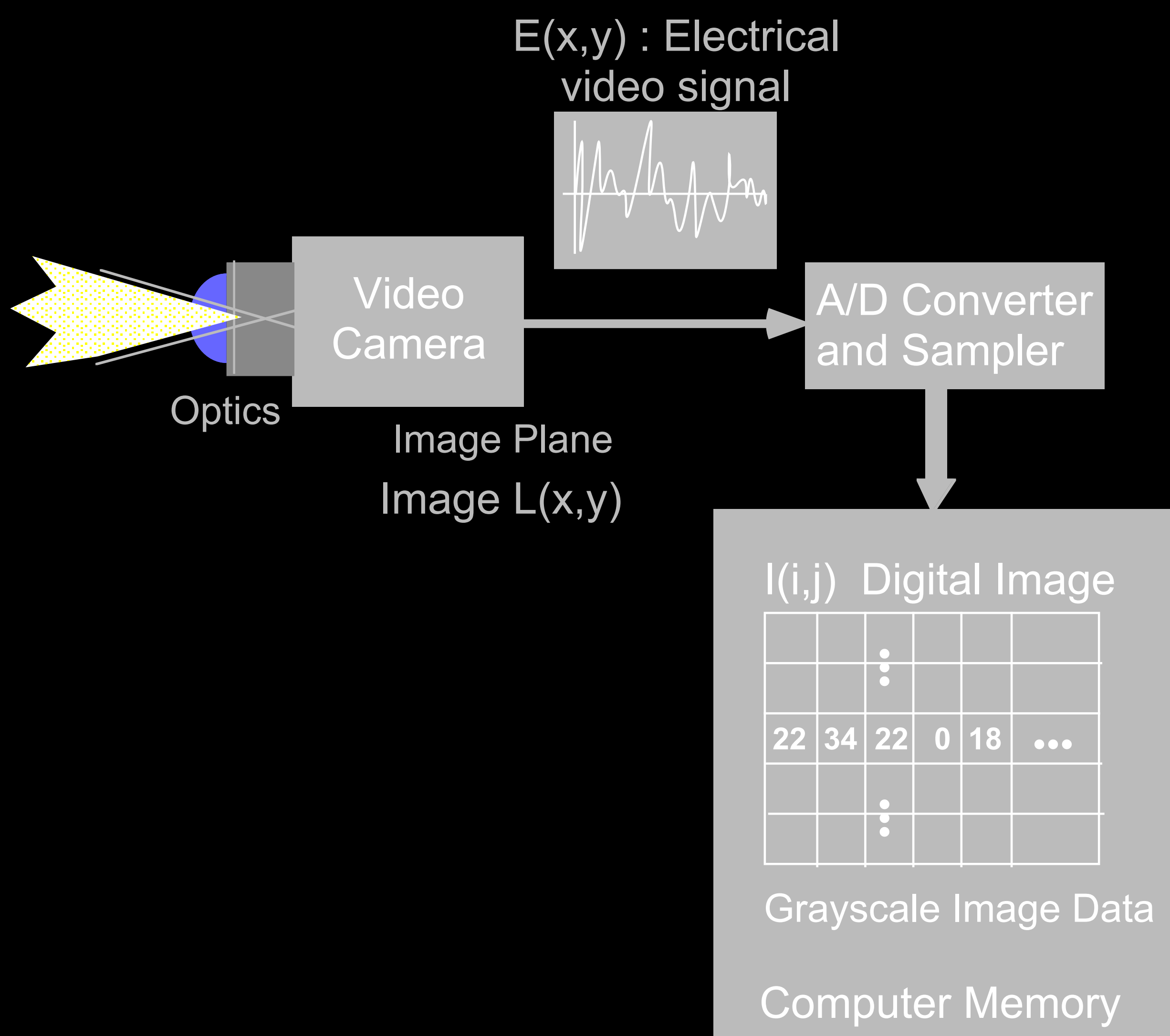
Photometry

- Photometry:

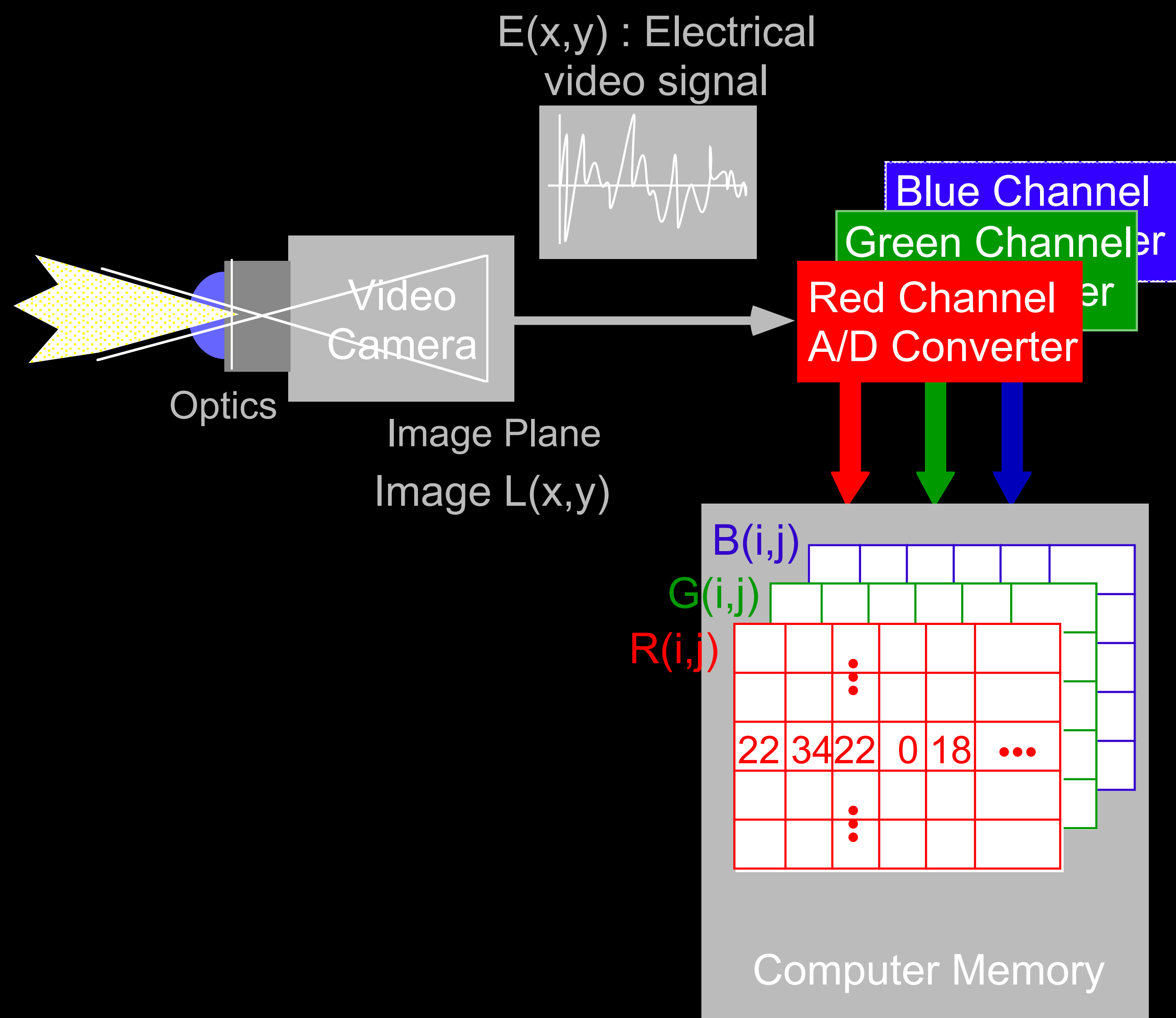
  Concerned with mechanisms for converting light energy into electrical energy.

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

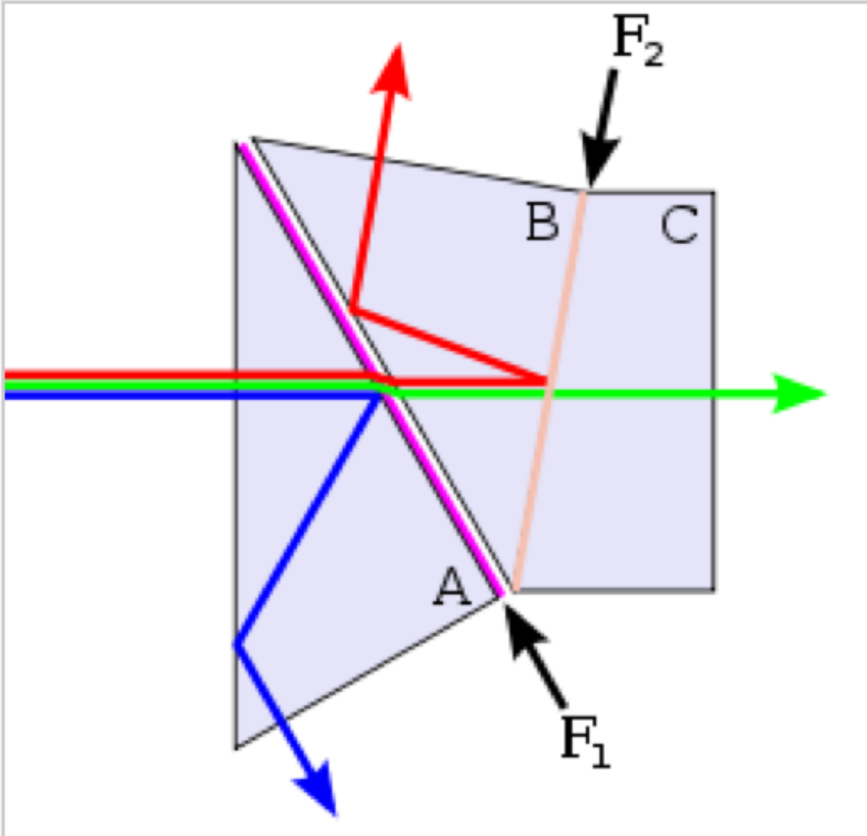
B&W Video System



Color Video System

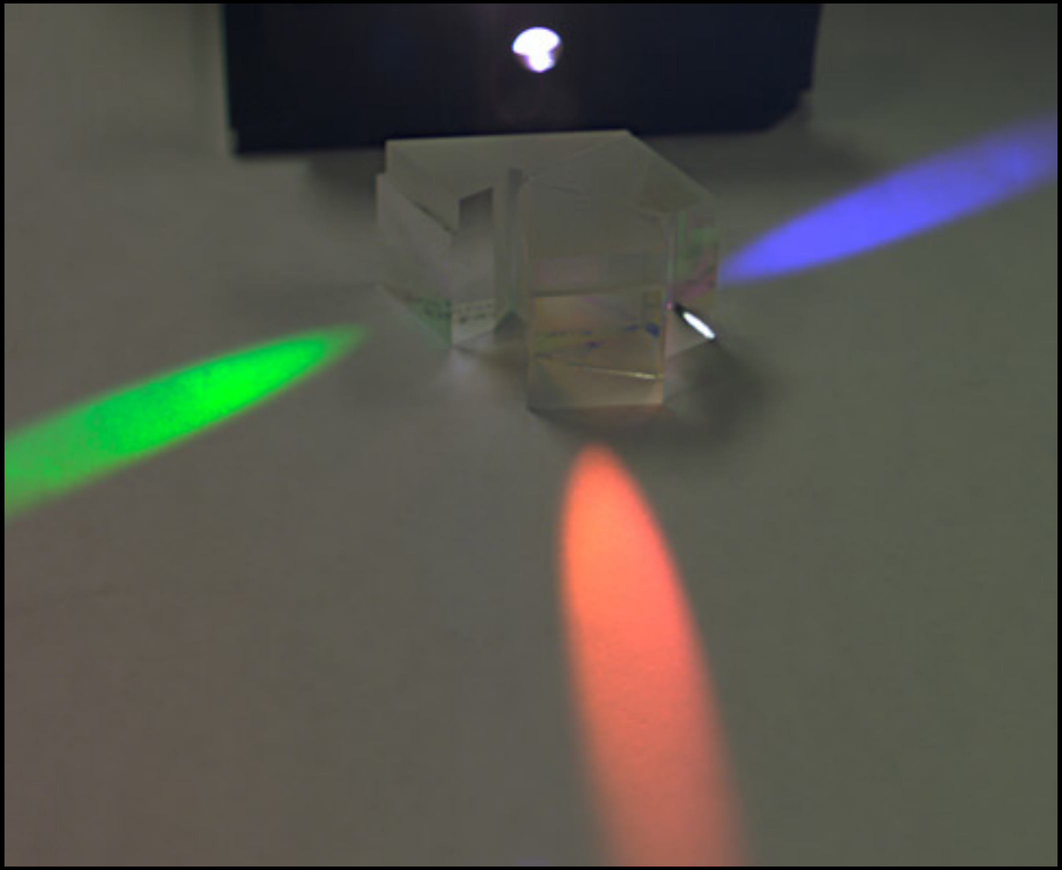


Beam Splitter



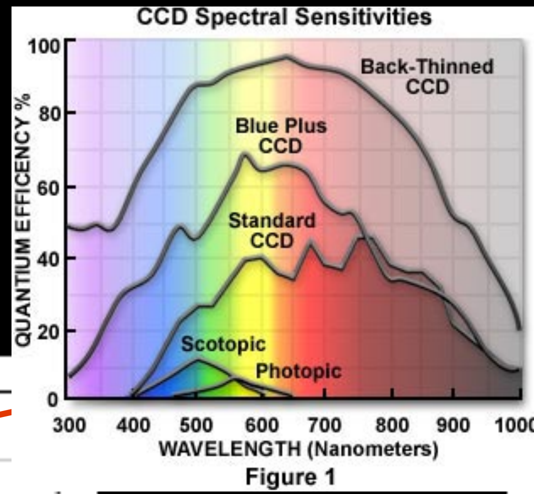
A Philips type trichroic beam splitter prism schematic, with a different color separation order than the assembly shown in the photo. The red beam undergoes total internal reflection at the air gap, while the other reflections are dichroic.

Beam splitter

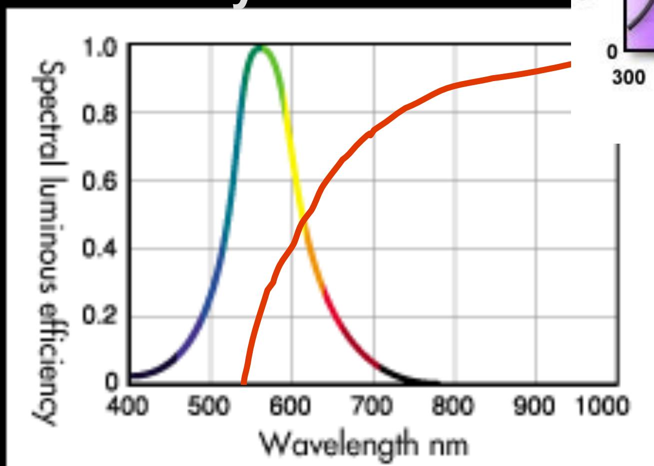


Sony 6 MegaPixel CCD

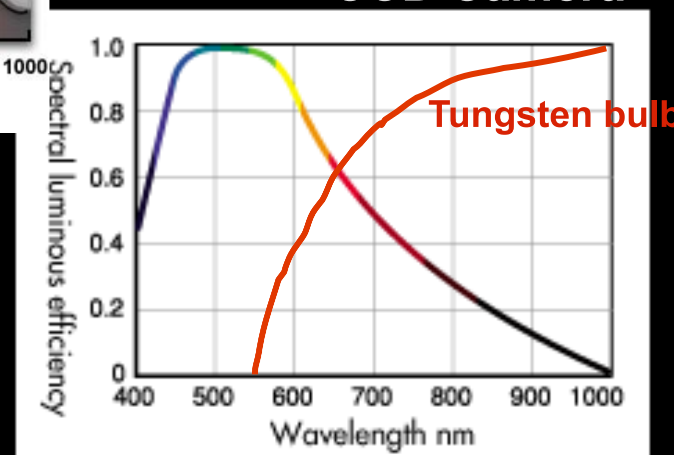
Spectral Sensitivity



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

Human Vision Regimes

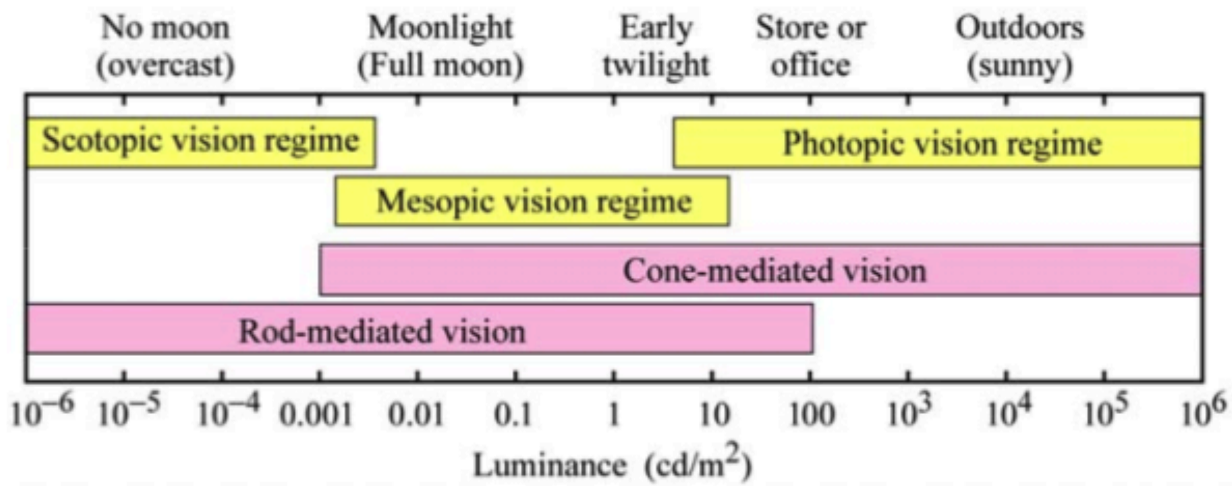
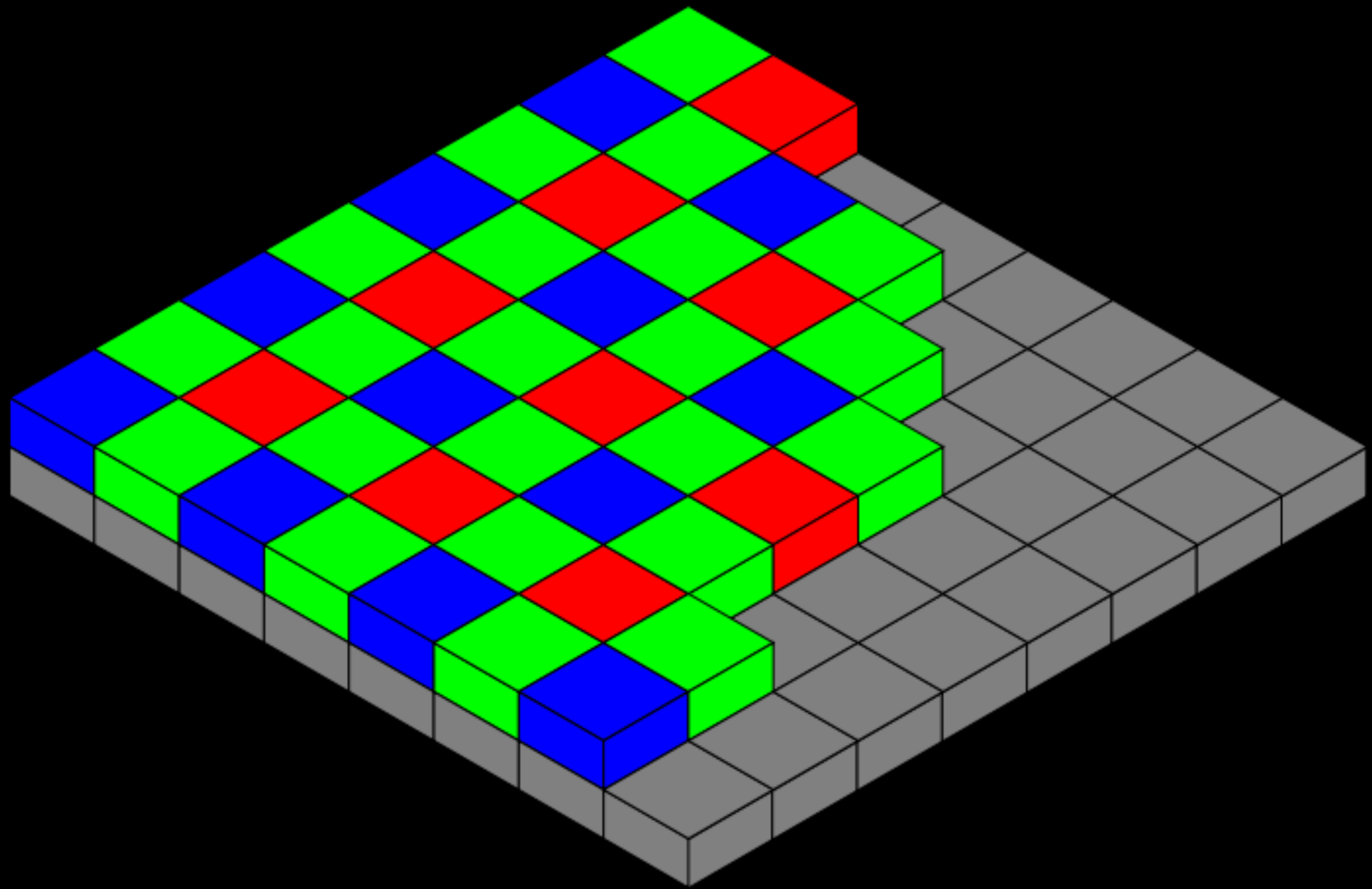
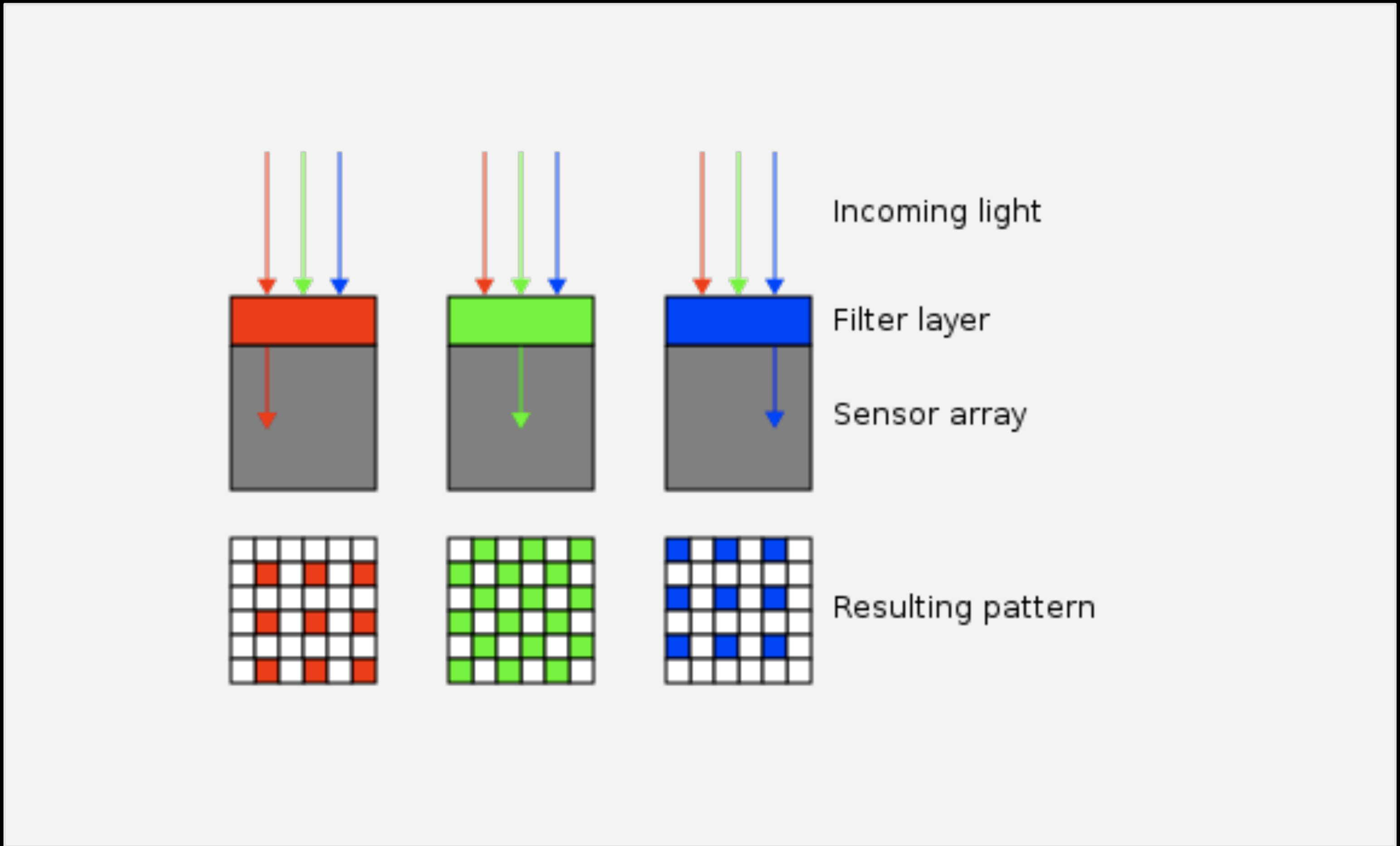


Fig. 16.2. Approximate ranges of vision regimes and receptor regimes (after Osram Sylvania, 2000).

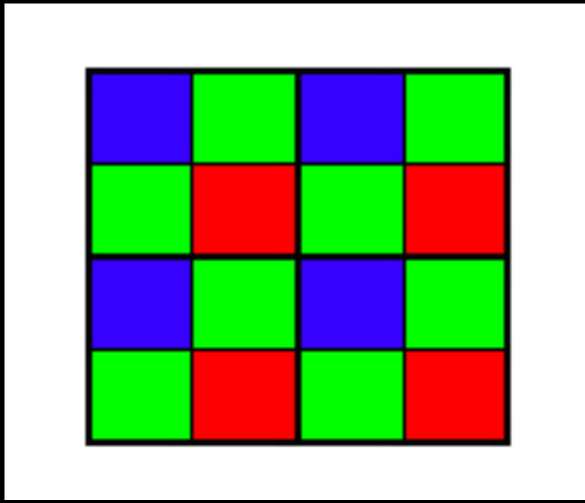
Bayer Filters



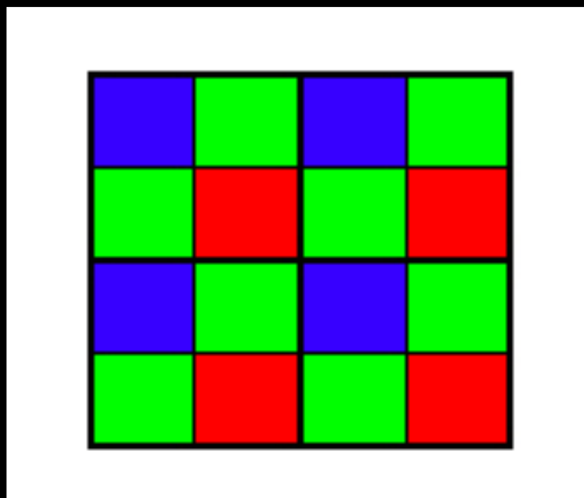
Bayer Filters

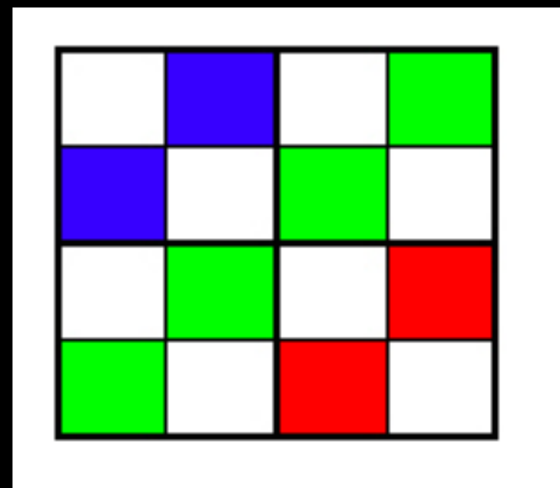


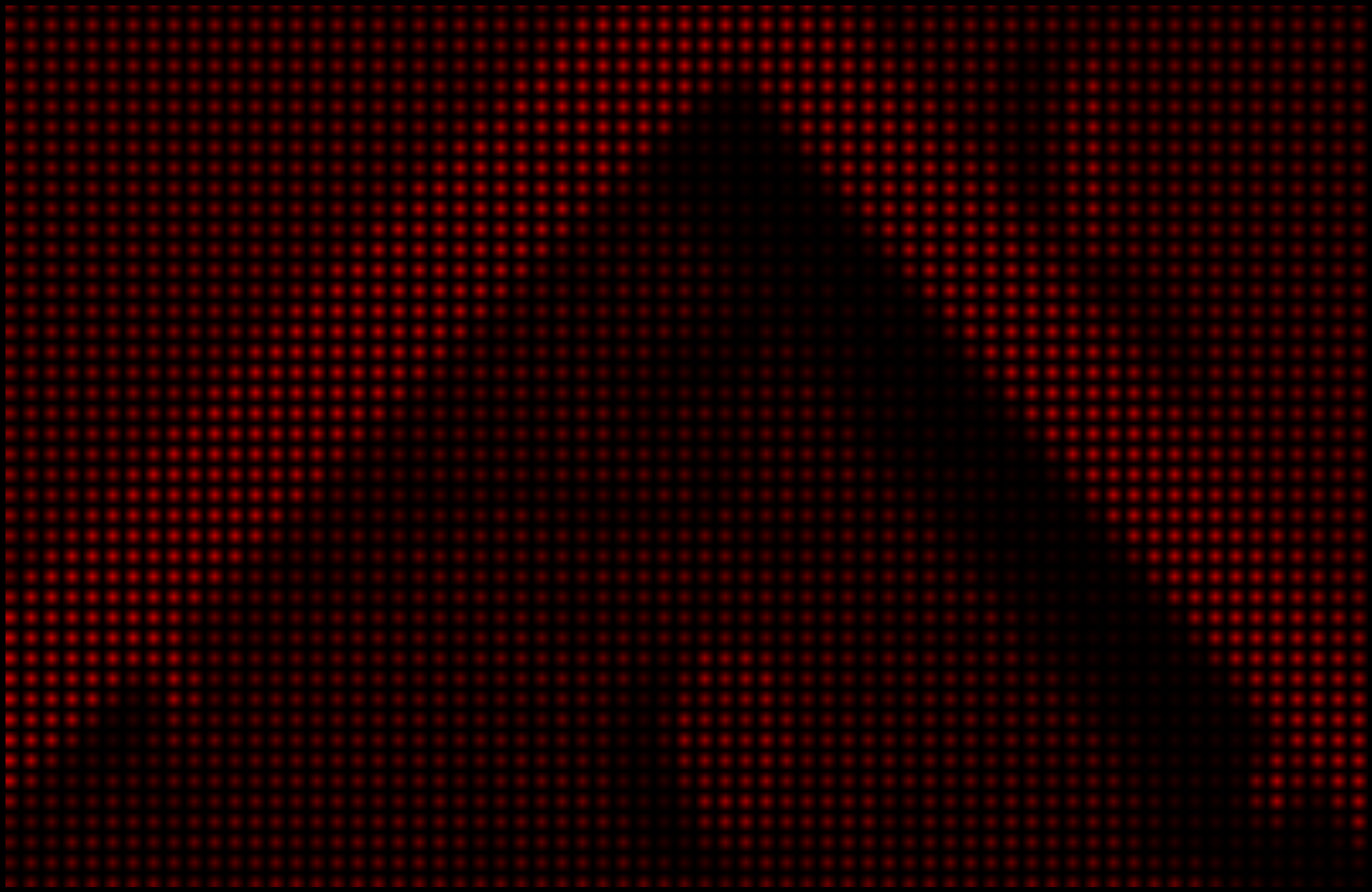
Bayer Filters



Bayer Filters



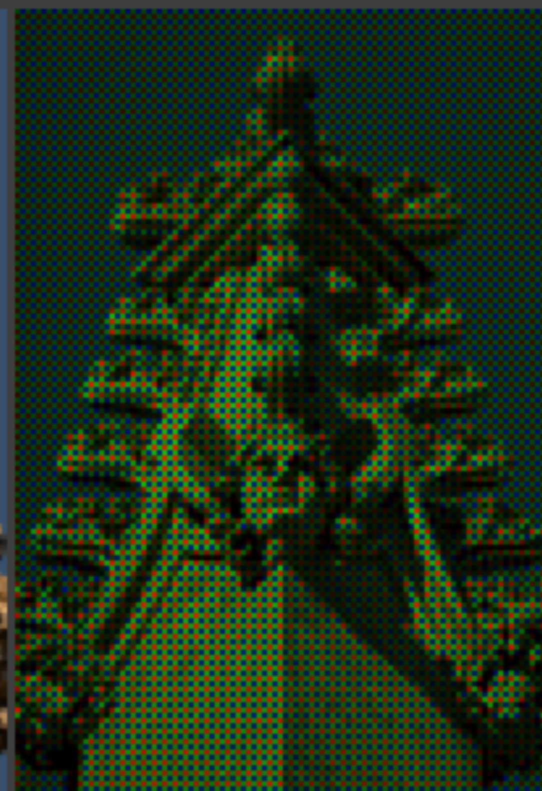




Bayer filtering

primary colors (see "Understanding Image Noise" for an example).

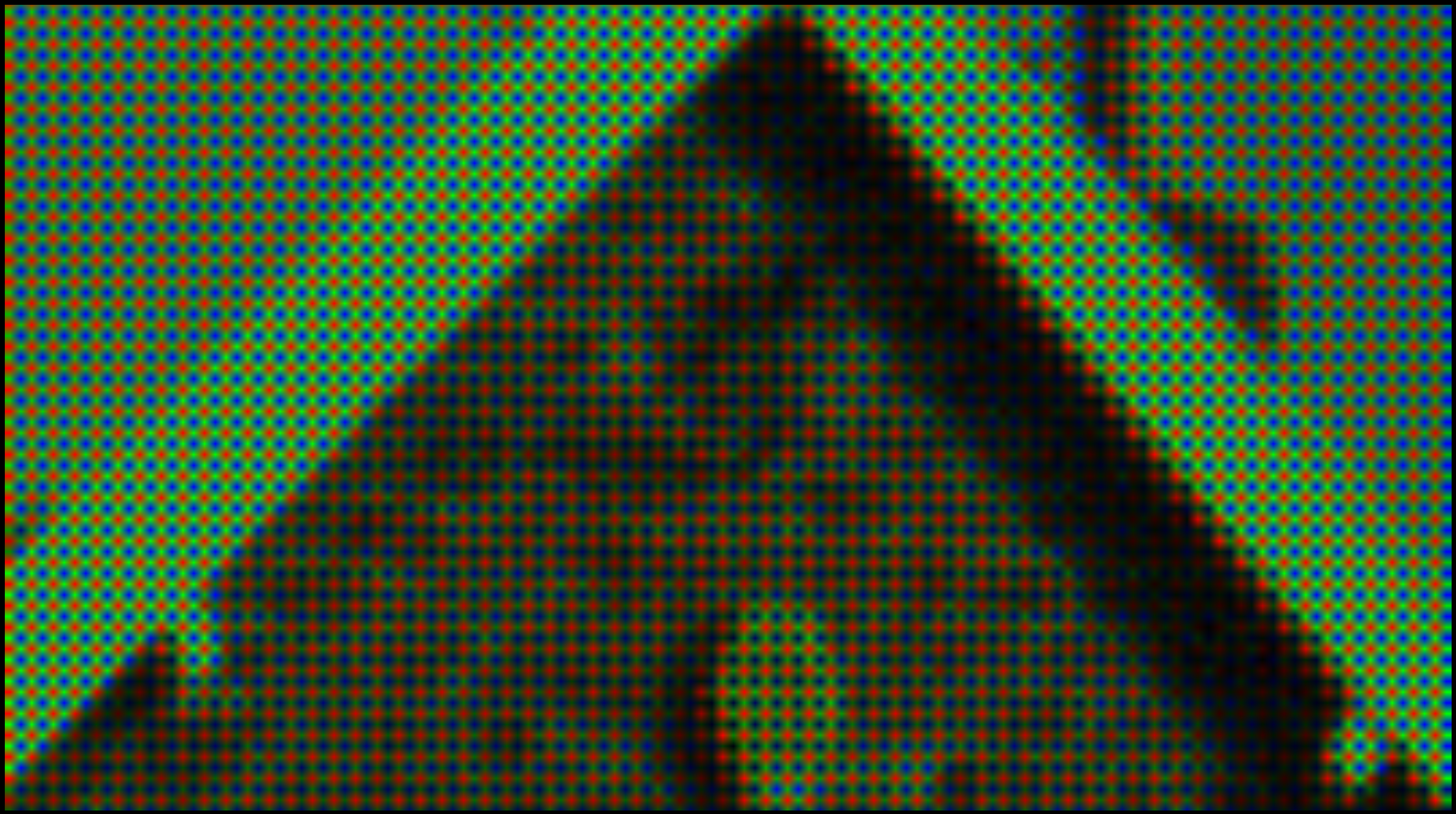
Original Scene
(shown at 200%)



What Your Camera Sees
(through a Bayer array)

Note: Not all digital cameras use a Bayer array, however this is by far the most common setup. The Foveon sensor used in Sigma's SD9 and SD10 captures all three colors at each pixel location. Sony cameras capture four colors in a similar array: red, green, blue and emerald green.

Bayer Image Before Interp.



Interpolating the Bayer Filter

- Most accurate interpolation?
- How to do it in hardware or firmware?
- Local averaging?

Characteristics

- In general, $V(x,y) = k\, E(x,y)^{g}$ where
  - k is a constant
  - **g is a parameter of the type of sensor**
    - **$g=1$ (approximately) for a CCD camera**
    - **$g=.65$ 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

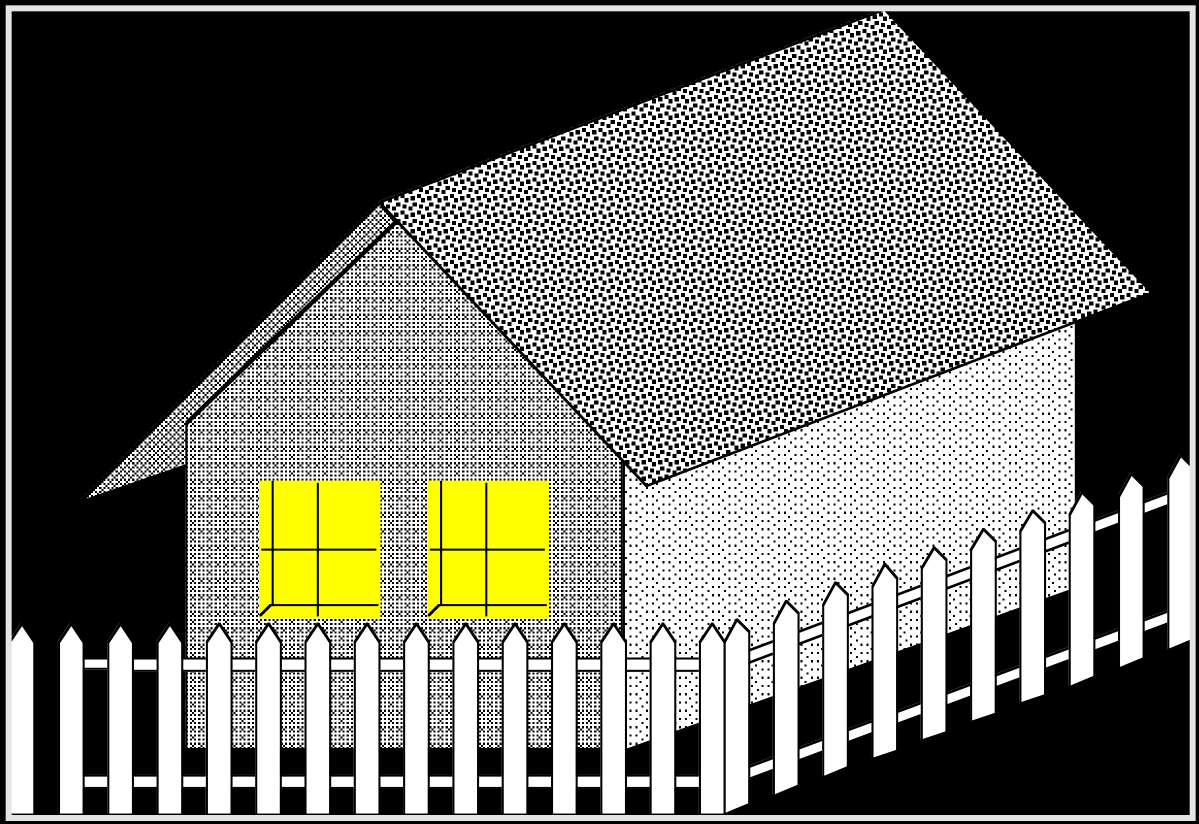
There is no “universal sensor”. Sensors must be selected/tuned for a particular domain and application.

Digitization

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

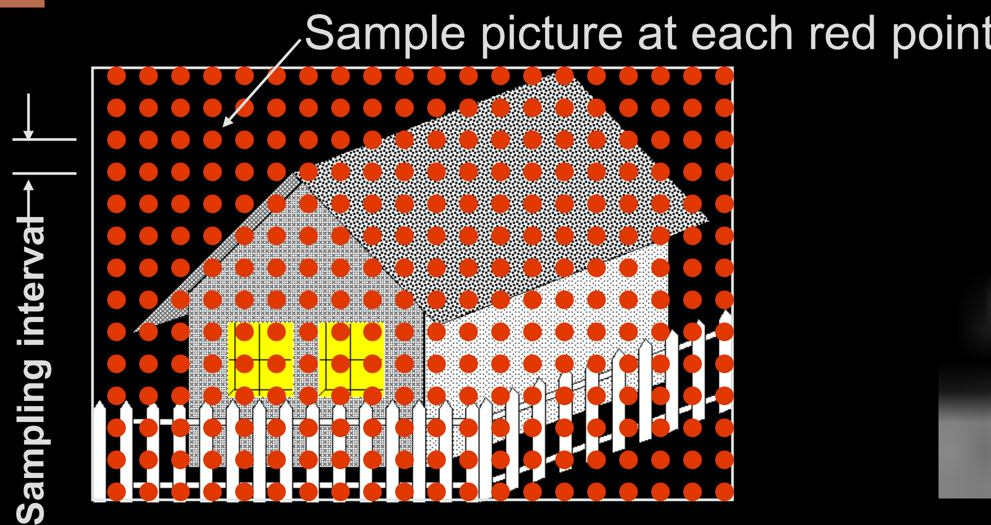
- Digitization: conversion of the continuous (in space and value) electrical signal into a digital signal (digital image)
- Three decisions must be made:
  - Spatial resolution (how many samples to take)
  - Signal resolution (dynamic range of values)
  - Tessellation pattern (how to 'cover' the image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

Digitization: Spatial Resolution

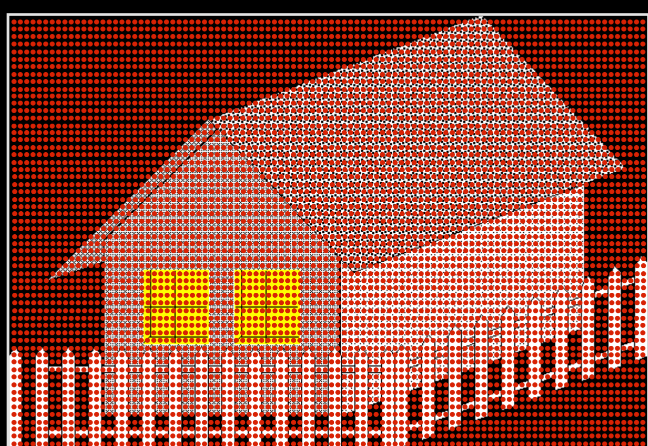


- Let's digitize this image
  - Assume a square sampling pattern
  - Vary density of sampling grid

Spatial Resolution



Coarse Sampling: 20 points per row by 14 rows

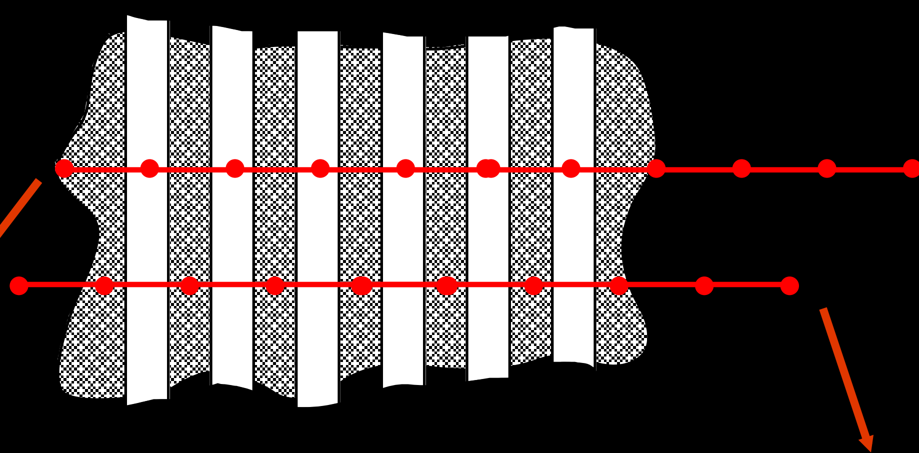


Finer Sampling: 100 points per row by 68 rows

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!

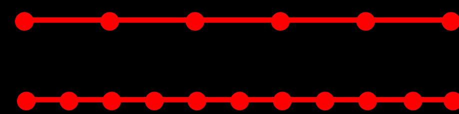
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40
40	40	40	40	40	40

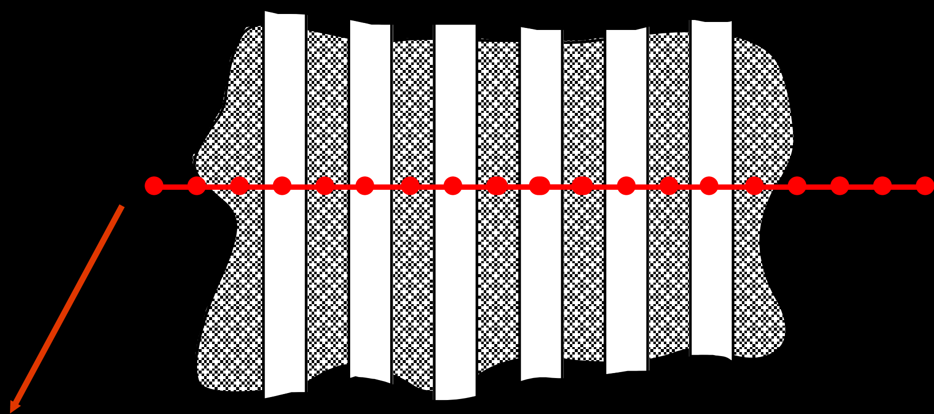
Dark Gray Image!

Effect of Sampling Interval - 2

- Look in vicinity of picket fence:

Sampling Interval:





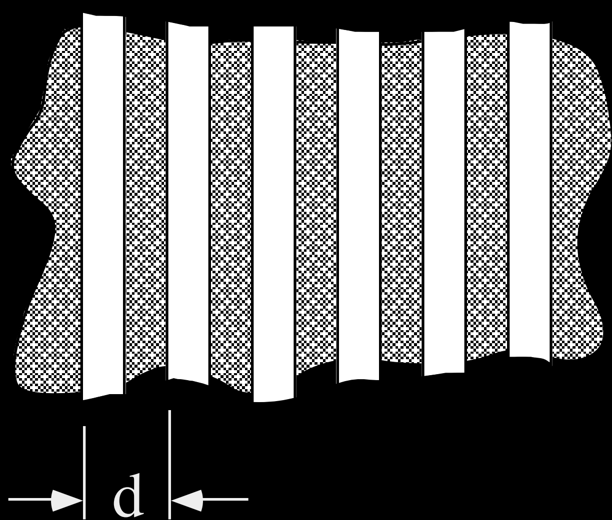
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40
40	100	40	100	40

Now we've got a fence!

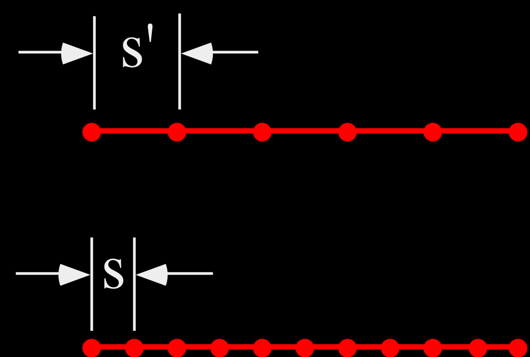
What's the difference between this attempt and the last one?

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

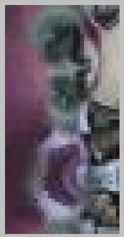
Human Eye Sampling

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

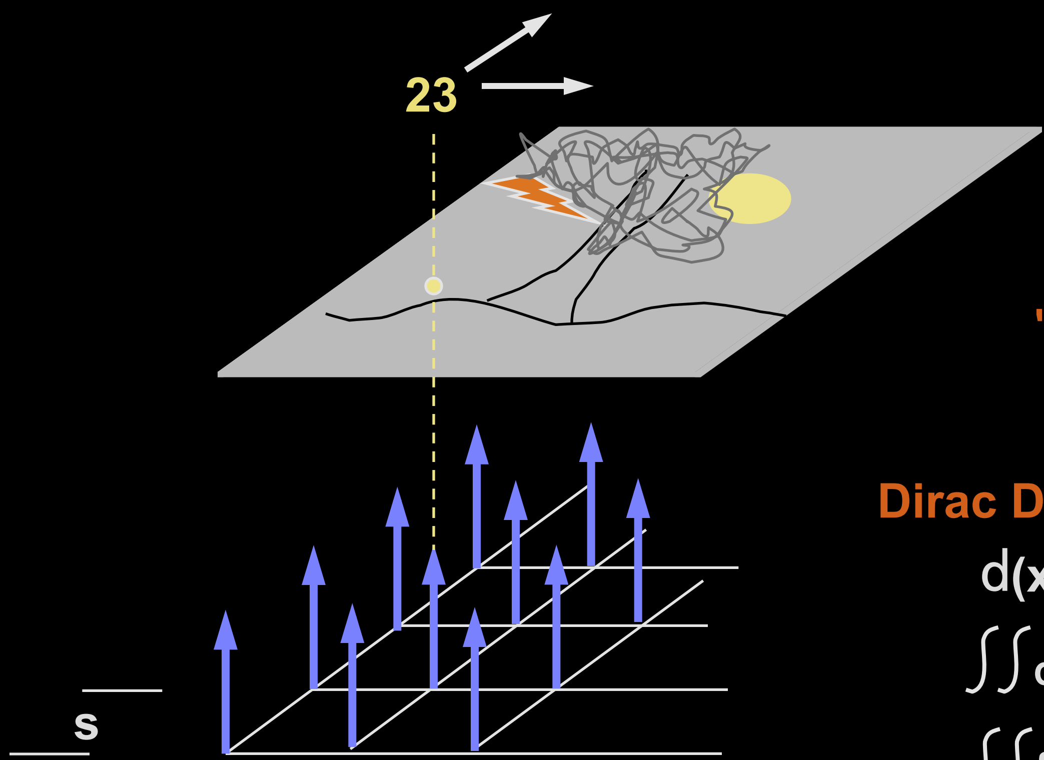
- Strategy:
  - Detect points of interest with low resolution sampling
  - “Foveate” to point of interest and use high resolution sampling.

Human Eye Sampling

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



- **Rough Idea: Ideal Case**



"Digitized Image"

"Continuous Image"

Dirac Delta Function 2D "Comb"

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

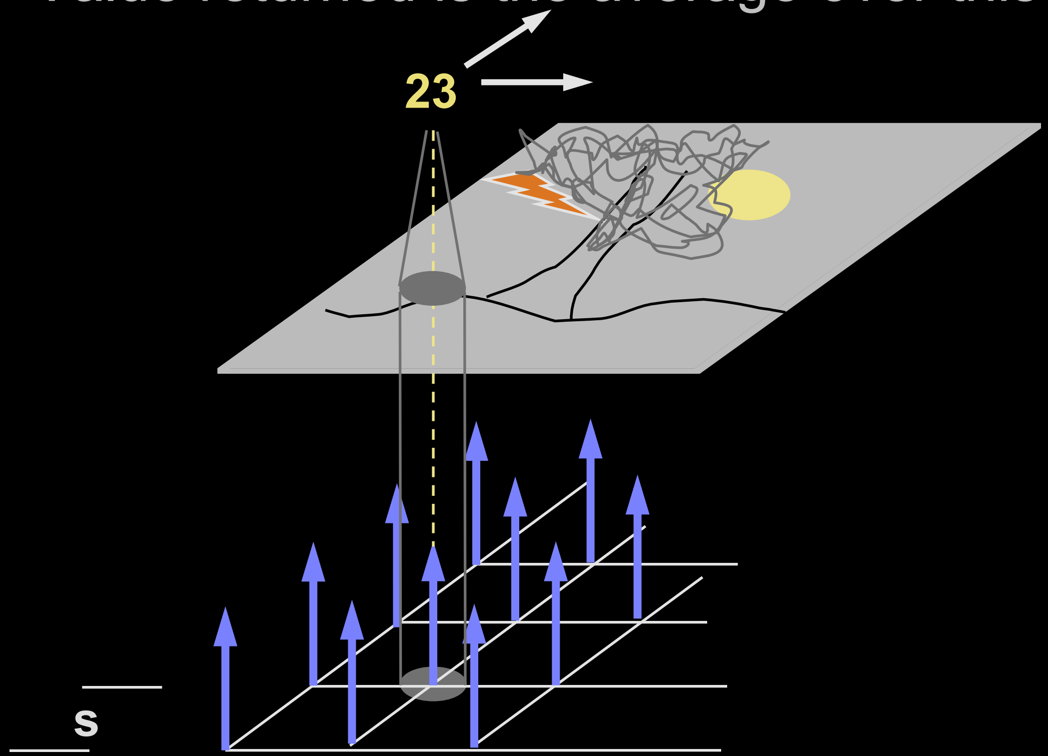
$\iint d(x,y)\, dx\, dy = 1$

$\iint f(x,y) d(x-a,y-b)\, dx\, dy = f(a,b)$

$d(x-ns,y-ns)$ for $n = 1….32$ (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

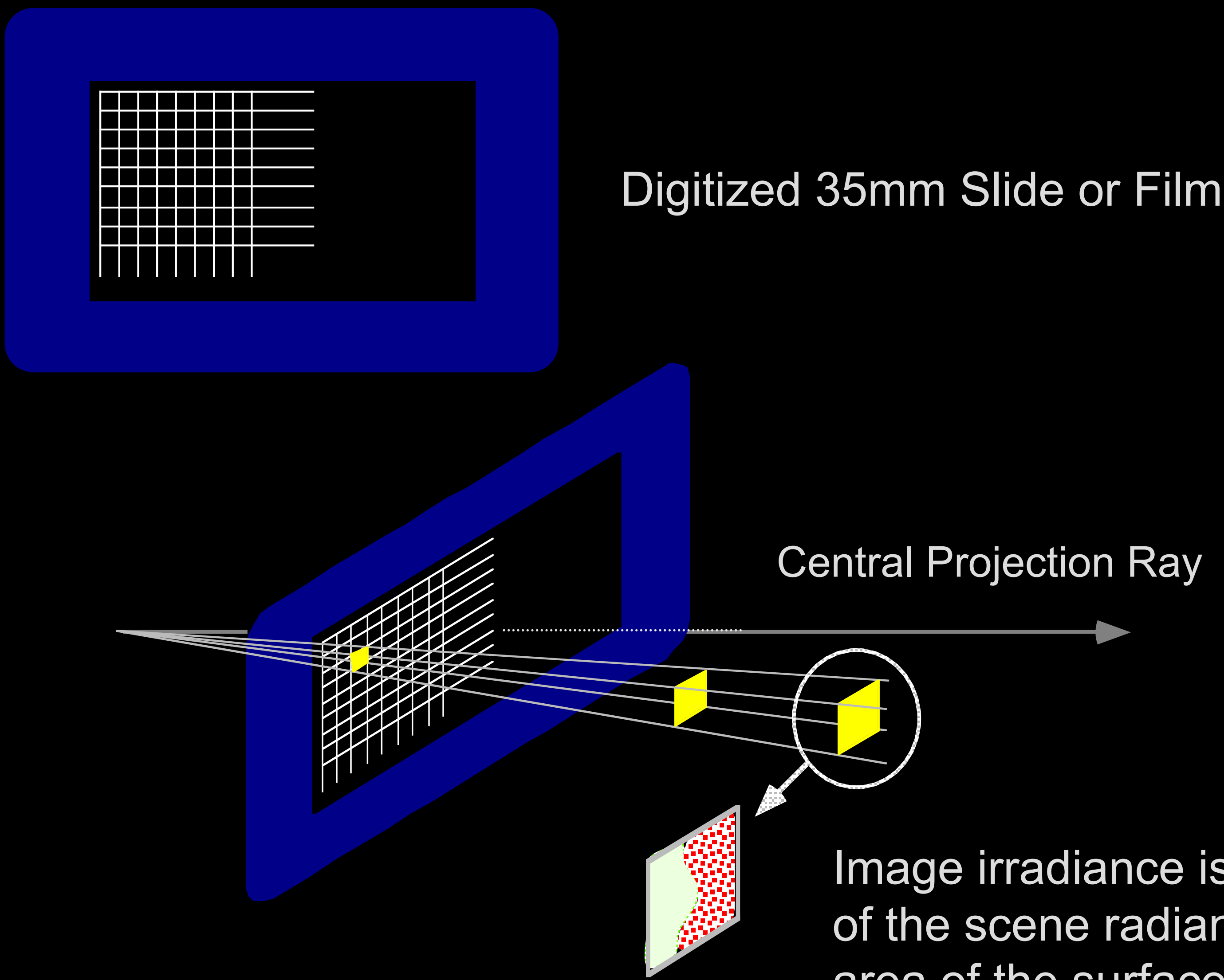
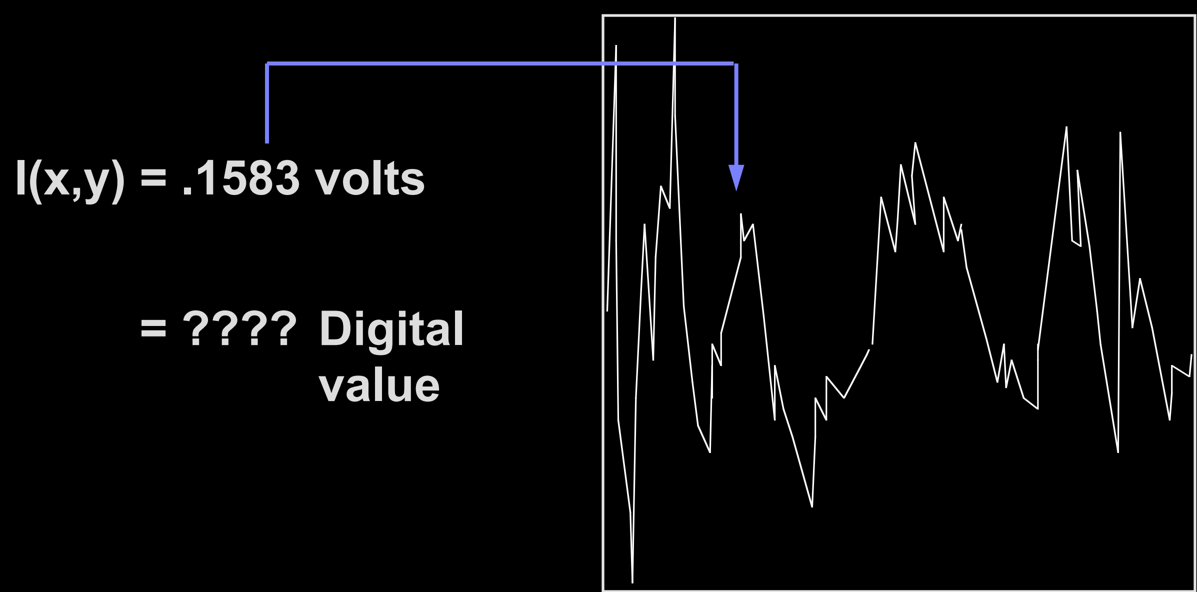


Image irradiance is the average of the scene radiance over the area of the surface intersecting the solid angle!

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: $0 \leq I \leq M$
- Want to quantize to K values 0,1,....K-1
- K usually chosen to be a power of 2:

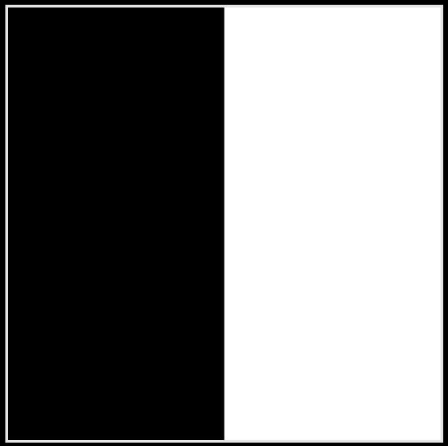
K: #Levels	#Bits
2	1
4	2
8	3
16	4
32	5
64	6
128	7
256	8

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

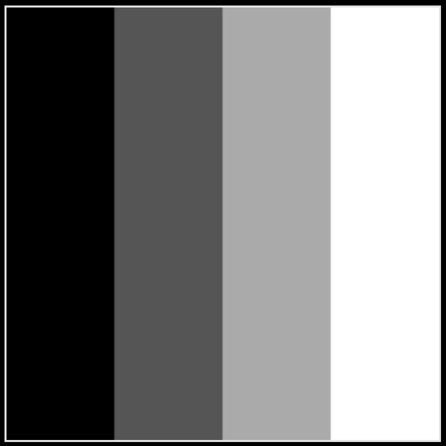
Choice of K

Original

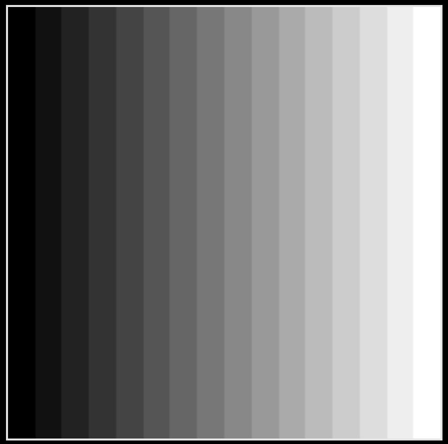
Linear Ramp



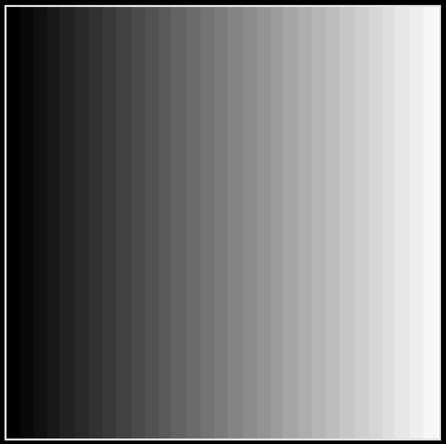
K=2



K=4



K=16



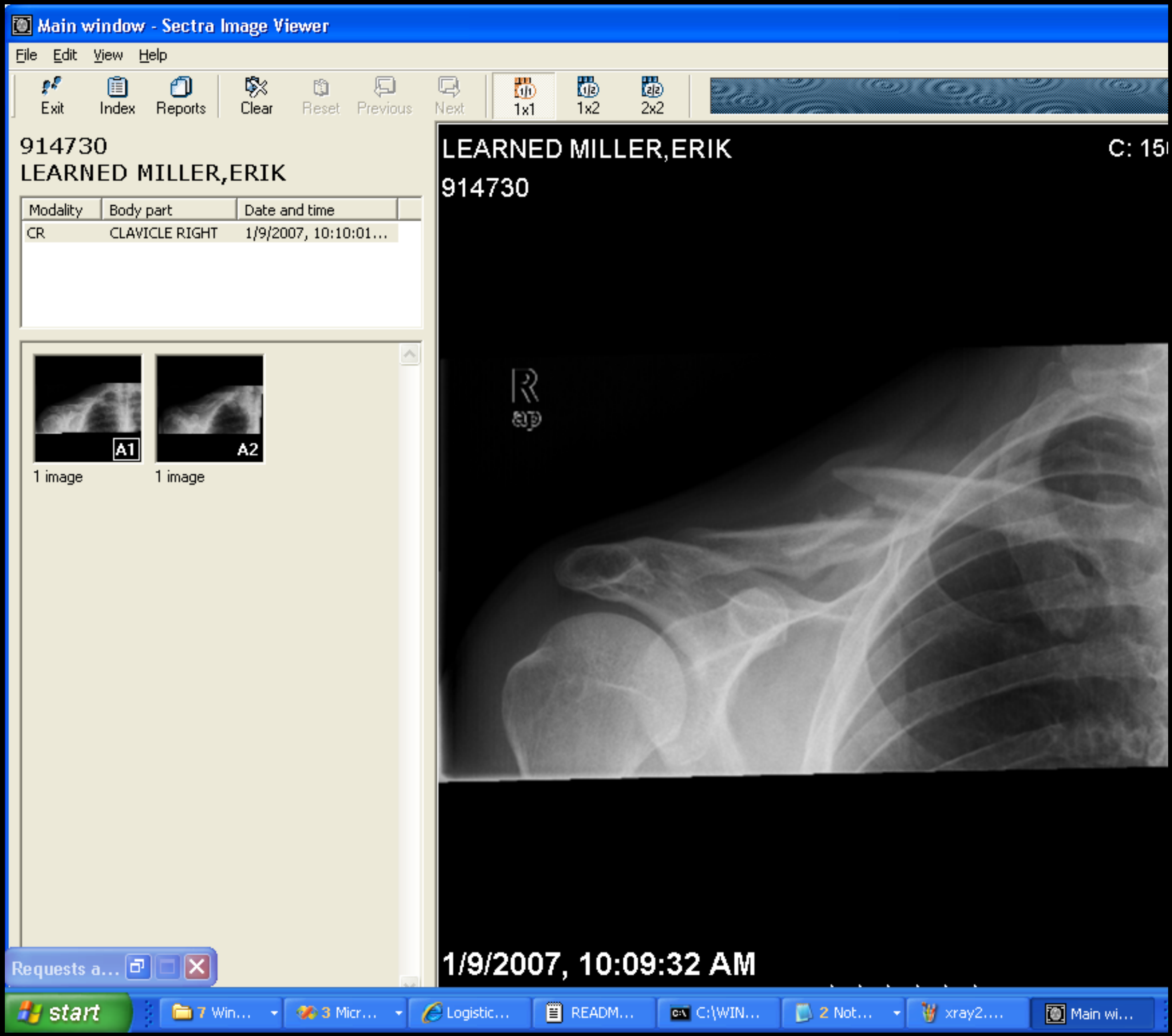
K=32

Choice of K

K=2 (each color)

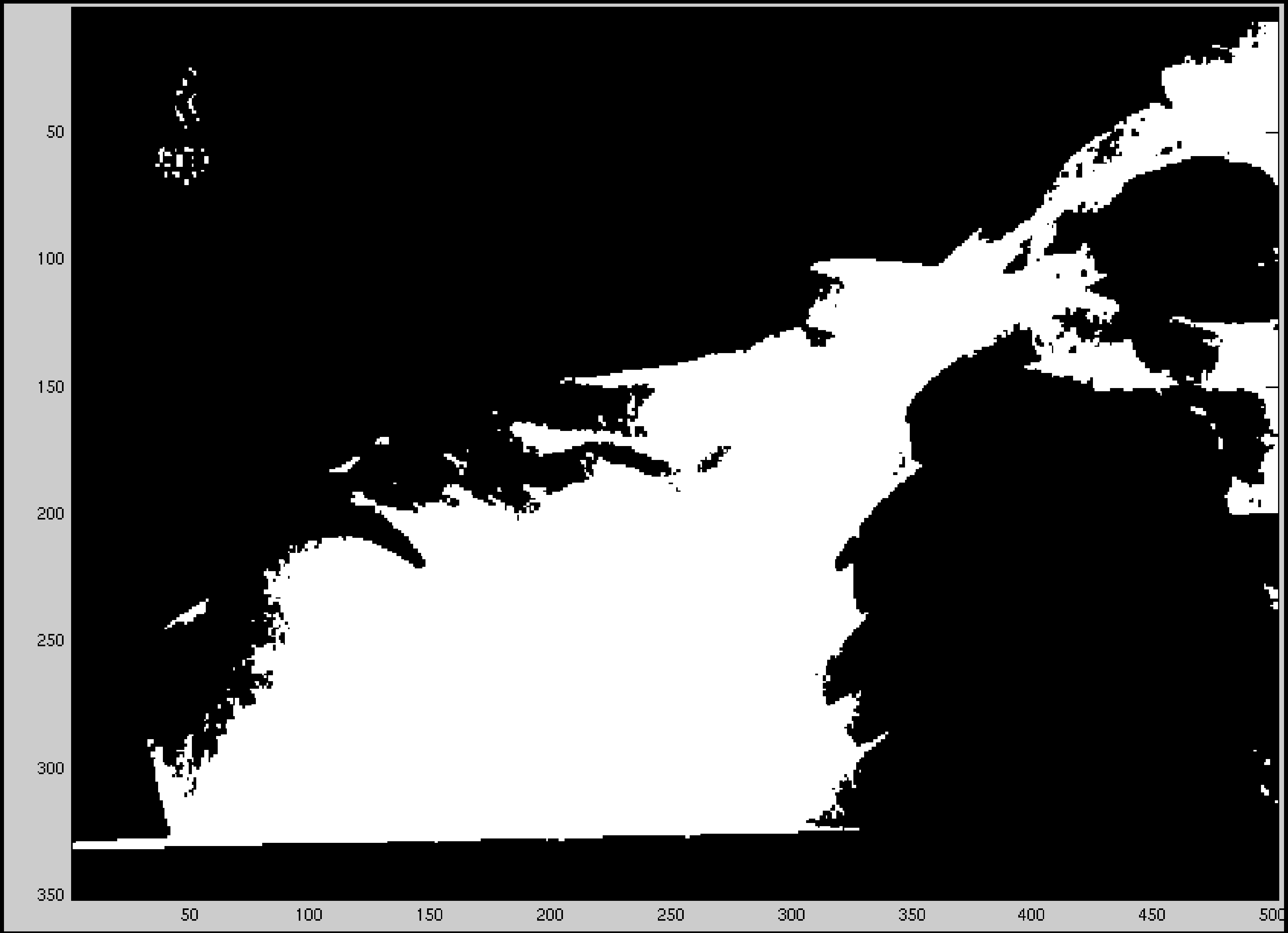
K=4 (each color)

Digital X-rays

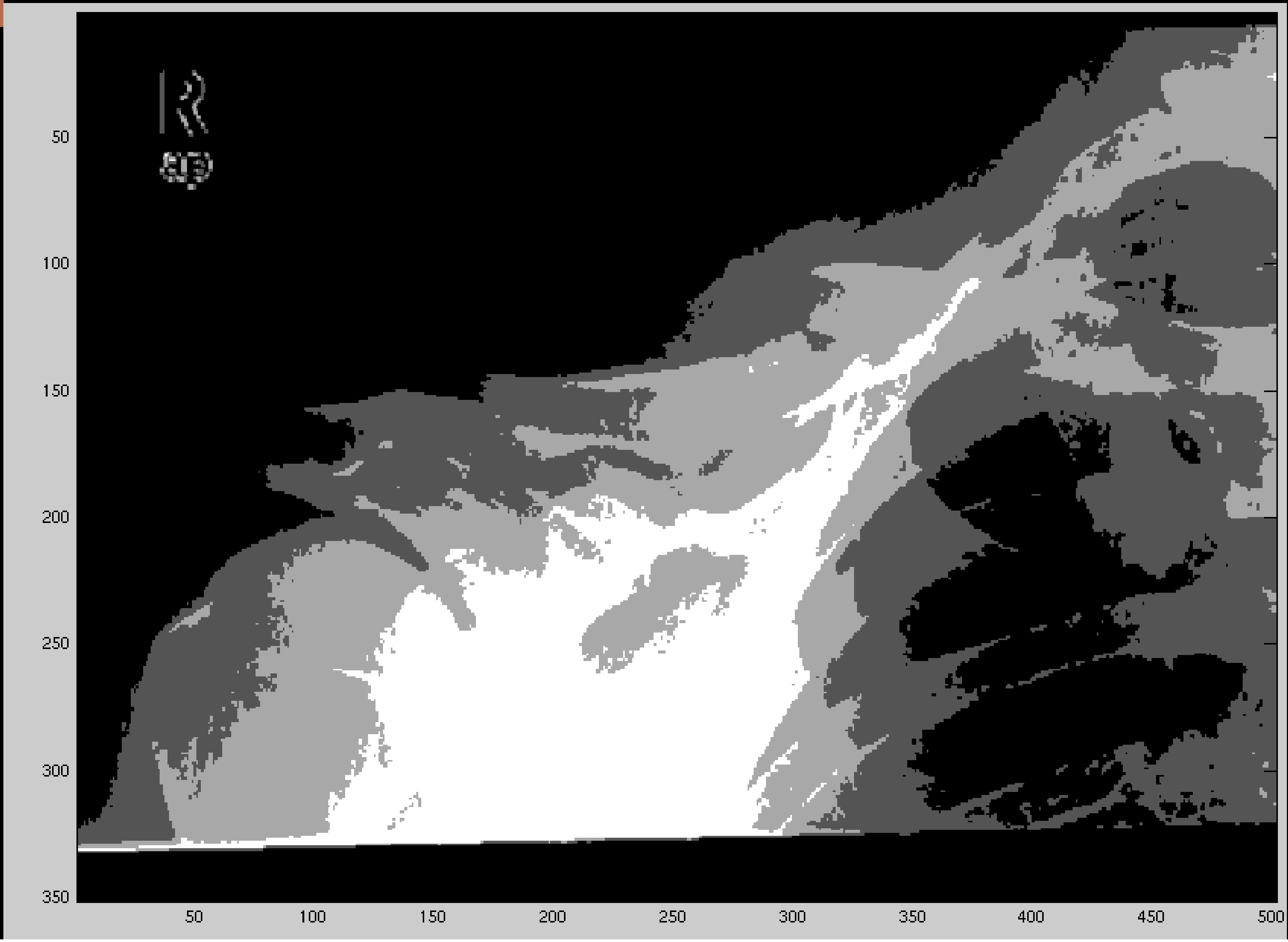


Digital X-rays: 8 is enough?

Digital X-rays: 1 bit

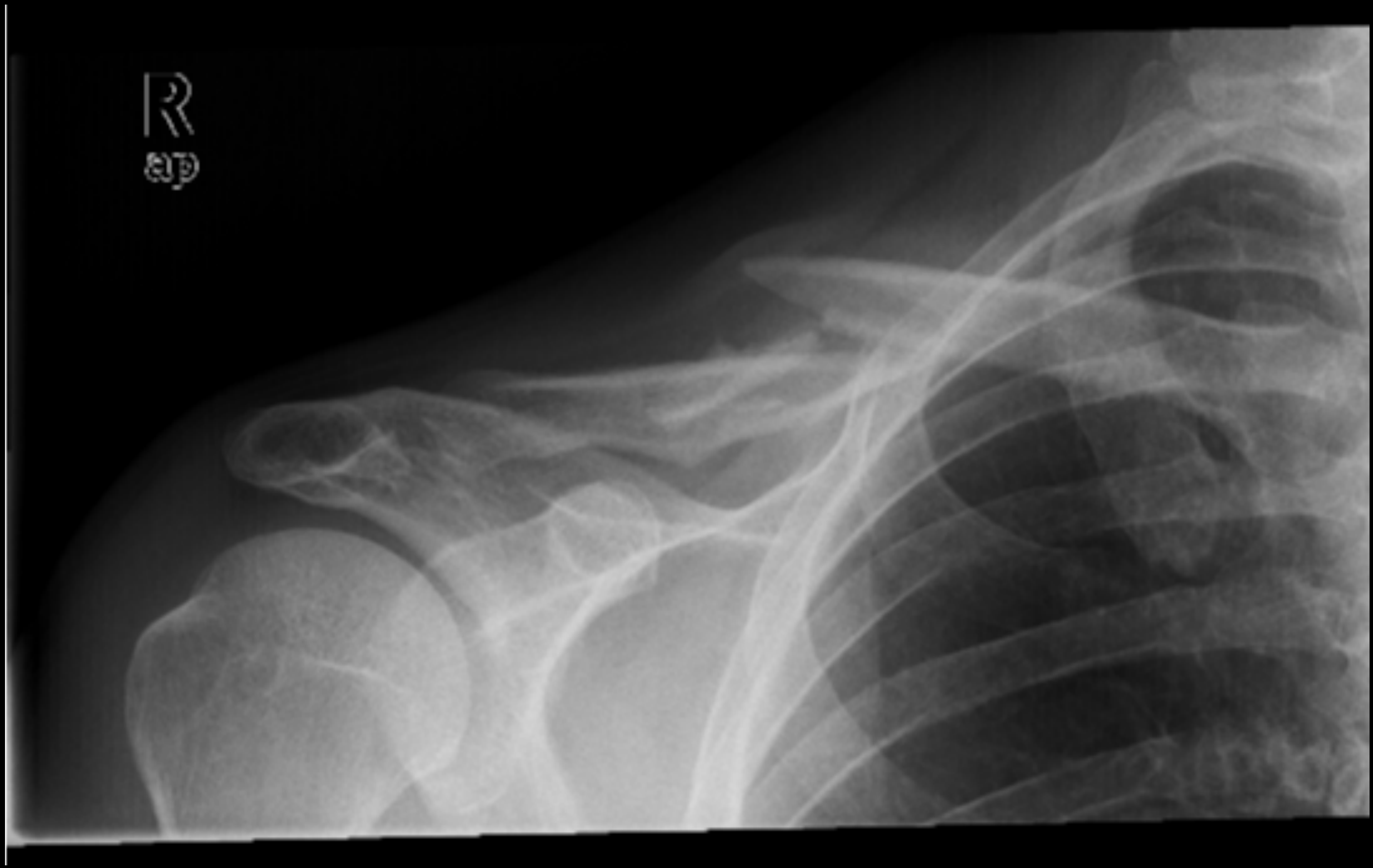


Digital X-rays: 2 bits



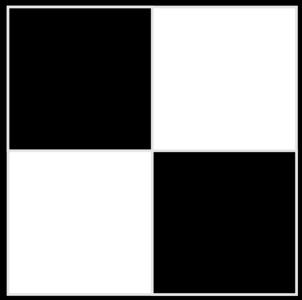
Digital X-rays: 3 bit

Digital X-rays: 8 is enough?



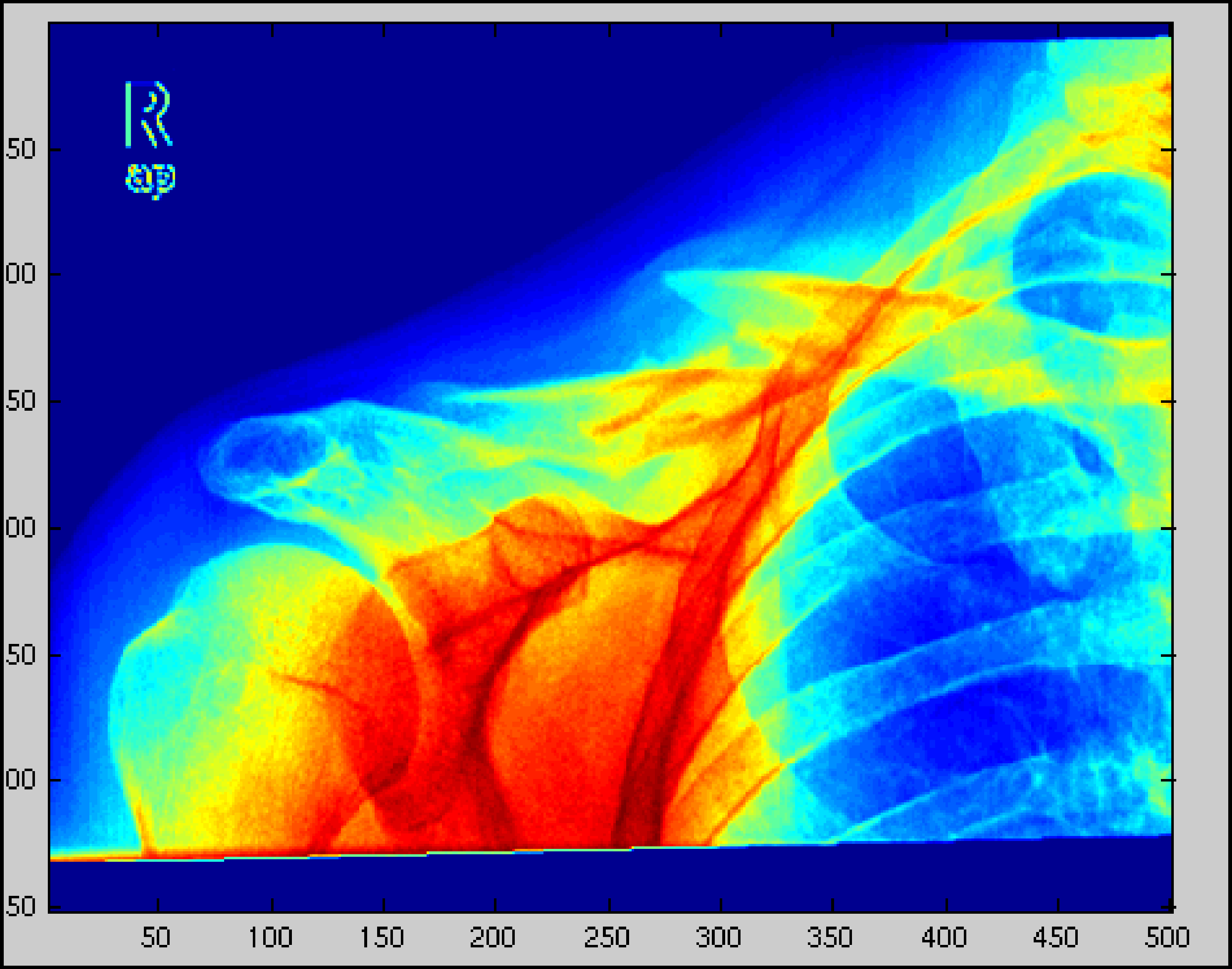
Gray Levels-Resolution Trade Off

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



- Doubling the resolution in each direction adds at least 3 new gray levels. But maybe more?

Pseudocolor

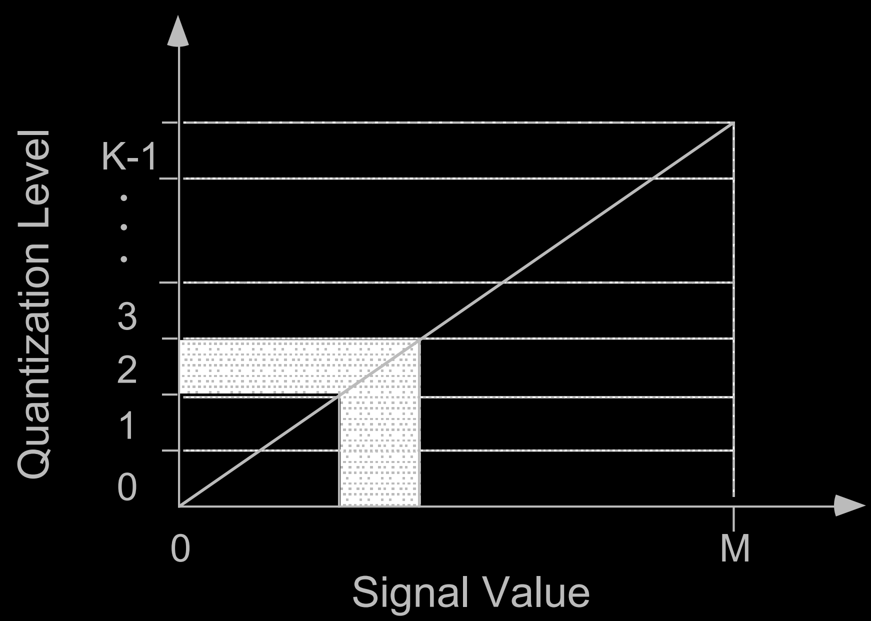


Digital X-rays: 8 is enough?

MRI

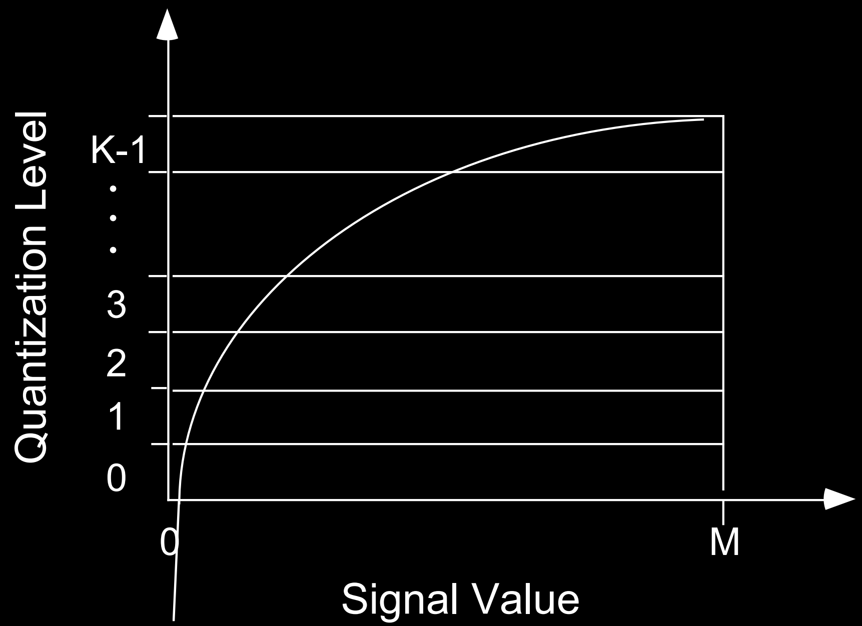
Choice of Function: Uniform

- 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

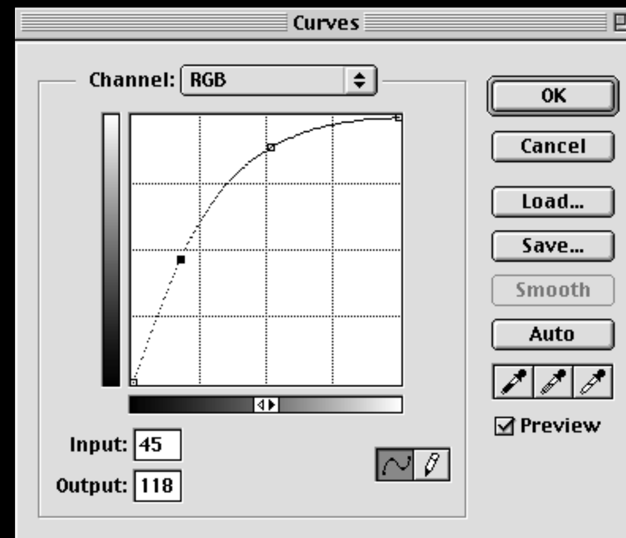
- Signal is log I(x,y).
- Effect is:



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

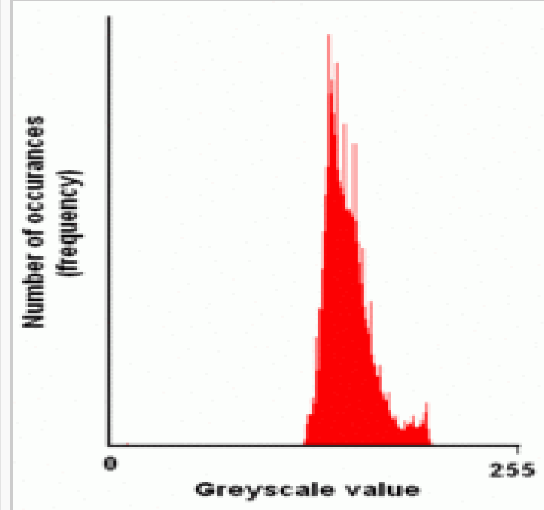
Logarithmic Quantization

Quantization Curve



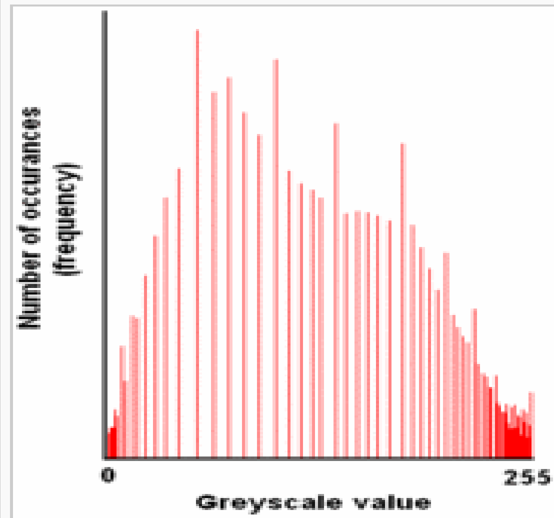
Histogram Equalization

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)

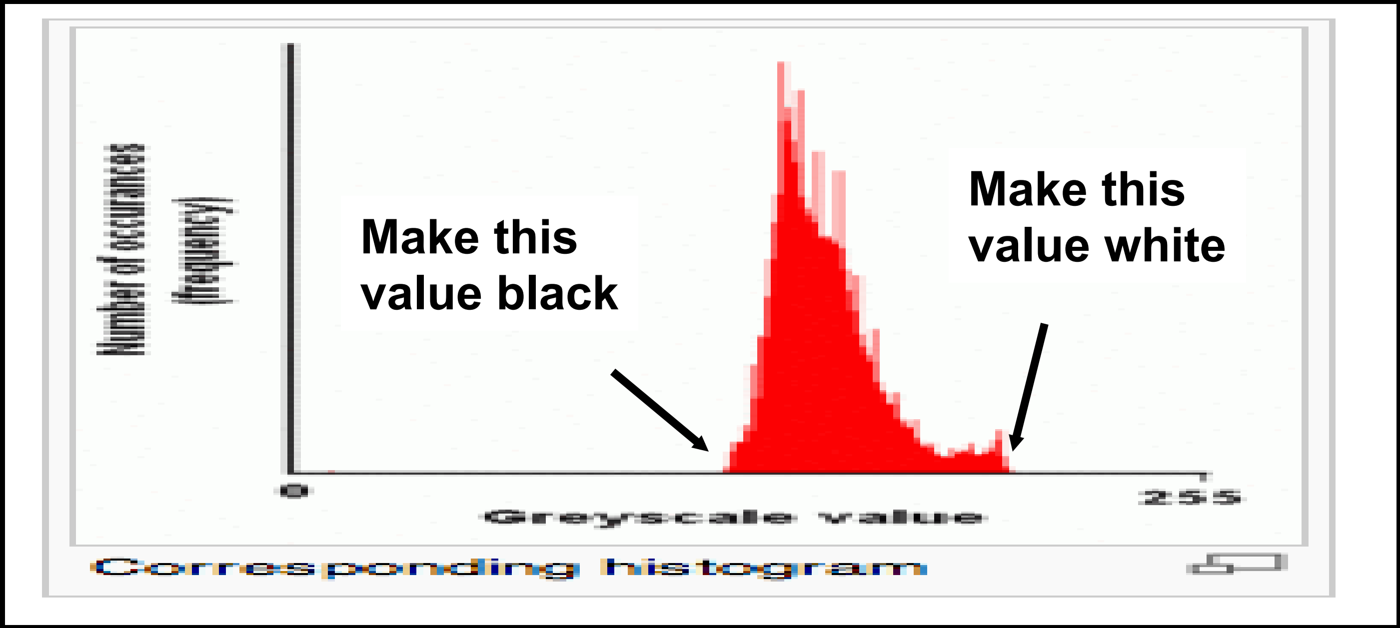
Look up tables

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 (histogram equalization).
  - Use a look up table (brightness equalization).



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