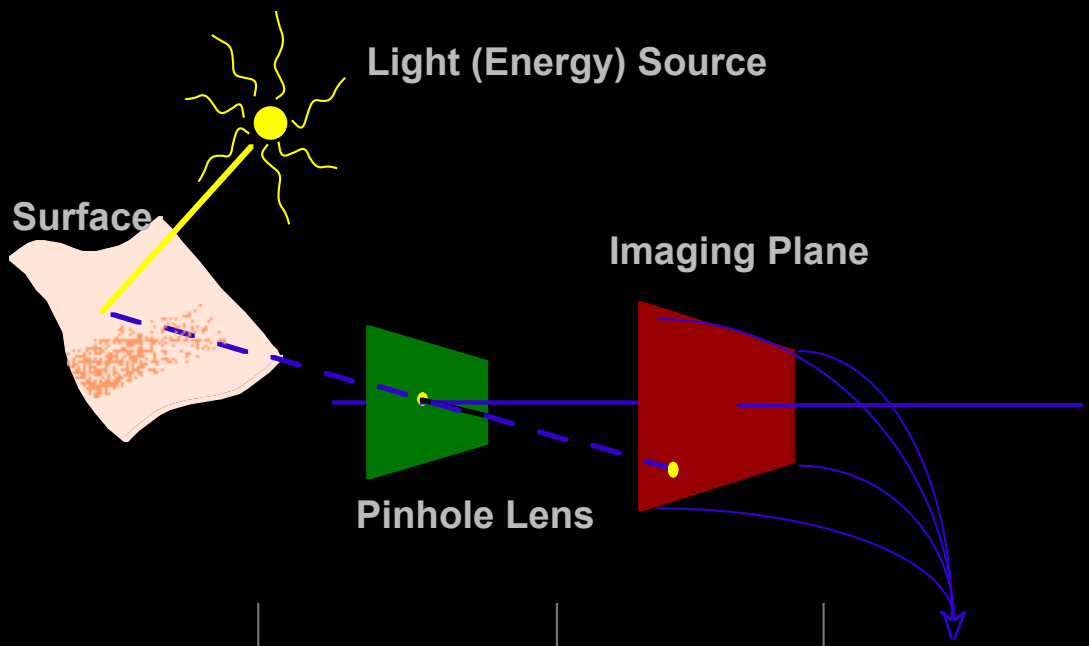
Image Formation



World	Optics	Sensor	Signal
		B&W Film	Silver Density
		Color Film	Silver density in three color layers
		TV Camera	Electrical

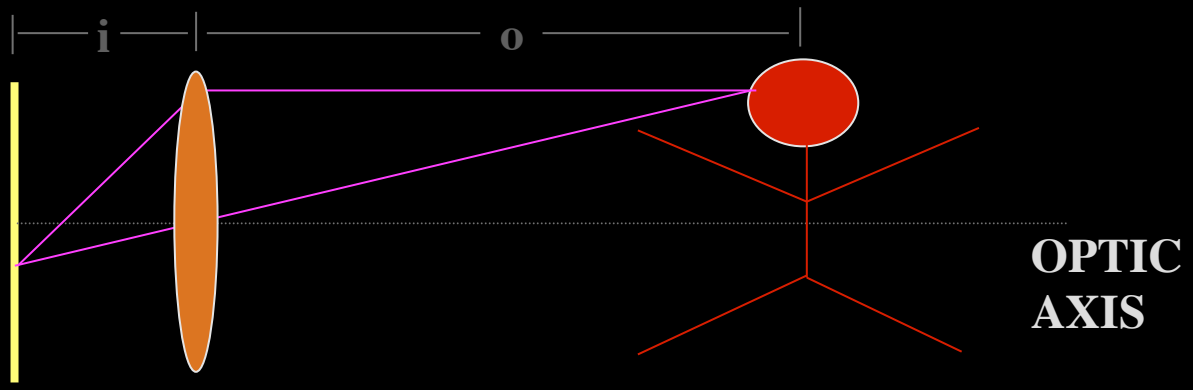
Today

- Optics:
  - Pinhole cameras (last time).
  - Lenses
- Artificial sensors
  - 1 sensor array vs. 3 sensor arrays
  - Bayer patterns

Thin Lens Model

- Rays entering parallel on one side converge at focal point.
- Rays diverging from the focal point become parallel.

PARALLEL rays converge at f.



NON-PARALLEL rays converge at i.

OPTIC AXIS

IMAGE PLANE

LENS

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$ **'THIN LENS LAW'**

Time of exposure

- Artificial cameras typically have a shutter that is opened and closed to let in light.
- The signal produced by the film or CCD array is typically *linear* in the exposure time.
- The more light that is let in, the less exposure time needed:
  - Bright light -> short exposure time
  - Low light -> long exposure time
  - Large aperture/lens -> short exposure time
  - Pinhole camera -> long exposure time.

Exposure

http://en.wikipedia.org/wiki/File:Shutter_speed_in_Greenwich.jpg

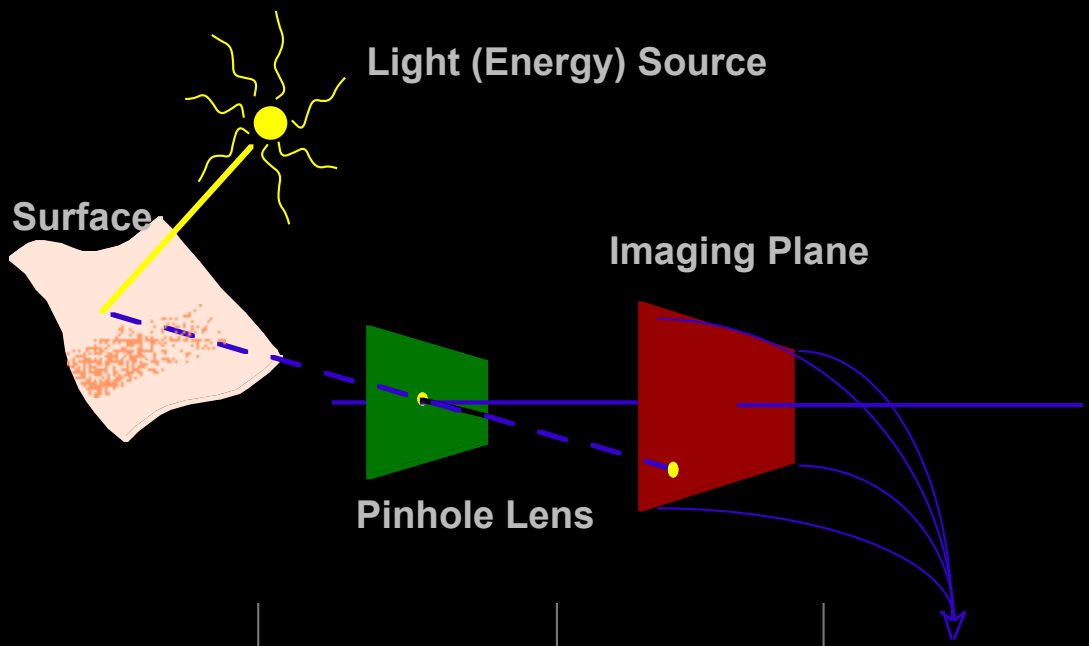
Lenses

- Lenses allow the capture of more light.
- Suppose a pinhole camera with pinhole 1mm^2 needs an exposure time of 10 seconds to take a photo of a certain brightness?
- Consider a lens with diameter 2cm. How long would a photo need to be exposed using this lens?

Lenses: practice

- Calculate “i” for objects at a certain distance.
- How much faster can we take a picture with a lens of diameter 2cm compared to a 1mm pinhole?

Image Formation



World	Optics	Sensor	Signal
		B&W Film	Silver Density
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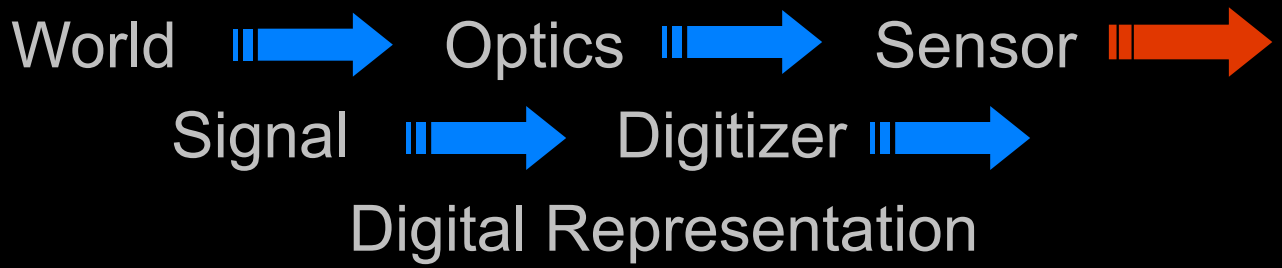
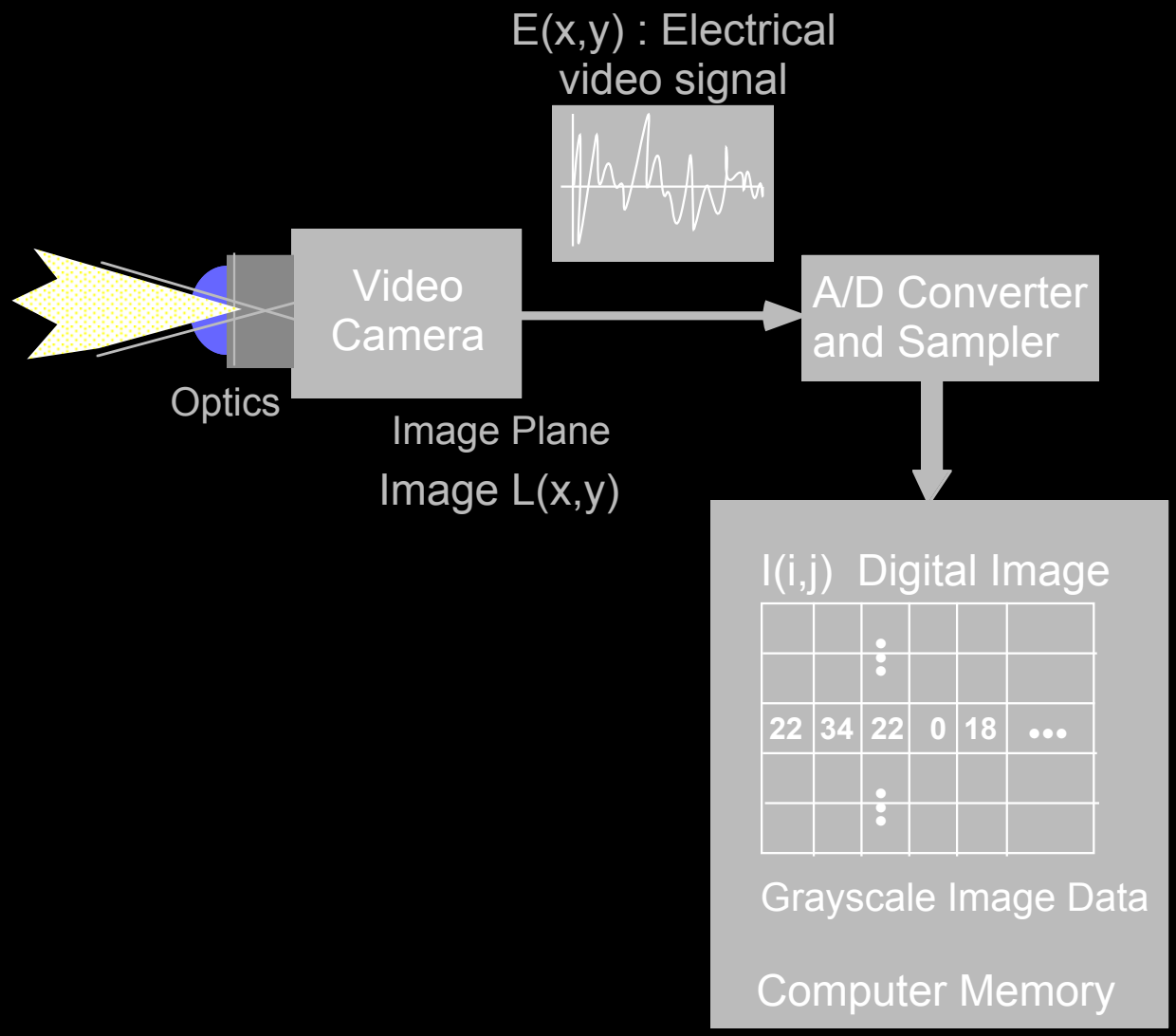
Photometry

- Photometry:

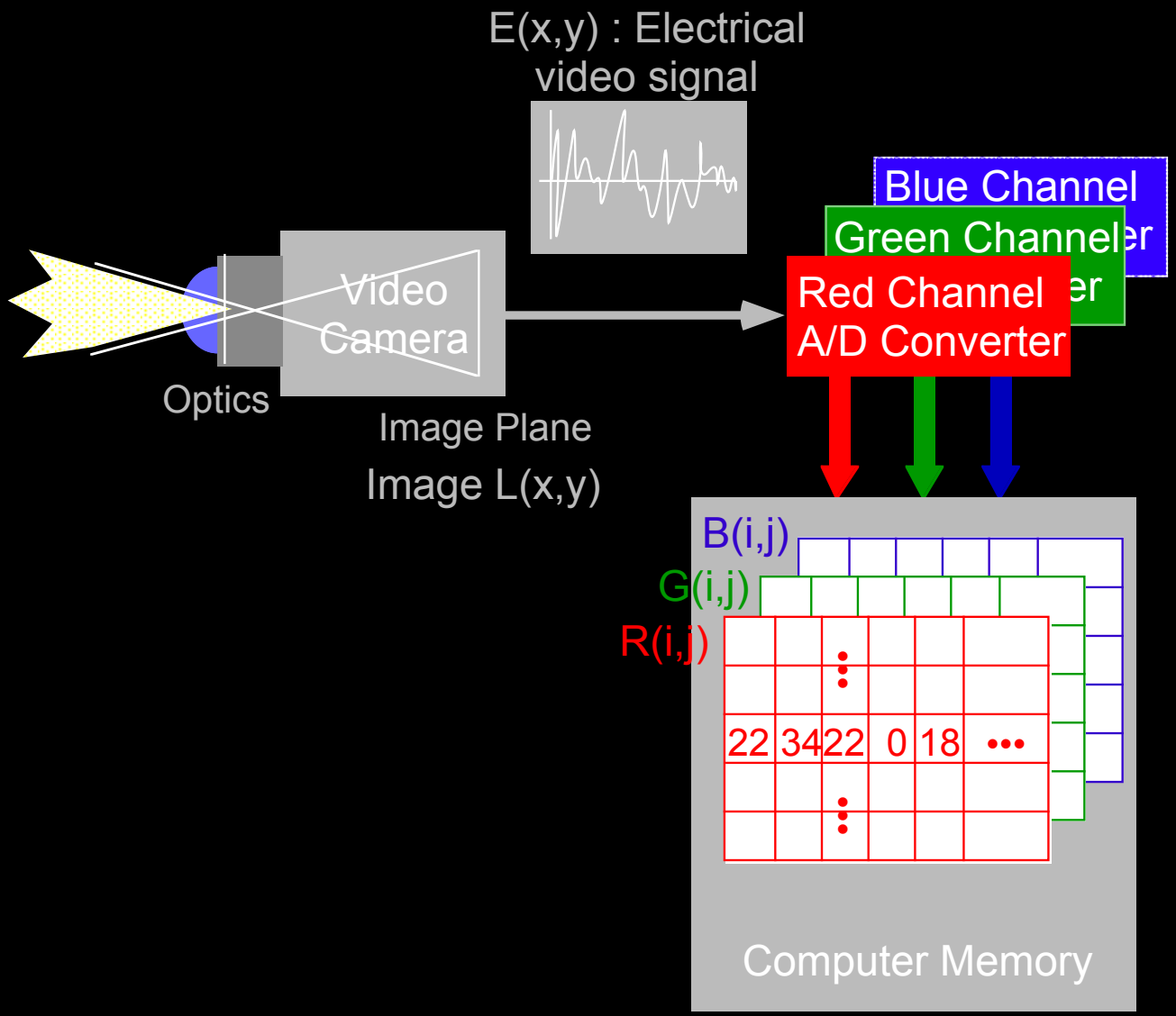
  Concerned with mechanisms for converting light energy into electrical energy.



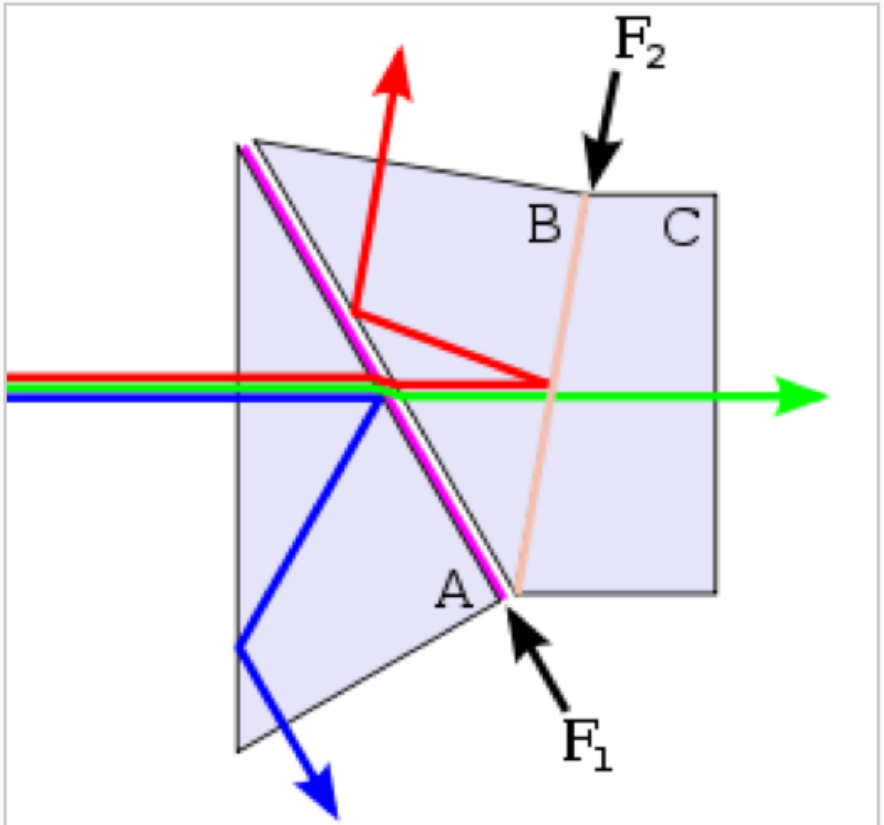
B&W Video System



Color Video System

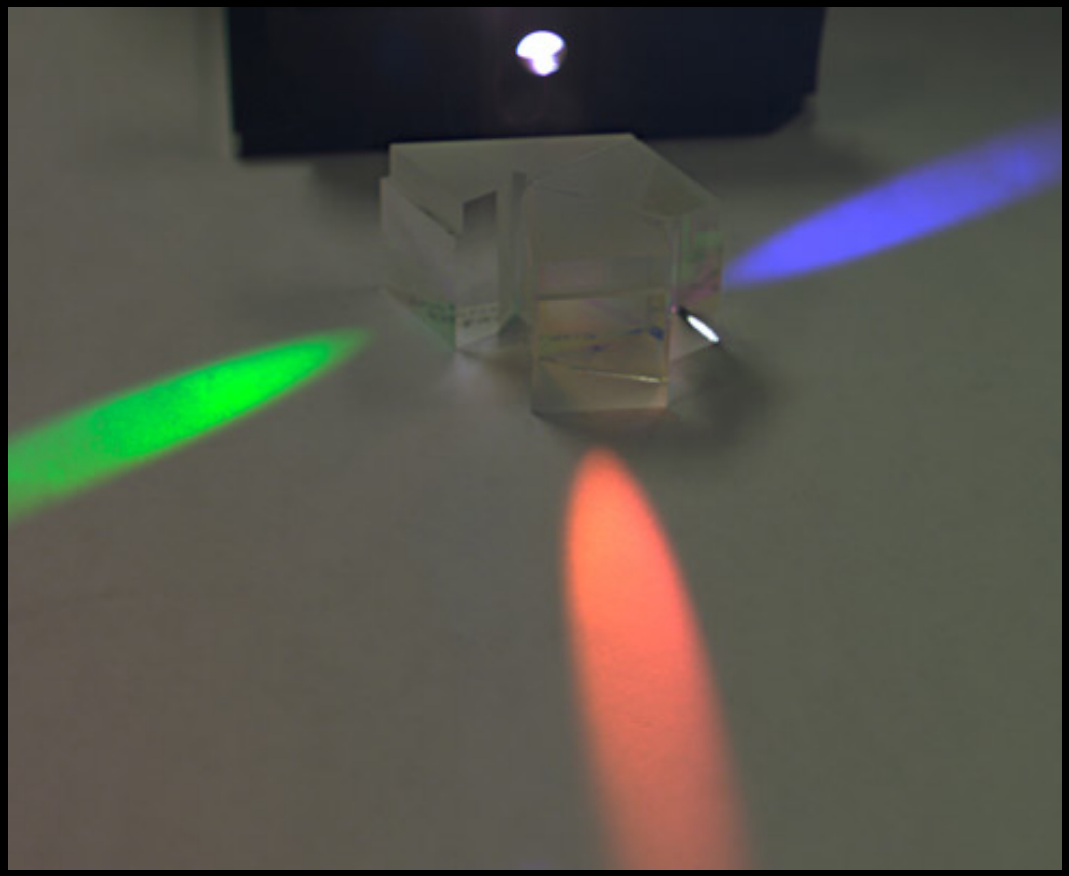


Beam Splitter

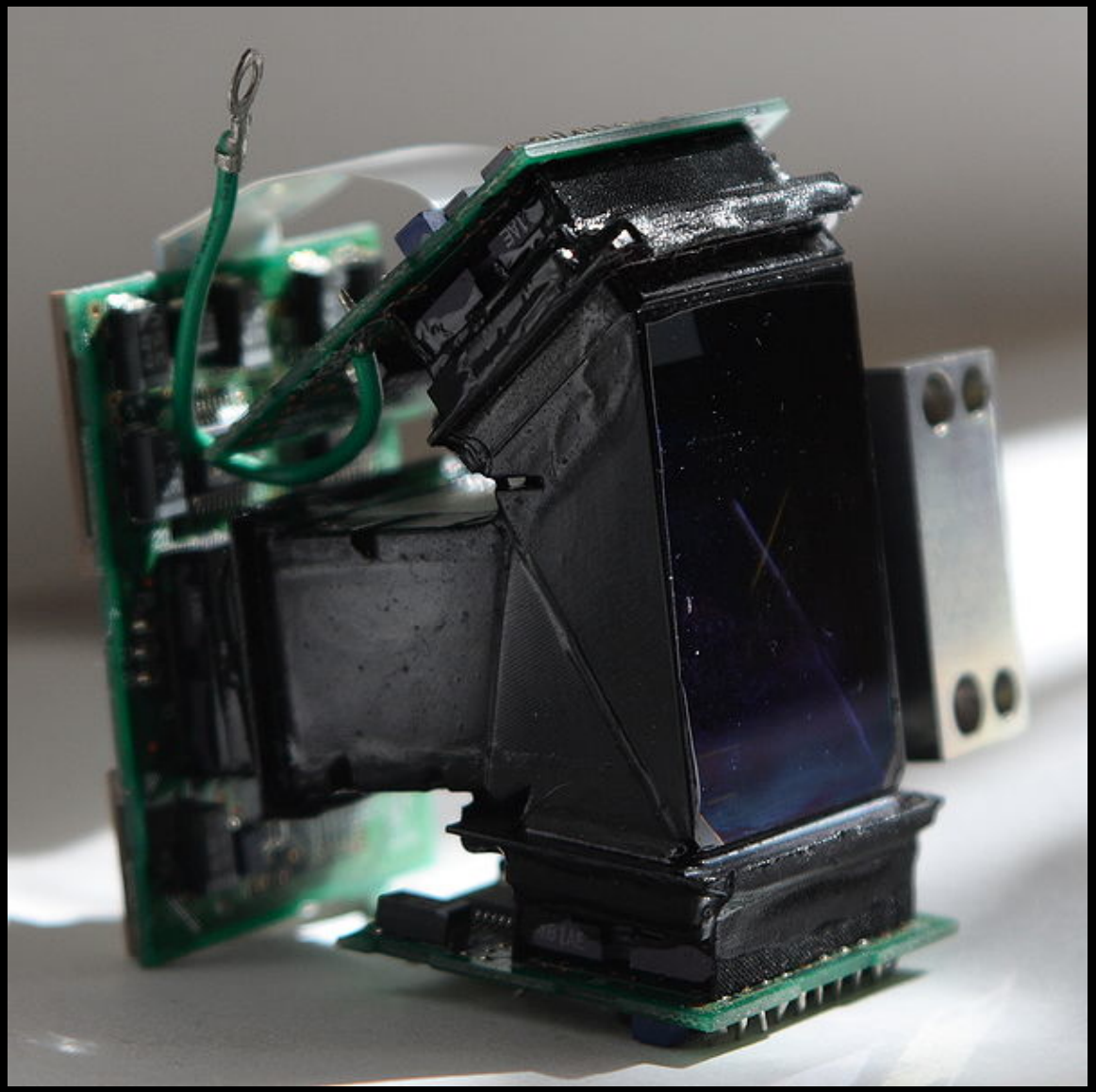


A Philips type trichroic beam splitter prism schematic, with a different color separation order than the assembly shown in the photo. The red beam undergoes total internal reflection at the air gap, while the other reflections are dichroic.

Trichroic Beam splitter



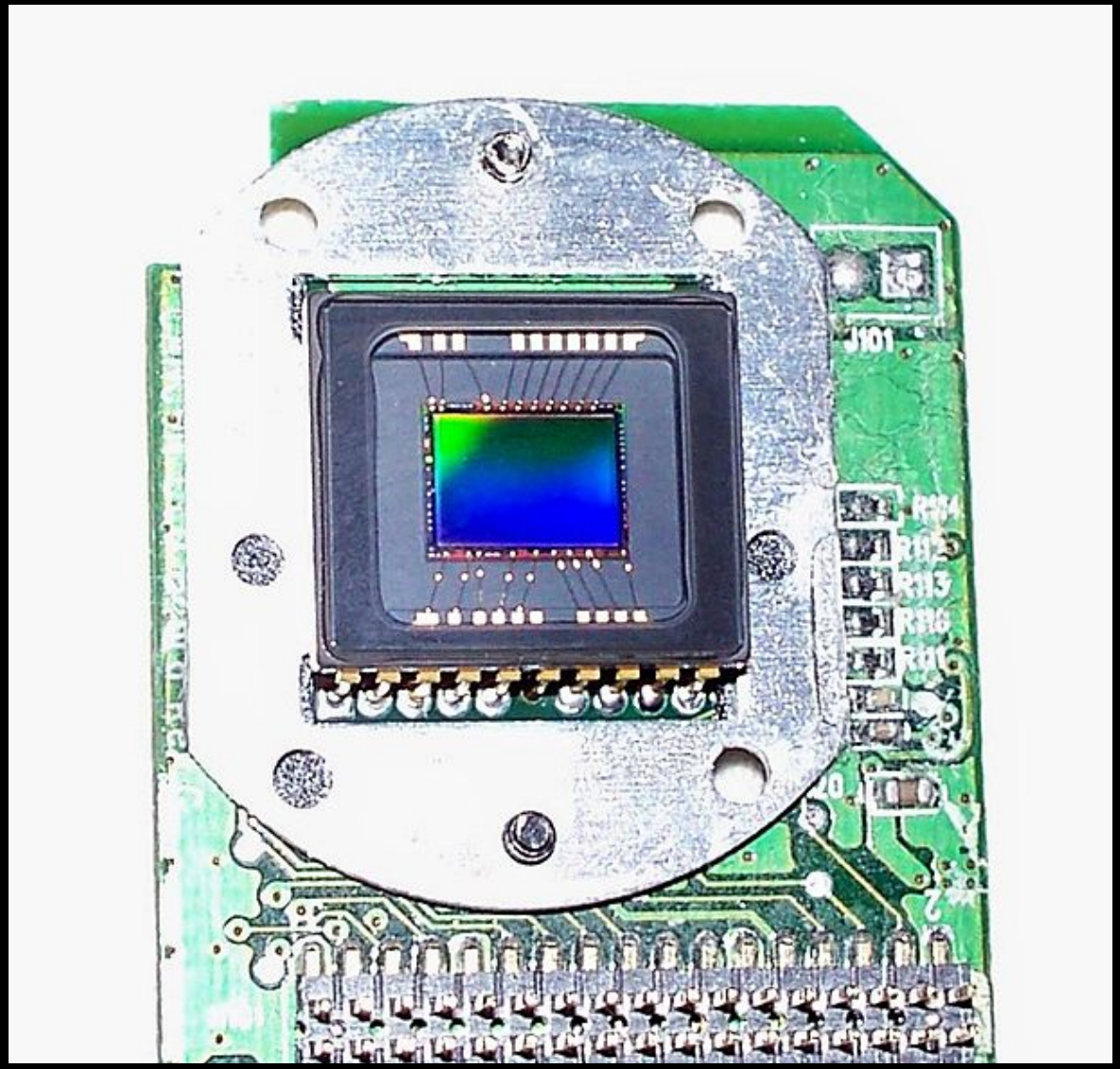
3CCD cameras



http://en.wikipedia.org/wiki/File:A_3CCD_imaging_block.jpg

Sony 6 MegaPixel CCD

CCD mounted on circuit board



http://en.wikipedia.org/wiki/File:2.1_MP_CCD_Close_Up.JPG

Spectral Sensitivity

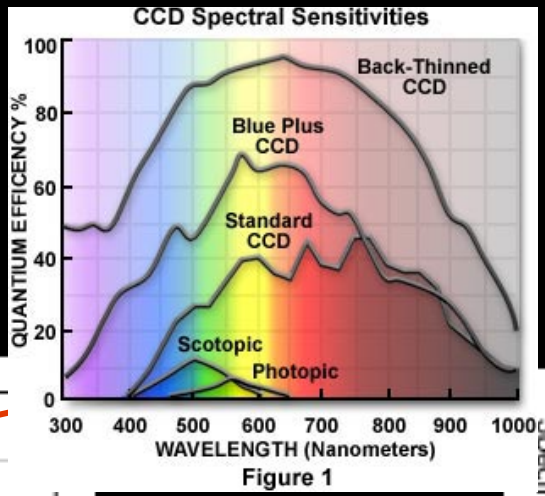
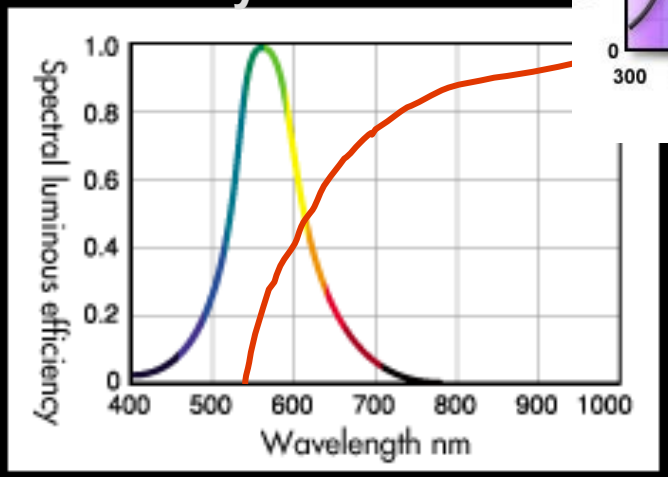
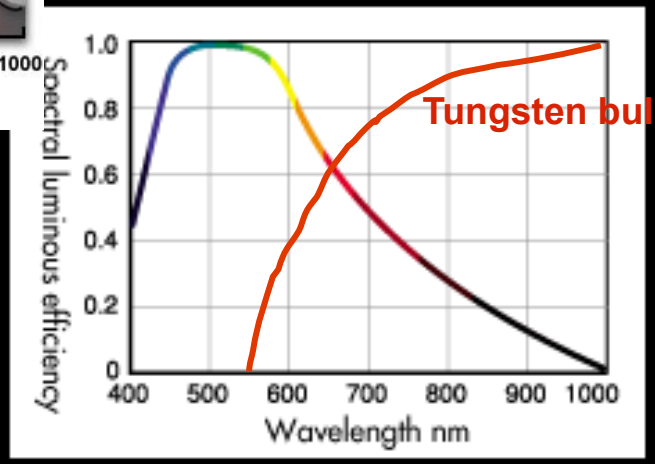


Figure 1

Human Eye



CCD Camera

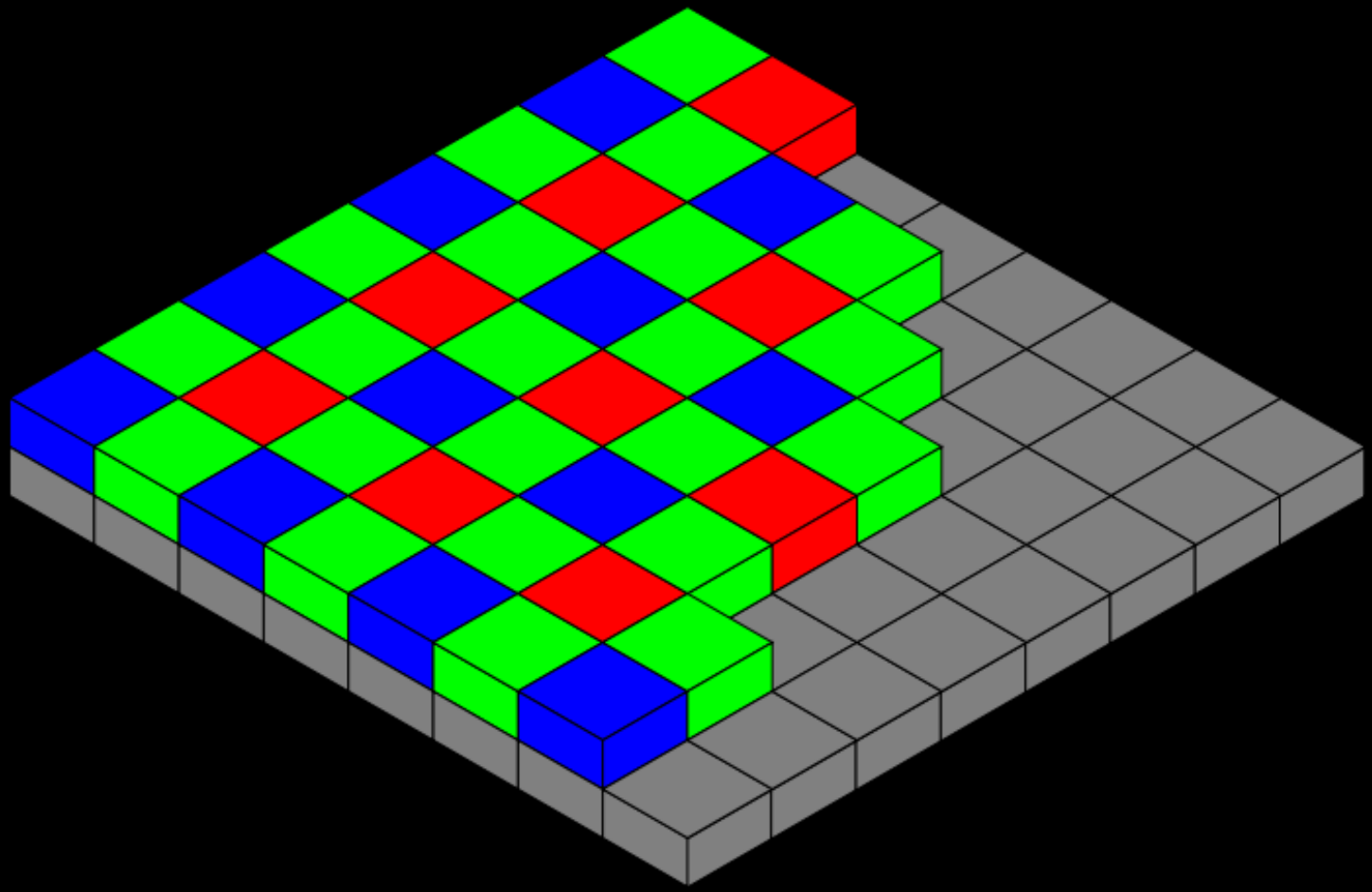


- Figure 1 shows relative efficiency of conversion for the eye (scotopic and photopic curves) and several types of CCD cameras. Note the CCD cameras are much more sensitive than the eye.
- Note the enhanced sensitivity of the CCD in the Infrared and Ultraviolet (bottom two figures)
- Both figures also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

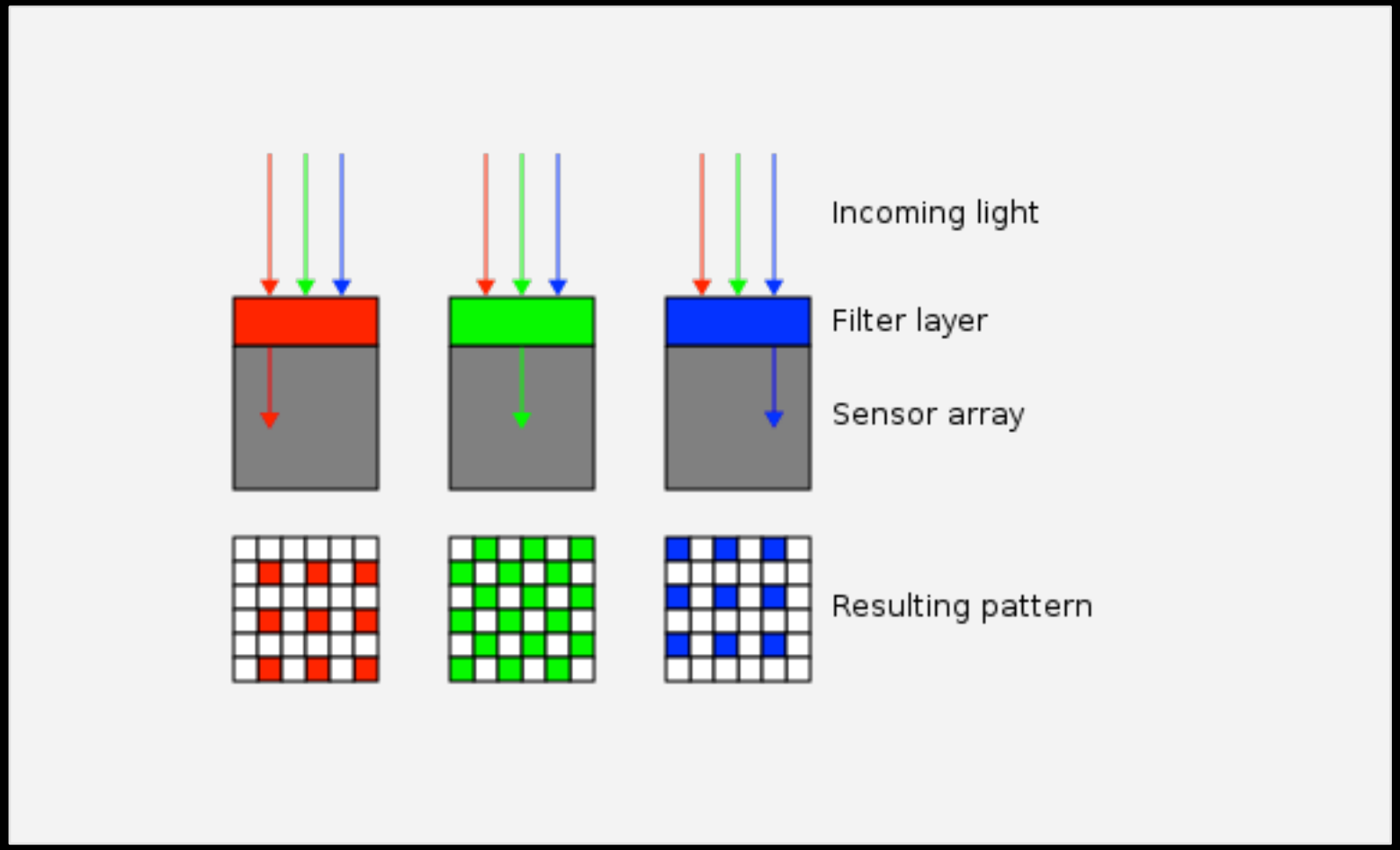
Building a camera with 1 CCD

- CCDs are expensive, and so are beam splitters.
- How do we build a camera with one CCD array?

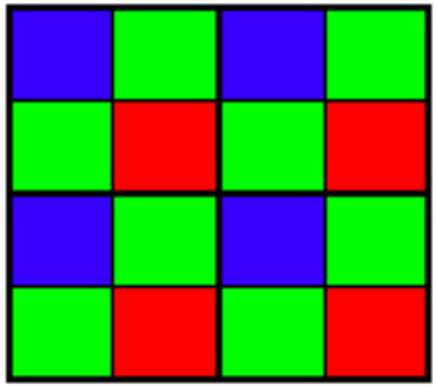
Bayer Filters



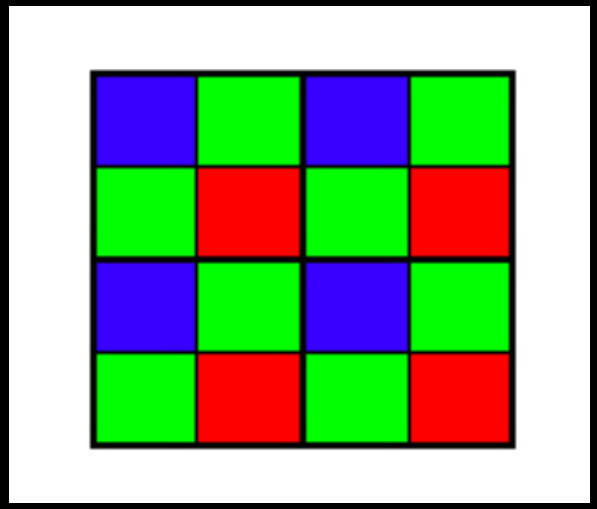
Bayer Filters



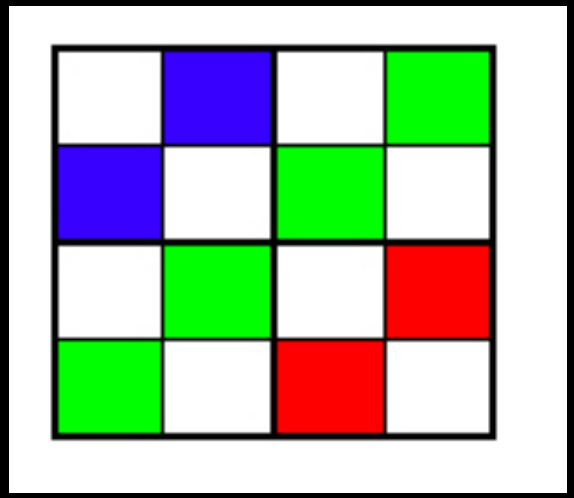
Bayer Filters



Bayer Filters



Traditional design



Recent Kodak design

http://en.wikipedia.org/wiki/Bayer_filter

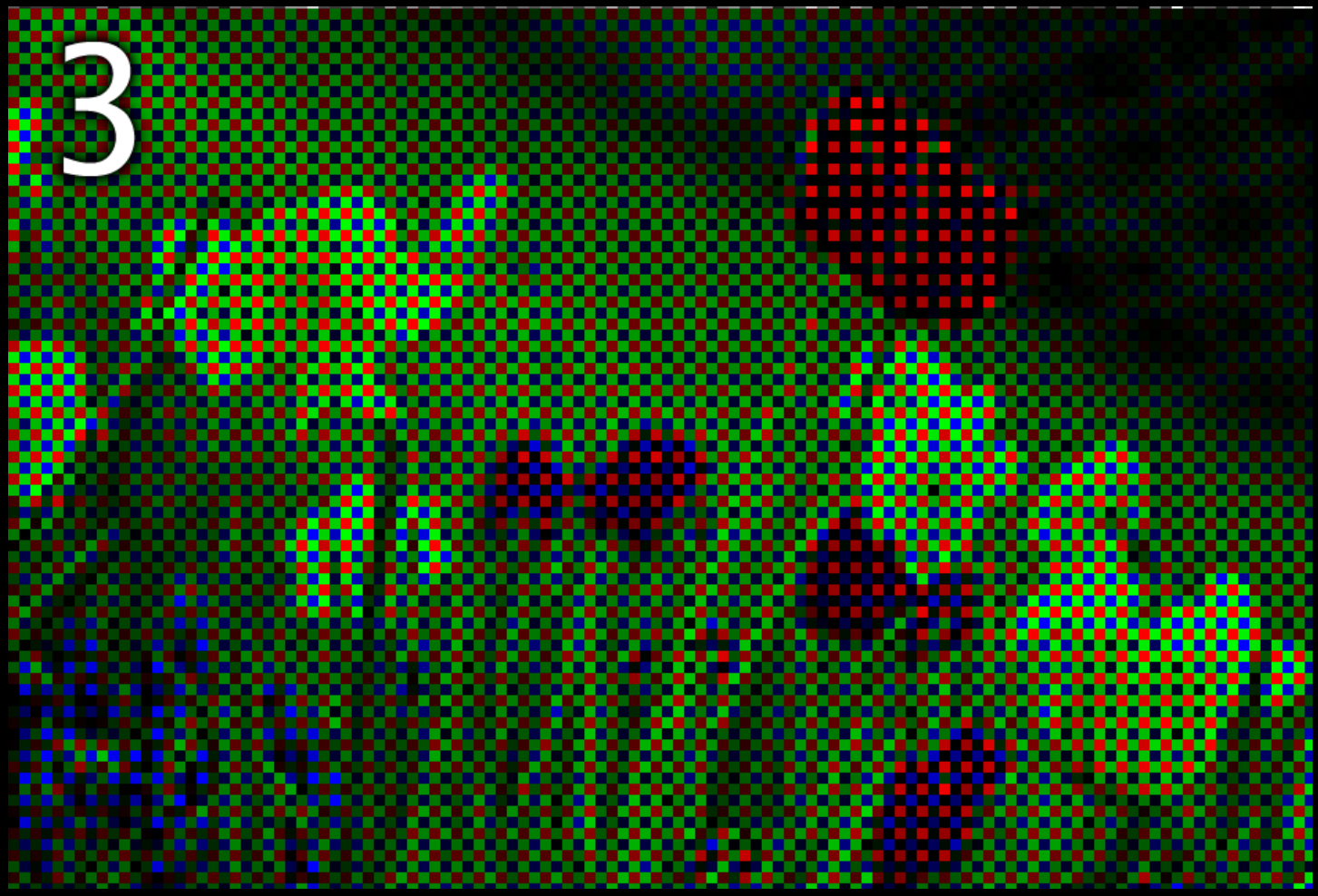
Bayer Filter Example

http://upload.wikimedia.org/wikipedia/commons/f/f2/Colorful_spring_garden_Bayer.png

Bayer Filter Example

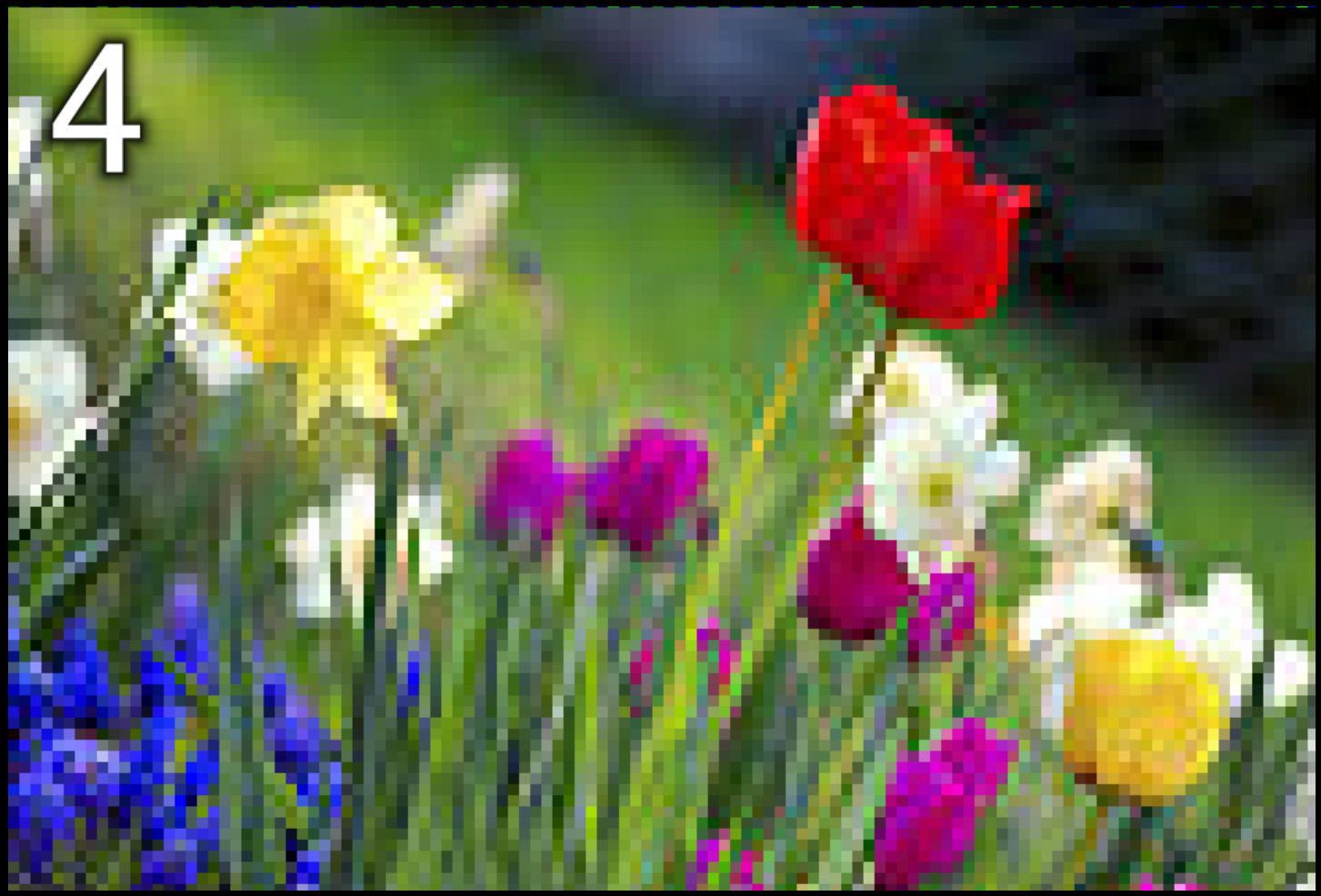
http://upload.wikimedia.org/wikipedia/commons/f/f2/Colorful_spring_garden_Bayer.png

Bayer Filter Example



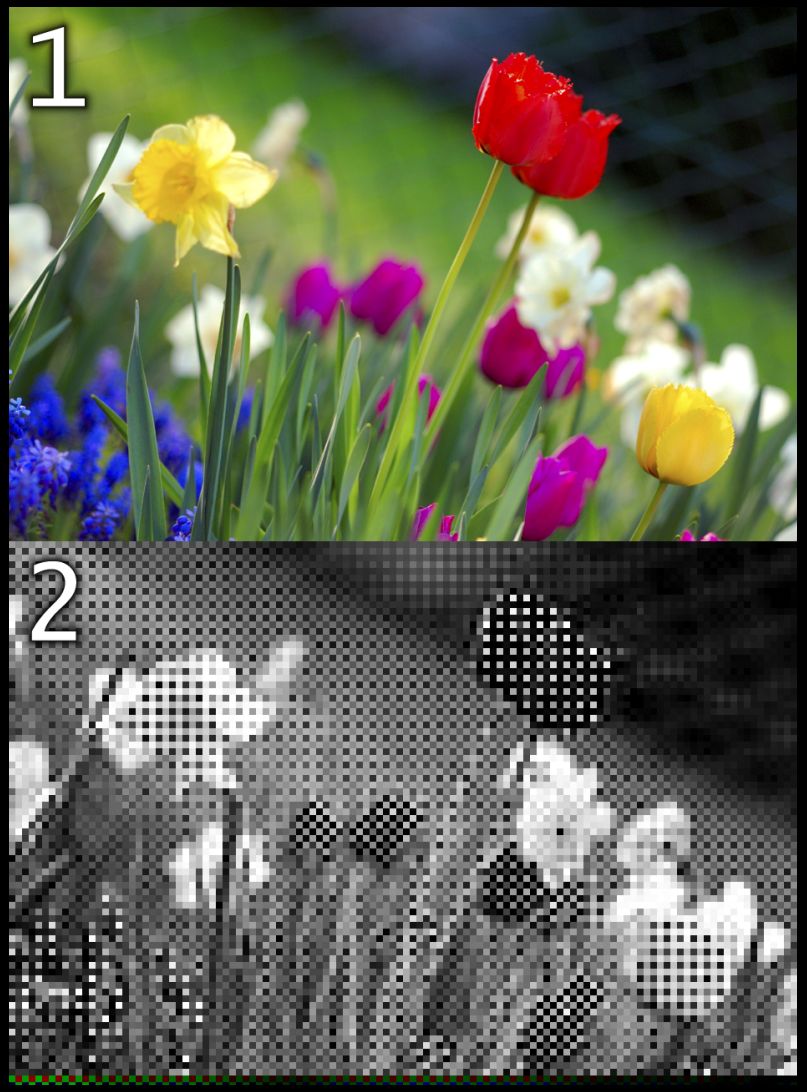
http://upload.wikimedia.org/wikipedia/commons/f/f2/Colorful_spring_garden_Bayer.png

Bayer Filter Example



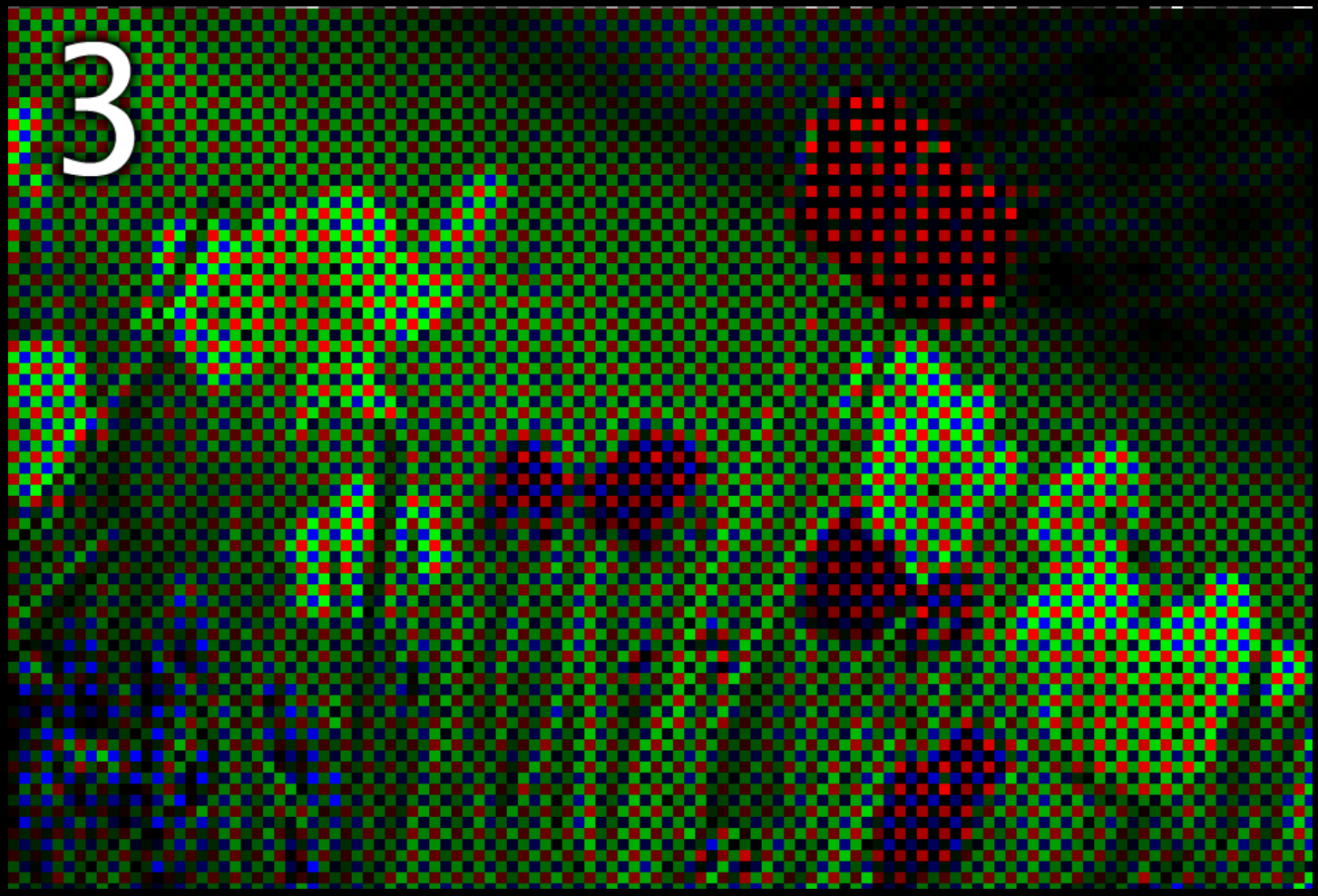
http://upload.wikimedia.org/wikipedia/commons/f/f2/Colorful_spring_garden_Bayer.png

Bayer Filter



http://upload.wikimedia.org/wikipedia/commons/f/f2/Colorful_spring_garden_Bayer.png

Interpolation techniques



http://upload.wikimedia.org/wikipedia/commons/f/f2/Colorful_spring_garden_Bayer.png

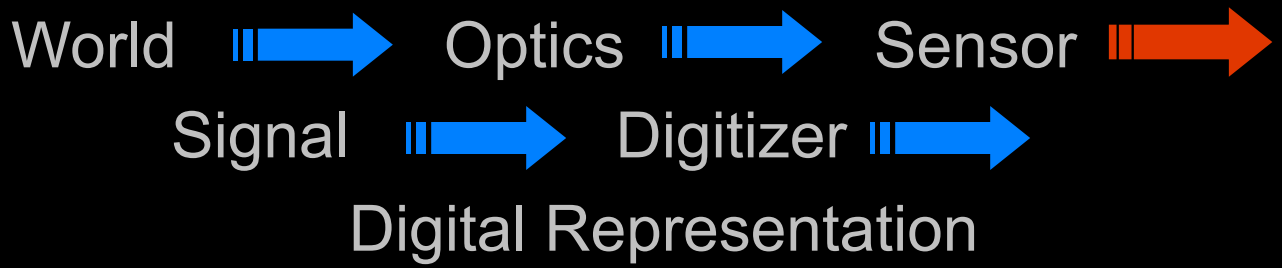
Interpolation

1. Copy pixel value to your left
2. Bilinear interpolation within one color channel.
    1. Between 4 pixels:
        - Take average of the 4.
    2. Between 2 pixels:
        - Take average of the 2.
3. Many more sophisticated methods.

Photometry

- Photometry:

  Concerned with mechanisms for converting light energy into electrical energy.



Pre-digitization image

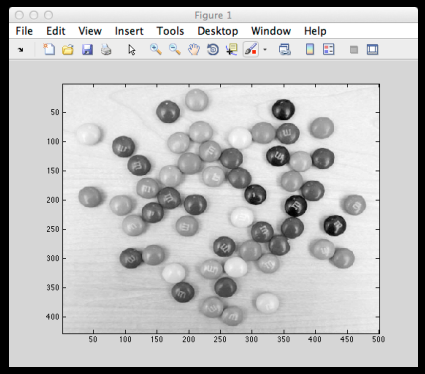
- What is an image before we digitize it?
  - Continuous range of wavelengths.
  - 2-dimensional extent
  - Continuous range of power at each point.

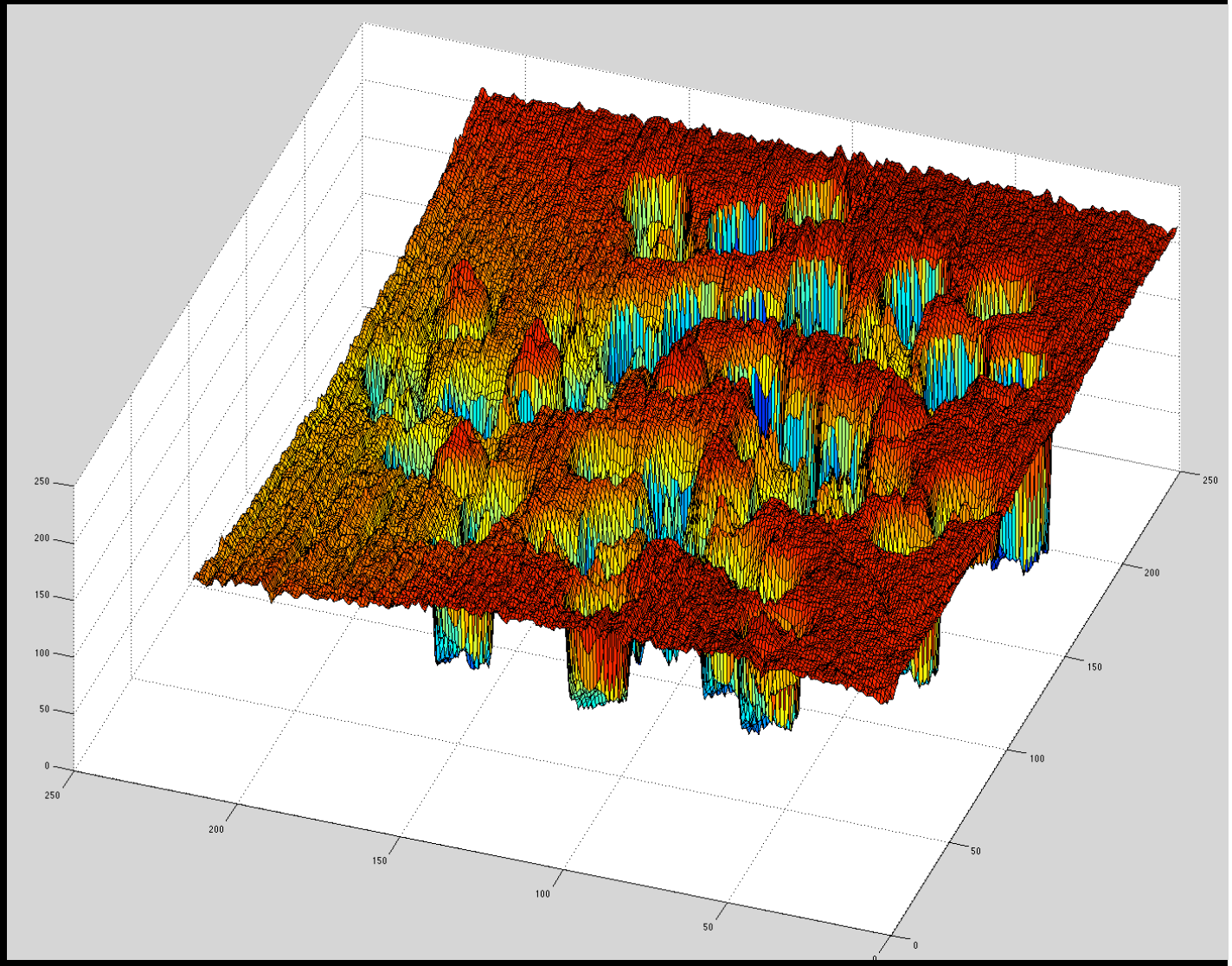
Brightness images

- To simplify, consider only a brightness image:
  - Two-dimensional (continuous range of locations)
  - Continuous range of brightness values.
- This is equivalent to a two-dimensional function over the plane.

Introduction to
Computer Vision

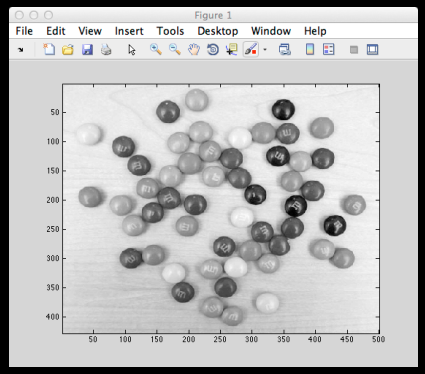
An image as a surface

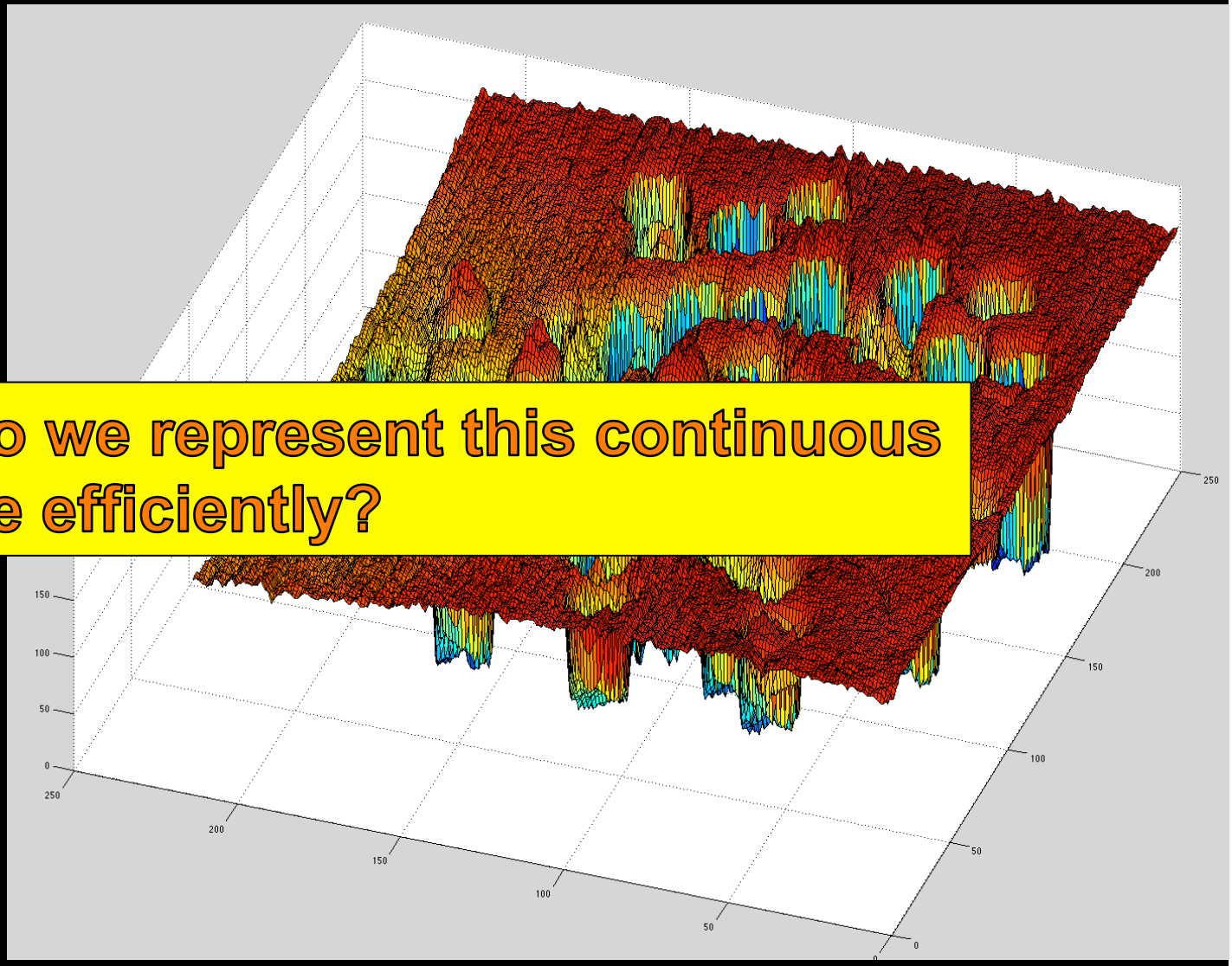




Introduction to
Computer Vision

An image as a surface



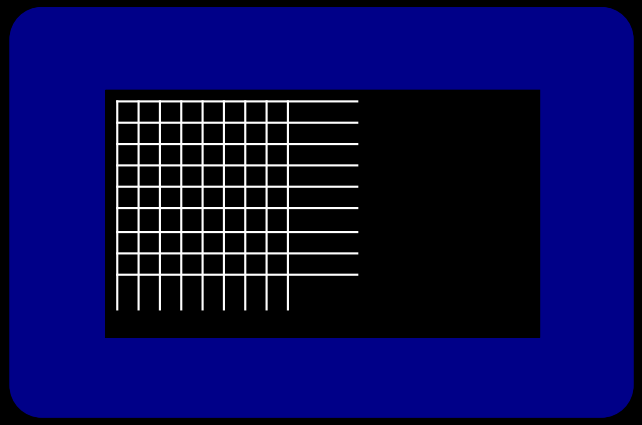


How do we represent this continuous surface efficiently?

Discretization

- Sampling strategies:
  - Spatial sampling
    - How many pixels?
    - What arrangement of pixels?
  - Brightness sampling
    - How many brightness values?
    - Spacing of brightness values?
  - For video, also the question of time sampling.

Projection through a pixel



Digitized 35mm Slide or Film

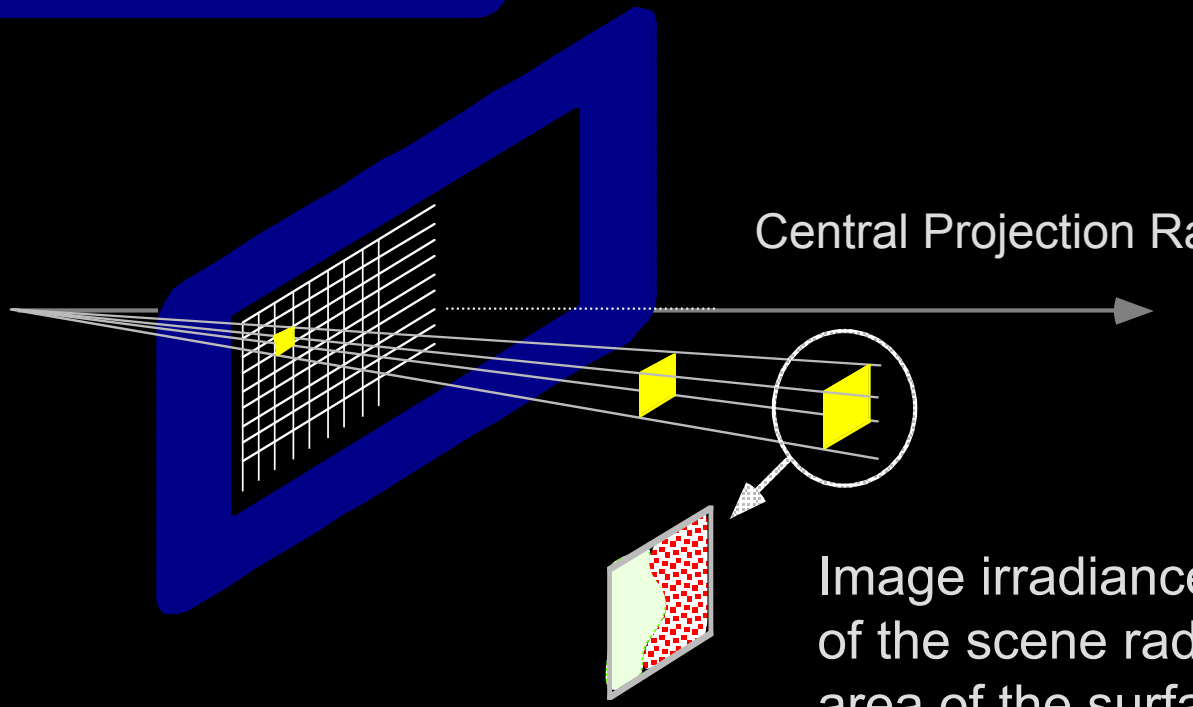
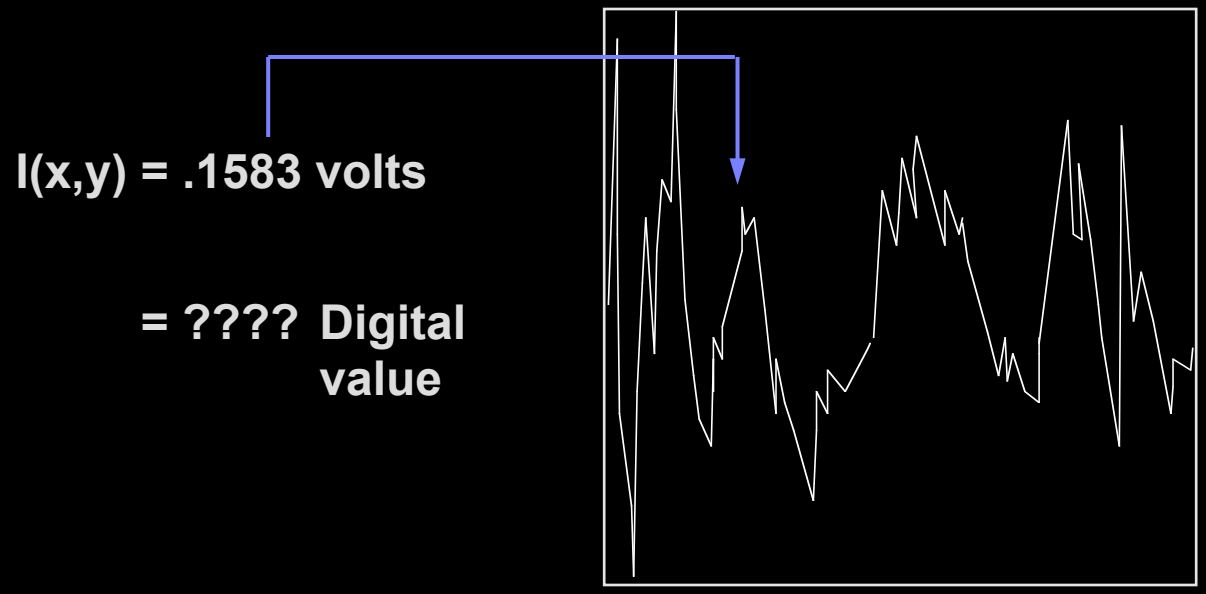


Image irradiance is the average of the scene radiance over the area of the surface intersecting the solid angle!

Signal Quantization

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



Quantization

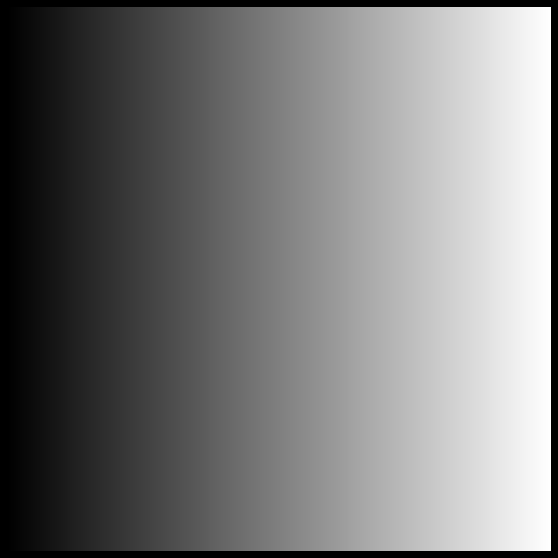
- I(x,y) = continuous signal: $0 \le I \le M$
- Want to quantize to K values 0,1,....K-1
- K usually chosen to be a power of 2:

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

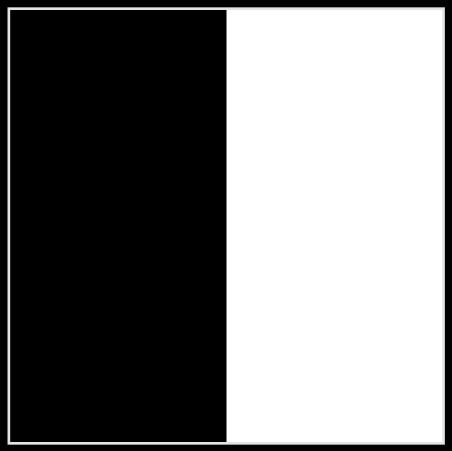
- Mapping from input signal to output signal is to be determined.
- Several types of mappings: uniform, logarithmic, etc.

Choice of K

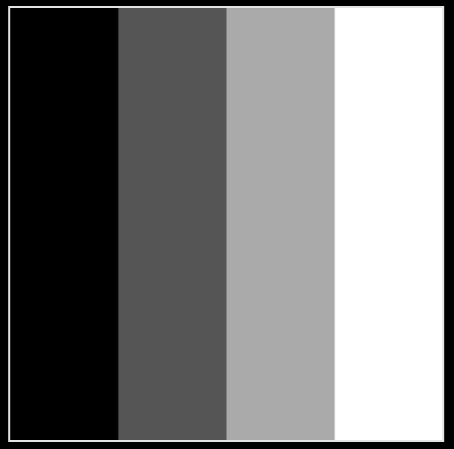
Original



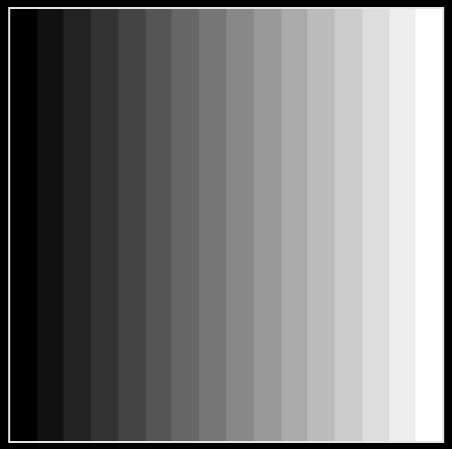
Linear Ramp



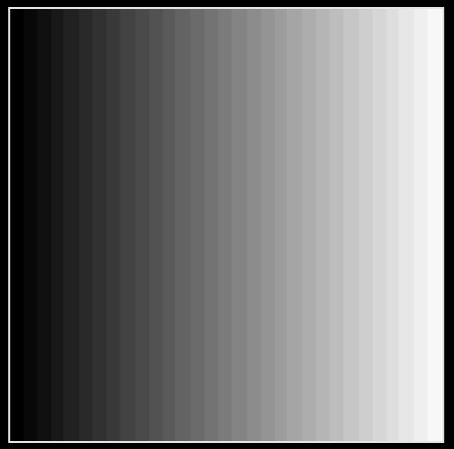
K=2



K=4



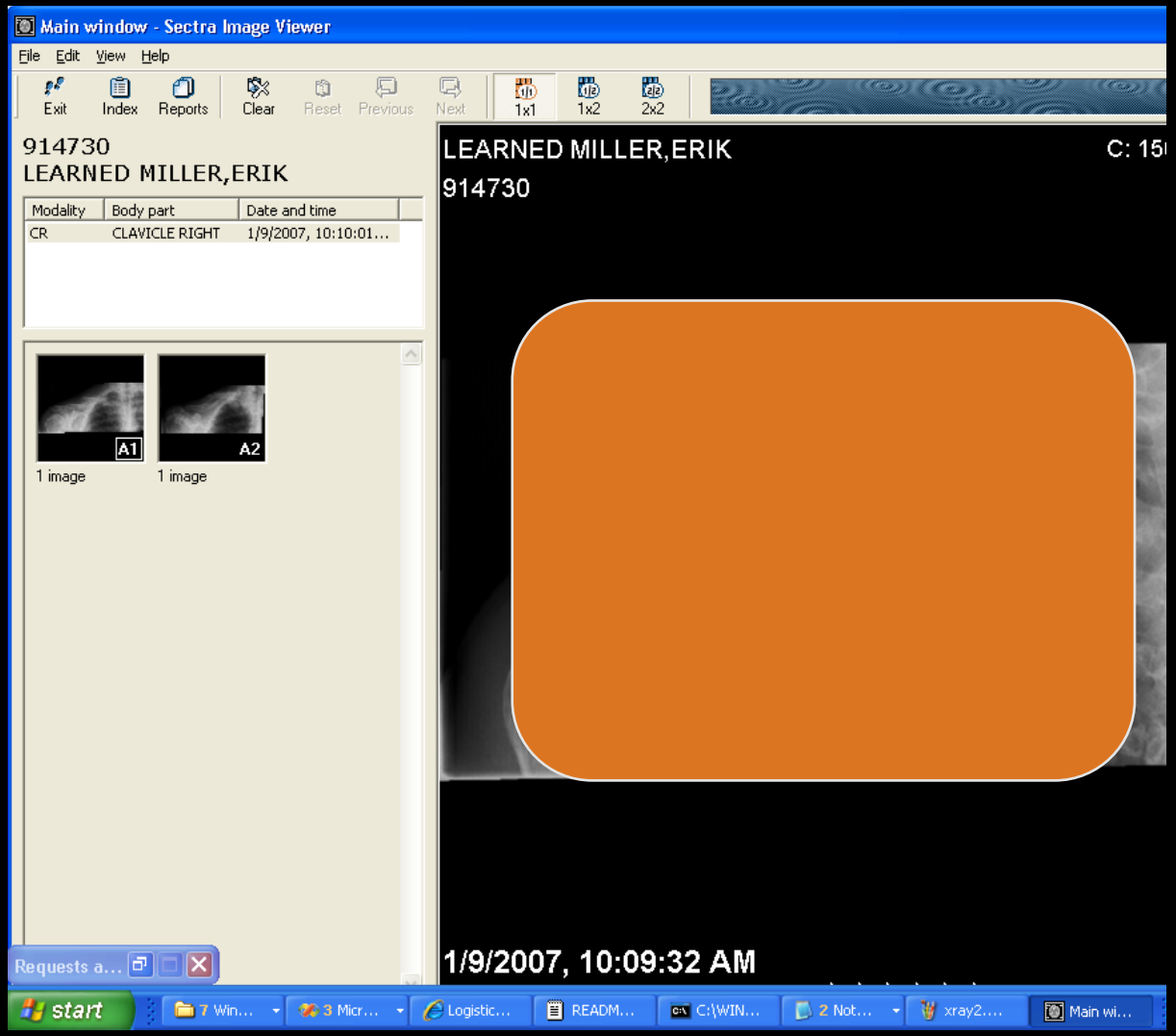
K=16



K=32

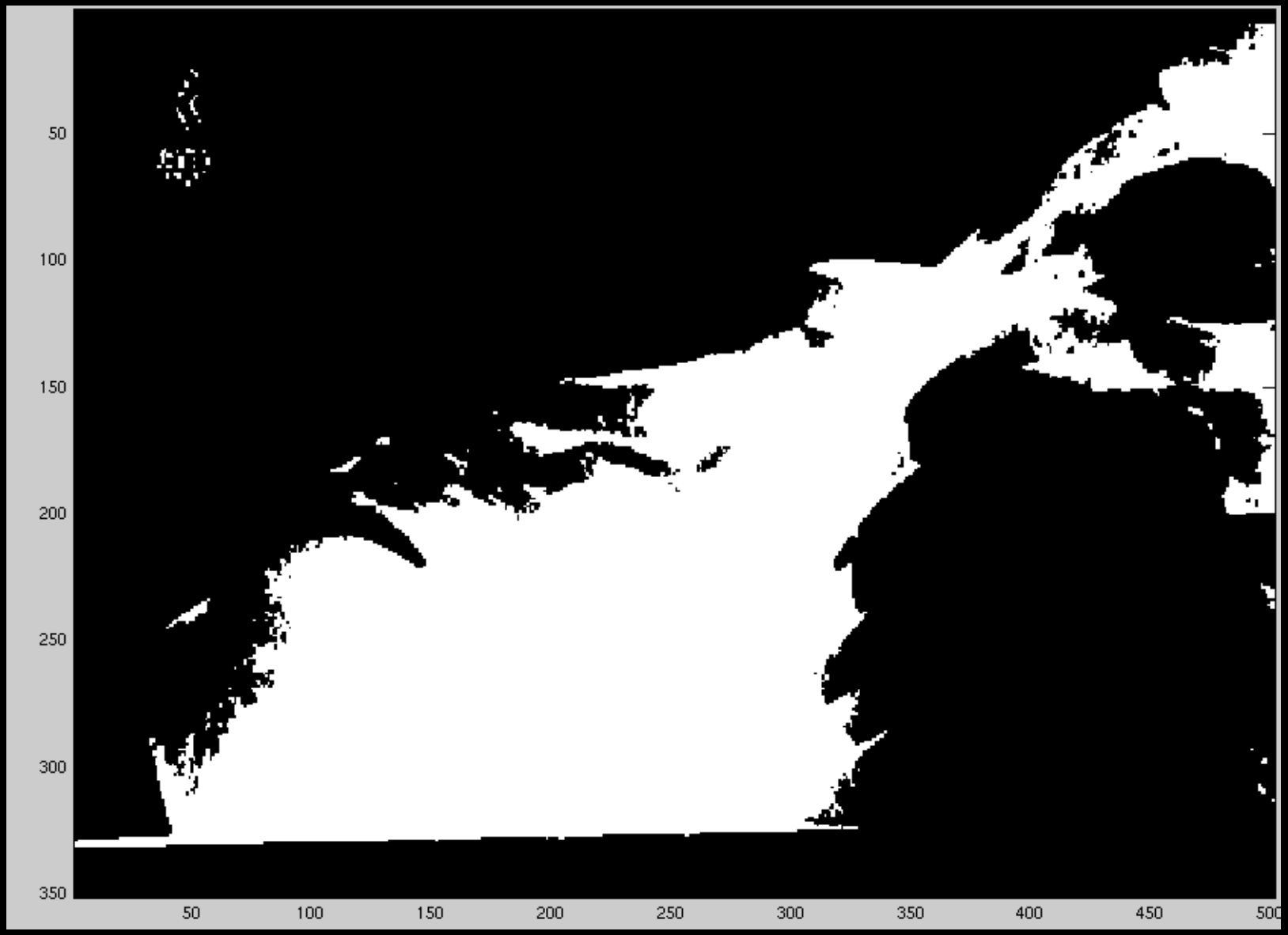
Introduction to
Computer Vision

Digital X-rays

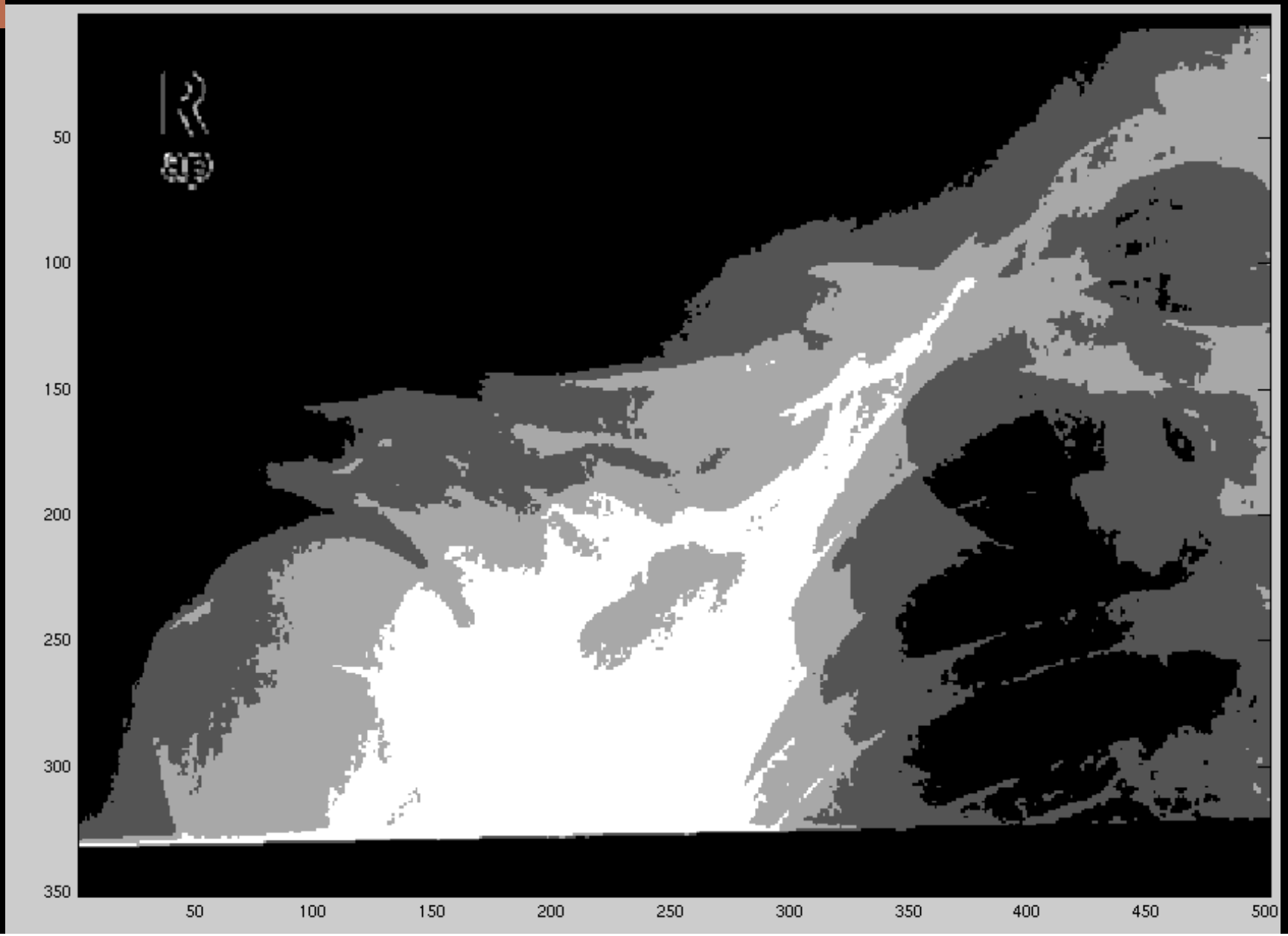


How many bits do we need?

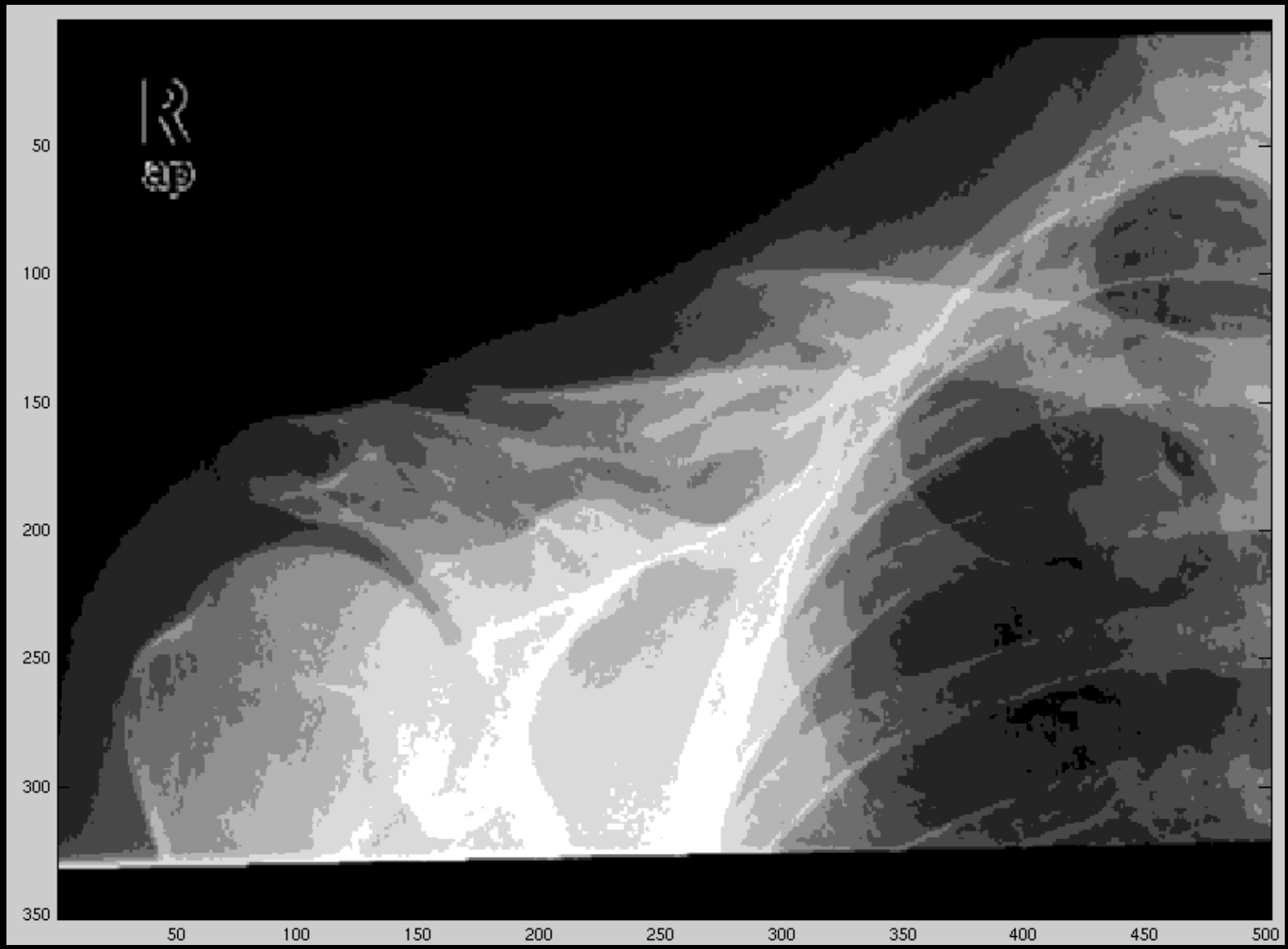
Digital X-rays: 1 bit



Digital X-rays: 2 bits



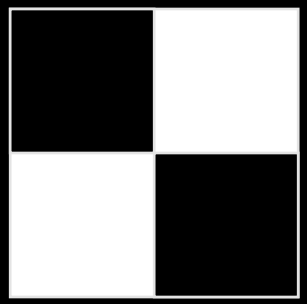
Digital X-rays: 3 bit



Digital X-rays: 8 is enough?

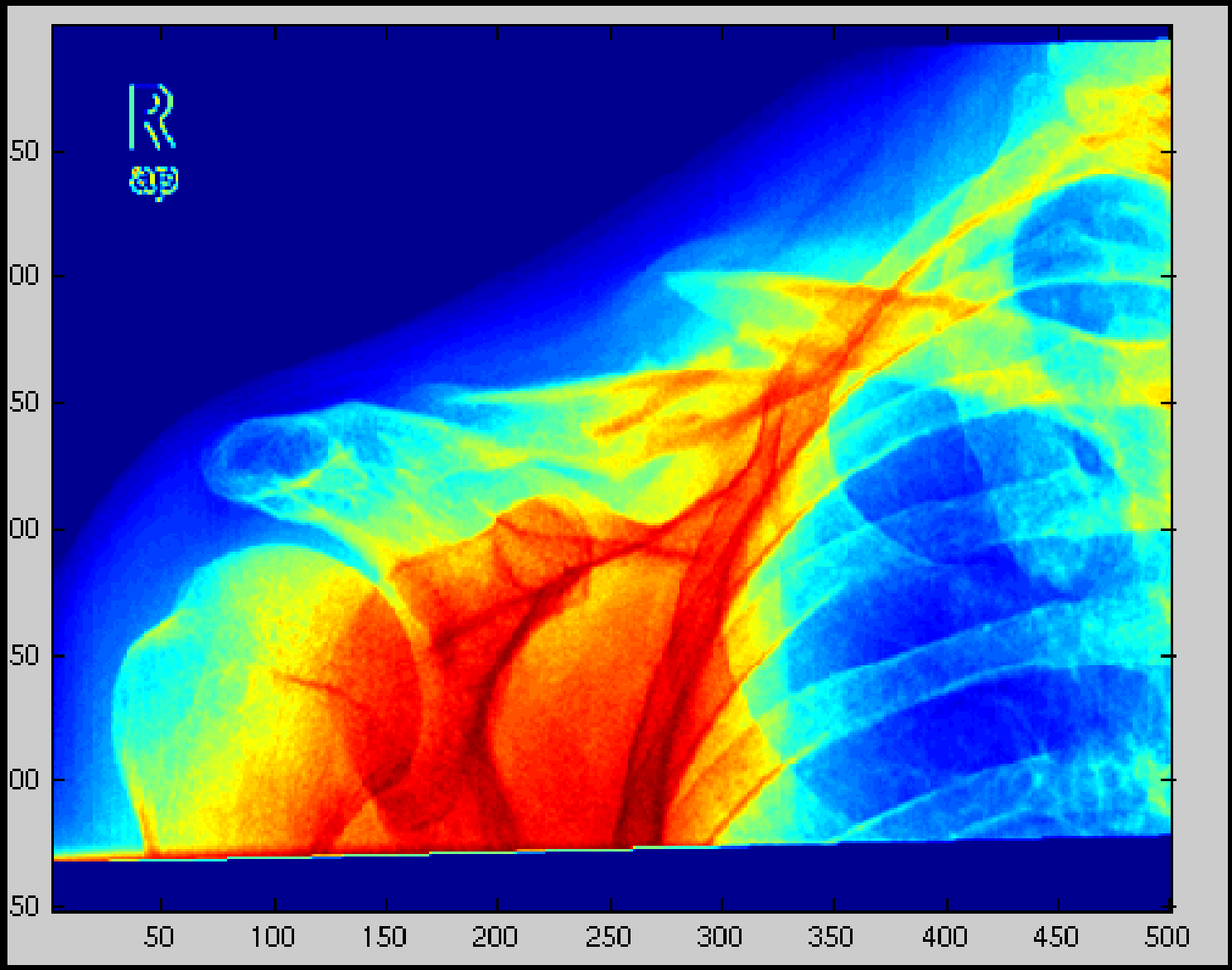
Gray Levels-Resolution Trade Off

- 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

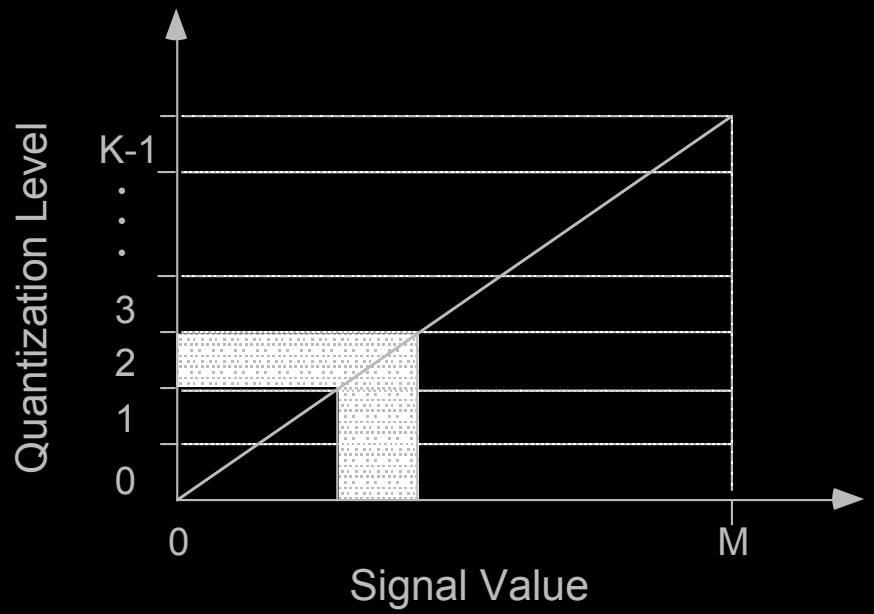
Choice of K

K=2 (each color)

K=4 (each color)

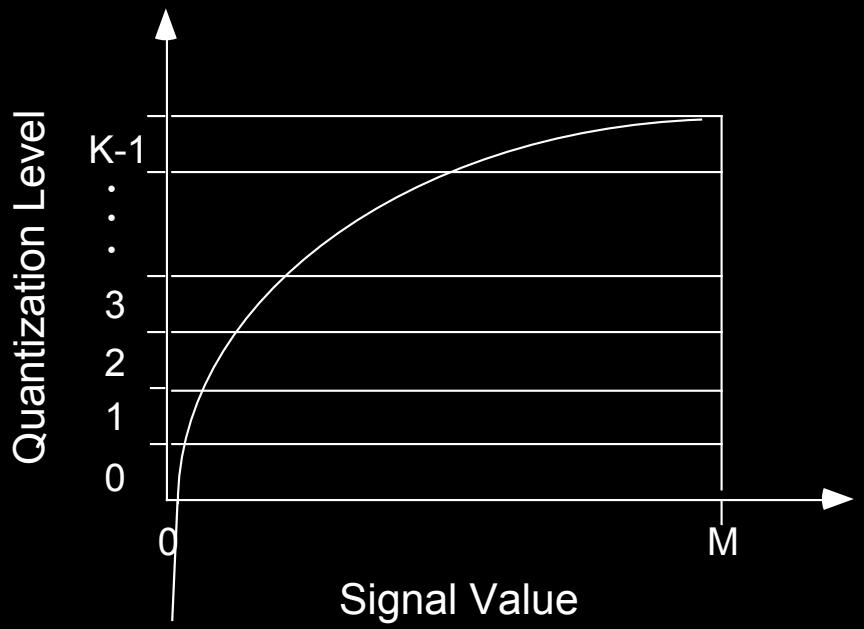
Choice of Function: Uniform

- 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

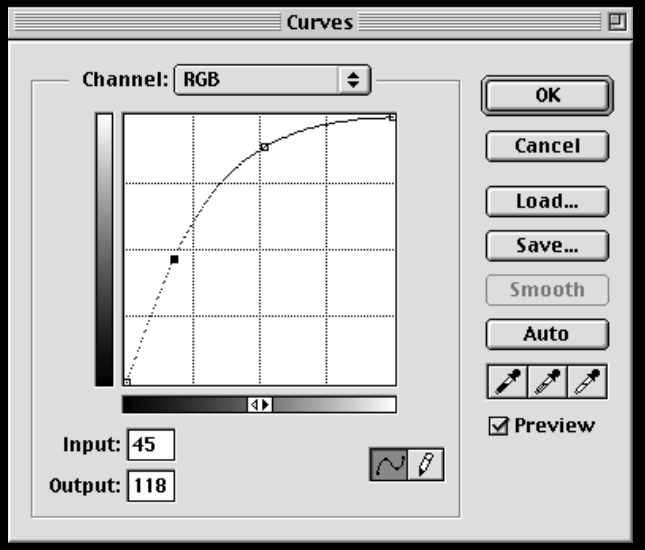
- Signal is log I(x,y).
- Effect is:



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

Logarithmic Quantization

Quantization Curve



End