CS334: Digital Imaging and Multimedia

Multimedia Digitization

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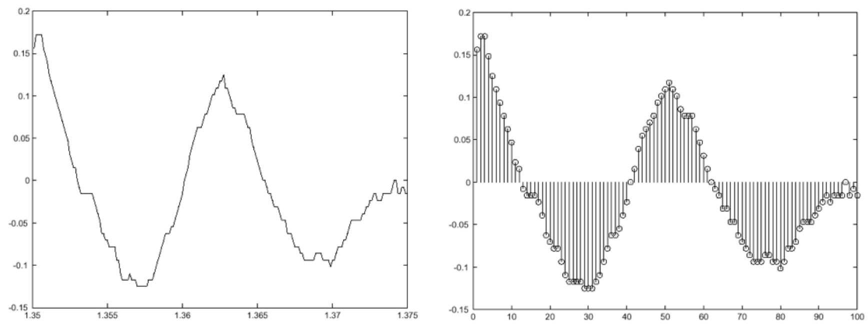
Outlines

- Digitizing Signals and Images
- Image histograms and its applications

- Sources:
  - Havaldar and Medioni "Multimedia Systems" Ch 2
  - Burger and Burge "Digital Image Processing" Ch. 2 and Ch. 4

Analog to Digital



Advantage of Digital over Analog

- Easy to random access and interact with: group of pixel, or a section of a sound track.
- Different processing can be applied
- Stored digital signal do not degrade over time
- Digital data can be efficiently compressed
- Unified representation of all media types, audio, images, video, …

Issues

- Sampling
- Quantization
- Bit Rate

Sampling

- *xs (n)= x (nT) ,* where T is the sampling period
- *F=1/T* is the sampling frequency
- In reality, more complex, as sampling comes with filtering

Surprisingly, we may not lose information in sampling

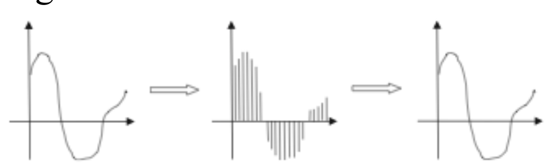


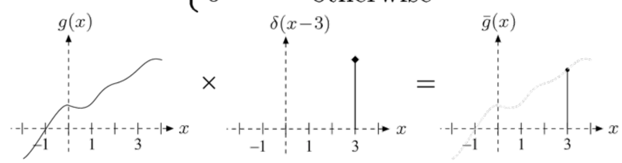
Figure 2-2 Analog-to-digital conversion and the corresponding interpolation from the digital-to-analog domain

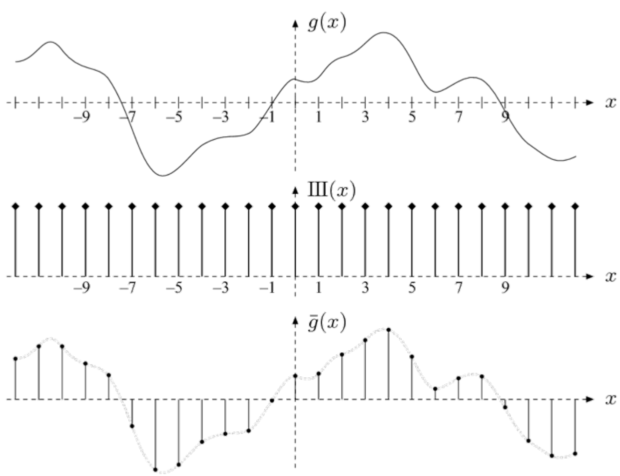
Impulse function

$$\delta(x) = 0 \quad \text{for} \quad x \neq 0 \quad \text{and} \quad \int_{-\infty}^{\infty} \delta(x)\, \mathrm{d}x = 1$$

$$\delta(sx) = \frac{1}{|s|} \cdot \delta(x) \quad \text{for } s \neq 0$$

$$\bar{g}(x) = g(x) \cdot \delta(x - x_0) = \begin{cases} g(x_0) & \text{for } \; x = x_0 \\ 0 & \text{otherwise} \end{cases}$$





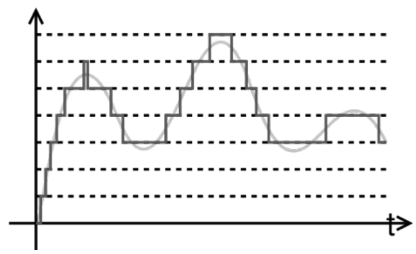
$$\bar{g}(x) = g(x) \cdot \text{Ш}(x)$$

$$\text{Ш}(x) = \sum_{i=-\infty}^{\infty} \delta(x - i)$$ Comb function

Quantization

- **quantization** is the process of approximating a continuous range of values (or a very large set of possible discrete values) by a relatively-small set of discrete symbols or integer values.
- Irreversible and lossy

  $x_q(n)$ = Q [$x_s(n)$], Q is a rounding function



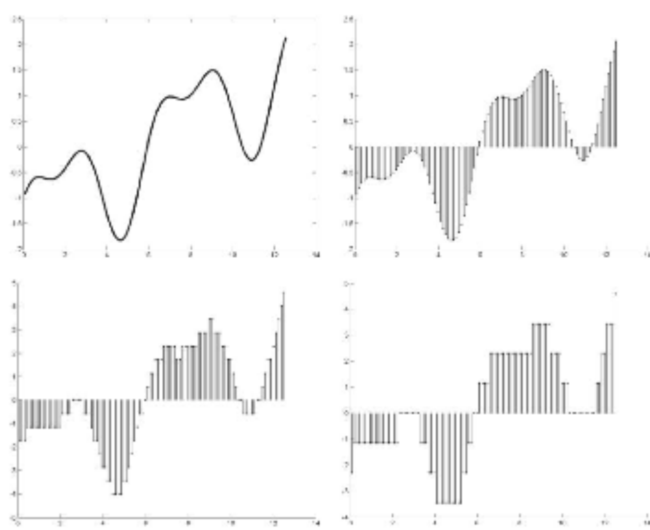
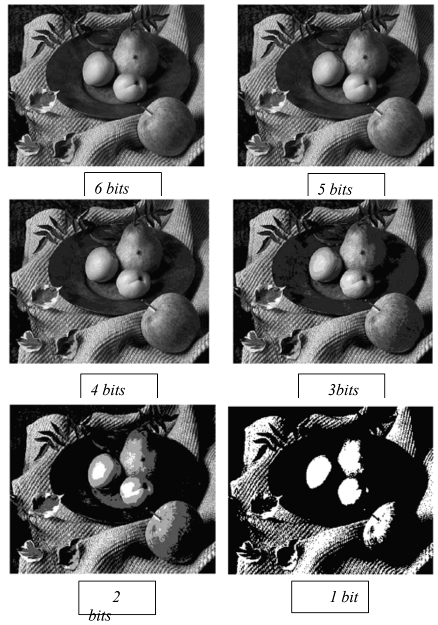
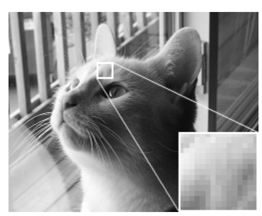
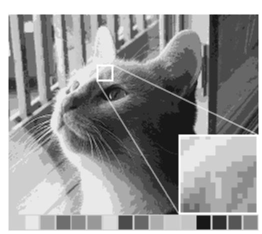


Figure 2-3 Original analog signal (upper left) is shown sampled and quantized at different quantization levels. For quantization, 8 bits (256 levels), 4 bits (16 levels), and 3 bits (8 levels) were used to produce the digital signals on the top right, bottom left, and bottom right, respectively.





24-bit RGB color



16 colors

Bit Rate

Bit Rate = *Sampling rate x Quantization per sample* (bits/ second)

Audio (MP3)
- 32 kbit/s — MW (AM) quality
- 96 kbit/s — FM quality
- 128–160 kbit/s — Standard Bitrate quality; difference can sometimes be obvious (e.g. bass quality192 kbit/s — DAB (Digital Audio Broadcasting) quality. Quickly becoming the new 'standard' bitrate for MP3 music; difference can be heard by few people
- 224–320 kbit/s — Near CD quality. Sound is nearly indistinguishable from most CDs.

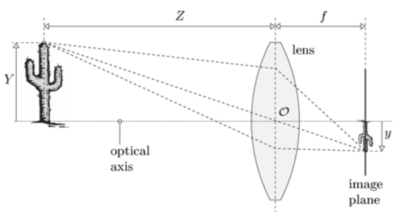
Other audio
- 800 bit/s — minimum necessary for recognizable speech (using special-purpose FS-1015 speech codecs)
- 8 kbit/s — telephone quality (using speech codecs)
- 500 kbit/s–1 Mbit/s — lossless audio
- 1411 kbit/s — PCM sound format of Compact Disc Digital Audio

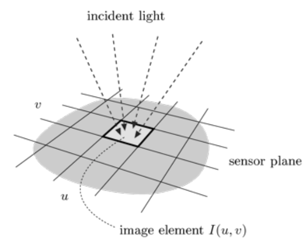
Video (MPEG2)
- 16 kbit/s — videophone quality (minimum necessary for a consumer-acceptable "talking head" picture)
- 128 – 384 kbit/s — business-oriented videoconferencing system quality
- 1.25 Mbit/s — VCD quality
- 5 Mbit/s — DVD quality
- 15 Mbit/s — HDTV quality
- 36 Mbit/s — HD DVD quality
- 54 Mbit/s — Blu-ray Disc quality

Signal	Sampling rate	Quantization	Bit rate
Speech	8 KHz	8 bits per sample	64 Kbps
Audio CD	44.1 KHz	16 bits per sample	706 Kbps (mono) 1.4 Mbps (stereo)
Teleconferencing	16 KHz	16 bits per sample	256 Kbps
AM Radio	11 KHz	8 bits per sample	88 Kbps
FM Radio	22 KHz	16 bits per sample	352 Kbps (mono) 704 Kbps (stereo)
NTSC TV image frame	Width – 486 Height – 720	16 bits per sample	5.6 Mbits per frame
HDTV (1080i)	Width – 1920 Height – 1080	12 bits per pixel on average	24.88 Mbits per frame

Digitizing images

- What is projected on the image plan is a distribution of light energy that is:
  - Two-dimensional
  - Time-dependent
  - Continuous
- To go digital:
  - Spatial sampling
  - Temporal sampling
  - Quantization of pixel values





- Digital image: two-dimensional, ordered matrix of integers, i.e., a two-dimensional function of integer coordinates NxN that maps a range of image values P

$$I(u,v) \in \mathbb{P} \quad \text{and} \quad u,v \in \mathbb{N}.$$

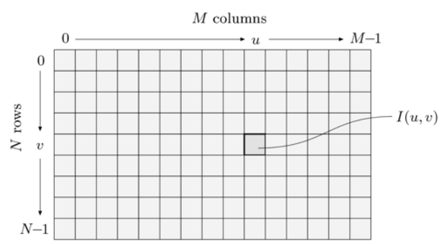
$F(x,y)$

→

148	123	52	107	123	162	172	123	64	89	⋯
147	130	92	95	98	130	171	155	169	163	⋯
141	118	121	148	117	107	144	137	136	134	⋯
82	106	93	172	149	131	138	114	113	129	⋯
57	101	72	54	109	111	104	135	106	125	⋯
138	135	114	82	121	110	34	76	101	111	⋯
138	102	128	159	168	147	116	129	124	117	⋯
113	89	89	109	106	126	114	150	164	145	⋯
120	121	123	87	85	70	119	64	79	127	⋯
145	141	143	134	111	124	117	113	64	112	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

$I(u,v)$

- Image resolution: number of image elements per measurement.
- Image coordinate system



Grayscale (Intensity Images):

Chan.	*Bits/Pix.*	*Range*	*Use*
1	1	0...1	Binary image: document, illustration, fax
1	8	0...255	Universal: photo, scan, print
1	12	0...4095	High quality: photo, scan, print
1	14	0...16383	Professional: photo, scan, print
1	16	0...65535	Highest quality: medicine, astronomy

Color Images:

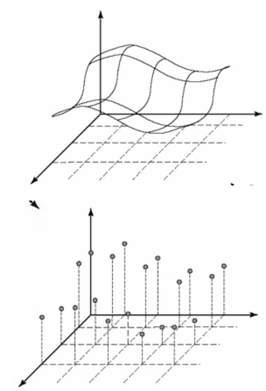
Chan.	*Bits/Pix.*	*Range*	*Use*
3	24	$[0\ldots255]^3$	RGB, universal: photo, scan, print
3	36	$[0\ldots4095]^3$	RGB, high quality: photo, scan, print
3	42	$[0\ldots16383]^3$	RGB, professional: photo, scan, print
4	32	$[0\ldots255]^4$	CMYK, digital prepress

Special Images:

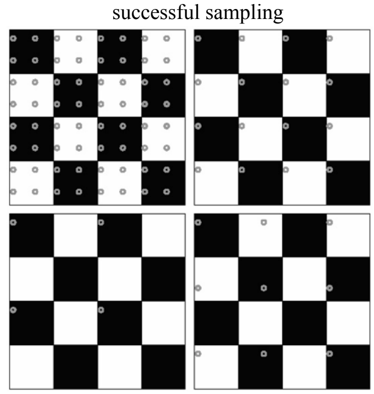
Chan.	*Bits/Pix.*	*Range*	*Use*
1	16	$-32768\ldots32767$	Whole numbers pos./neg., increased range
1	32	$\pm3.4 \cdot 10^{38}$	Floating point: medicine, astronomy
1	64	$\pm1.8 \cdot 10^{308}$	Floating point: internal processing

Sampling and Aliasing

- Images are sampled version of a continuous brightness function.



successful sampling

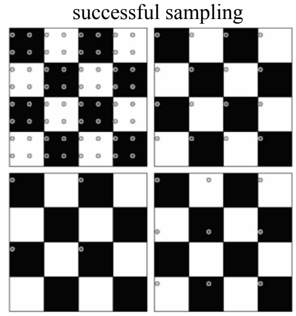


unsuccessful sampling

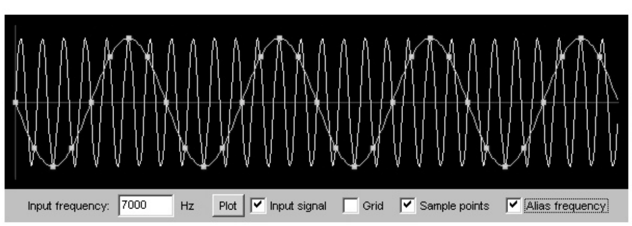
Sampling and Aliasing

- Sampling involves loss of information
- <u>Aliasing:</u> high frequency components appear as low frequency components in the sampled signal

successful sampling

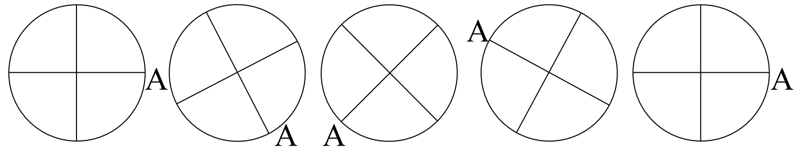


unsuccessful sampling



Java applet from: http://www.dsptutor.freeuk.com/aliasing/AD102.html

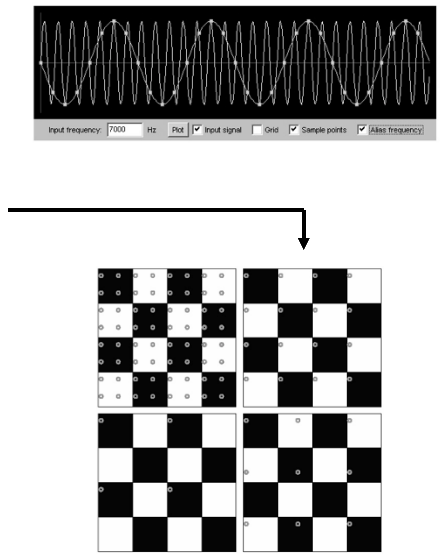
Temporal Aliasing



The wheel appears to be moving backwards at about ¼ angular frequency

Aliasing

- *Nyquist theorem*: The sampling frequency must be at least twice the highest frequency present for a signal to be reconstructed from a sampled version. *(Nyquist frequency)*

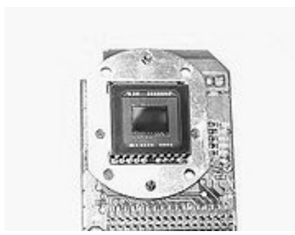


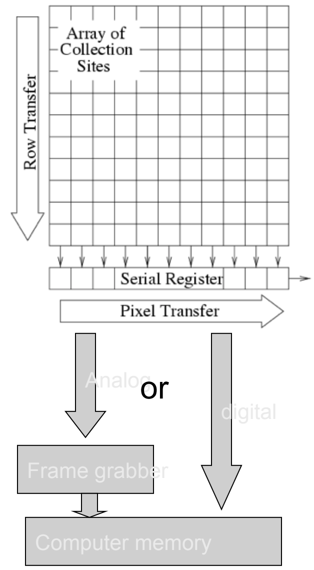
CCD & CMOS

- CCD Cameras (Charge Couple Device) (1970)
  - Accumulate signal charge in each pixel proportional to the local illumination intensity
  - CCD transfers each pixel's charge packet sequentially to convert its charge to a voltage
- CMOS Cameras (Complementary Metal Oxide Silicon)
  - Accumulate signal charge in each pixel proportional to the local illumination intensity
  - The charge-to-voltage conversion takes place in each pixel

CCD cameras

- Charge-coupled device CCD
- Image is read one row at a time
- This process is repeated several times per second (frame rate)





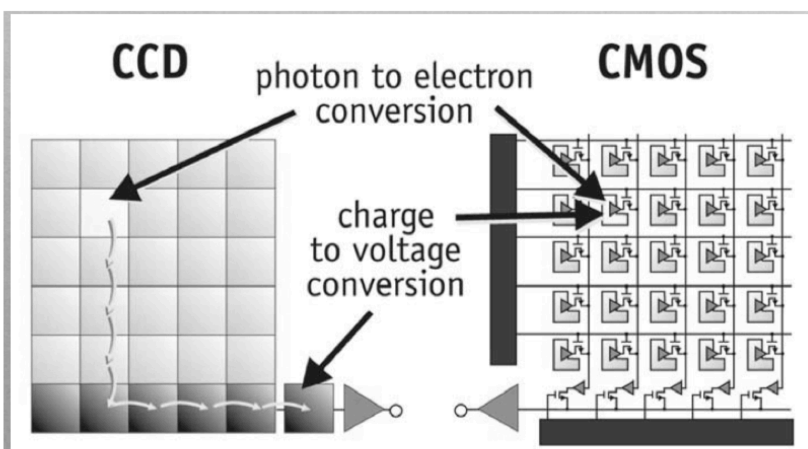


Image from Photonics Spectra

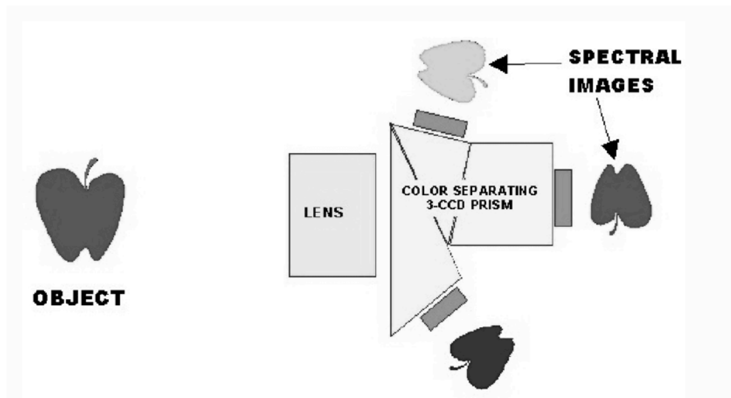
CMOS	*CCD*
Easier to manufacture	*Higher fill factor*
Camera-on-a-chip	*Smaller noise*
Lower power consumption	*Smaller dark current*
Smaller sensor	*Better pixel uniformity*
Higher speeds	*Better dynamic range*
Selective ROI windowing	*Non-rolling electronic shutter*
Natural anti-blooming	

Check out: CCD vs. CMOS: Facts and Fiction by Dave Litwiller, in Photonics Spectra, January 2001

Color cameras

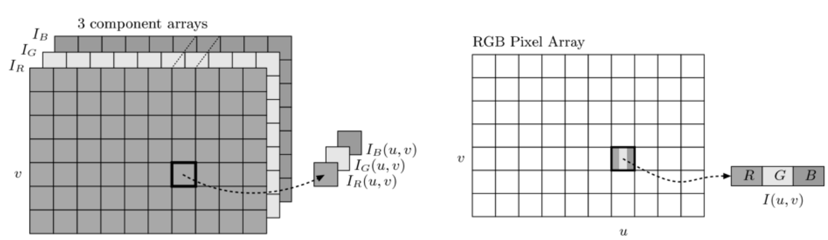
- Two types of color cameras
  - Single CCD array
    - in front of each CCD element is a filter - red, green or blue
    - color values at each pixel are obtained by hardware interpolation
      - subject to artifacts
      - lower intensity quality than a monochromatic camera
      - similar to human vision
  - 3 CCD arrays packed together, each sensitive to different wavelengths of light

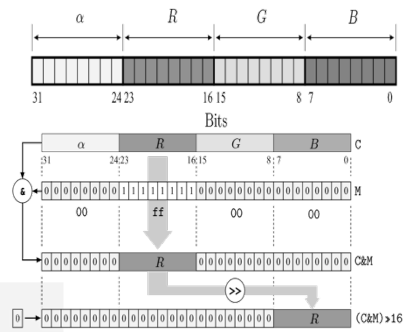
3 CCD cameras



RGB representation

- True color images: represent each pixel with its R,G,B values.
  - Component ordering
  - Packed ordering






```
int c = ip.getPixel(u,v); // a color pixel
int r = (c & 0xff0000) >> 16; // red value
int g = (c & 0x00ff00) >> 8;  // green value
int b = (c & 0x0000ff);       // blue value
```

```
int[] RGB = new int[3];
...
RGB = ip.getPixel(u,v,RGB);
int r = RGB[0];
int g = RGB[1];
int b = RGB[2];
...
ip.putPixel(u,v,RGB);
```

RGB representation

- Alternative representation: Indexed images:
  - make a color table
  - each pixel's color is represented by its color's index in the table
- Advantages?
- Limitations?