Lecture 2:

Digital Image Fundamentals and Image Acquisition

Image Acquisition

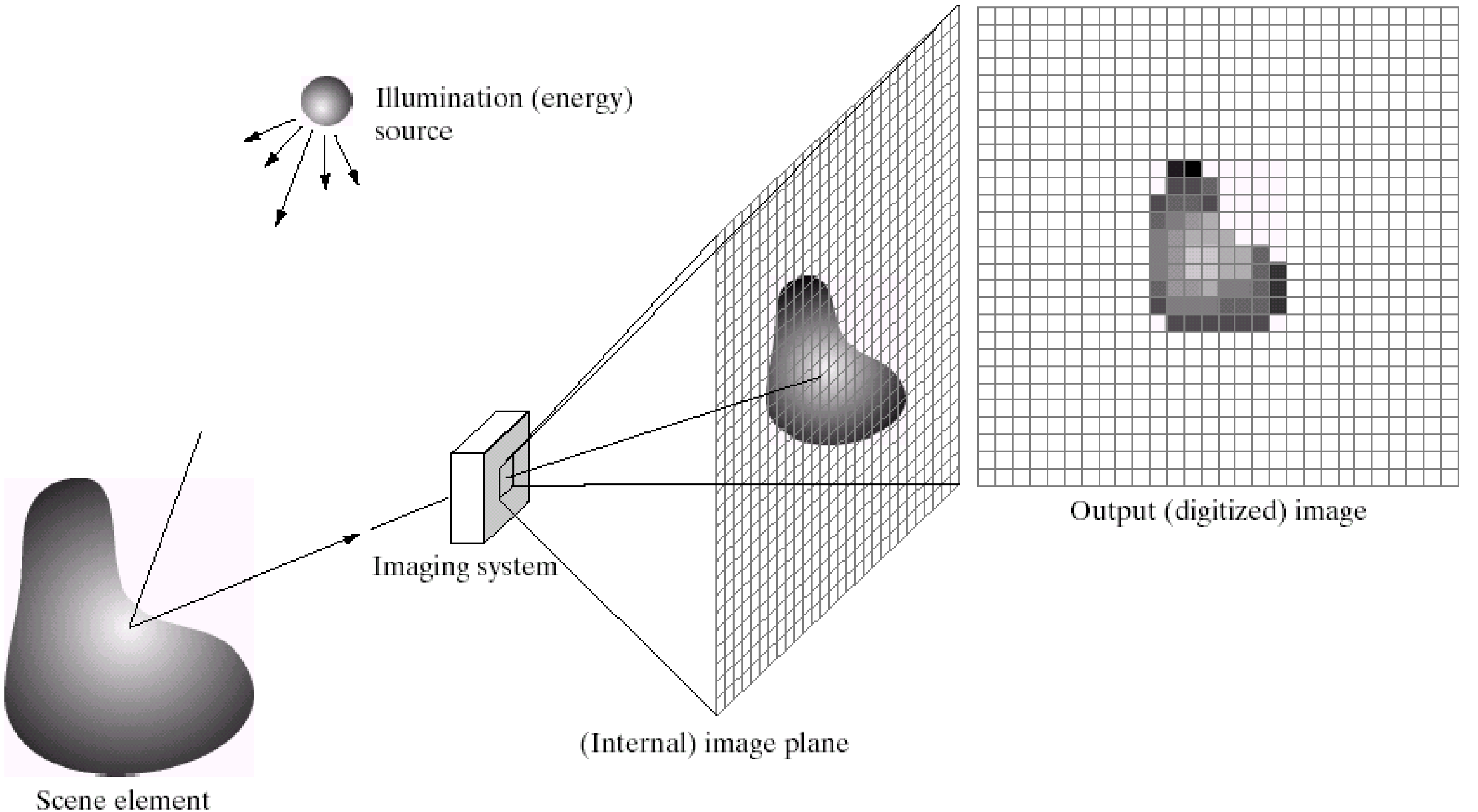


Image description

$f(x,y)$: intensity/brightness of the image at spatial coordinates (x,y)

$0 < f(x,y) < \infty$ and determined by 2 factors:

illumination component $i(x,y)$: amount of source light incident

reflectance component $r(x,y)$: amount of light reflected by objects

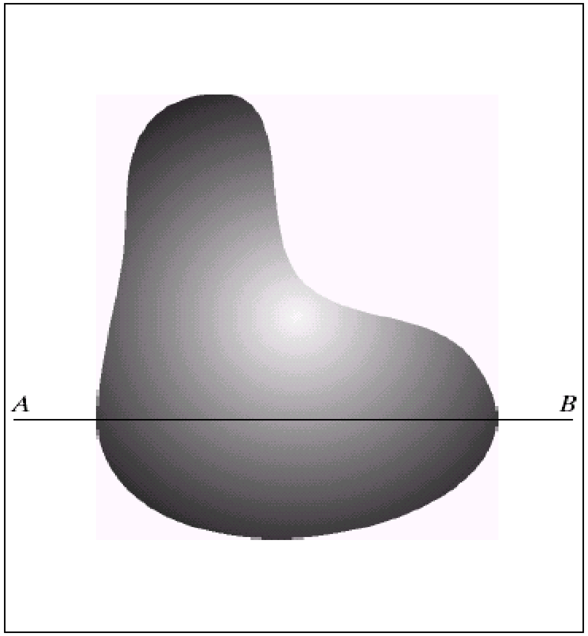
$$f(x,y) = i(x,y)\, r(x,y)$$

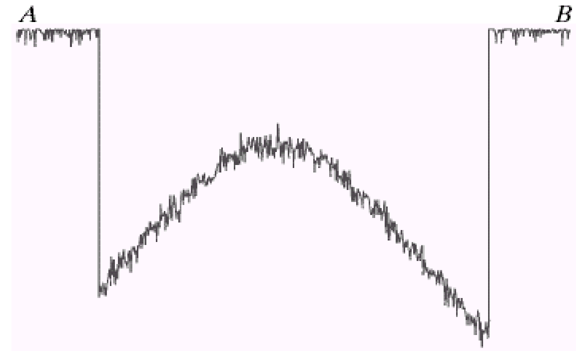
where

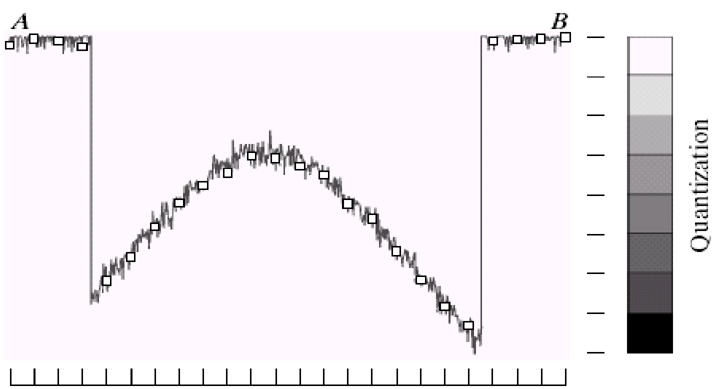
$0 < i(x,y) < \infty$: determined by the light source

$0 < r(x,y) < 1$: determined by the characteristics of objects

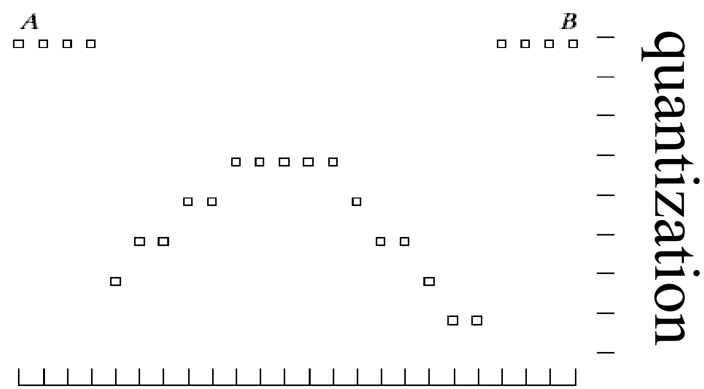
Sampling and Quantization







sampling



sampling

Sampling and Quantization

Sampling: Digitization of the spatial coordinates (x,y)

Quantization: Digitization in amplitude (also called *gray-level quantization*)

8 bit quantization: $2^8 = 256$ gray levels (0: black, 255: white)

Binary (1 bit quantization): 2 gray levels (0: black, 1: white)

Commonly used number of samples (resolution)

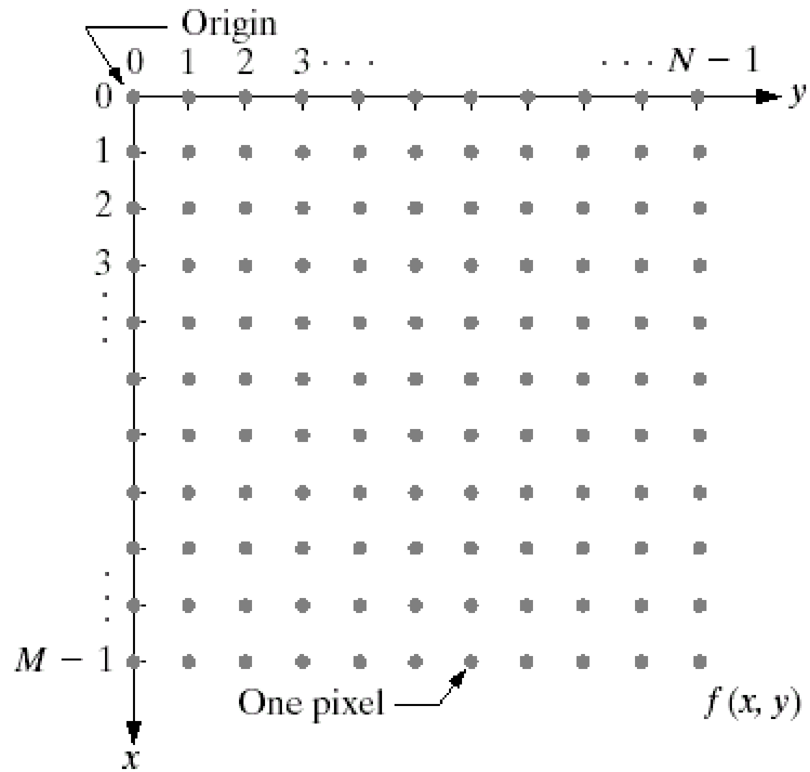
Digital still cameras: 640x480, 1024x1024, up to 4064 x 2704

Digital video cameras: 640x480 at 30 frames/second
1920x1080 at 60 f/s (HDTV)

Sampling and Quantization

An M x N digital image is expressed as

$$\begin{array}{cc} & \xrightarrow{\text{Columns}} \\ \text{Rows}\big\downarrow & \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & \cdots & f(1,N-1) \\ \vdots & \vdots & \vdots & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1,N-1) \end{bmatrix} \end{array}$$

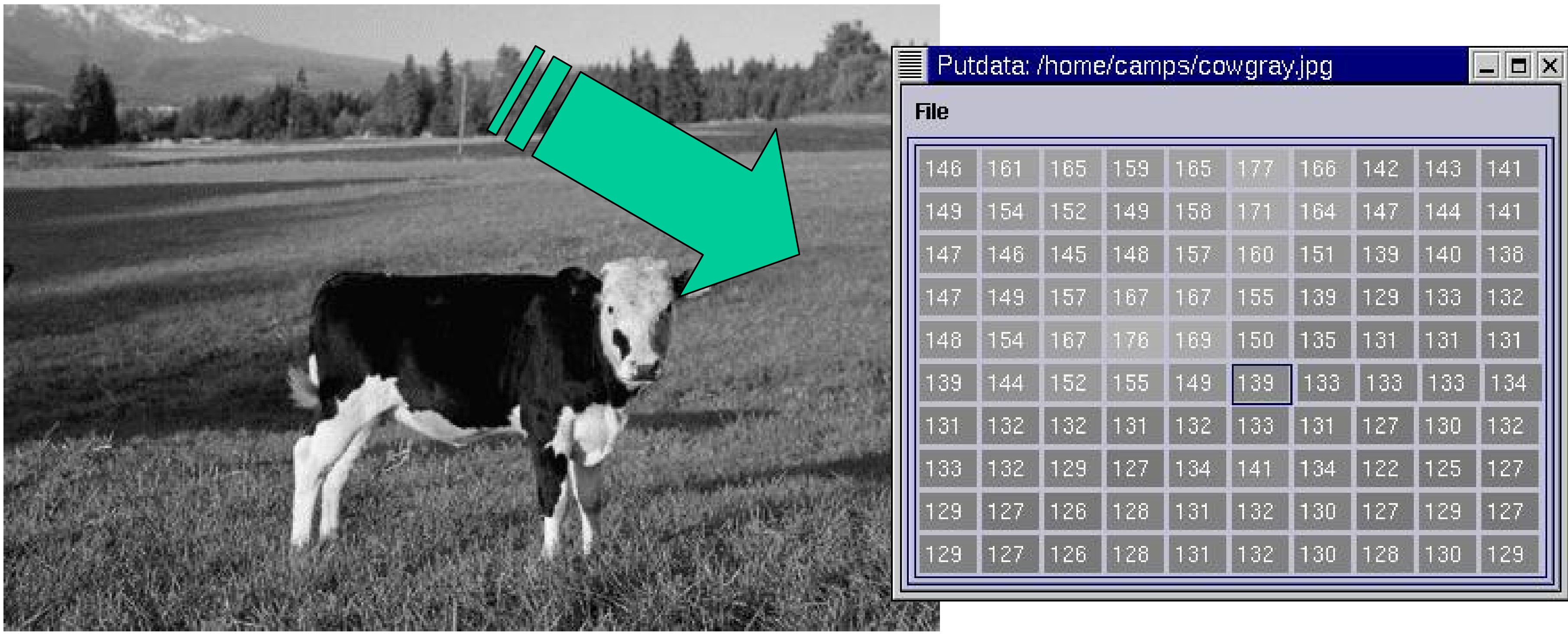


N : No of Columns

M : No of Rows

Digital Images

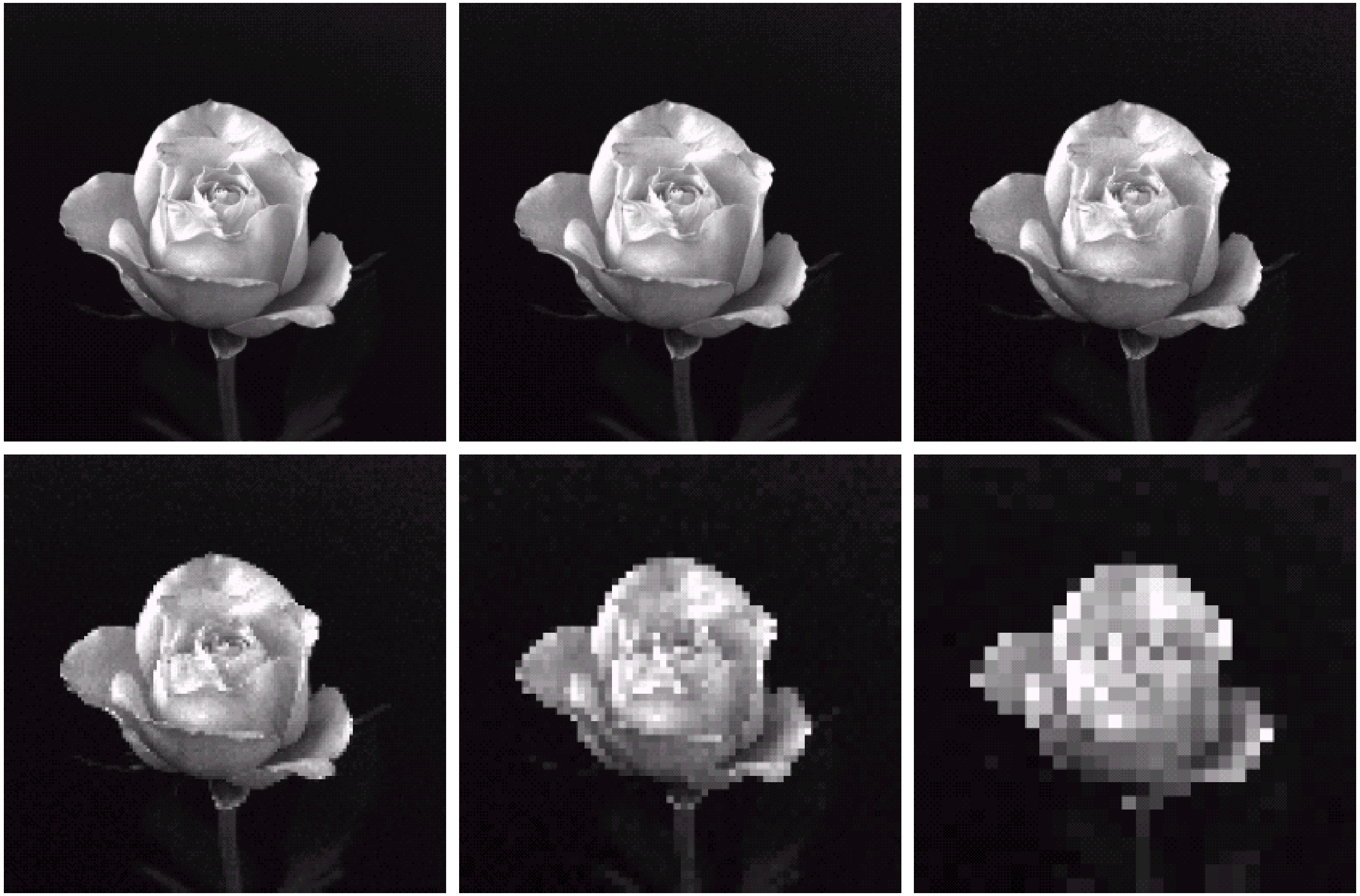
Digital images are 2D arrays (matrices) of numbers:



146	161	165	159	165	177	166	142	143	141
149	154	152	149	158	171	164	147	144	141
147	146	145	148	157	160	151	139	140	138
147	149	157	167	167	155	139	129	133	132
148	154	167	176	169	150	135	131	131	131
139	144	152	155	149	139	133	133	133	134
131	132	132	131	132	133	131	127	130	132
133	132	129	127	134	141	134	122	125	127
129	127	126	128	131	132	130	127	129	127
129	127	126	128	131	132	130	128	130	129

Sampling

Sampling



a b c
d e f

FIGURE 2.20 (a) 1024×1024, 8-bit image. (b) 512×512 image resampled into 1024×1024 pixels by row and column duplication. (c) through (f) 256×256, 128×128, 64×64, and 32×32 images resampled into 1024×1024 pixels.

Effect of Sampling and Quantization

250 x 210 samples
256 gray levels

125 x 105 samples

50 x 42 samples

25 x 21 samples

16 gray levels

8 gray levels

4 gray levels

Binary image

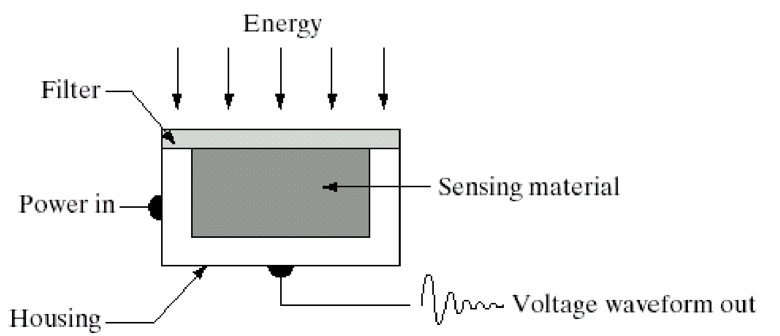
RGB (color) Images

Red + Blue + Green

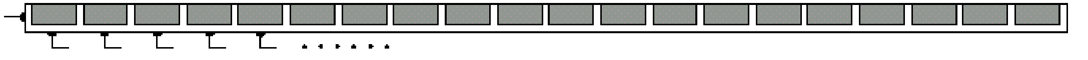
Red Green Blue

Image acquisition

Single imaging sensor



Line sensor



Array sensor

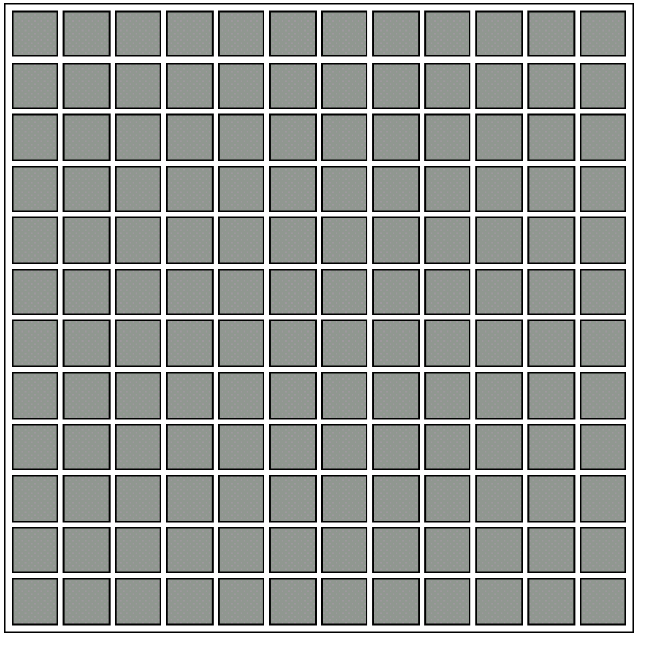
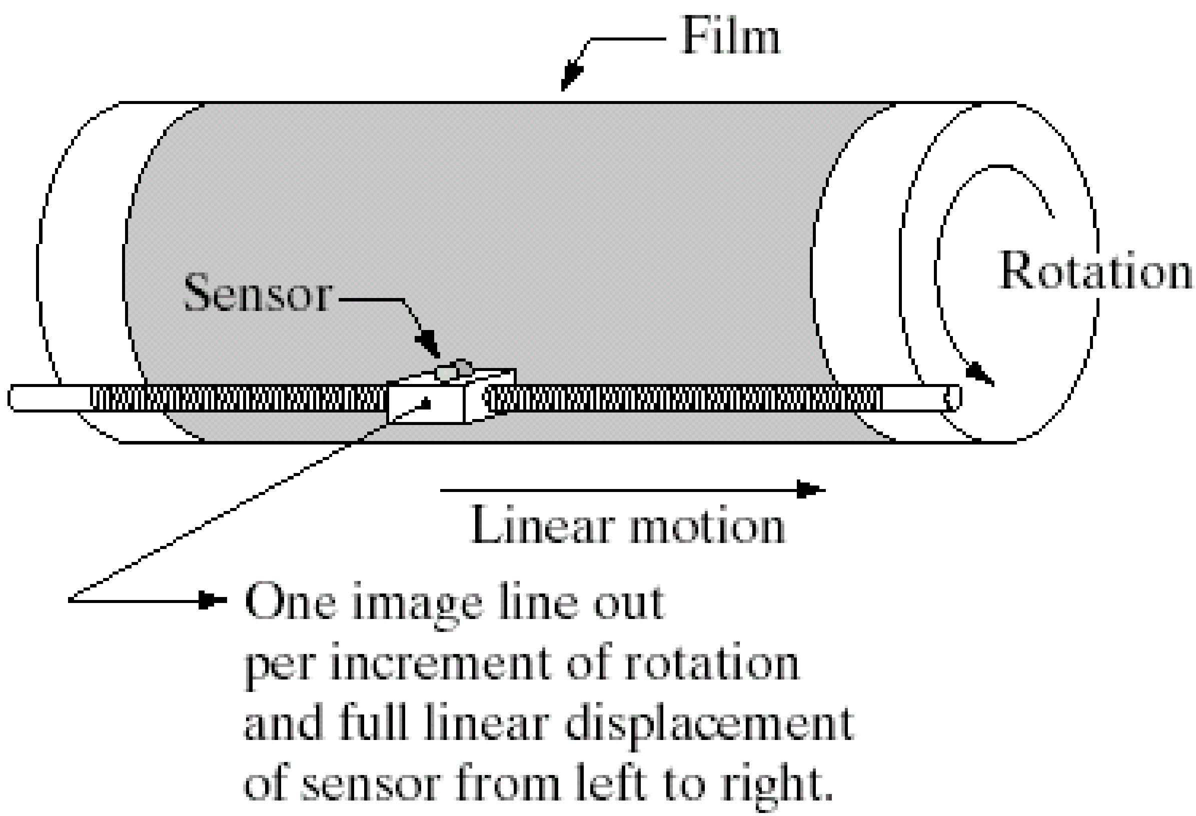


Image acquisition



Combining a single sensor with motion to generate a 2-D image.

Image acquisition

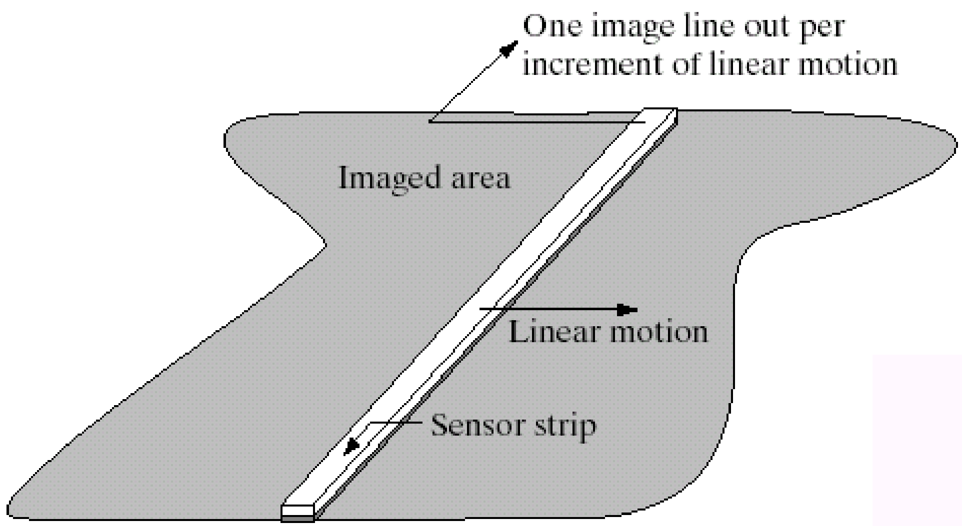


Image acquisition through linear sensor strip

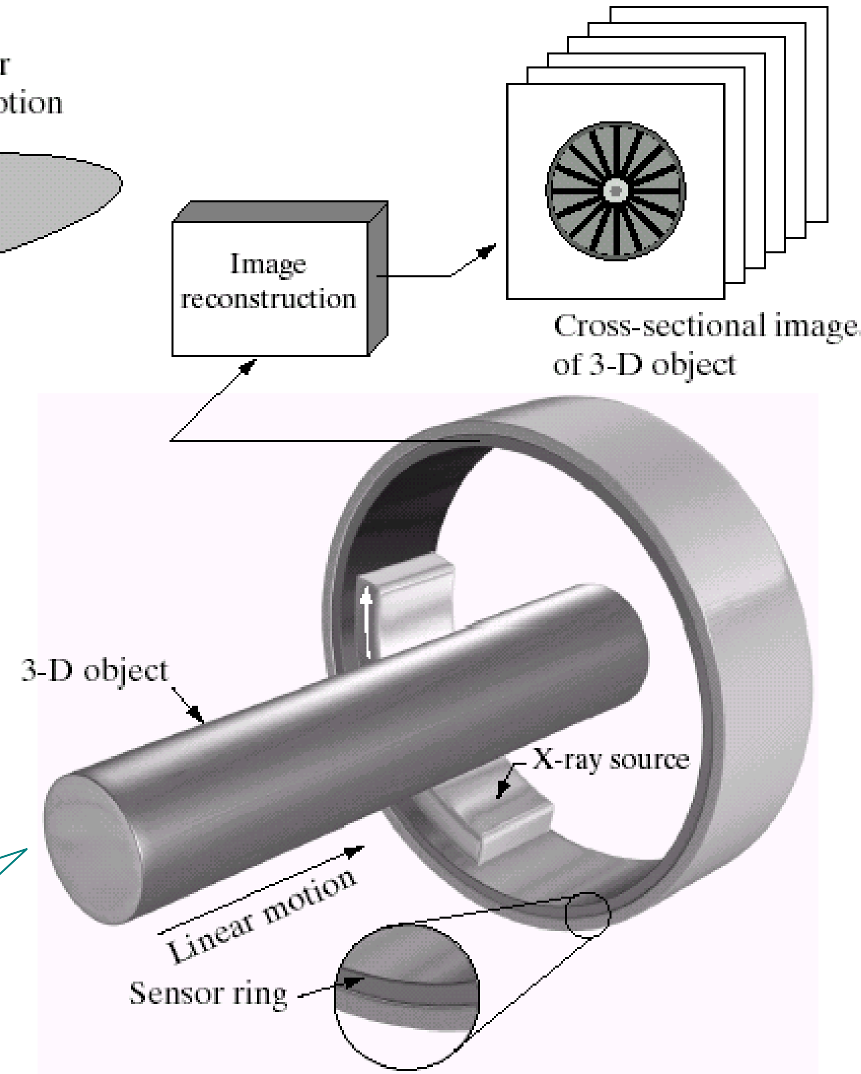


Image acquisition through circular sensor strip

Digital Camera Technologies

- CCD (Charge Coupled Device)
  - *Capacitive device*
  - *Proper mechanism for charge transfer*
- CMOS (Complementary magnetic oxide)
  - *Fabricated in standard semiconductor production line*
  - *A CCD system typically requires 2–5 watts (digital output), compared to 20–50 milliwatts for the same pixel throughput using an active-pixel system*

Digital Camera Technologies

CCD Array Cameras

Consists of sensor elements/ photo detectors (active devices) and charge storage devices also called charge buckets

Every element in the array is linked (charge coupled) to other element.

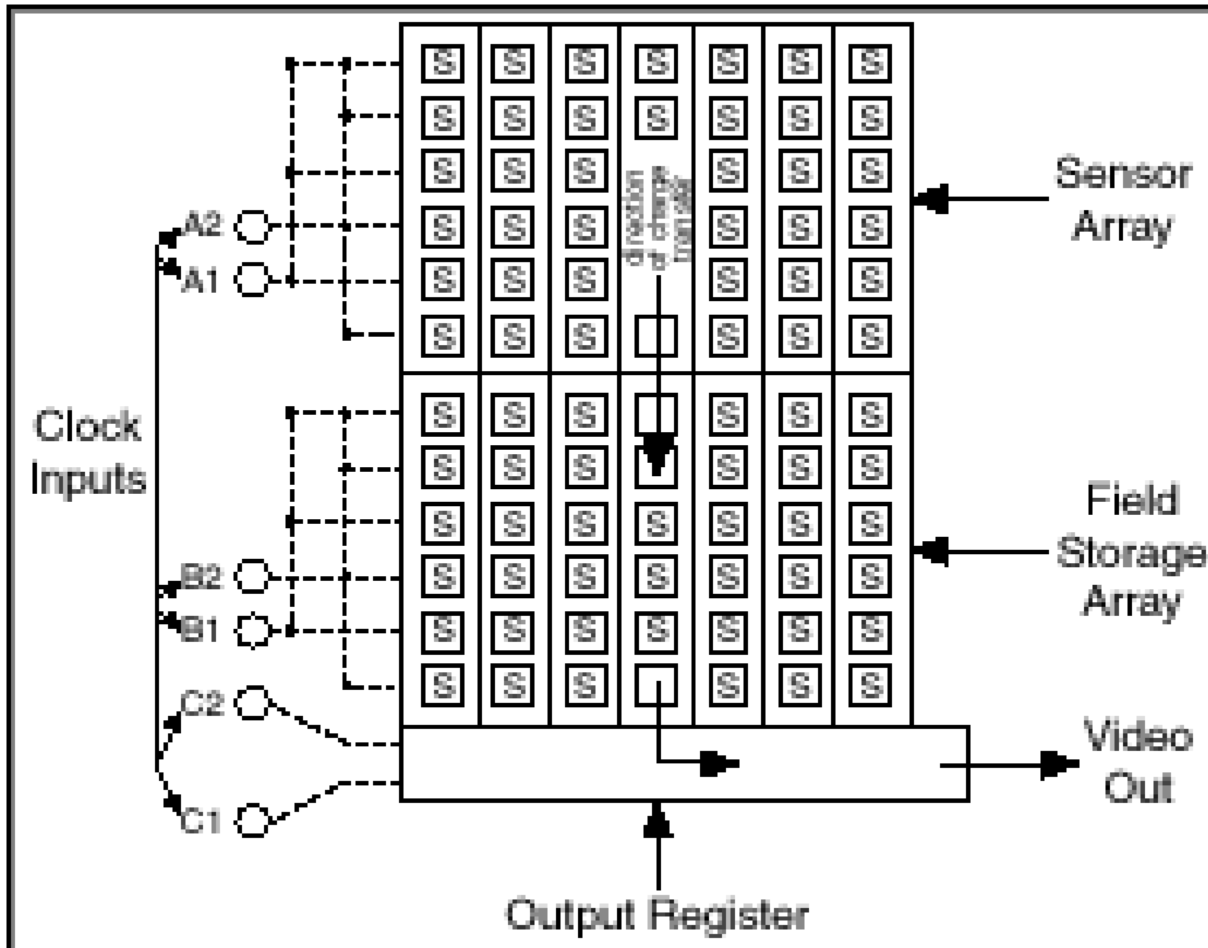
Charges are transferred serially out of the array through shifting charges from one element to the other.

Digital Camera Technologies

CCD Array Cameras

Frame Transfer

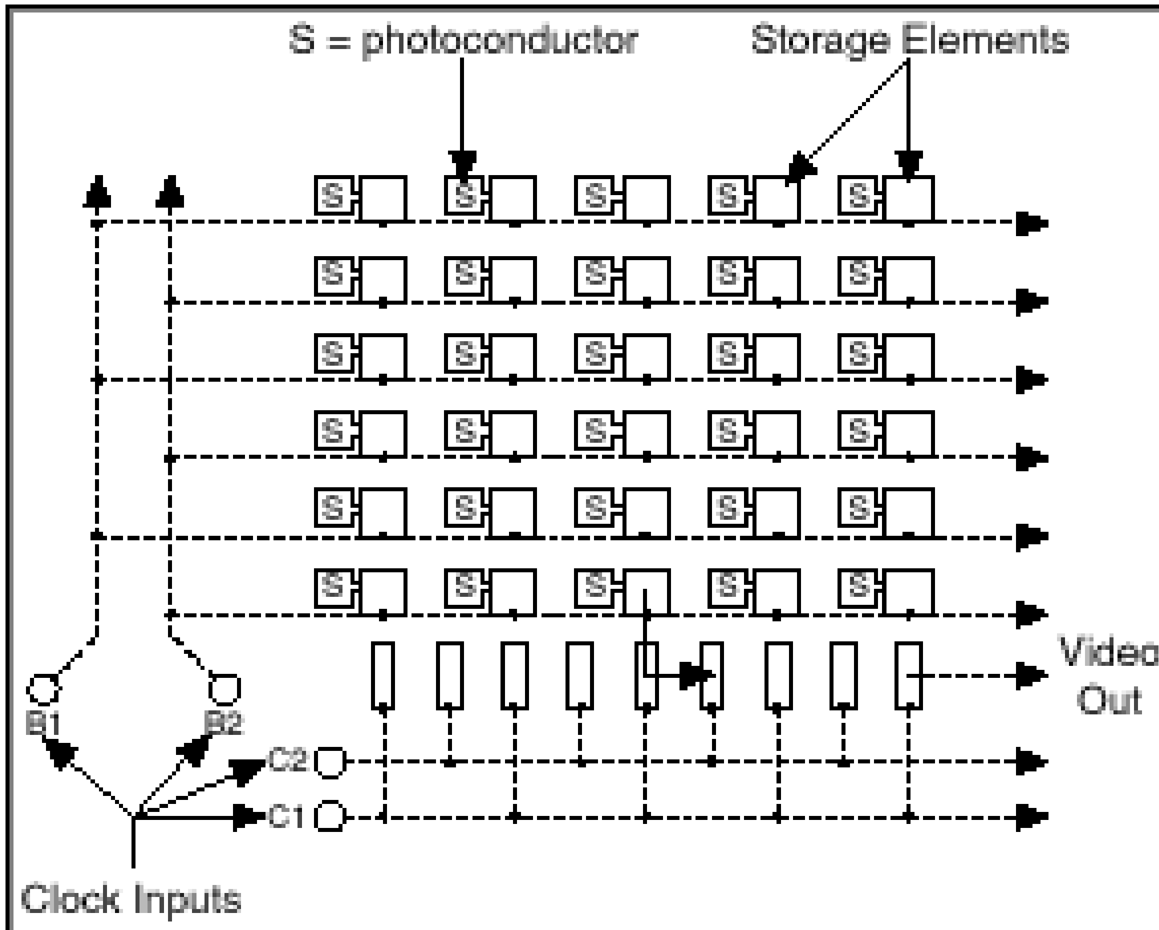
Architecture



Digital Camera Technologies

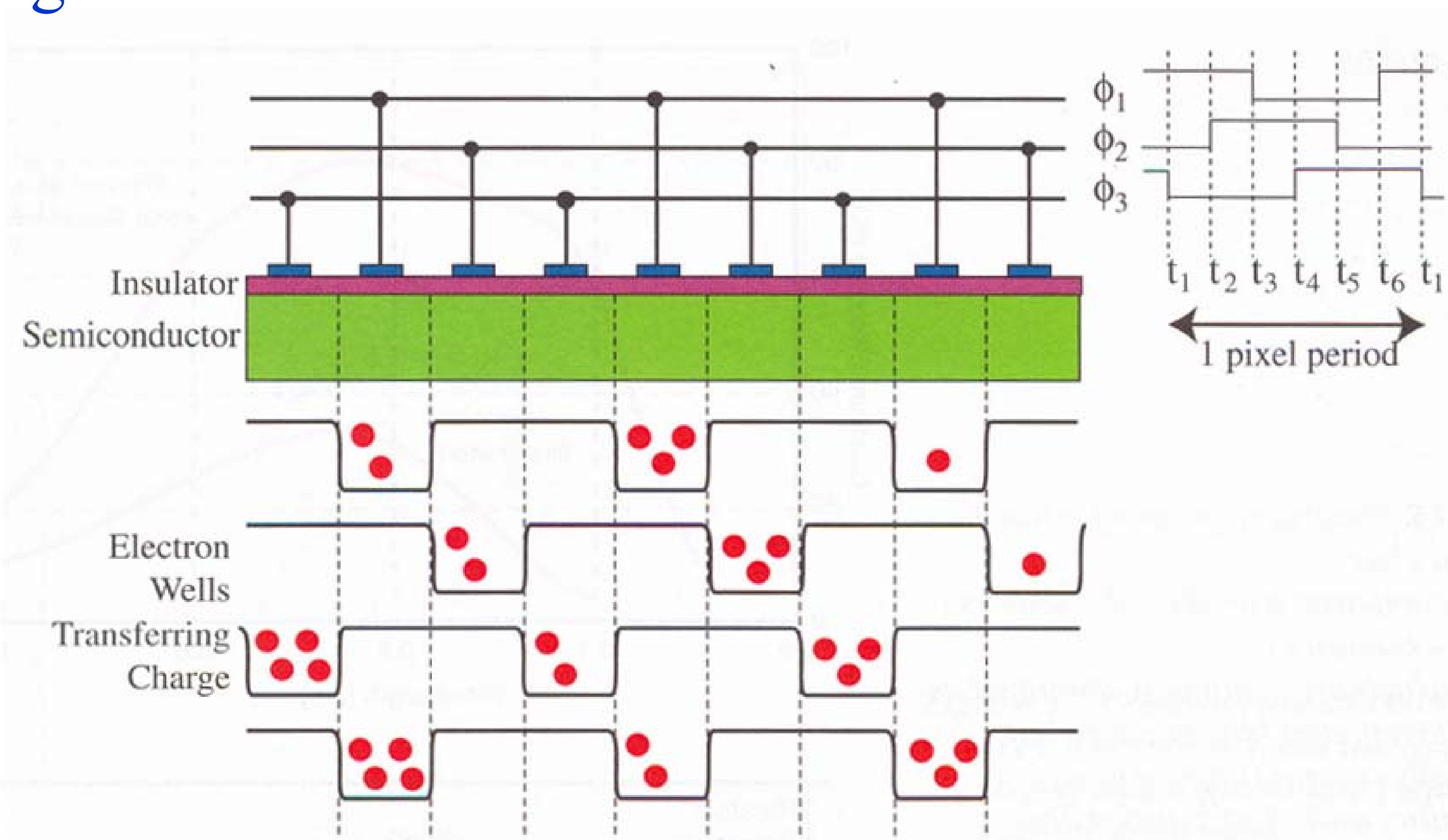
CCD Array Cameras

Interline Transfer
Architecture



Digital Camera Technologies

Charge transfer in CCD Cameras



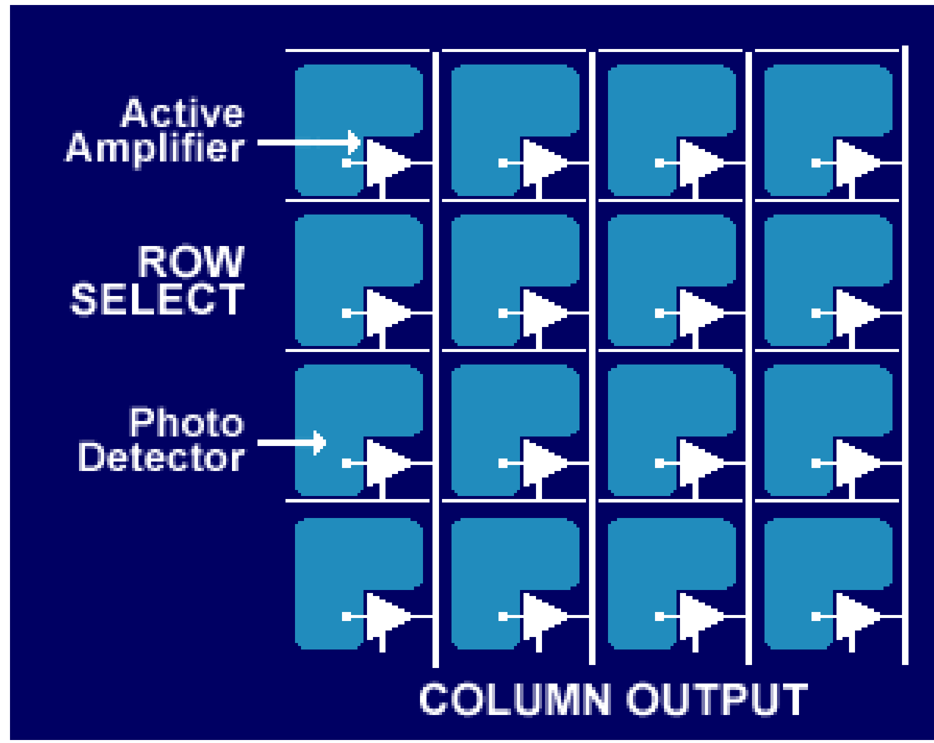
Varying voltages on a set of three electrodes shift electrons from one pixel to another

Digital Camera Technologies

CMOS Array Cameras

Standard semiconductor production line

Active pixel architecture
Photo-detector and amplifier are both fabricated inside each pixel.



Digital camera technologies comparison

CCD (Charge Coupled Device)

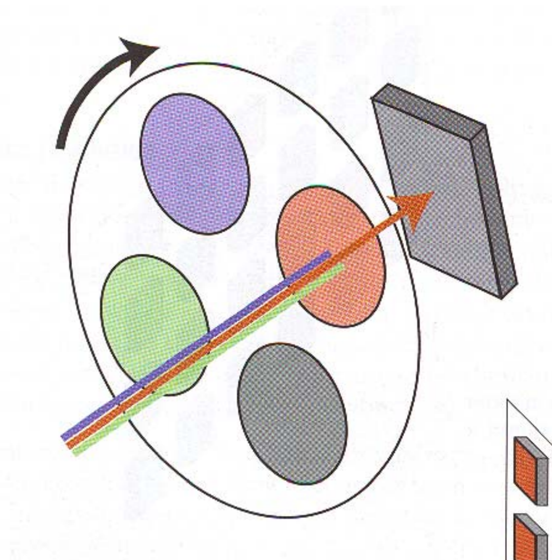
- *Specialized fabrication techniques are used so expensive technology*
- *Larger size*
- *Higher power consumption because of the capacitive architecture*
- *Always have to read out the whole image*
- *Resolution is limited by sensor elements size*
- *Less on-chip circuitry so lesser dark currents and noise*

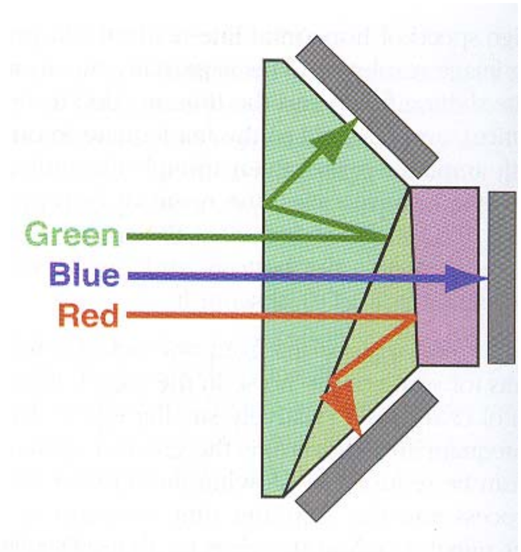
CMOS (Complementary Metal Oxide Semiconductor)

- *Cheaper technology*
- *Smaller size*
- *Low power consumption*
- *Readout for selective area of an image is possible*
- *Amplifier and additional circuitry can be fabricated inside each pixel.*
- *Higher resolution possible*
- *Stronger noise due to higher dark currents because of more on-chip circuitry*

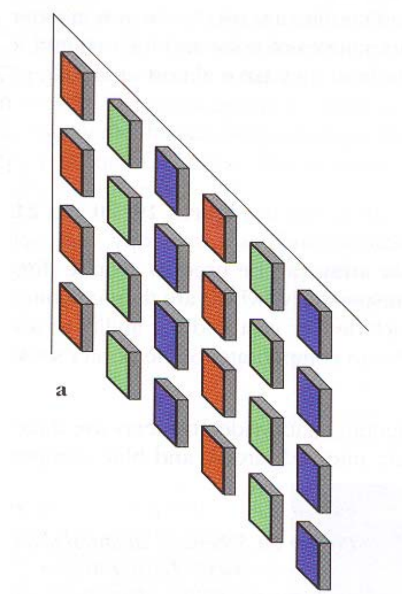
Acquisition of color images

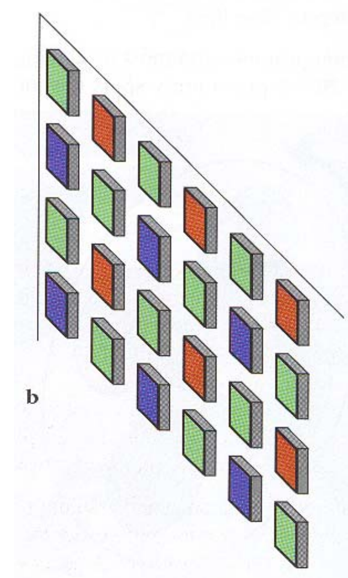
Single sensor assembly
For still scenes





Three sensors with prisms





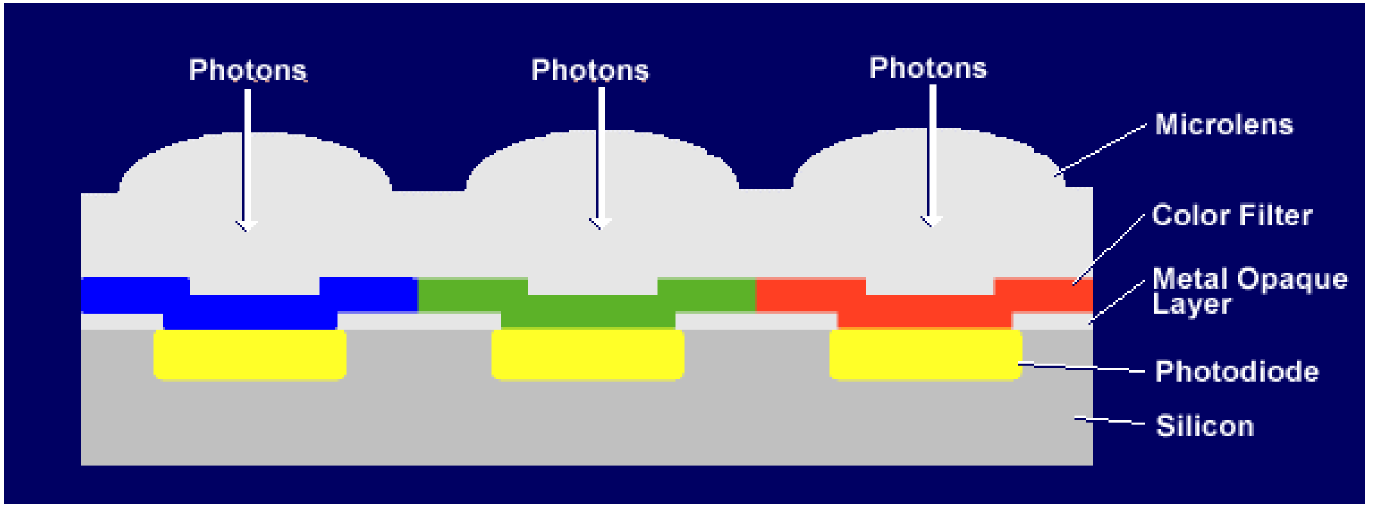
Sensor arrays

a. Stripe filter pattern

b. Bayers filter pattern

Acquisition of color images

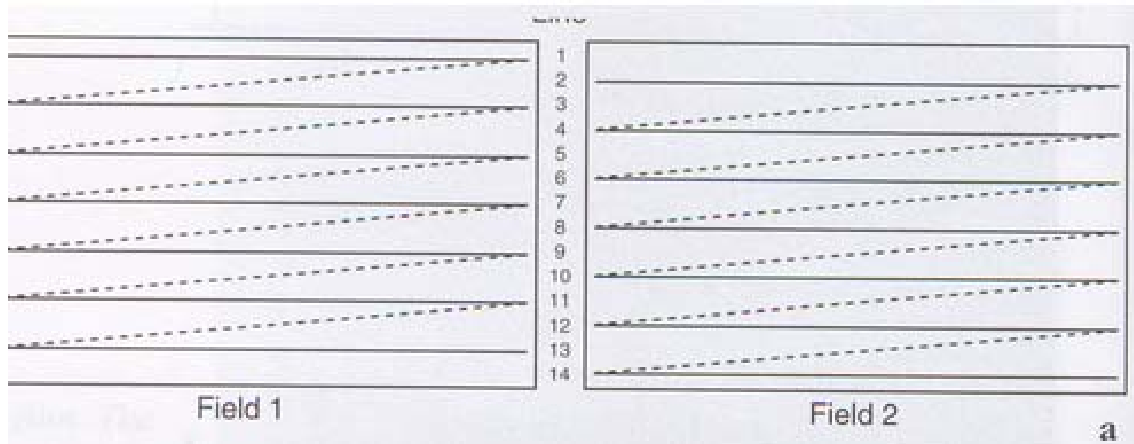
- Fabrication of CMOS colored sensors



Scanning Schemes

Interlaced scanning (used in TV)

- Read/display all even-numbered lines (even field, half-size)
- Restart
- Read/display all odd-numbered lines (odd field, half-size)
- Stitch the even and odd fields together and form a single, full-size frame
- Output the full-size frame



A typical Interlaced Scanning scheme

Interlaced scanning

When motion is present the interlaced scanning produces blurring in the image

Scanning Schemes

Progressive Scanning

- Immediately transfer an entire frame at once from the image sensor without performing any line-interlacing.
- Suitable for fast motion detection applications
- Incompatible with standard television systems.
- Popular in digital cameras (computer applications)

Basic relationships between pixels

Arrangement of pixels:

0	1	1
0	1	0
0	0	1

4 neighbours $N_4(p)$:

	1	
0	1	0
	0	

Diagonal neighbours $N_D(p)$:

0		1
	1	
0		1

8 neighbours $N_8(p) = N_D(p) \cup N_4(p)$:

0	1	1
0	1	0
0	0	1

Basic relationships between Pixels

- Connectivity between pixels:

  An important concept used in establishing boundaries of objects and components of regions

  Two pixels p and q are connected if

  – They are adjacent in some sense

  – If their gray levels satisfy a specified criterion of similarity

V: Set of gray level values used to define the criterion of similarity

4-connectivity: If gray-level p , q $\in V$, and q $\in$ N4(p)

8-connectivity: If gray-level p , q $\in V$, and q $\in$ N8(p)

m-connectivity (mixed connectivity):

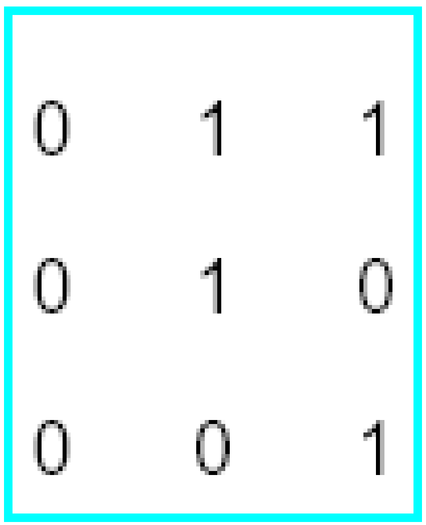
Gray-level p , q $\in V$, and q satisfies one of the following:

1) $q \in N4(p)$, 2) $q \in N_D(p)$ **and** $N_4(p) \cap N_4(q)$ has no values from V

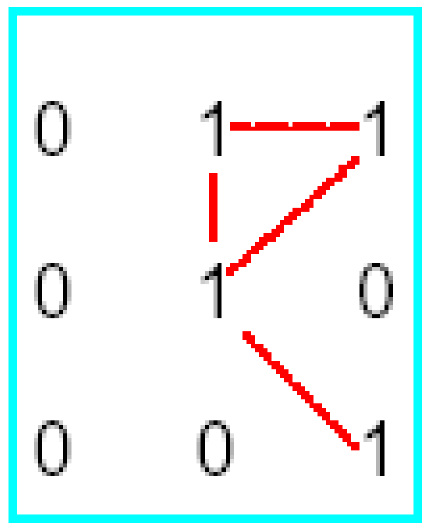
Basic relationships between pixels

Mixed Connectivity:

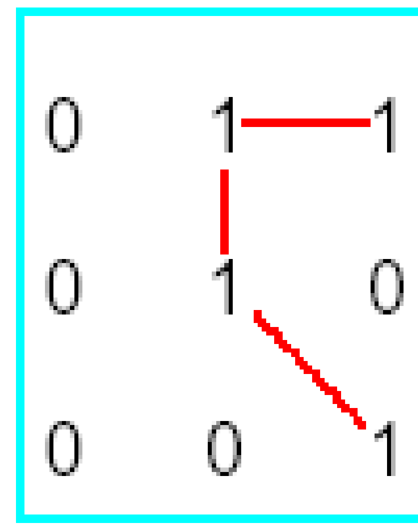
Note: Mixed connectivity can eliminate the multiple path connections that often occurs in 8-connectivity



Pixel arrangement



8-adjacent to the center pixel



m-adjacency

Basic relationships between pixels

Path

Let coordinates of pixel p: (x, y), and of pixel q: (s, t)

A *path* from p to q is a sequence of distinct pixels with coordinates: $(x_0, y_0), (x_1, y_1), \ldots\ldots, (x_n, y_n)$ where

$(x_0, y_0) = (x, y)$ & $(x_n, y_n) = (s, t)$,

and (x_i, y_i) is adjacent to (x_{i-1}, y_{i-1}) $1 \leq i \leq n$

Regions

A set of pixels in an image where all component pixels are connected

Boundary of a region

A set of pixels of a region R that have one of more neighbors that are not in R

Distance Measures

Given coordinates of pixels p, q, and z: (*x*,*y*), (*s*,*t*), and (*u*,*v*)

Euclidean distance between p and q:

$$D_e(p,q) = \sqrt{(x-s)^2 + (y-t)^2}$$

– *The pixels with D_e distance $\leq r$ from (x,y) define a disk of radius* r *centered at* (x,y)

City-block distance between p and q:

$$D_4(p,q) = |x-s| + |y-t|$$

– *The pixels with D_4 distance $\leq r$ from (x,y) form a diamond centered at* (x,y)

– *the pixels with D_4*=1 *are the 4-neighbors of (x,y)*

- Chessboard distance between p and q:

$$D_8(p,q) = \max(|x-s|,|y-t|)$$

– *The pixels with D_8 distance $\leq r$ from (x,y) form a square centered at* (x,y)

– *The pixels with D_8*=1 *are the 8-neighbors of (x,y)*

Reading Assignment

- Chapters 1 and 2 of "*Digital Image Processing*" by Gonzalez.
- Chapter 2 of "*Digital Image Processing using MATLAB*" by Gonzalez.