MULTIMEDIA SYSTEMS IN ICT

UNIT 2

Multimedia Images & Graphics

An image could be described as two-dimensional array of points where every point is allocated its own color. Every such single point is called pixel, short form of picture element. Image is a collection of these points that are colored in such a way that they produce meaningful information/data. Pixel (picture element) contains the color or hue and relative brightness of that point in the image. The number of pixels in the image determines the resolution of the image.

Types of Images

There are two basic formats of computer graphics: bit-maps and vector graphics. The kind you use determines the tools you choose:

1. **Bitmap formats:** are the ones used for digital photographs.
2. **Vector formats:** are used only for line drawings.

1. **Bit-map images** (also called **Raster Graphics**)

They are formed from pixels, a matrix of dots with different colors. Bitmap images are defined by their dimension in pixels as well as by the number of colors they represent, Figure (3.1).

For example, a 640 x 480 image contains 640 pixels and 480 pixels' in horizontal and vertical direction respectively.

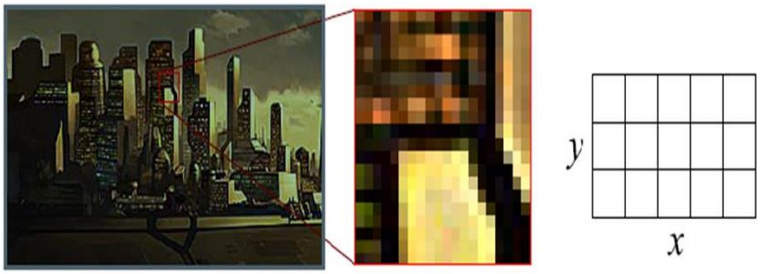


Figure (3.1): Bitmap image

Each of the small pixels can be a shade of gray or a color. Using 24-bit color, each pixel can be set to any one of 16 million colors. All digital photographs and paintings are bit-mapped, and any other kind of image can be saved or exported into a bitmap format. In fact, when you print any kind of image on a laser or ink-jet printer, it is first converted by either the computer or printer into a bitmap form so it can be printed with the dots the printer uses. To edit or modify bit-mapped images you use a paint program. Bitmap images are widely used but they suffer from a few unavoidable problems. They must be printed or displayed at a size determined by the number of pixels in the image. Bitmap images also have large file sizes that are determined by the image's dimensions in pixels and its color depth. To reduce this problem, some graphic formats such as GIF and JPEG are used to store images in compressed format.

2. **Vector Graphics**

They are really just a list of graphical objects such as lines, rectangles, ellipses, or curves called primitives (Figure (3.2)). Draw programs, also called vector graphics programs, are used to create and edit these vector graphics

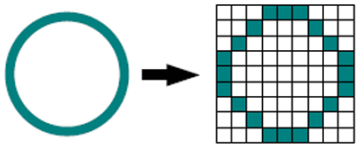


Figure (3.2): Vector graphics

These programs store the primitives as a set of numerical coordinates and mathematical formulas that specify their shape and position in the image. This format is widely used by computer-aided design programs to create detailed engineering and design drawings. It is also used in multimedia when 3D animation is desired.

Graphic/ Image data types

Images can be created by using different techniques of representation of data called data type like monochrome and colored images. Monochrome image is created by using single color whereas colored image is created by using multiple colors. Some important data types of images are as follows:

- **1-bit images:** An image is a set of pixels. Note that a pixel is a picture element in digital image. In 1-bit images, each pixel is stored as a single bit (0 or 1). A bit has only two states either on or off, white or black, true or false. Therefore, such an image is also referred to as a binary image, since only two states are available. 1-bit images are also known as 1-bit monochrome images because it contains one color that is black for off state and white for on state.
  A 1-bit image with resolution 640*480 needs a storage space of 640*480 bits.

  640 x 480 bits. = (640 x 480) / 8 bytes = (640 x 480) / (8 x 1024) KB= 37.5KB.

  The clarity or quality of 1-bit image is very low.

- **8-bit Gray level images:** Each pixel of 8-bit gray level image is represented by a single byte (8 bits). Therefore, each pixel of such image can hold 28=256 values between 0 and 255. Therefore, each pixel has a brightness value on a scale from black (0 for no brightness or intensity) to white (255 for full brightness or intensity). For example, a dark pixel might have a value of 15 and a bright one might be 240.
  A grayscale digital image is an image in which the value of each pixel is a single sample, which carries intensity information. Images are composed exclusively of gray shades, which vary from black being at the weakest intensity to white being at the strongest. Grayscale images carry many shades of gray from black to white. Grayscale images are

also called monochromatic, denoting the presence of only one (mono) color (chrome). An image is represented by bitmap. A bitmap is a simple matrix of the tiny dots (pixels) that form an image and are displayed on a computer screen or printed.
A 8-bit image with resolution 640 x 480 needs a storage space of:
640 x 480 bytes = (640 x 480)/1024 KB = 300KB. Therefore, an 8-bit image needs 8 times more storage space than 1-bit image.

- **24-bit color images:** In 24-bit color image, each pixel is represented by three bytes, usually representing RGB (Red, Green and Blue). Usually true color is defined to mean 256 shades of RGB (Red, Green and Blue) for a total of 16777216 color variations. It provides a method of representing and storing graphical image information an RGB color space such that a colors, shades and hues in large number of variations can be displayed in an image such as in high quality photo graphic images or complex graphics.

  Many 24-bit color images are stored as 32-bit images, and an extra byte for each pixel used to store an alpha value representing special effect information.

  A 24-bit color image with resolution 640 x 480 needs a storage space of 640 x 480 x 3 bytes = (640 x 480 x 3) / 1024=900KB without any compression. Also 32-bit color image with resolution 640 x 480 needs a storage space of 640 x 480 x 4 bytes= 1200KB without any compression.

  Disadvantages
  - Require large storage space
  - Many monitors can display only 256 different colors at any one time. Therefore, in this case it is wasteful to store more than 256 different colors in an image.

- 8-bit color images - 8-bit color graphics is a method of storing image information in a computer's memory or in an image file, where one byte (8 bits) represents each pixel. The maximum number of colors that can be displayed at once is 256. 8-bit color graphics are of two forms. The first form is where the image stores not color but an 8-bit index into the color map for each pixel, instead of storing the full 24-bit color value. Therefore, 8-bit image formats consists of two parts: a color map describing what colors are present in the image and the array of index values for each pixel in the image. In most color maps each color is usually chosen from a palette of 16,777,216 colors (24 bits: 8 red, 8green, 8 blue).

  The other form is where the 8-bits use 3 bits for red, 3 bits for green and 2 bits for blue. This second form is often called 8-bit true color as it does not use a palette at all. When a 24-bit full color image is turned into an 8-bit image, some of the colors have to be eliminated, known as color quantization process.

  A 8-bit color image with resolution 640 x 480 needs a storage space of 640 x 480 bytes=(640 x 480) / 1024KB= 300KB without any compression.

Color lookup tables

A color loop-up table (LUT) is a mechanism used to transform a range of input colors into another range of colors. Color look-up table will convert the logical color numbers stored in each pixel of video memory into physical colors, represented as RGB triplets, which can be displayed on a computer monitor. Each pixel of image stores only index value or logical color number. For example, if a pixel stores the value 30, the meaning is to go to row 30 in a color look-up table (LUT). The LUT is often called a Palette.

Characteristic of LUT are following:

- The number of entries in the palette determines the maximum number of colors which can appear on screen simultaneously.
- The width of each entry in the palette determines the number of colors which the wider full palette can represent.

A common example would be a palette of 256 colors that is the number of entries is 256 and thus each entry is addressed by an 8-bit pixel value. Each color can be chosen from a full palette, with a total of 16.7 million colors that is each entry is of 24 bits and 8 bits per channel which sets the total combinations of 256 levels for each of the red, green and blue components 256 x 256 x 256 =16,777,216 colors.

Popular File Formats

i. GIF - Graphics Interchange Formats

The GIF format was created by CompuServe. It supports 256 colors. GIF format is the most popular on the Internet because of its compact size. It is ideal for small icons used for navigational purpose and simple diagrams. GIF creates a table of up to 256 colors from a pool of 16 million. If the image has less than 256 colors, GIF can easily render the image without any loss of quality. When the image contains more colors, GIF uses algorithms to match the colors of the image with the palette of optimum set of 256 colors available. Better algorithms search the image to find and the optimum set of 256 colors.

Thus GIF format is lossless only for the image with 256 colors or less. In case of a rich, true color image GIF may lose 99.998% of the colors. GIF files can be saved with a maximum of 256 colors. This makes it is a poor format for photographic images.

GIFs can be animated, which is another reason they became so successful. Most animated banner ads are GIFs. GIFs allow single bit transparency that is when you are creating your image, you can specify which color is to be transparent. This provision allows the background colors of the web page to be shown through the image.

ii. JPEG - Joint Photographic Experts Group

The JPEG format was developed by the Joint Photographic Experts Group. JPEG files are bitmapped images. It stores information as 24-bit color. This is the format of choice for nearly all

photograph images on the internet. Digital cameras save images in a JPEG format by default. It has become the main graphics file format for the World Wide Web and any browser can support it without plug-ins. In order to make the file small, JPEG uses lossy compression. It works well on photographs, artwork and similar materials but not so well on lettering, simple cartoons or line drawings. JPEG images work much better than GIFs. Though JPEG can be interlaced, still this format lacks many of the other special abilities of GIFs, like animations and transparency, but they really are only for photos.

iii. PNG - Portable Network Graphics

PNG is the only lossless format that web browsers support. PNG supports 8 bit, 24 bits, 32 bits and 48 bits data types. One version of the format PNG-8 is similar to the GIF format. But PNG is the superior to the GIF. It produces smaller files and with more options for colors. It supports partial transparency also. PNG-24 is another flavor of PNG, with 24-bit color supports, allowing ranges of color akin to high color JPEG. PNG-24 is in no way a replacement format for JPEG because it is a lossless compression format. This means that file size can be rather big against a comparable JPEG. Also PNG supports for up to 48 bits of color information.

iv. TIFF - Tagged Image File Format

The TIFF format was developed by the Aldus Corporation in the 1980 and was later supported by Microsoft. TIFF file format is widely used bitmapped file format. It is supported by many image editing applications, software used by scanners and photo retouching programs.

TIFF can store many different types of image ranging from 1 bit image, grayscale image, 8 bit color image, 24 bit RGB image etc. TIFF files originally use lossless compression. Today TIFF files also use lossy compression according to the requirement. Therefore, it is a very flexible format. This file format is suitable when the output is printed. Multi-page documents can be stored as a single TIFF file and that is way this file format is so popular. The TIFF format is now used and controlled by Adobe.

v. BMP - Bitmap

The bitmap file format (BMP) is a very basic format supported by most Windows applications. BMP can store many different type of image: 1 bit image, grayscale image, 8 bit color image, 24 bit RGB image etc. BMP files are uncompressed. Therefore, these are not suitable for the internet. BMP files can be compressed using lossless data compression algorithms.

vi. EPS - Encapsulated Postscript

The EPS format is a vector based graphic. EPS is popular for saving image files because it can be imported into nearly any kind of application. This file format is suitable for printed documents. Main disadvantage of this format is that it requires more storage as compare to other formats.

vii. PDF - Portable Document Format

PDF format is vector graphics with embedded pixel graphics with many compression options. When your document is ready to be shared with others or for publication. This is only format that is platform independent. If you have Adobe Acrobat, you can print from any document to a PDF file. From illustrator you can save as .PDF.

viii. EXIF - Exchange Image File

Exif is an image format for digital cameras. A variety of tags are available to facilitate higher quality printing, since information about the camera and picture - taking condition can be stored and used by printers for possible color correction algorithms.it also includes specification of file format for audio that accompanies digital images.

ix. WMF - Windows MetaFile:

WMF is the vector file format for the MS-Windows operating environment. It consists of a collection of graphics device interface function calls to the MS-Windows graphic drawing library. Metafiles are both small and flexible, hence images can be displayed properly by their proprietary software only.

x. PICT

PICT images are useful in Macintosh software development, but you should avoid them in desktop publishing. Avoid using PICT format in electronic publishing-PICT images are prone to corruption.

xi. Photoshop

This is the native Photoshop file format created by Adobe. You can import this format directly into most desktop publishing applications.

How to store the original gray scale images into new format (e.g. 8 bits per pixel to 48 bits per pixel in RGB)

1. Grayscale Image (8-bit per pixel)

- Each pixel is stored using **8 bits (1 byte)**.
- Value range: **0 (black) → 255 (white)**.
- Only one channel exists: **Intensity (brightness)**.
- Example: A pixel with value 120 means medium gray.

2. RGB Image (48-bit per pixel)

- An RGB image has **3 color channels**: Red, Green, and Blue.
- In a **48-bit image**, each channel uses **16 bits**.
- Total = **16 × 3 = 48 bits per pixel**.
- Value range: **0 – 65,535** for each channel.

3. Conversion Process (8-bit → 48-bit RGB)

a. **Start with the grayscale value (0–255)**.
   - Example: Pixel = `120`.

b. **Expand the value to 16 bits**.
   - 8-bit max = 255
   - 16-bit max = 65,535.

- **The Scaling Factor:**

  To map one scale into the other:

$$\text{Scaling Factor} = \frac{65,535}{255} \approx 257$$

So every grayscale value is multiplied by **257** to fit into 16-bit.

- Multiply the grayscale value by a scaling factor to fit the 16-bit range.
- Example: `120 → 120 × 257 ≈ 30,840`.

c. **Copy the value into all three channels (R, G, B)**.
   - R = 30,840
   - G = 30,840
   - B = 30,840

d. **Store as 48-bit RGB**.
   - The pixel visually looks **gray** (since R = G = B), but technically it's in full **48-bit RGB format**.

Video, Audio, Sound, and Digitization

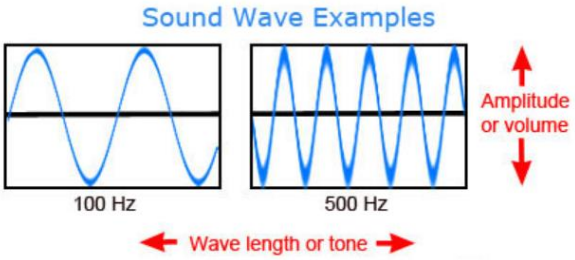
What is a video?
A video is a multimedia format that combines visual images and sound to convey information, tell a story, or provide entertainment. It is typically recorded, stored, and played back on electronic devices such as cameras, smartphones, computers, or televisions. Videos can range from short clips, like social media videos, to long-form content, such as movies, documentaries, or instructional videos.

What is audio?
Audio is sound that is within the acoustic range of human hearing. It is the audible portion on the spectrum of sound frequencies, distinct from inaudible sounds heard by certain animals or used in science and medicine. An elephant, for example, can hear sounds at lower frequencies than humans, and porpoises can hear sounds at higher frequencies. In both cases, they hear sounds that fall outside the range of human hearing.

Sound is a form of mechanical energy that travels in waves through air and other substances. It is measured in hertz (Hz), with one Hz equal to one full wave cycle per second. Humans can hear only a portion of the full spectrum of sound frequencies. The audio portion is typically between 20 to 20,000 Hz, but aging and hearing damage can shorten this range.

What is Sound?
A sound refers to a vibration that is picked up by the human ear. As a sound is generated, it is blasted in waves that vibrate in a frequency measured in hertz (Hz). In the picture below is two

sound waves, the lower tone (longer wave) on the left and the higher tone (shorter wave) on the right. For example, a very low deep base sound could be 30 Hz and a high or an upper treble sound could be 2.6 kHz. The average human can hear between 15 Hz to 20 kHz.



Computers generate sound using a sound card that is either connected to headphones or speakers to output the sound.

Digitization

Digitization is the process of converting analog signals (continuous forms like natural sound or light) into digital form (discrete binary data: 0s and 1s) that a computer can store, process, and transmit. This involves transforming analog data, such as paper documents, photographs, or audio recordings, into digital files that can be easily stored, processed, and accessed by computers and other digital devices. Digitization makes multimedia content editable, storable, sharable, and reproducible without quality loss.

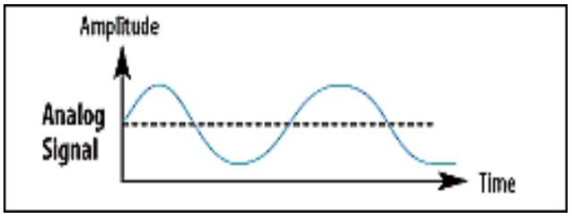
Examples:

- Scanning a printed photo into a digital JPEG.
- Converting a cassette tape into MP3 format.
- Recording a lecture on a smartphone (sound → digital file).

Video standards

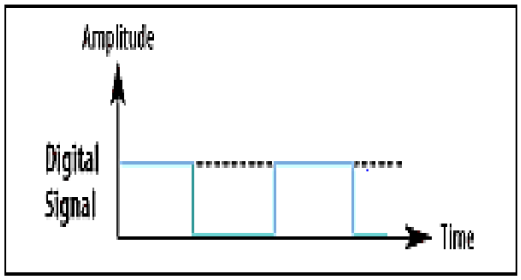
1. **Analog Video**

Analog is the process of taking audio or video signal and translating it into electrical pulses. In an analog system, the output of the CCD (Charge Coupled Devices) is processed by the camera into three channels of color information and synchronization pulses (sync) and the signals are recorded onto magnetic tape. Three analog broadcast video standards commonly in use around the world are: National Television Standards Committee (NTSC), Phase Alternating Line (PAL), and Sequential Color and Memory (SECAM).



2. Digital Video

Digital video is a sequence of picture signals (frames) that are represented by binary data (bits) that describe a finite set of color and luminance levels. The digital information contains characteristics of the video signal and the position of the image (bit location) that will be displayed. The basic process of creating digital video is the image digitization process, compression analysis that produces key frames and difference frames, and formatting the data into files or streams (video formats). It supports high-definition (HD) and even ultra-high-definition (UHD) resolutions like MP4, AVI, MKV, Blu-ray, streaming services (YouTube, Netflix).



Types of Video signals

Video signals are electrical signals that transmit video information from a source to a display device. They are used in a wide range of applications, from television broadcasting to surveillance systems. The quality of the video signal is determined by various factors such as resolution, color depth, and refresh rate. There are several types of video signals used in different applications, each with its unique features and specifications. Video Signals can be classified as:

1. Composite Video
2. S-Video
3. Component Video

1. Composite Video Signal:

Composite video signal is the most basic type of video signal. It consists of a single signal that carries all the video information, including the color and brightness. The composite video signal is typically transmitted using an RCA (Radio Corporation of America) connector or a BNC connector. The signal is not separated into different components, which means that it has lower quality compared to other types of video signals.



Figure 1: RCA connector

Composite video signal is widely used in consumer electronics such as DVD players, VCRs, and older TVs. It has a resolution of 480i and a refresh rate of 60Hz.

Advantages:

- Low cost of implementation
- Compatible with a wide range of devices
- Can be transmitted over long distances

Disadvantages:

- Poor video quality compared to digital signals
- Prone to noise and interference
- Limited color resolution

2. S-Video Signal:

S-Video signal, also known as Y/C signal, is an improvement over the composite video signal. It splits the video into **two separate signals**:

- Luminance (Y) → brightness details.
- Chrominance (C) → color details.

It separates the color and brightness information into two separate signals. This separation improves the image quality by reducing the color bleeding and improving the sharpness of the image.

S-Video signal is transmitted using a 4-pin mini-DIN connector. It has a resolution of 480i and a refresh rate of 60Hz. S-Video signal is commonly used in older TVs, camcorders, and video game consoles.

Advantages:

- Better video quality than composite video
- Reduced noise and interference
- Improved color resolution

Disadvantages:

- Not as widely supported as composite video
- Limited resolution compared to digital signals

3. Component Video Signal:

Component video signal is an analog video signal that separates the video information into three separate signals: red, green, and blue (RGB). This separation allows for higher quality video transmission compared to composite and S-video signals.

Component video signal is typically transmitted using three RCA connectors or three BNC connectors. It has a resolution of 480p, 720p, or 1080i, depending on the device. Component video signal is commonly used in high-definition TVs, DVD players, and video game consoles.

Advantages:

- Excellent video quality
- High color resolution
- Reduced noise and interference

Disadvantages:

- Requires three cables to transmit the signal
- Not as widely supported as composite video

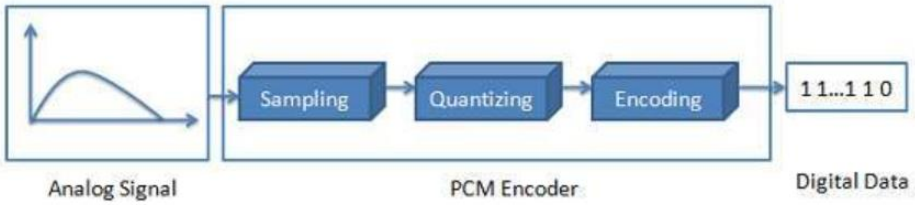
Differences between Analog and Digital video

Feature	Analog Video	Digital Video
Nature of Signal	Continuous electrical waveforms	Discrete binary data (0s and 1s)
Quality	Degrades over distance/copies	Consistent quality, lossless duplication
Editing	Difficult, needs special equipment	Easy, done on computers with software
Storage	Physical tapes/discs, bulky	Compact files (MP4, AVI), cloud storage
Transmission	Broadcast over radio/TV signals	Over internet, HDMI, satellite
Noise Interference	Highly susceptible to noise	Resistant to noise (error correction used)
Examples	VHS, NTSC, PAL, SECAM	MP4, Blu-ray, YouTube, Netflix

Digitalization of Sound

Digitalization of sound refers to the process of converting analog sound waves into digital signals that can be stored, manipulated, and reproduced using digital technology. Analog sound waves are continuous, meaning they are a continuous stream of electrical signals that fluctuate in amplitude and frequency. In contrast, digital signals are discrete, meaning they are a series of binary digits (0's and 1's) that represent the amplitude and frequency of the original sound wave.

How Does Digitalization of Sound Work?
The process of digitalizing sound involves three main steps: sampling, quantization, and encoding.



1. **Sampling:** The first step in digitalizing sound is to sample the analog signal at a regular interval. This is done using an analog-to-digital converter (ADC), which measures the amplitude of the signal at regular intervals and converts it into a digital value. The rate at which the signal is sampled is known as the sampling rate, and it is typically measured in Hertz (Hz). The higher the sampling rate, the more accurately the digital signal will represent the original analog signal.

2. **Quantization:** The second step in digitalizing sound is to quantize the digital signal. This involves converting the continuous range of amplitude values into a finite number of discrete levels. The number of levels is determined by the bit depth of the digital signal, which is typically 16 bits or 24 bits. The more bits used, the more accurately the digital signal will represent the original analog signal.

3. **Encoding:** The final step in digitalizing sound is to encode the digital signal into a format that can be stored and processed by digital devices. This is typically done using a codec (coder-decoder), which compresses the digital signal into a smaller file size for storage and transmission.

Audio Filtering

Audio Filtering refers to the process of modifying or shaping an audio signal by allowing certain frequencies to pass through while reducing or eliminating others. It is widely used in sound engineering, communication systems, music production, hearing aids, and multimedia applications to improve sound quality or achieve specific audio effects.

Purpose:

- To remove unwanted noise.
- To enhance desired audio frequencies.
- To prepare signals for further processing (e.g., compression, transmission).

Types of Audio Filters:

1. **Low-Pass Filter (LPF):** Allows low frequencies to pass while attenuating (reducing) high frequencies. Example: removing hiss from recordings.
2. **High-Pass Filter (HPF):** Allows high frequencies to pass while attenuating low frequencies. Example: eliminating hum or rumble from microphones.

3. **Band-Pass Filter (BPF):** Allows only a specific range of frequencies to pass. Example: isolating speech frequencies in telecommunication.
4. **Band-Stop / Notch Filter:** Eliminates a specific narrow frequency range. Example: removing 50/60 Hz electrical interference.
5. **All-Pass Filter:** Keeps all frequencies but changes the phase of signals; used in audio effects like reverb.

Applications of Audio Filtering:

- Noise reduction in recordings.
- Equalization (bass, mid, treble adjustment in music systems).
- Improving clarity in telecommunication and broadcasting.
- Enhancing voice or instruments in audio production.
- Medical devices (e.g., filtering heart or brain signals for analysis).

Audio Quality versus Data Rate

Audio Quality

Audio Quality refers to how clear, accurate, and natural the sound is to human ears. High audio quality means the sound is closer to the original source (less distortion, more detail). It depends on factors like:

- ✓ Sampling Rate (how many times per second audio is captured, e.g., 44.1 kHz, 48 kHz).
- ✓ Bit Depth (precision of each sample, e.g., 16-bit, 24-bit).
- ✓ Compression (lossless vs lossy).

Data Rate (Bitrate)

Data Rate is the amount of digital data transferred or processed per second to represent audio or video. It is measured in kbps (kilobits per second) or Mbps (megabits per second).

Example:

- MP3 at 128 kbps = smaller file, lower quality.
- MP3 at 320 kbps = larger file, higher quality.

Thus,

- ✓ Higher data rate → higher audio quality, because more bits are used to represent the sound (less compression, more detail).
- ✓ Lower data rate → lower audio quality, since compression removes parts of the sound (often high frequencies) to save space.

Examples

- Telephone Audio: ~8 kbps (low data rate, low quality, only voice frequencies kept).
- FM Radio: ~128 kbps equivalent (medium quality).
- CD Quality: 1,411 kbps (44.1 kHz, 16-bit, stereo, uncompressed).
- Studio Quality: Even higher (96 kHz, 24-bit).

Audio quality versus data rate

Data Rate (kbps)	Audio Quality	Use Case and Commentary
8–32 kbps	Very low	Best for voice-only content like walkie-talkie transmissions or very low-quality internet streaming. Quality is significantly compromised.
64 kbps	Low	Similar to AM radio quality. Often used for podcasts or basic streaming where high fidelity is not required.
96–160 kbps	Mid-range	Audible loss for trained ears, but generally acceptable for casual listening. Used by some streaming services and for low-quality MP3s.
192 kbps	Medium-high	Considered good quality for most listeners. The loss is not significant for most people. A standard for many streaming services.
256 kbps	High	A commonly used high-quality bitrate for streaming music and high-quality downloads.
320 kbps	Highest MP3	The maximum quality supported by the MP3 standard, often considered indistinguishable from CD quality for most listeners.
1,411 kbps	CD quality	Uncompressed, lossless quality that is the standard for audio CDs and WAV files. Offers the greatest detail and dynamic range but results in very large file sizes.
>1,411 kbps	High-resolution	Lossless formats that exceed CD quality, such as 24-bit/96kHz or 24-bit/192kHz audio. Captures even more detail for professional production and audiophiles, but requires a large amount of storage and bandwidth.

Musical Instrument Digital Interface (MIDI)

MIDI (Musical Instrument Digital Interface) is a standard protocol used for communication between digital musical instruments, computers, and other related devices. It was first introduced in 1983 by a group of manufacturers, including Roland, Yamaha, and Korg. MIDI has become an essential component of modern music production, allowing for easy communication between instruments, software, and hardware.

What is MIDI?
MIDI is a digital language that allows electronic musical instruments to communicate with each other. It is a set of protocols that define the format and timing of musical data transmission between devices. MIDI messages are transmitted in a series of digital signals, containing information such as pitch, duration, volume, and modulation. These messages can be sent and received by any device that supports the MIDI protocol.

MIDI messages can be triggered by a variety of sources, including electronic keyboards, drum machines, and software sequencers. Once a MIDI message is triggered, it can be transmitted to other devices, allowing for complex musical arrangements to be created. MIDI data can be stored in a computer or sequencer, edited, and played back as needed.

How does MIDI work?
MIDI is a digital language that uses a set of protocols to define the format and timing of musical data transmission. MIDI data is transmitted over a standard 5-pin DIN cable or a USB cable. MIDI messages are sent and received by devices that support the MIDI protocol. When a MIDI message is received by a device, it is interpreted by the device's microprocessor and used to generate a sound or trigger an action.

MIDI messages contain information about the note played, its duration, and its velocity. MIDI also supports control messages that can change the way a note is played. For example, MIDI messages can be used to change the volume or the modulation of a note.

MIDI devices can be connected to each other in a variety of configurations. For example, a keyboard can be connected to a computer, which can then be connected to a synthesizer. This allows the keyboard to control the synthesizer's sound and to record MIDI data on the computer for later playback.

Types of MIDI messages:
There are several types of MIDI messages that can be sent between devices. These include:

1. **Note On/Note Off messages:** These messages are used to trigger a sound when a note is played on a keyboard or other MIDI device. The Note On message contains information about the note being played, its velocity, and its channel. The Note Off message tells the receiving device to stop playing the note.

2. **Control Change messages:** These messages are used to change the way a note is played. For example, a Control Change message can be used to change the volume or the modulation of a note.

3. **Program Change messages:** These messages are used to change the sound of a device. For example, a Program Change message can be used to switch between different instrument sounds on a synthesizer.

4. **Pitch Bend messages:** These messages are used to change the pitch of a note. Pitch Bend messages can be used to create subtle variations in pitch or to create dramatic pitch shifts.

Advantages of MIDI:

MIDI has several advantages over traditional analog recording and playback methods. These advantages include:

1. **Flexibility:** MIDI data can be edited and modified, allowing for precise control over musical arrangements. MIDI data can be easily copied, pasted, and rearranged, allowing for quick experimentation and creative freedom.

2. **Compatibility:** MIDI is a standard protocol that is supported by a wide range of devices and software. This makes it easy to connect and integrate different musical devices and software applications.

3. **Efficiency:** MIDI data is small in size and can be easily stored and transferred. This makes it ideal for use in music production, where large amounts of data must be processed and stored.

4. **Non-destructive editing:** MIDI data can be edited without altering the original audio file. This means that changes can be made to a track without permanently altering the sound of the original recording.

5. **Automation:** MIDI data can be used to automate various aspects of a musical performance, such as changing the volume, panning, or effects of a track. This allows for more dynamic and expressive performances.

Disadvantages of MIDI:

1. **Limited Sound Quality:** MIDI data only contains information about the notes and control messages. It does not contain any audio information, such as the timbre or character of a sound. This means that MIDI files cannot capture the nuances of a live performance or the unique characteristics of different instruments.

2. **Latency:** MIDI data can experience latency, or a delay between the time a note is played and when it is heard. This delay can be exacerbated by slow or overloaded computer systems, which can affect the timing and accuracy of musical performances.

3. **Complexity:** MIDI can be complex and difficult to understand for beginners. Learning how to use MIDI software and hardware requires a certain level of technical knowledge and skill.
4. **Dependence on Technology:** MIDI relies on hardware and software to function properly. If a MIDI device or software application fails, it can disrupt a performance or production.

5. **Limited Expression:** MIDI messages can only convey a limited range of musical expression. For example, subtle variations in a performer's playing, such as vibrato or inflection, cannot be captured by MIDI data alone.

Uses of MIDI:
MIDI is used in a wide range of musical applications, including:

- **Music production:** MIDI is used extensively in music production to create, edit, and arrange musical compositions. It is often used in conjunction with software sequencers and digital audio workstations (DAWs).
- **Live performance:** MIDI is used in live performance to trigger sounds and control various aspects of a performance, such as changing the tempo or the key of a track.
- **Sound design:** MIDI is used in sound design to create and manipulate sound effects and other audio elements. It is often used in conjunction with software synthesizers and samplers.
- **Education:** MIDI is used in music education to teach students about music theory and composition. It is often used in conjunction with software tools that allow students to create and edit their own musical compositions.

Quantization and Transmission of Audio

1. Quantization of Audio

Quantization is the process of converting sampled audio values (which are continuous in amplitude) into discrete numerical values so that they can be represented and stored in digital form.

Steps in Quantization

a) Sampling

- The continuous sound wave is measured at fixed time intervals (e.g., 44,100 times per second in CD audio)
- Each measurement = one "sample".
- The higher the sampling rate, the more accurately the sound wave is captured.

b) Quantization

- Each sample has an amplitude (loudness level).
- Since computers cannot store infinite values, these amplitudes are rounded (mapped) to the nearest **discrete level**.
- Number of levels = $\mathbf{2^{bit\ depth}}$
  - 8-bit → 256 levels.
  - 16-bit → 65,536 levels.
  - 24-bit → over 16 million levels.

c) Encoding

- Each quantized sample is then encoded into binary (0s and 1s).
- Example: A 16-bit audio sample may be stored as `1001011010100110`.

Why Quantization Matters

- Higher bit depth → more levels → smoother and more accurate sound.
- Lower bit depth → more rounding → distortion (called quantization noise).

2. Transmission of Audio

Once audio has been quantized and encoded, it is ready to be stored, processed, or transmitted. Transmission refers to sending the digital audio data from one place to another.

a) Traditional Analog Transmission

- Used in old systems like AM/FM radio or cassette tapes.
- Sound is transmitted as a continuous wave.
- Limitation: Noise, interference, and signal loss easily affect quality.

b) Digital Transmission (Modern Systems)

- Audio is transmitted as binary data.
- Advantages:
  - ✓ More resistant to noise.
  - ✓ Easier to compress, encrypt, and transmit over long distances.
  - ✓ Supports higher quality.

Examples of Digital Transmission:

- Over Networks: VoIP (Skype, Zoom), Online music streaming.
- Wireless: Bluetooth headphones, Wi-Fi streaming.
- Broadcasting: Digital radio (DAB), digital TV.

c) Compression for Efficient Transmission

- Raw digital audio is very large.
  - ➢ Example: 1 minute of CD-quality stereo audio = ~10 MB.
- To save bandwidth and storage, compression is applied:
  - ➢ Lossless Compression: FLAC, ALAC (keeps all data).
  - ➢ Lossy Compression: MP3, AAC (removes inaudible parts to reduce size).
- Compression helps transmit audio smoothly over the internet (e.g., Spotify, YouTube).

d) Methods of Transmission

1. ***Streaming*** – Audio is sent in real-time as small packets. The user can listen almost immediately.
   - ➢ Example: Online radio, Zoom meetings, Spotify.

2. ***Downloading*** – Entire file is transmitted first, then played.
   - ➢ Example: Downloading an MP3 file.