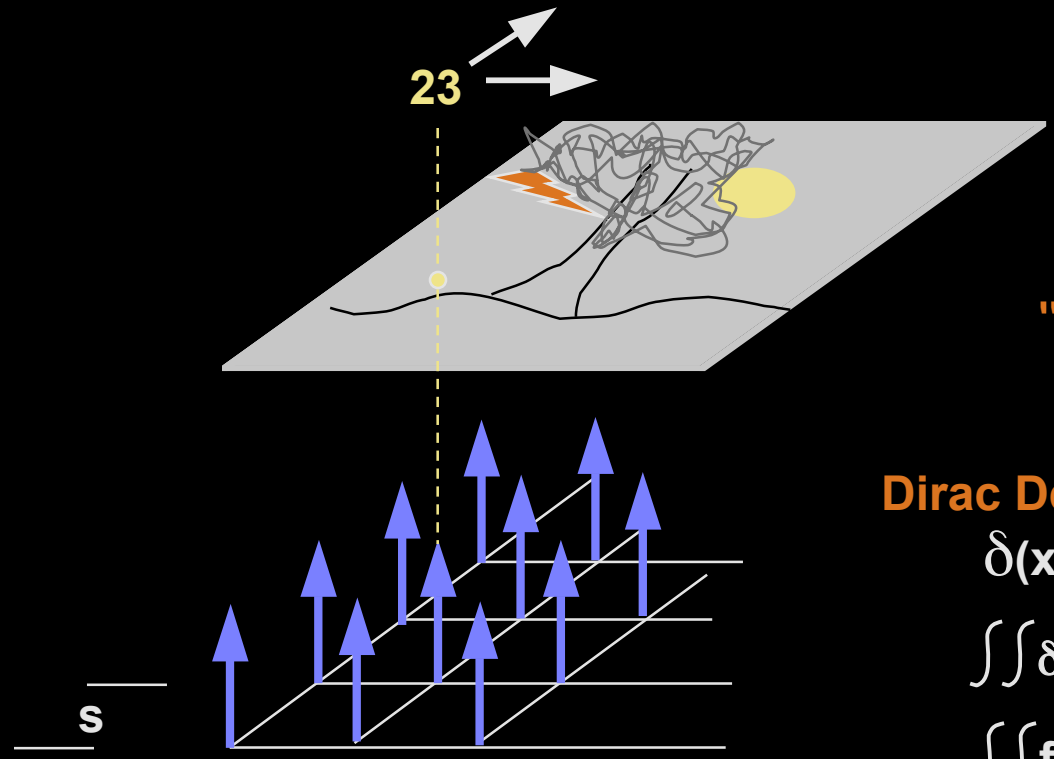
Cartesian image ----- Log-Polar representation ----- Retinal representation





Sampling

- Rough Idea: Ideal Case



"Digitized Image"

"Continuous Image"

Dirac Delta Function 2D "Comb"

$\delta(x,y) = 0$ for $x \neq 0$, $y \neq 0$

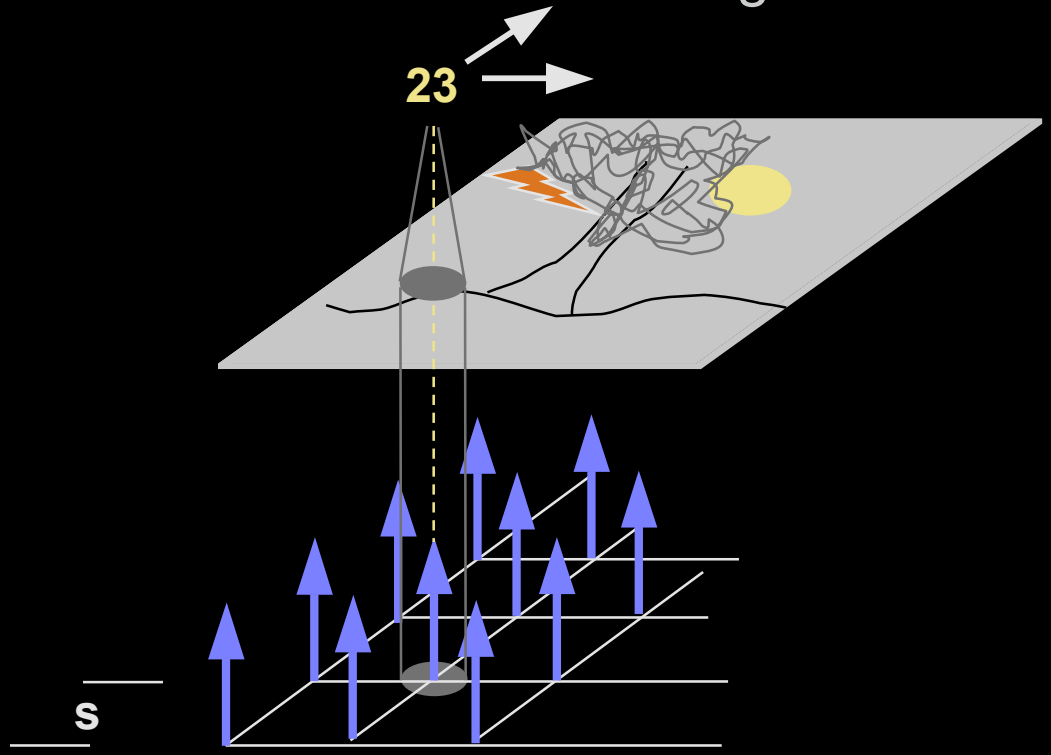
$\int\int \delta(x,y)\, dx\, dy = 1$

$\int\int f(x,y)\delta(x-a,y-b)\, dx\, dy = f(a,b)$

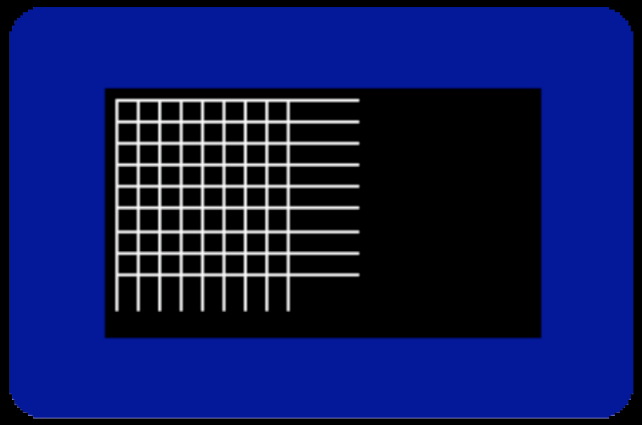
$\delta(x-ns,y-ns)$ for $n = 1\ldots.32$ (e.g.)

Sampling

- Rough Idea: Actual Case
  - Can't realize an ideal point function in real equipment
  - "Delta function" equivalent has an area
  - Value returned is the average over this area



Projection through a pixel



Digitized 35mm Slide or Film

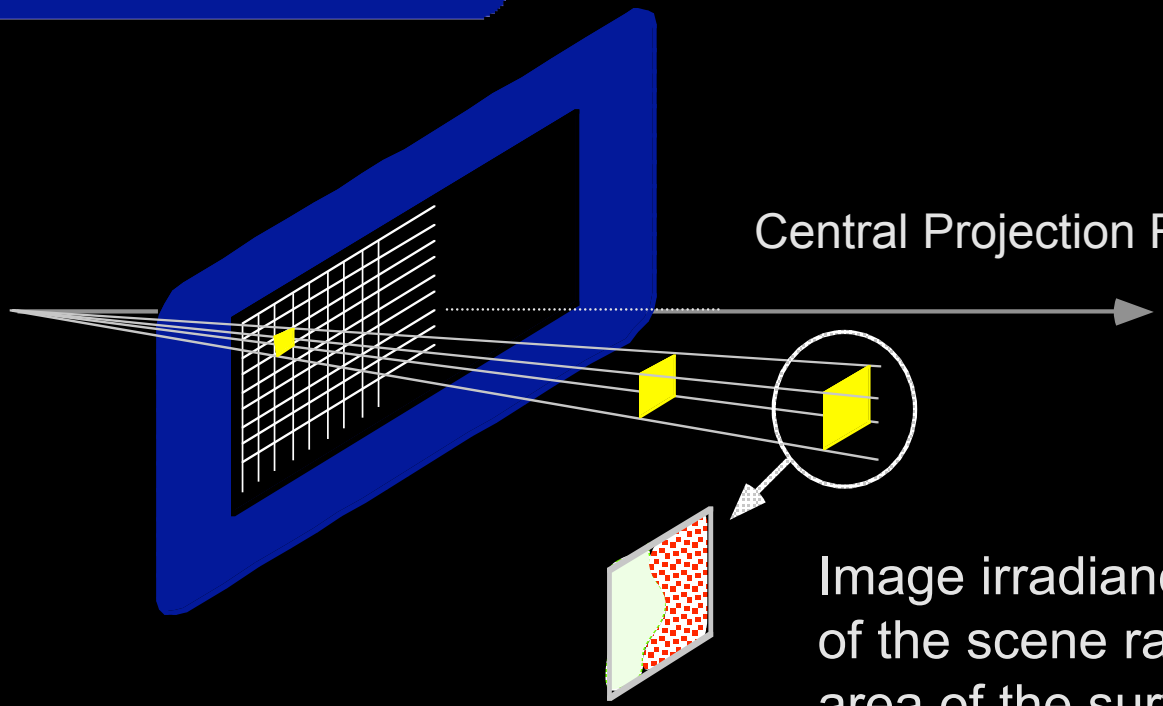
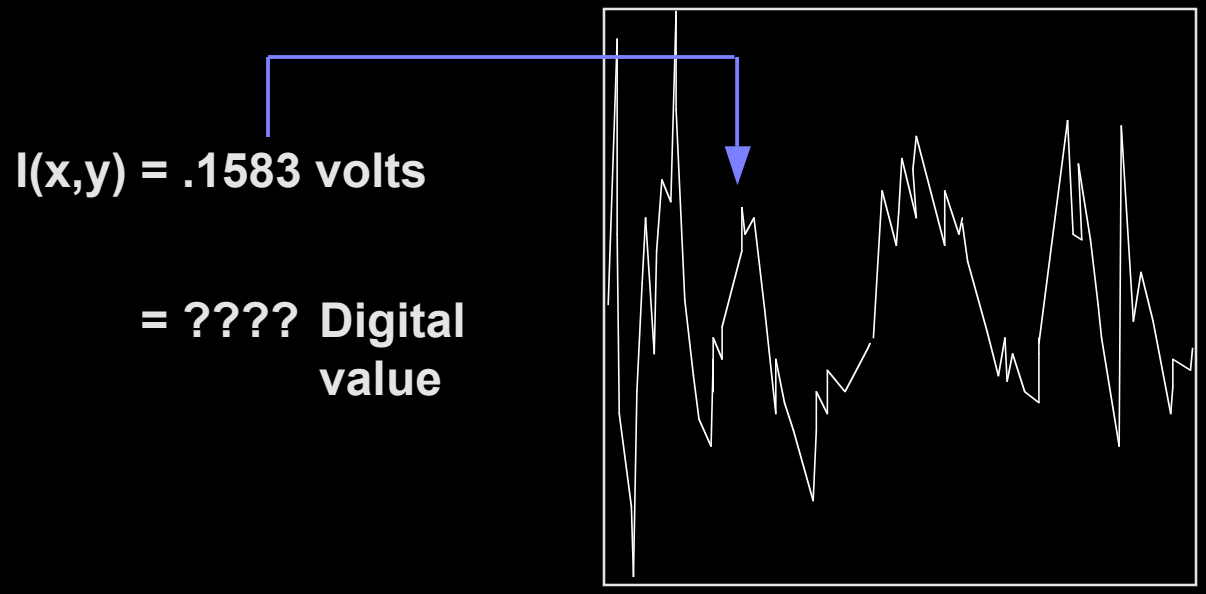


Image irradiance is the average of the scene radiance over the area of the surface intersecting the solid angle!

Mixed Pixel Problem

Signal Quantization

- Goal: determine a mapping from a continuous signal (e.g. analog video signal) to one of K discrete (digital) levels.



Quantization

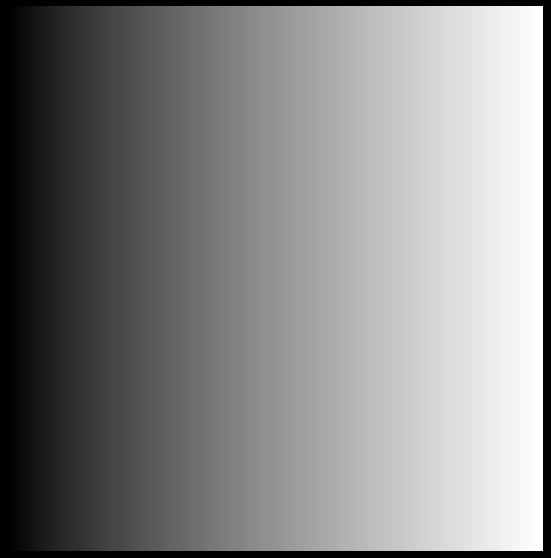
- I(x,y) = continuous signal: $0 \le I \le M$
- Want to quantize to K values 0,1,....K-1
- K usually chosen to be a power of 2:

K: #Levels	#Bits
2	1
4	2
8	3
16	4
32	5
64	6
128	7
256	8

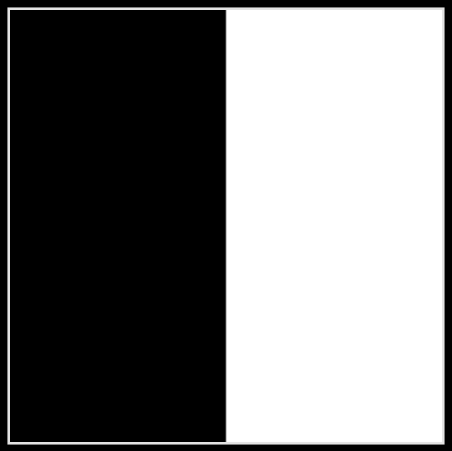
- Mapping from input signal to output signal is to be determined.
- Several types of mappings: uniform, logarithmic, etc.

Choice of K

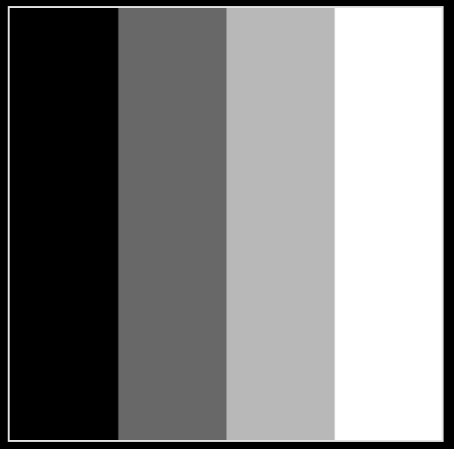
Original



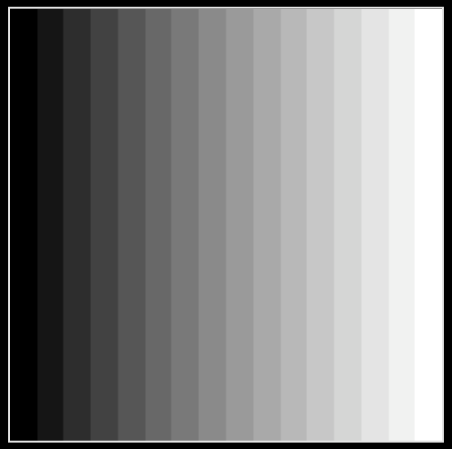
Linear Ramp



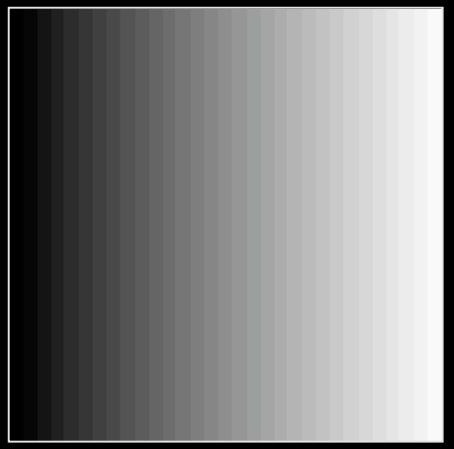
K=2



K=4



K=16



K=32

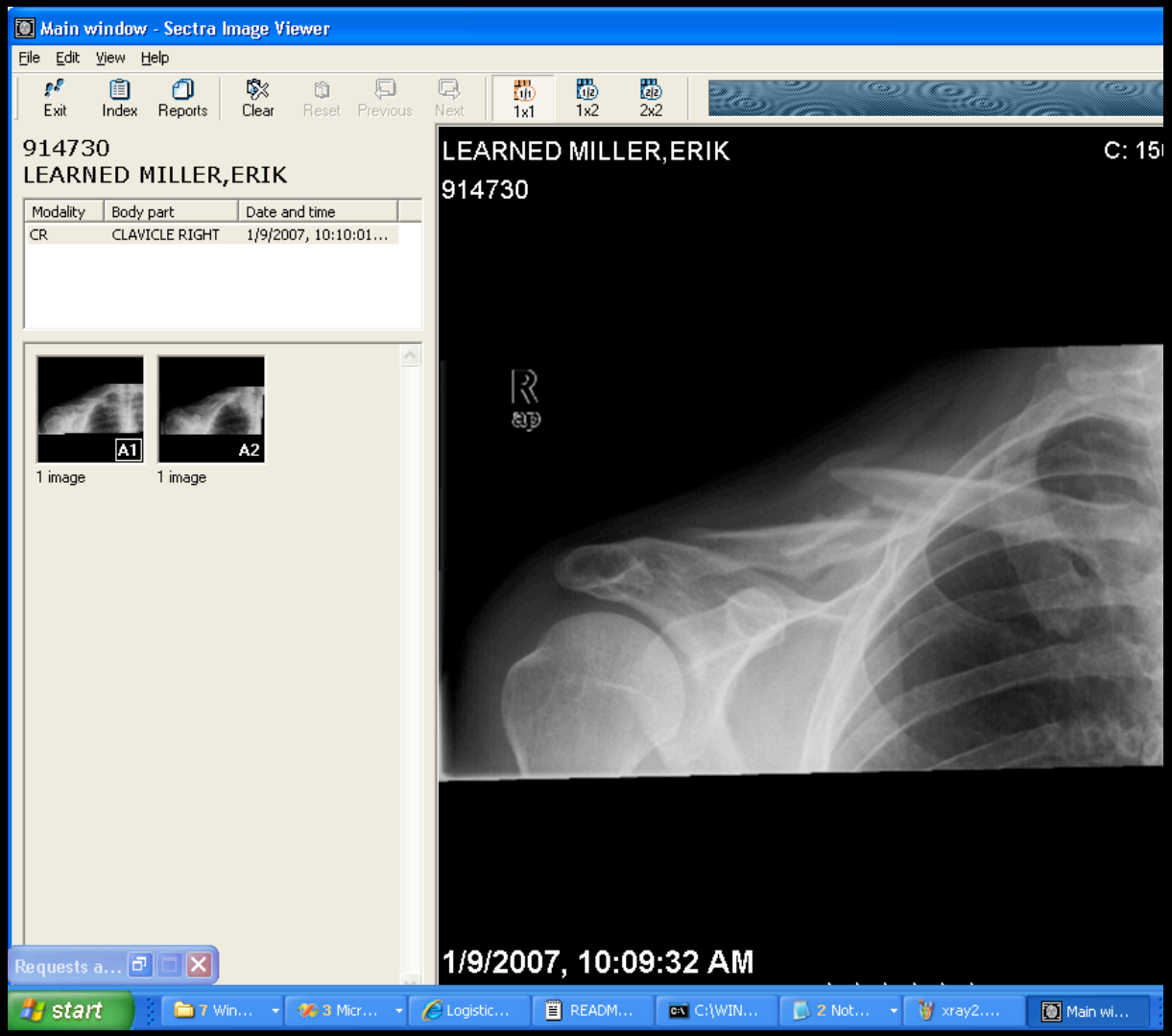
Choice of K

K=2 (each color)

K=4 (each color)

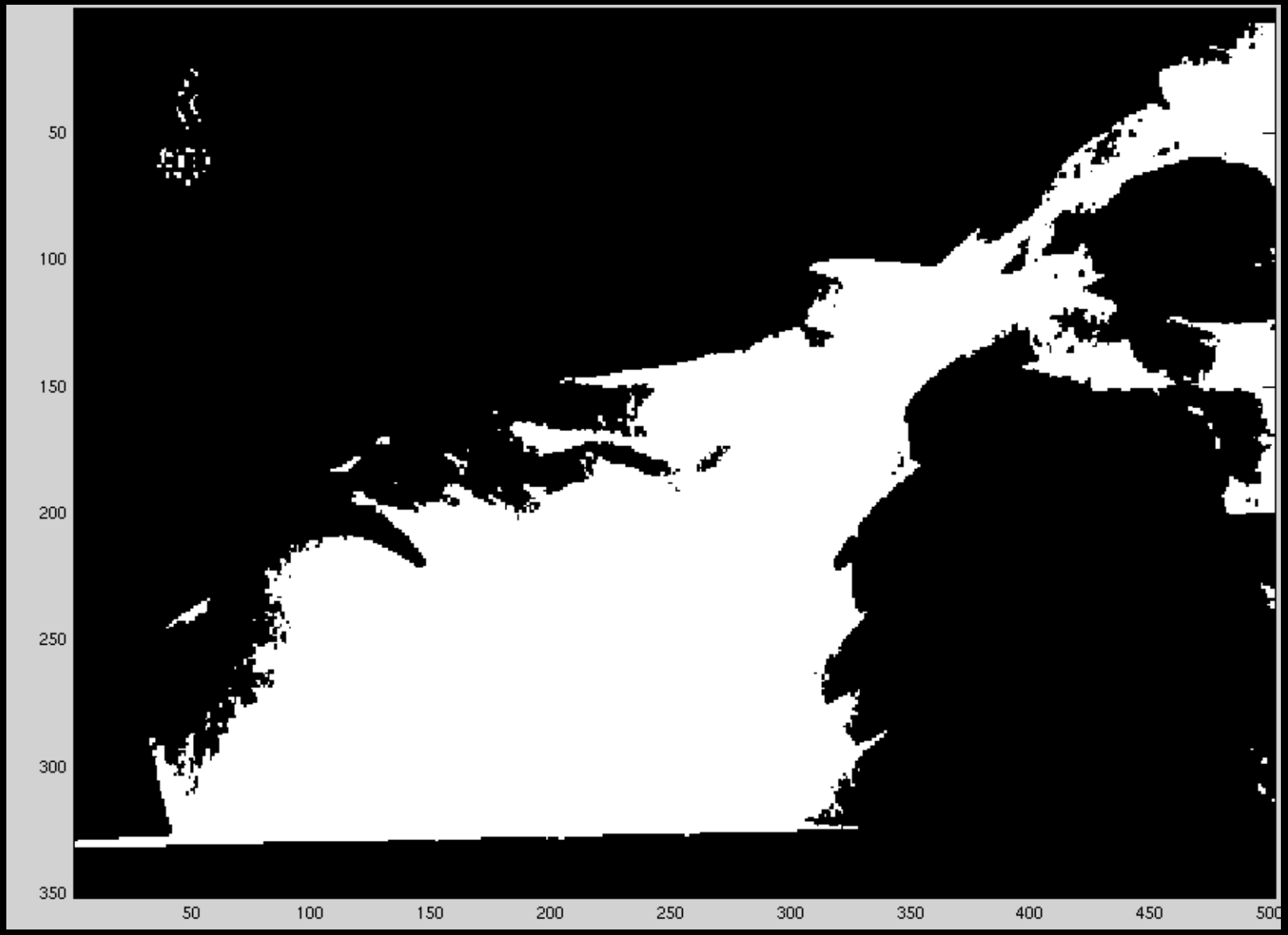
Introduction to
Computer Vision

Digital X-rays

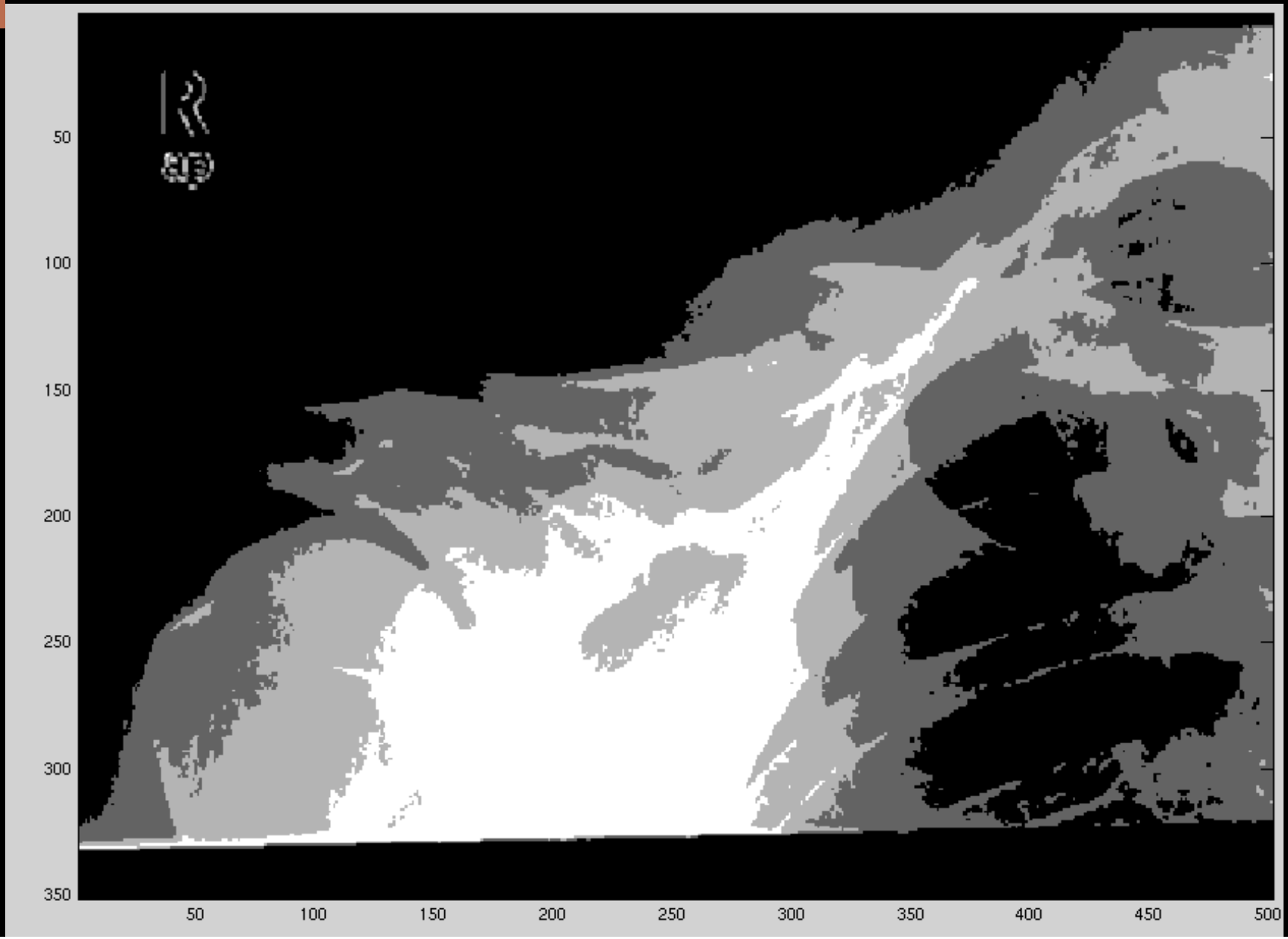


Digital X-rays: 8 is enough?

Digital X-rays: 1 bit



Digital X-rays: 2 bits

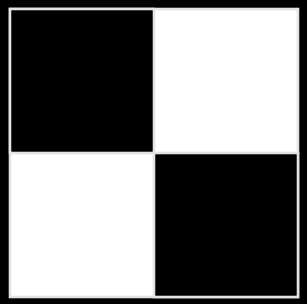


Digital X-rays: 3 bit

Digital X-rays: 8 is enough?

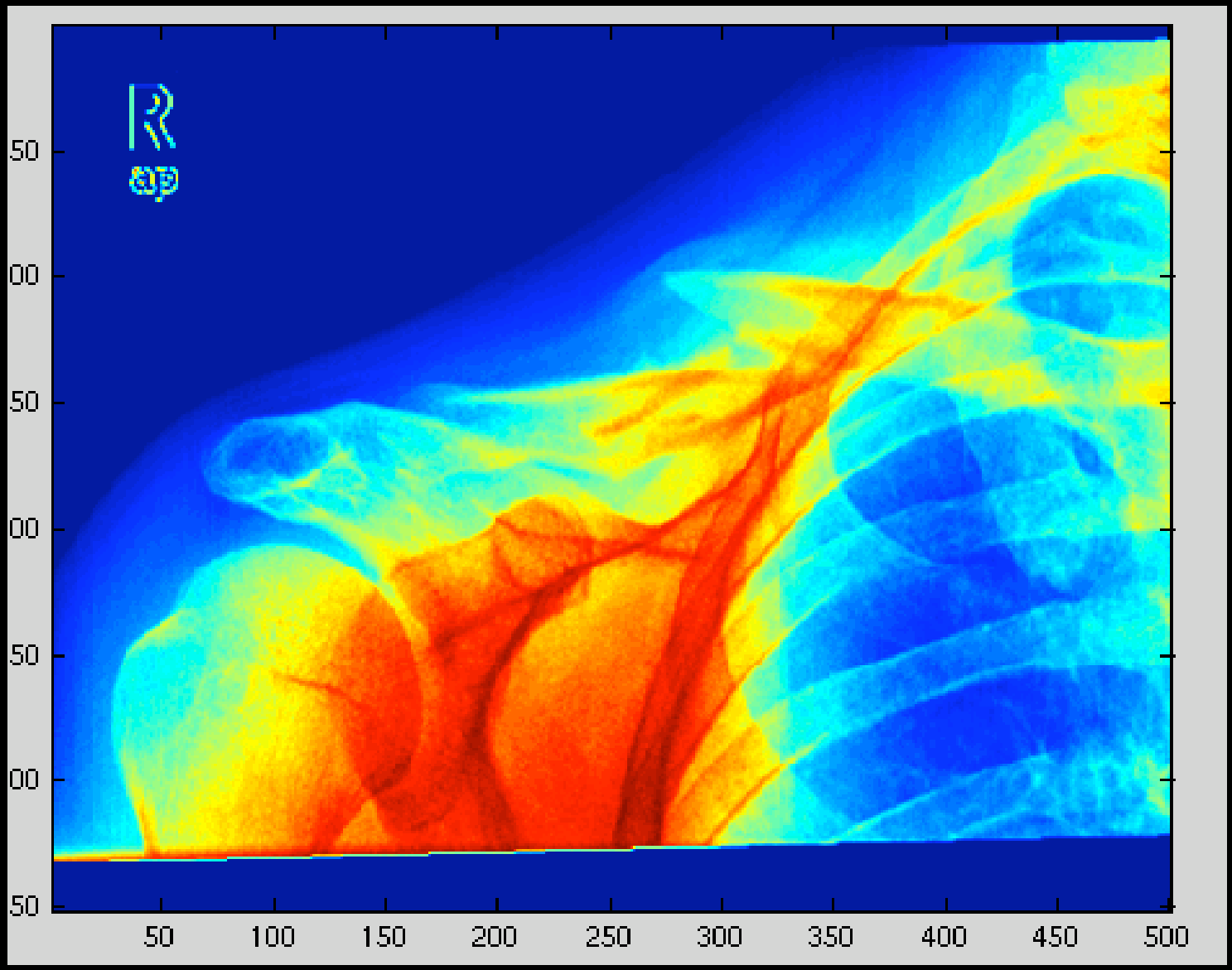
Gray Levels-Resolution Trade Off

- More gray levels can be simulated with more resolution.
- A “gray” pixel:



- Doubling the resolution in each direction adds at least four new gray levels. But maybe more?

Pseudocolor

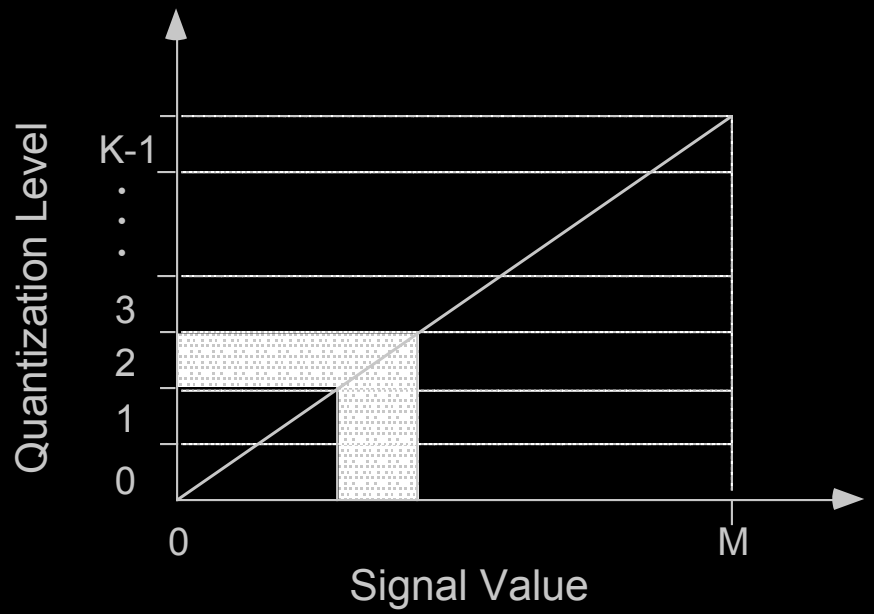


Digital X-rays: 8 is enough?

MRI

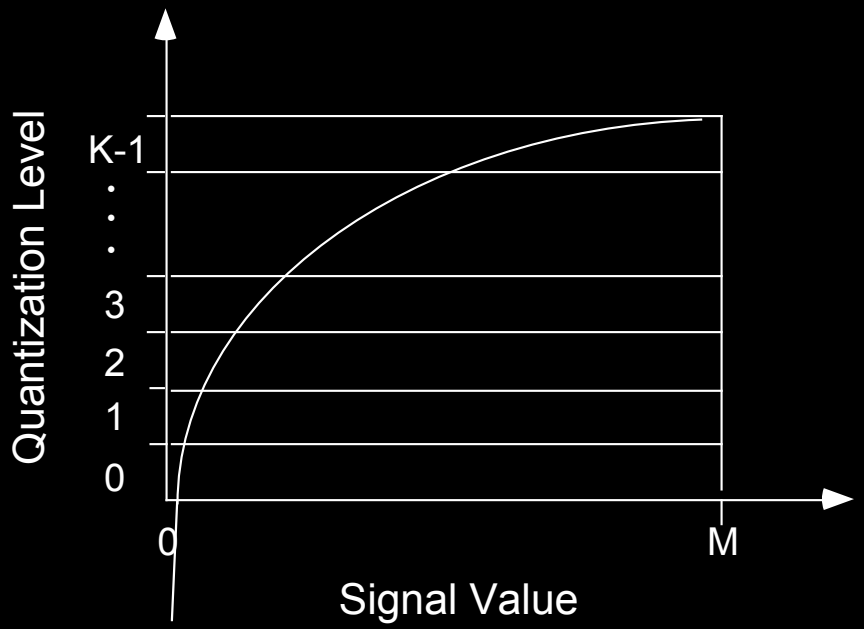
Choice of Function: Uniform

- Uniform sampling divides the signal range [0-M] into K equal-sized intervals.
- The integers 0,...K-1 are assigned to these intervals.
- All signal values within an interval are represented by the associated integer value.
- Defines a mapping:



Logarithmic Quantization

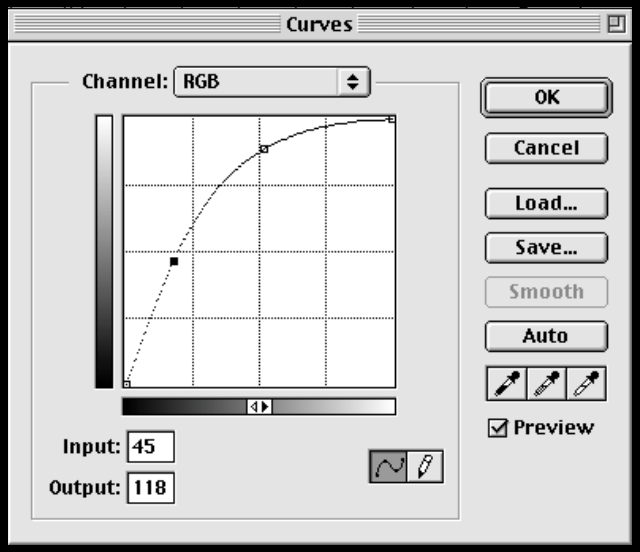
- Signal is log I(x,y).
- Effect is:



- Detail enhanced in the low signal values at expense of detail in high signal values.

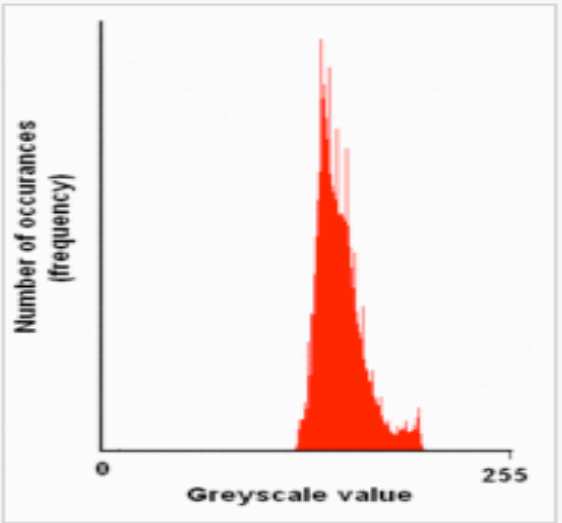
Logarithmic Quantization

Quantization Curve



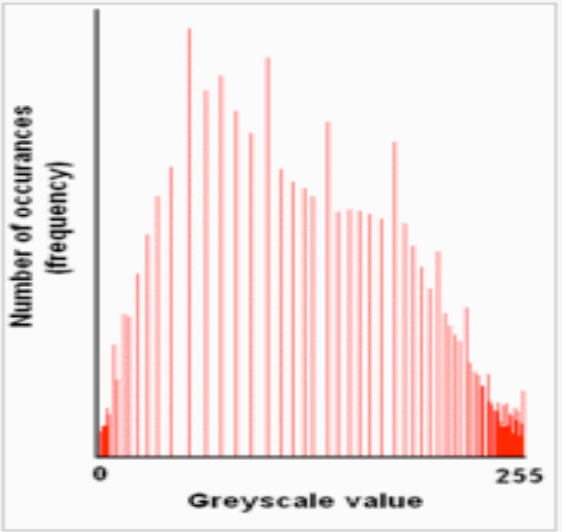
Histogram Equalization

An unequalized image



Corresponding histogram

Same image after histogram equalization



Corresponding histogram

Brightness Equalization

- Two methods:
  - Change the data (histogram equalization)
  - Use a look up table (brightness or color remapping)

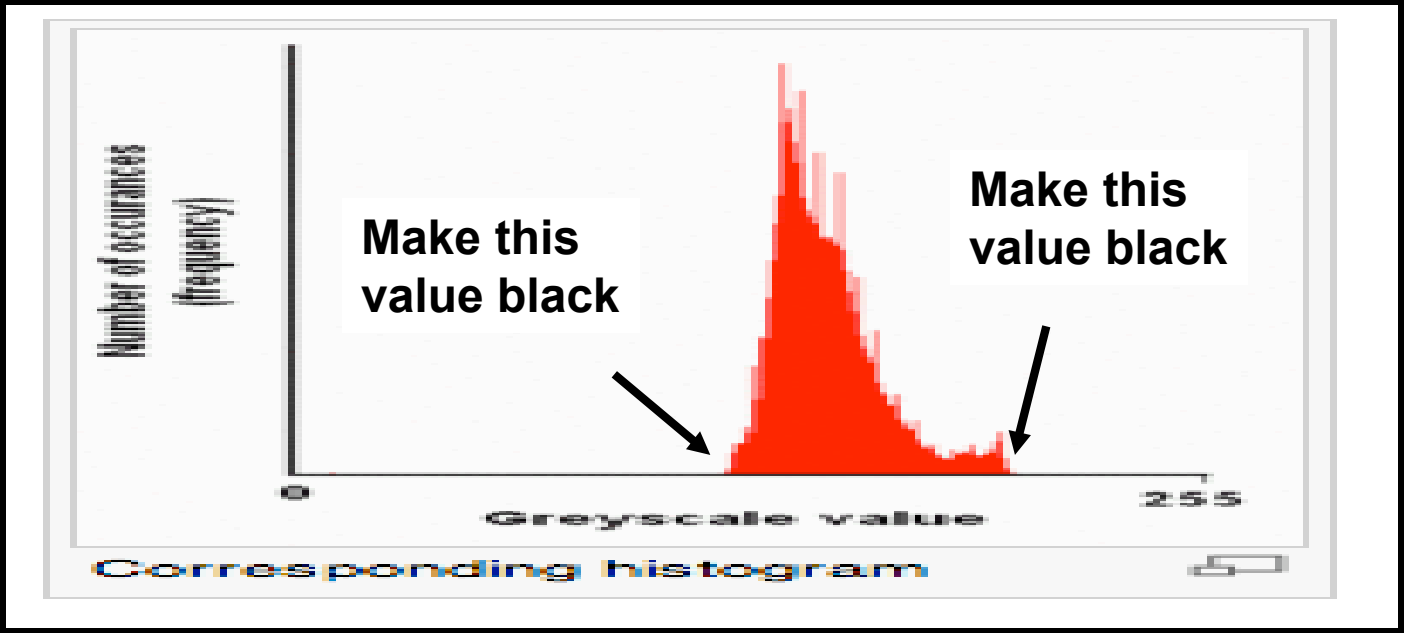
Look up tables

Maps Brightness Value -> RGB Color

- 0 -> (1, 0, 0)
- 1 -> (0, 1, 0)
- 2 -> (0, 0, 1)
- 3 -> (0 , 1, 1)
- ...
- 255 -> (1, 1, 1)

Brightness Equalization

- Two methods:
  - Change the data.
  - Use a look up table.



Look up tables

Maps Brightness Value -> RGB Color

- 0 -> (0, 0, 0)
- 1 -> (0, 0, 0)
- 2 -> (0, 0, 0)
- 3 -> (0 , 0, 0)
- ...
- 130-> (0,0,0)
- 131-> (.01, .01, .01)
- 132-> (.02,.02,.02)
- ...
- 200->(1,1,1)
- 201->(1,1,1)
- ...
- 255 -> (1, 1, 1)

Brightness Equalization

An unequalized image