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Programme: M.Sc., Medical Physics

Course Title : Advanced Medical Imaging
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Unit-I
Computers in Medical Imaging

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Data Storage - Number Systems:

4 types of the number systems: Decimal, Binary, Octal and Hexadecimal

Decimal Form (Base 10):

- Uses digits 0 to 9 (0, 1, 2, 3, 4, 5, 6, 7, 8, 9)
- Position indicates power of 10 exponent

Ex: $3506_{10} = (\mathbf{3} \times 10^3) + (5 \times 10^2) + (0 \times 10^1) + (\mathbf{6} \times 10^0)$

The leftmost digit is called the most significant number or digit (MSD) and the rightmost the Least significant number or digit (LSD).

Binary Form (Base 2):

- Uses digits 0, 1
- Position indicates power of 2 exponent

Ex: $1101 = (\mathbf{1} \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (\mathbf{1} \times 2^0)$

Most significant number or digit or MSB

Least significant number or digit or LSB

Decimal	Binary	Decimal	Binary
0	0	8	1000
1	1	9	1001
2	10	10	1010
3	11	11	1011
4	100	12	1100
5	101	13	1101
6	110	14	1110
7	111	15	1111
		16	10000

- Octal (Base = 8), Hexadecimal (Base = 16)

Conversion between Binary into Decimal Forms:

Ex:

$101010(\text{binary}) = (1 \times 2^5) + (0 \times 2^4) + (1 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (0 \times 2^0)$

$2^5 = 32 \quad 2^4 = 16 \quad 2^3 = 8 \quad 2^2 = 4 \quad 2^1 = 2 \quad 2^0 = 1$

$= (1 \times 32) + (0 \times 16) + (1 \times 8) + (0 \times 4) + (1 \times 2) + (0 \times 1)$

$= \mathbf{42}$ decimal

Conversion between Decimal into Binary Forms:

Ex: 42 (decimal)

		Remainder
42 (decimal)/2	21	**0** (LSB)
21/2	10	1
10/2	5	0
5/2	2	1
2/2	1	0
1/2	0	**1** (MSB)

= 101010 binary

Data Storage - Digital Representation of Data

- Digital Representation of Different Types of Data:
  - ✓ Alphanumeric text,
  - ✓ Integers and
  - ✓ Non-integer data.
- Computer memory and storage consists of many elements called bits (for binary digits).
- Smallest unit of storage capacity is 1 bit (binary digit: 0 or 1)
- Bit can be in one of two states: 0 or 1.
- Bits are grouped into bytes: 8 bits is a byte, 1000 bits is a kilobyte, 10^6 bits is a macrobyte, 10^9 bits is a gigabyte, 10^{12} bits is a terabytes etc.,
- Bits are also grouped into words (16, 32, and 64 bits, depending on the computer system addressing architecture).
- Computer storage capacity is measured in:
  - ❖ kilobytes (kB) - 2^{10} bytes = 1024 bytes ≈ a thousand bytes,
  - ❖ megabytes (MB) - 2^{20} bytes = 1024 kilobytes ≈ a million bytes,
  - ❖ gigabytes (GB) - 2^{30} bytes = 1024 megabytes ≈ a billion bytes,
  - ❖ terabytes (TB) - 2^{40} bytes = 1024 gigabytes ≈ a trillion bytes.

Storage of positive integers:

- Computer memory and storage consists of many elements called bits.
- 1 bit have 2 possible configuration in binary format is 0, 1.
- 2 bits (2^2) have 4 possible configuration: 00, 01, 10 or 11 that can represent the decimal numbers 0, 1, 2 and 3.
- 3 bits (2^3) have 8 possible configuration: 000, 001, 010, 011, 100, 101, 110 or 111 that can represent the decimal numbers 0, 1, 2, 3, 4, 5, 6 and 7.
- 8 bits (2^8) have 256 possible configuration: 00000000 to 11111111 that can represent the decimal numbers 0 to 255.
- 10 bits (2^{10}) have 1024 possible configuration: 0000000000 to 1111111111 that can represent the decimal numbers 0 to 1023.
- 12 bits (2^{12}) have 4096 possible configuration: 000000000000 to 111111111111 that can represent the decimal numbers 0 to 4095.
- 16 (2^{16}) bits have 65,536 possible configuration: 0000000000000000 to 1111111111111111 that can represent the decimal numbers 0 to 65,535.
- In general, n bits have 2^n possible configurations and can represent decimal (integers) numbers from 0 to 2^n-1.

Number of Bits	Possible Configurations	Number of Configurations	Represent Integers (Decimal Form)
1	0,1	2	0,1
2	00,01,10,11	4	0,1,2,3
3	000,001,010,011,100,101,110,111	8	0,1,2,3,4,5,6,7
8	00000000 to 11111111	256	0 to 255
16	0000000000000000 to 1111111111111111	65,536	0 to 65,535
N		2^N	0 to $2^N - 1$

Storage of signed integers:

• 1, 2, 3 and 8 bit's are called "signed" integers (signed meaning positive or negative integers).
• Setting the first bit to 0 indicates that the number is positive.
• Setting the first bit to 1 indicates that the number is negative.
• Reserve first bit for the sign (+/-): [-127,127] – one's complement.

Ex: 8 bit number,

11111111 (binary) = -127 (decimal) is the most –ve number.
01111111 (binary) = 127 (decimal) is the largest +ve number.

• Two complement notation: Needed to add +ve and –ve integers.

Floating point numbers:

❑ 3 and 8 bit's is called "floating-point numbers".
❑ 3 byte - single precision
❑ 8 byte - double precision
❑ For Very large numbers such as Avogadro's number (6.022×10^{23} molecules per gram-mole).
❑ For Very small numbers such as the mass of proton (1.673×10^{-27} kilograms).

Ex: $0.11111111_2 \times 2^{01001111_2}$

Binary representation of text:

- Binary representation of Alphanumeric date in text.
- Data in binary form is the American Standard Code for Information Interchange (ASCII).
- The byte values from 00000000 to 01111111 (binary)
- Stored in one byte (128 characters)
- 128 characters are:
  - Upper and lower case letters,
  - Digits 0 through 9,
  - Punctuation marks, and
  - Several carriage-control characters or carriage return.

Ex:

- Upper is represented by 01000001
- Digit is represented by 00110010
- Comma is represented by 00111010
- Carriage return is represented by 00001101

Data Storage - Digital Data Transfer:

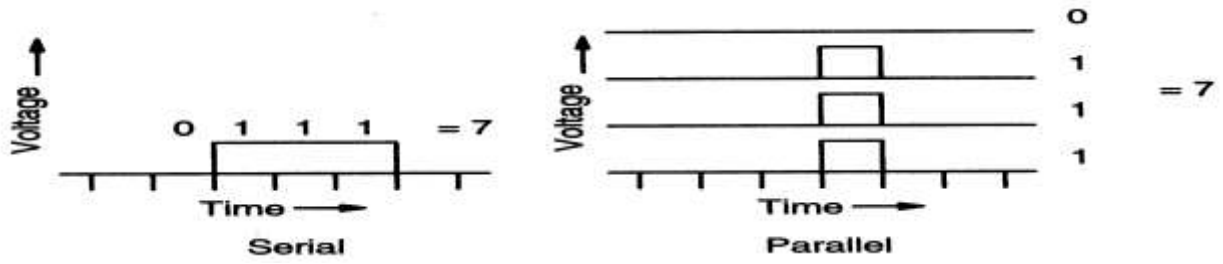
- Two types of data: Analog & Digital.
  - Analog data can be converted to digital information.
  - Aanalog is transmitted quicker, but digital is more resistant to errors)

Transfer of data in digital form:

- ✓ Data are transferred between memory and CPU (Central Processing Unit) in binary format (0 and 1).
- ✓ Frequency = V/t (usually given in MHz or GHz).
- ✓ Changes between the voltage states occur through the signals, the minimum time increment (t) at which a 1 → 0 or 0 → 1 transition can occur.

Serial vs Parallel transfer of digital data

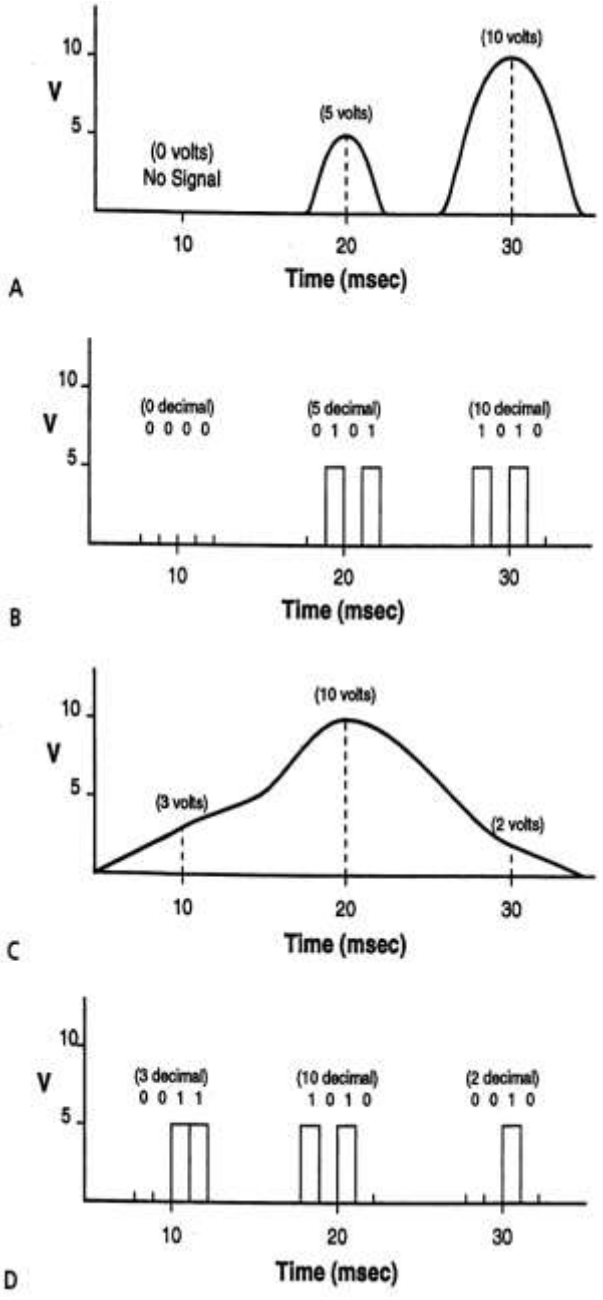
- Date can be transferred in serial (multiple pulse over a single wire) or in parallel (all pulses over several wires).
- Each bit value being transferred over its own wire is called "parallel data transfer."
- Parallel - All pulses transmitted simultaneously over several wires.
- If N wires are used, parallel transmission is predominantly N times faster than serial transmission .
- A "Bus" a bundle of wires used for parallel data transfers.



Analog and digital representation of numerical data:

Analog: continuous waveform where the amplitude represents the numerical signal magnitude.

a) Three analog voltage pluses, similar to those produced by photomultiplier tube attached to a scintillator. The height of each pulse represents a number.
b) These same numbers represented in digital form.
c) A continuously varying analog signal, such as that from video camera in fluoroscopy system. The height of signal at each point in time represents a number.
d) Values of this signal, sampled at 3 points, represented in digital form.



Conversion between Analog and Digital Data

Advantages of analog data:

- ❖ Captures small details in signal.
- ❖ Data can be transmitted quicker using analog form.

Disadvantages of analog data:

- ❖ Signals become distorted (signals are amplified attenuation losses, and electronic noise).

Advantages of digital data:

- ❖ Data stored or transferred in digital form are remarkably resistance to accumulated error .
- ❖ Error correction possible with the transmission of redundant information.
- ❖ Digital circuitry most often less expensive than analog.

Disadvantages of digital data:

- ❖ Fidelity of digitized signal depends on number of bits used.
- ❖ More bits mean higher fidelity but more storage and transmission bandwidth required.
- ❖ More complex circuitry.
- ❖ Digitized values only approximate analog signal.

Conversion:

- Transducers, sensors or detectors of most electronic measuring equipment, medical imaging devices, produce analog data.
- Devices that perform conversion called analog-to-digital converters (ADCs) or digital-to-analog converters (DACs).
- Most analog signals are continuous in time.
- Certain points in time must be selected at which the conversion is to be performed. Process is called “sampling”.
- Each analog sample is then converted into a digital signal. This conversion is called “digitization” or “quantization”.
- ADCs is characterized by its sampling rate and number of bits of output it provides.
- Most radiologic applications required very high resolution and sampling rates.
- An ADCs produces a digital signal of a fixed number of bits. (Ex: 8-bit ADC, 10-bit ADC, or 12-bit ADCs).
- The number of bits of output is just the number of bits in the digital number produced each time the ADC samples and quantizes the input analog signal.
- Digital representation of data is superior to analog in its resistance to accumulation of errors.

Disadvantages:

- ❑ The conversion of an analog signal to digital form causes potential loss of information (Data).
- ❑ This loss is due to both sampling and quantization.
- ❑ ADC samples the input signal, the values of the analog signal between the moments of sampling are lost.
- ❑ Minimum sampling frequency (Nyquist limit) to accurately represent signal Quantization error minimized through use of large number of bits/sample.

Quantization error:

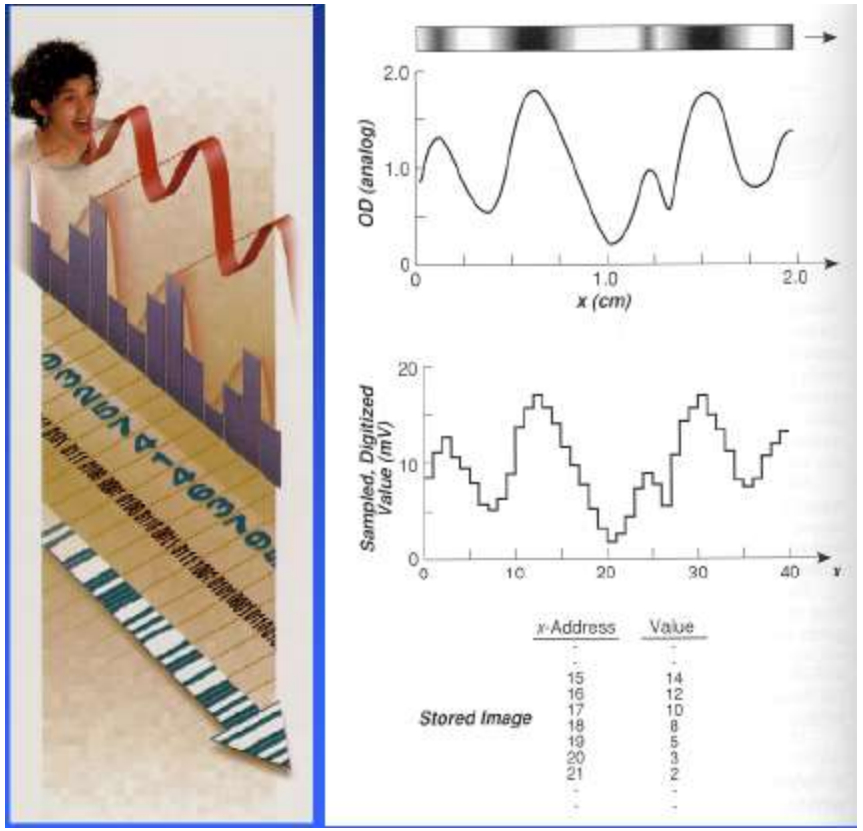
- ➢ Loss of information.
- ➢ Can only approximate value of analog signal (minimum and maximum).

Ex: An analog voltage signal may be 1.0, 2.5, or 1.7893 V.

- ✓ Digital signal is limited to finite number of possible values, determined by number of bits used for signal.
- ✓ 1-bit digital signal is limited to two values, 2-bit signal is limited to four values, N-bit signal is restricted to 2^N.
- ➢ Quantization error is similar to error introduced when number is rounded off.
- ➢ ADC must sample at sufficiently high rate and provide a sufficient number of bits so error is less than uncertainty in analog signal being digitized.
- ➢ Analog signal with a large signal-to-noise ratio (SNR) requires an ADC providing a large number of bits to avoid reducing the SNR.

Maximal errors when different numbers of bits are used to approximate an analog signal are:

Number of Bits	Number of Values	Maximal Quantization Error (%)
1	2	25
2	4	12.5
3	8	6.2
8	256	0.20
12	4,096	0.012



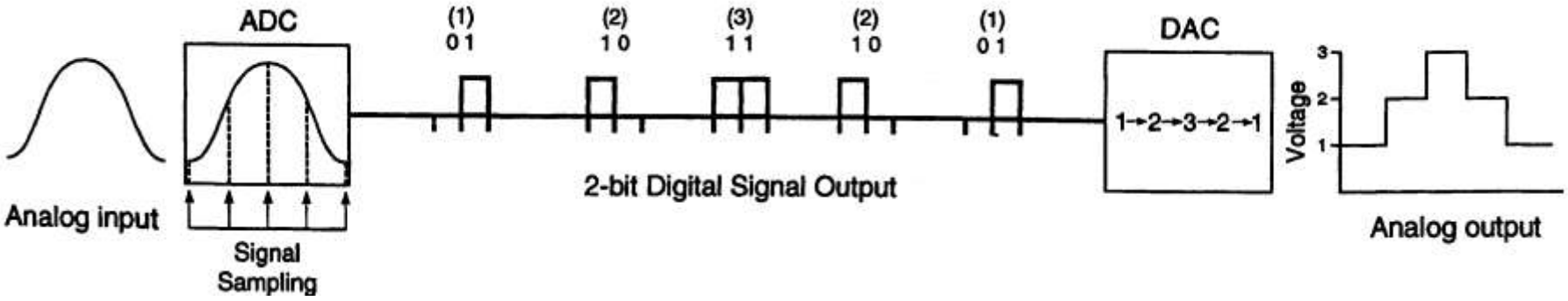
Digital-to-Analog Conversion

❖ Image information must be converted from digital form to an analog voltage signal called Digital-to analog converter (DAC).

❖ Information lost by analog-to-digital conversion is not restored by sending signal through DAC.

Analog-to-digital (ADC) conversion and digital – to – analog (DAC) conversion:

- The electronic measuring devices of medical scanners (Ex: transducers and detectors) produce analog signals.
- In this figure, 2 bit ADC samples input signal 5 times.
- Output signal from DAC is only approximation of input signal to ADC because 2-bit digital numbers produced by ADC can only approximate continuously varying analog signal.
- ADCs characterized by
  - ❖ sampling rate or frequency (Ex: samples/sec – 1 MHz)
  - ❖ number of bits output per sample (Ex: 12 bits/sample = 12-bit ADC)



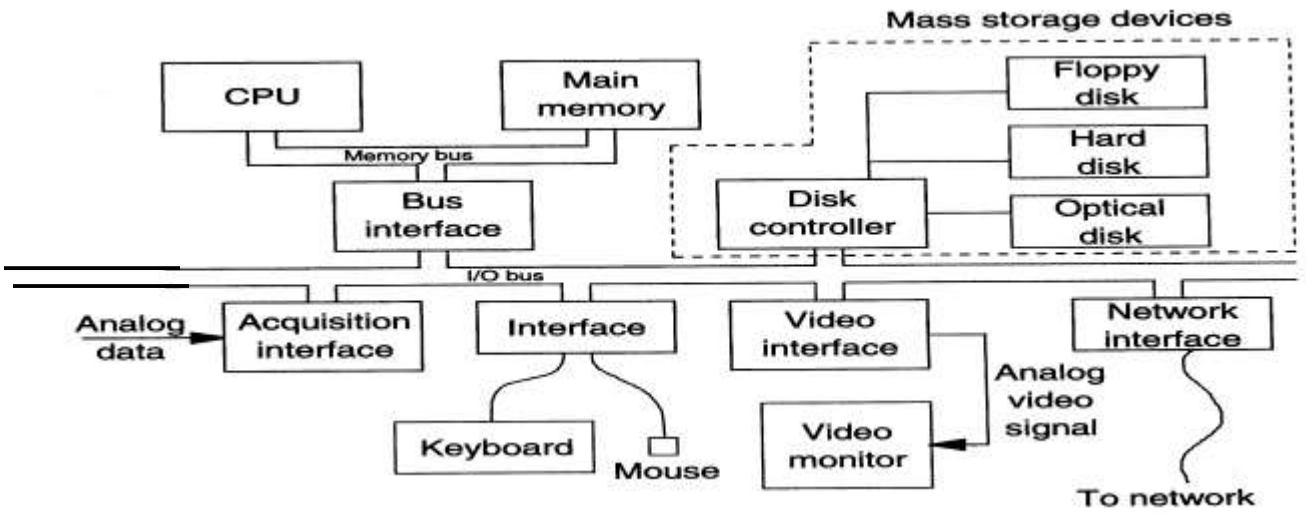
Computer parts:

A computer consists of a

- Main memory: stores the program being executed and the data being processed.
- CPU: executes the instructions in the program to process the data.
- Input/output (I/O) devices: enable information to be entered into and retried from the computer and to be stored. (Ex: keydoard, mouse or other pointing device, a video interface and video monitor, several mass storage devices and often a printer).

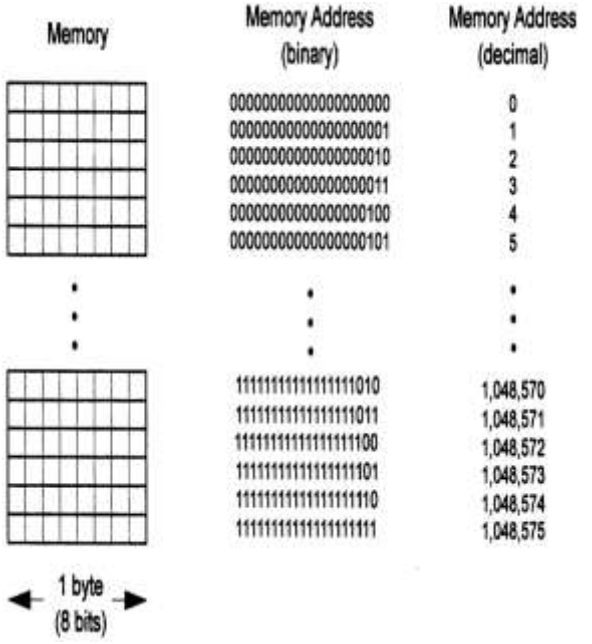
All linked together by one or more data pathways called “data buses”.

- ✓ Keydoard, pointing device, video interface and video monitor enable he operator to communicate with the computer.
- ✓ Mass storage devices permit the storage of large volumes of programs and data. They include floppy magnetic disk drives, fixed magnetic dis drives, optical disk drives and magnetic tape drives.



Main Memory:

- ❑ Main memory is used for these functions instead of mass storage devices because the date transfer rate between the CPU and main memory is much faster than that between the CPU and the mass storage devices.
- ❑ Main memory consists of a large number of data storage locations is called “memory address“ (where data and instructions reside).
- ❑ CPU performs memory write, sends both memory address and data to memory.
- ❑ One type of memory is called “random access memory” (RAM) (read-write memory). Disadvantage, data stored in it are lost when electrical power is turned off.
- ❑ Read-only memory (ROM) cannot write or erase data on ROM. Advantage, data stored in it are not lost when power lost to computer.
- ❑ Size of the main memory can affect the speed.
- ❑ DRAM: dynamic RAM (One capacitor and one transistor for each bit must be read and refreshed several times a second to maintain the date.
- ❑ SRAM: static RAM (cache)
- ❑ Cache memories - maintain exact copies of memory (multiple reads).



Central Processing Unit (CPU)

- ❖ CPU executes a sequence of instructions in program.
- ❖ A CPU contained in single computer chip called microprocessor.
- ❖ An instruction can cause CPU to perform one or more actions.
  - ✓ Transfer unit of data from memory address, CPU storage register or I/O device.
  - ✓ CPU also contains an arithmetic logic unit (ALU) that performs mathematical operations between two numbers in storage registers in CPU (faster) or in memory (slower).
  - ✓ Compare 2 numbers or other pieces of data in registers or in memory.
  - ✓ Change address of next instruction in program to be executed to another location in program which is called branching instruction.
- ❖ CPU is a bottleneck in conventional computer.
- ❖ One way to improve is to increase speed.
- ❖ Relieving bottleneck is to design CPU to perform parallel processing.

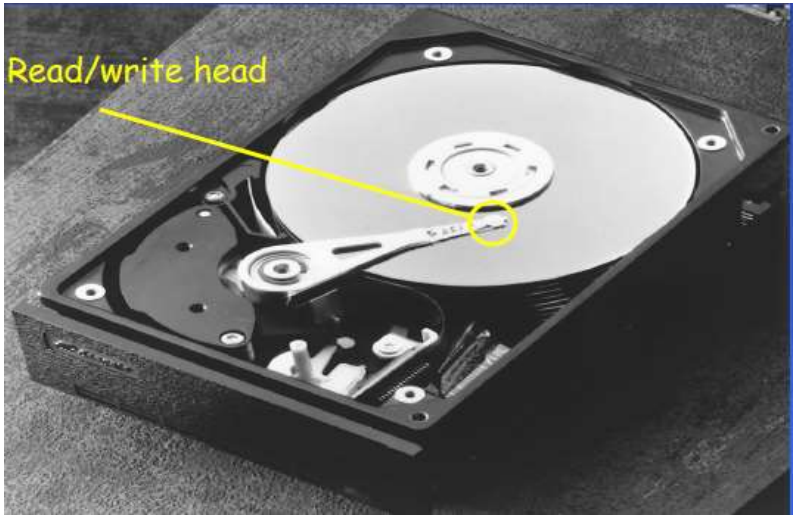
Input-Output (I/O) Bus and Expansion Slots:

- Bus described under serial vs. parallel data transfer
- Most I/O buses are provided with expansion slots to accommodate printed circuit (PC) cards with multiple functions,

  Ex: Modem card → modem and video display card → video monitor
- Makes it possible to customize general-purpose computers for specific applications (e.g., MRI scanner) and to add additional functions and capabilities (e.g., ADC) .
- I/O Ports: serial, parallel, USB (Universal Serial Bus) and SCSI (Small Computer System Interface).
- Connect other components together - Disks, graphics display, keyboards, etc.
- Generally high-performance 32 or 64 bit connections.

Mass Storage Devices

- Mass storage devices include floppy disks drives, hard disk drives (non-removable hard disks are called fixed disks), magnetic tape drives, and optical (laser) disk units.
- Floppy disks are removable plastic disks coated with magnetizable material.
- Optical disk is removable disk that rotates during data access and from which data are read and written using a laser.
- Three categories of optical disks: Read-only, Write-once and Rewritable
- CD-RWs are common type of rewritable optical disk.
- CD likely to be displaced by DVD, that provides greater storage capacity. DVDs are available in read-only, recordable, and rewritable forms.
- Advantages of optical disks include large storage capacity, on order of 650 megabytes to several gigabytes, and faster data access than magnetic tape.



Comparison of characteristics of mass storage devices and memory

	Removable	Storage Capacity	Access Time (Average)	Transfer Rate	Cost per Disk/Tape	Media Cost per GB
Floppy disk	Yes	1.2 to 1.4 MB	300 msec	0.03 MB/sec	$0.30	$210
Hard disk	Usually not	10 to 182 GB	6 to 15 msec	3 to 50 MB/sec	NA	
Optical disk, CD-ROM,	Yes	650–700 MB	100 to 150 msec (for 24×)	3.6 MB/sec (for 24×)		
CD-R,					$.50 (CD-R)	$.80 (CD-R)
CD-RW					$1.10 (CD-RW)	$1.70 (CD-RW)
Optical disk, DVD-ROM,	Yes	4.7 to 17 GB		8.1 MB/s		
DVD-R,		3.9 GB				
DVD-RAM		5.2 GB			$24 (DVD-RAM)	$4.60 (DVD-RAM)
Magnetic tape (cartridge)	Yes	45 MB to 110 GB	Seconds to minutes	0.125 to 10 MB/sec	$150 (110 GB super DLT)	$1.35 (110 GB super DLT)
Solid-state memory	No	64 MB to 1.5 GB	1 to 80 msec	24 to 250 MB/sec	NA	

Display Interface:

- Display computer information in visual form
- Usually displayed on a video monitor or printed
  - Cathode ray tube (CRT)
  - Flat-panel display (TFT = thin-film transistors)
- Video display controller/card
  - Receive digital data from computer memory
  - Store locally on card with VRAM (video RAM)
  - Registers to manipulate the original image or text data
  - DACs to convert into on-screen video image

Keyboard and Pointing/Printing Devices:

- Usually computer equipped with keyboard and pointing device such as mouse, trackball or joystick (could be head-less though) to enable the user to direct its operations and to enter data.

Acquisition Interface:

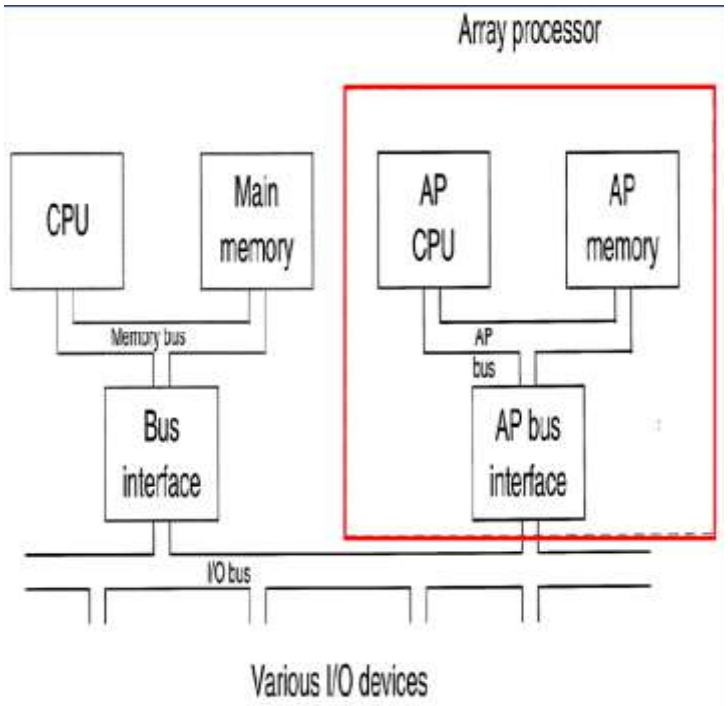
- Acquisition interface = ADC card(s), though more efficient for the modality electronics to perform ADC

Communications Interface:

- Modem permits computer to transfer information to another computer over network by analog telephone
- Computers also communications devices (PACS)
- Modem = modulator/de-modulator (DAC - encoded signal on wire - ADC)
- Asynchronous Transfer Mode (ATM)
- Ethernet, Gigabit , Fiber Channel

Array Processor

- In the past when general-purpose CPU speeds were slow, custom-designed hardware (array processors) to perform compute-intense mathematical operations (Ex: e.g., floating point computation) were manufactured achieved speed through specially designed circuits to make use of parallel processing and pipelining operation.
- Attaches to the computer bus for fast I/O operation.
- Not needed as much these days with very fast general-purpose microprocessors with parallel processing capabilities inherent in some operating systems.



Performance of Computers:

• One indicator of CPU speed is speed of its clock (Ex: 2.5 GHz Pentium IV).
• Speed of CPU may be measured in millions of instructions per second (MIPS).
• Speed of CPU may be measured in millions of floating point operations per second (MFLOPS).
• Programs used for assessing performance are called benchmarks.

Computer Software: Programs to perform specific functions desired by the user

- May be written in either high-level or machine language
- Generally an executable program run by the OS
- Hopefully user-friendly, flexible and intuitive to use

- Computer Languages

✓ Machine language

✓ High-level languages

- Fortran, Basic
- C, C++
- Java

✓ Applications Programs

✓ Operating Systems

- Windows
- Linux
- Mac OS on Apple computers
- Unix for workstations
- Computer security

- Operating System (OS) - the program that, after being initially loaded into the computer by a boot program, manages all the other programs in a computer
  - On instruction to run a program, the OS copies it from mass storage to memory, initiates execution of the first instruction by the CPU, transfers control to the program and regains control on completion of the task
  - Handles complex I/O tasks and sharing of resources
  - Examples: Windows, Mac OS, Linux, UNIX

Computer Languages:

- Machine Language
  - Binary instructions to be executed by CPU requiring detailed knowledge of the particular computer
- High-Level Languages
  - Program writing without detailed knowledge of the machine
  - This program is translated into machine language via a compiler
  - Include FORTRAN, Basic, Pascal, C, Java
  - Requires an compiler or interpreter program to translate to binary

Computer Security: Boot-sector viruses.

- Goals
  - Deny unauthorized persons access to data
  - Protect programs and data from accidental or deliberate loss
- Data Backup
- Practicing “Safe Computing”
  - Malicious programs exist, such as viruses, worms, Trojans, time bombs, and password grabbers
  - Types of viruses: executable file, boot sector and macro infectors
- Deny unauthorized users access to your system
  - Good password selection (8-14 characters, not in the dictionary of any known language, mix of upper/lower case and numbers, and should contain at least one non-alphanumeric character, e.g., !, @, #, %, etc.)
  - Firewall software/hardware, e.g., Zone Alarm or Black Ice
- Grant each user only sufficient privileges required to accomplish required tasks

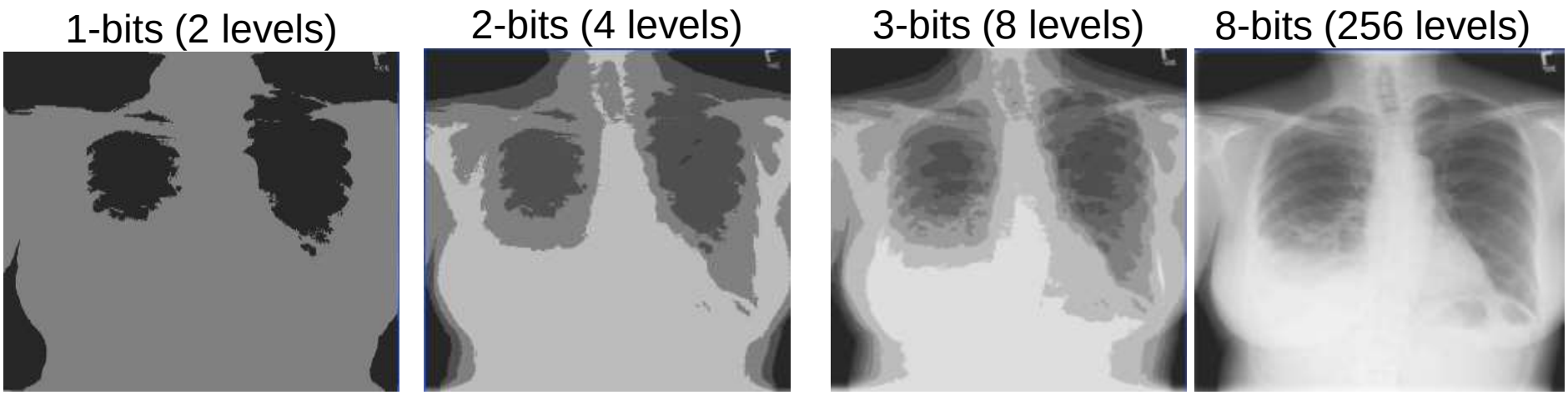
Digital Images: A pixel (picture element) is an addressable location on the screen by gray scale level (more contrast), Houns feld unit, digital value, etc.,

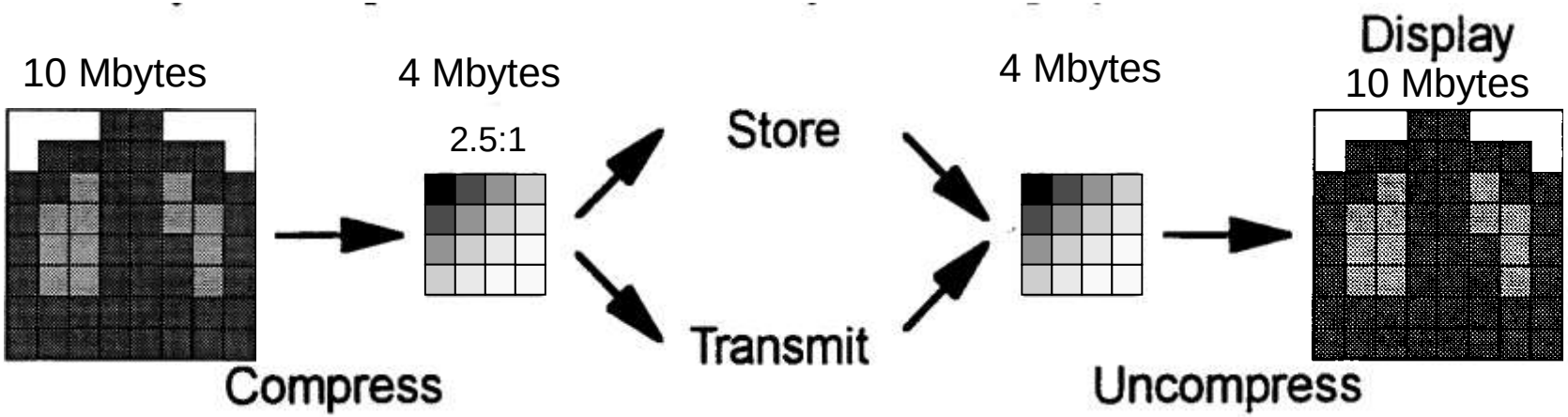
- Imaging modalities with higher spatial resolution require more pixels per image so that image format does not degrade the resolution.
- Images are stored in a 2D array (columns and row), to given each pixel an address.
- Typical CT matrices (bits/pixel)
- Higher bits/pixel means better resolution.
- Pixel size is determined by dividing distance between two points in subject being imaged by number of pixels between these two points.

Modality	Pixel Format	Bits per Pixel
Scintillation camera planar	64^2 or 128^2	8 or 16
SPECT	64^2 or 128^2	8 or 16
PET	128^2	16
Digital fluoroscopy, cardiac catheter lab	512^2 or 1024^2	8 to 12
Computed radiography, digitized chest films	Typically $2,000 \times 2,500$	10–12
Mammography (18×24 cm) or (24×30 cm)	Typically $1,800 \times 2,300$ to $4,800 \times 6,000$	12–16
X-ray CT	512^2	12
MRI	64^2 to $1,024^2$	12
Ultrasound	512^2	8

CT, computed tomography; MRI, magnetic resonance imaging; PET, positron emission tomography; SPECT, single photon emission computed tomography.

Digital Images Contrast Resolution - Pixels





Standard Image Matrices

- **NUCLEAR MEDICINE IMAGES**
  - ✓ **128 x 128 MATRIX**
  - ✓ **256 LEVELS PER PIXEL**
- **MRI IMAGES**
  - ✓ **256 x 256 MATRIX**
  - ✓ **4096 LEVELS PER PIXEL**
- **CT IMAGES**
  - ✓ **512 x 512 MATRIX**
  - ✓ **4096 LEVELS PER PIXEL**
- **ULTRASOUND**
  - ✓ **512 x 512 MATRIX**
  - ✓ **256 LEVELS PER PIXEL**
- **ANGIO & CATH IMAGES**
  - ✓ **1029 x 1029 MATRIX**
  - ✓ **4096 LEVELS PER PIXEL**
- **CR & DR IMAGES**
  - ✓ **2000 x 2000 MATRIX**
  - ✓ **4096 LEVELS PER IMAGE**

Image Processing:

- Output not be visible at all the image date. So, subtraction or addition processing is used in imaging devices.
- Subtraction: each pixel in one image is subtracted from the corresponding image in a second image to yield the corresponding pixel value in the difference image. (Ex: angiography to remove the effects of an atomic structures not of interest from the images of contrast enhanced blood vessels).
- Addition: similar but with pixel by pixel addition instead of subtraction.
- Spatial filtering
  - ✓ Smoothing (removing quantum mottle – noise)
  - ✓ Edge enhancement, e.g., computed radiography (CR)
- Reconstruction from projections
  - ✓ Back-projection, e.g., computed tomography (CT), single photon and positron emission tomography (SPECT and PET)
  - ✓ Fast Fourier Transform, e.g., magnetic resonance imaging (MRI)
- Calculation of physiological performance indices, e.g., nuclear medicine
- Generation and manipulation of volumetric data sets
- Image co-registration (“fusion”), e.g., CT and PET

Computer-Aided Detection:

– Computer program to detect features likely to be of clinical significance in images.

– Computer-aided detection improve sensitivity of interpretation, but also may reduce the specificity.

Image Display:

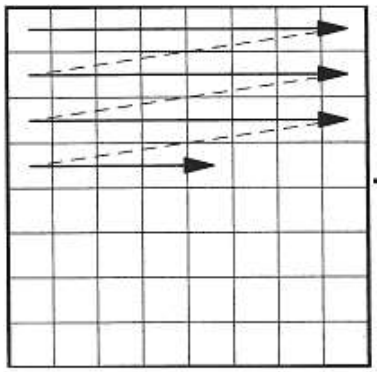
- Conversion of digital Image into an analog video signal.
- Conversion of a digital image matrix in the display card memory (VRAM) into an analog video signal using a digital to analog converter (DAC). Matrix digital values are scanned in raster fashion as a function of time which through the DAC provides a time-varying analog signal.

Gray-Scale Cathode Ray Tube Monitors:

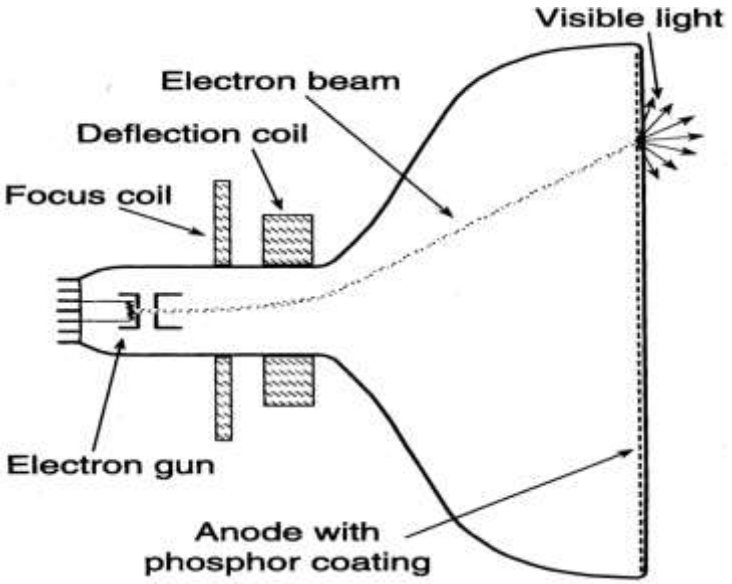
- Gray-scale monitors provide better range of brightness and dynamic range than CRTS color monitors.

Color CRT Monitors:

- Intensity of light is proportional to the electric current in the beam, which is determined by the analog voltage signal applied from the video card.
- A color CRT uses three independent electron guns with tightly clustered red, green and blue phosphor regions.

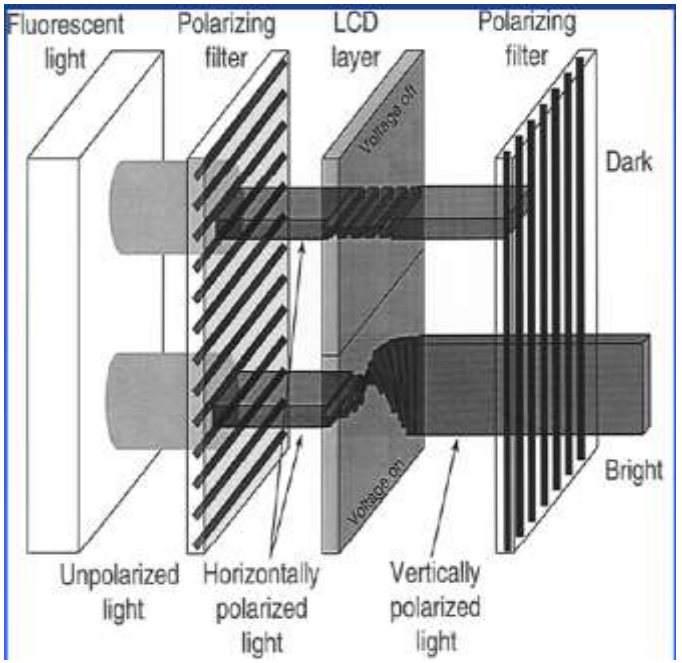


Video display memory
in video interface



Flat Panel Monitors:

- Most flat-panel monitors use liquid crystal display (LCD) technology.
- LCD does not produce light, it modulates the intensity of light from another source.
- The brightest LCDs are backlit, its consists of a uniform light source, typically containing fluorescent tubes, layer of diffusing materials and a two polarizing filters.
- When voltage is applied to the lLC material it rotates incident polarized light.
- This rotated light then passes through another polarizer (90° to the first) so that the input voltage modulates the intensity of fluorescent tube backlight.
- Active matrix LCDs are also called thin-film transistor (TFT) displays.



Contrast Enhancement:

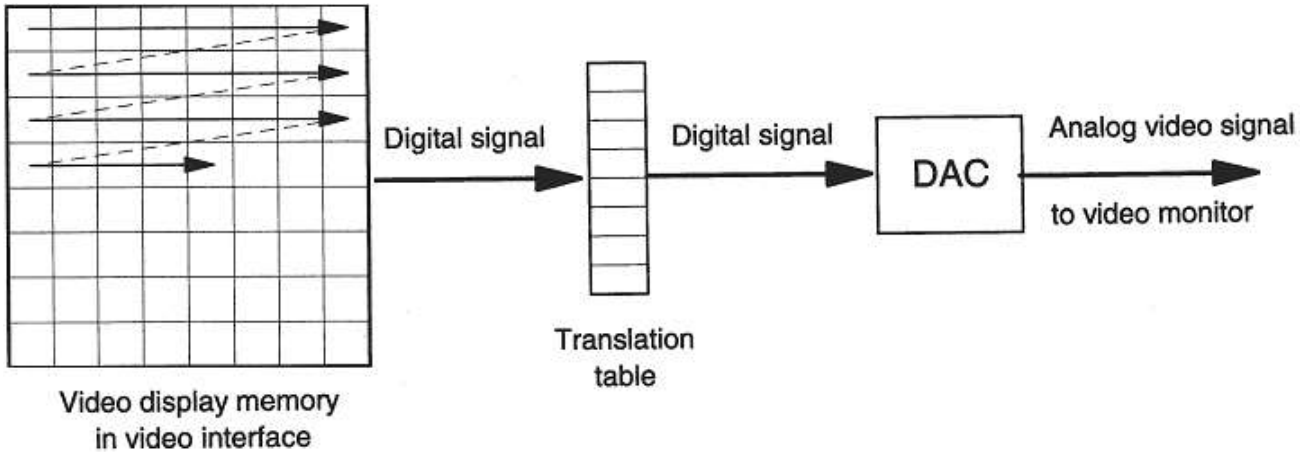
– Amount of choice in how mapping from pixel value to video intensity is to be performed. It is called "contrast enhancement".

– Two methods of contrast enhancement on most medical image-processing computers

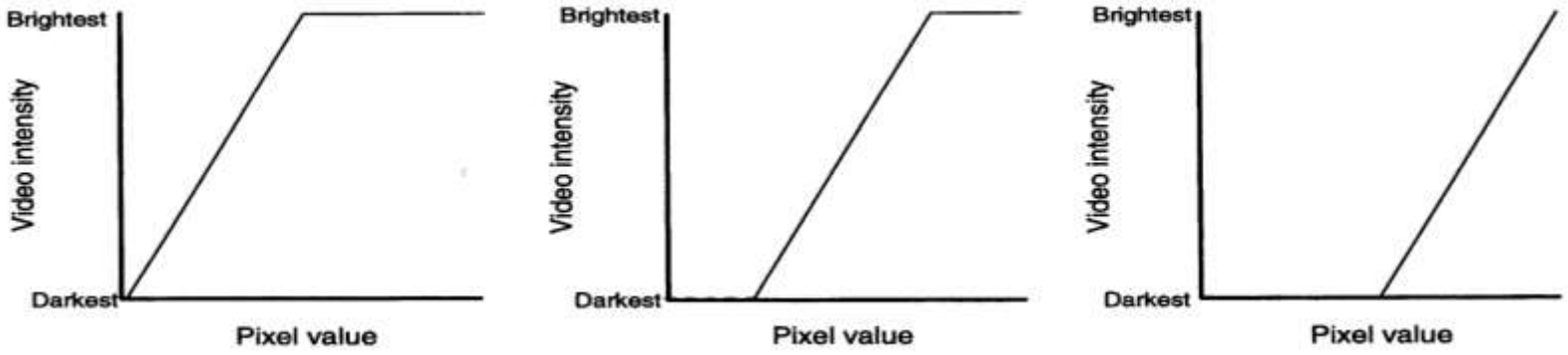
• Translation table selection and

• windowing

- Modification of the translation table causes changes in the displayed image brightness and contrast and is usually done through window (contrast) and level (brightness) controls.

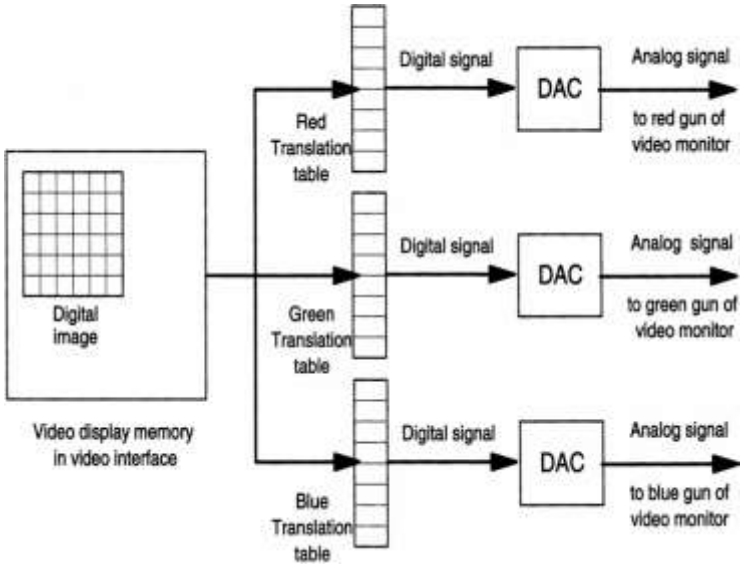


- The window is kept constant as the level is increased, causing the image to become darker and darker.
- The narrower the window, the greater the displayed image contrast.



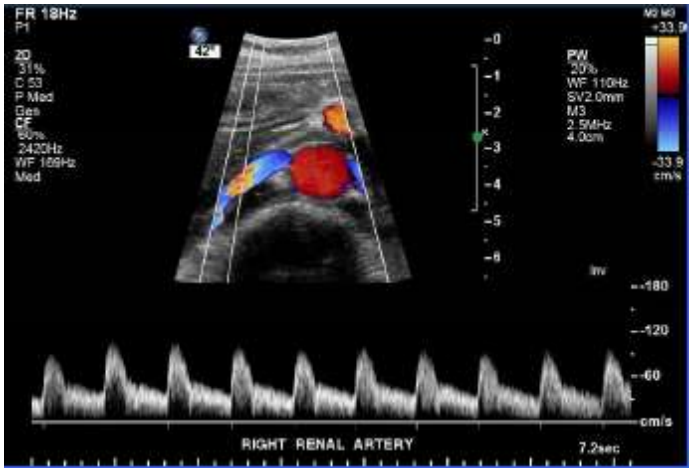
False Color Displays:

- The amplitude of the signals generated in the production of radiographic images do not have inherent color information.
- When color is used to display some aspect of the received signal then the resulting images are called false-color or pseudo-color images.
- Each individual pixel value in image being displayed is used to look up red, green, and blue intensity value.
- These are simultaneously displayed adjacent to one another within a single pixel of color video monitor.
- Mix of these three colors creates perception of single color for that pixel.



Common Uses of False Color include:

- Nuclear medicine, in which color is often used to enhance perception of contrast.
- Ultrasound, in which color is used to superimpose flow information on images displaying anatomic information.



Hard copy devices:

- Hardcopy Devices - permit the recording of digital images on photographic film or paper, e.g., laser imager.
- Digital images recorded on a film with video imager or laser imager.
- Video imager focuses image onto the film.
- Laser imager raster-scans the image onto the film.

PACS and Teleradiology

- Picture Archiving and Communications Systems
- Teleradiology
- Standards
  - ACR Standards for Teleradiology
  - Digital Imaging and Communications in Medicine (DICOM)
- Networks for Image and Data Transfer
- Acquisition of Digital Images
- Storage of Images
  - Data Compression
- Display of images for Interpretation and Consultation

Network interface card (NIC):

- ✓ Network Connection
- ✓ Twisted Pair
- ✓ Coaxial
- ✓ Fiber Optic
- ✓ Wireless

RAM (Random Access Memory): The more you have, the more programs/images can be open at once.

✓ Storage devices: RAM (temporary), hard disks, optical disks (CD-ROM, DVD-ROM), magnetic tape. ROM (Read only memory) (cannot overwrite).

✓ Operating System: Manages all the programs on the computer (i.e. windows, Mac OS).

✓ Modems convert digital signal into frequency coded signals for transmission over phone lines.