Digital Technology

Lecture 01

BIL464 Multimedia Systems

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Overview

- Analog to Digital Conversion
- Data Storage
- Data Communication

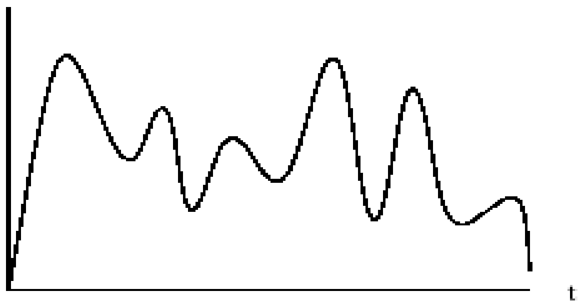
Analog vs Digital

- Analog signals are continuous—like a steady stream of water, a line on a graph, or a continuously rotating dial on a radio. With analog phenomena, there is no clear separation between one point and the next; in fact, between any two points, an infinite number of other points exist.
- Discrete signals, on the other hand, *are* clearly separated. There's a point (in space or time), and then there's a neighboring point, and there's nothing between the two. A live orchestra presents music to us in analog form, as continuous sound waves. A standard microphone is an analog device, detecting and recording sounds over time and transmitting them as a continuous wave of varying voltages.

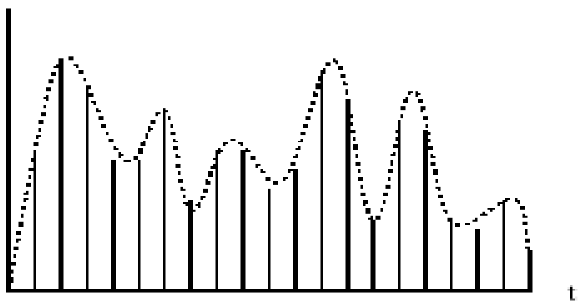
Analog to Digital Conversion

- However, we need to find a way to represent continuous signals in computers. That is digital representation, i.e., we use a series of numbers to represent the continuous signals.
- Converting the continuous data of images, sound, and motion into a discrete representation that can be handled by a computer is called analog-to-digital conversion.

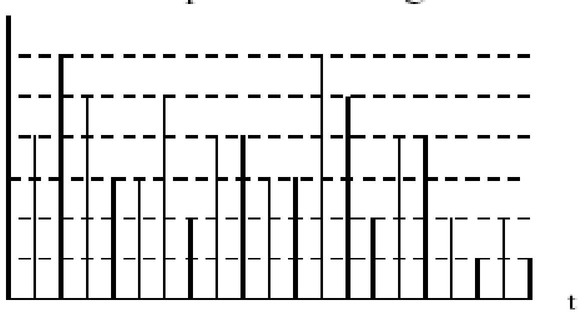
Analog to Digital Conversion – *Cont.*



A Continuous Signal



Samples of the signal



Quantised Samples

- The first step in the digitisation process is sampling, which takes samples of the continuous signal.
- The number of samples taken during a time period is known as sampling rate.
- The second step is known as quantisation, where we restrict the value of the samples to a fixed set of levels.

Analog to Digital Conversion – *Cont.*

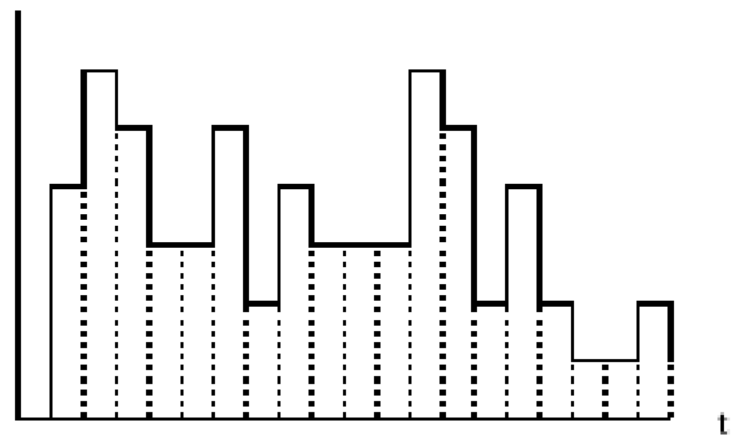
- Regardless of the medium, analog-to-digital conversion requires the same two steps: sampling and quantization.
  - The first step, **sampling**, chooses discrete points at which to measure a continuous phenomenon (which we will also call a ***signal***). In the case of images, the sample points are evenly separated in space. In the case of sound, the sample points are evenly separated in time. The number of samples taken per unit time or unit space is called the ***sampling rate*** or, alternatively, the ***resolution***.
  - The unit of sampling rate is Hertz (Hz), i.e., 1Hz means taking one sample per second. For many signals, this is far too slow, therefore, we often use kHz, i.e., kiloHertz.

Analog to Digital Conversion – *Cont.*

- The second step, quantization, requires that each sample be represented in a fixed number of bits, called the sample size, or, equivalently, the bit depth. The bit depth limits the precision with which each sample can be represented.
  - Because modern digital computers often store data in bytes, each sample is usually stored using either 8 bits (1 byte) or 16 bits (2 bytes). This corresponds to either 256 or 65536 levels for a digitised sample.
- The device that we use to convert analogue signal to digital signal is known as an *analogue-to-digital converter* (ADC).

Analog to Digital Conversion – *Cont.*

- After being processed by the computer, the signal will be played-back, i.e., we need to reconstruct the signal from the digital representation.
  - One commonly used technique is known as sample and hold.
- In order to reconstruct a signal that is as closed to the original signal as possible, we need to take sufficiently many samples, and we need to have as many levels to record the sample values in as possible.



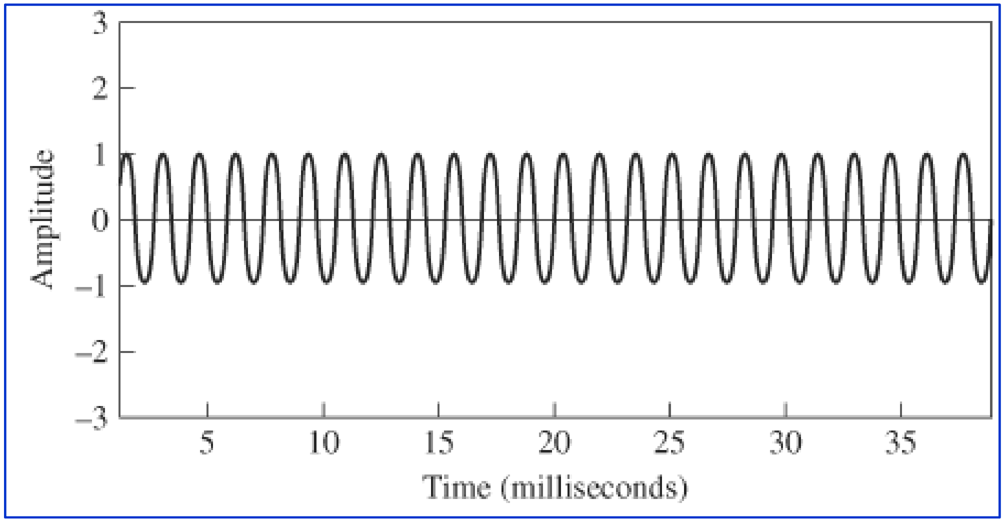
Sample and hold reconstruction

Analog to Digital Conversion – *Cont.*

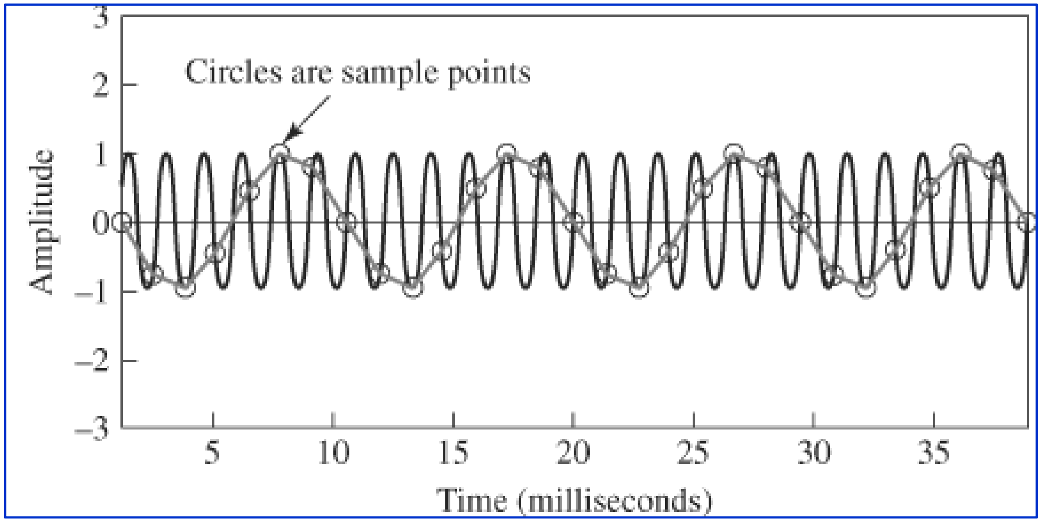
- The Nyquist Sampling Theorem tells us that, in order to reconstruct the signal, the sampling rate must not be less than twice the maximum frequency of the original signal.
- For instance, if the maximum frequency is 3000Hz, the sampling rate must not be less than 6000Hz.
- If we undersample, i.e., taking less samples than as required by Nyquist sampling theorem, some of the frequency components will be mistakenly converted into other frequencies. This is known as aliasing.

Analog to Digital Conversion – *Cont.*

- Aliasing in a sound wave is depicted in the below figures:



Audio wave at 637 Hz



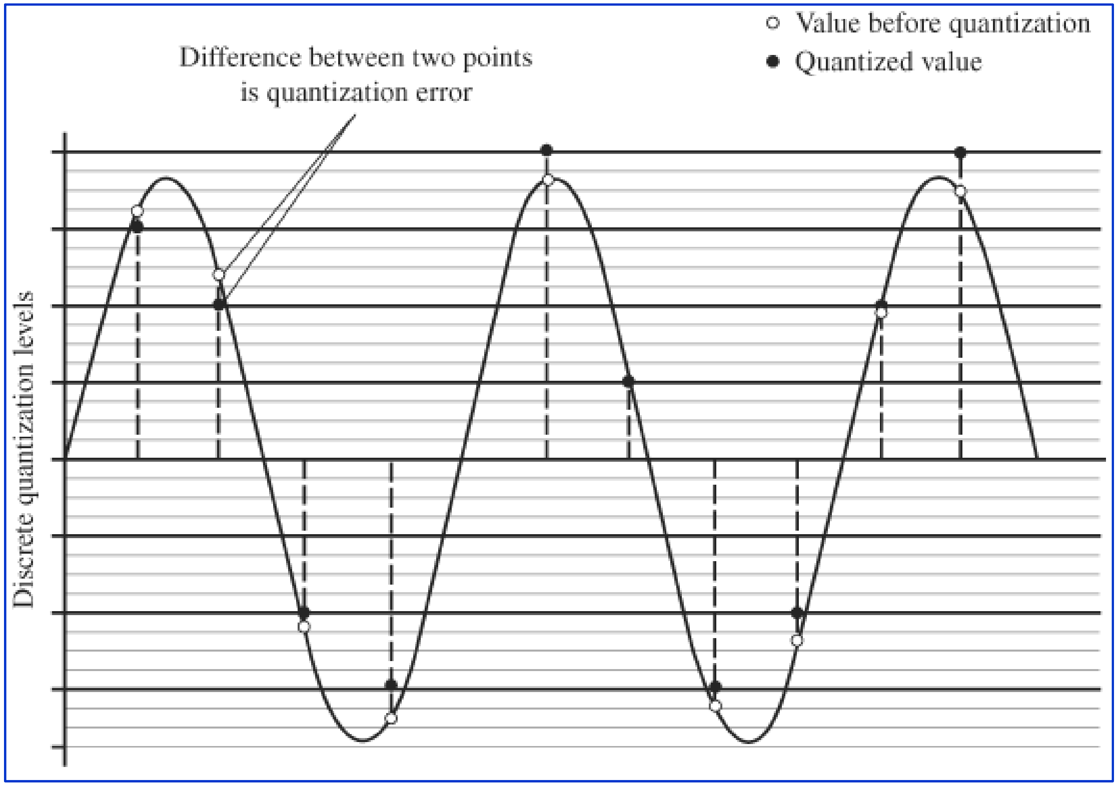
637 Hz audio wave sampled at 770 Hz

- The lower-frequency wave connected through the circles is the aliased frequency that results from reconstructing the wave from too few samples. This is obviously not the original wave, and because the wave reconstructed from the samples has a different frequency from the original, it won't sound the same.

Analog to Digital Conversion – *Cont.*

- If we use too few levels to represent each sample value, there will be large amount of error for each sample. The samples, which are taken at evenly spaced points in time, can take on the values only at the discrete quantization levels on the y-axis. A sample must be rounded to the closest discrete level. The difference between its actual value and its rounded value (represented by pairs of points parallel to the y-axis in the figure) is the quantization error.

Quantization error



Analog to Digital Conversion – *Cont.*

- The amount of error implicit in a chosen bit depth can be measured in terms of the signal-to-noise ratio (SNR). It also defines the quality of a sample. The higher the resolution, the smaller the noise, and the better the quality. The unit of SNR is dB (deci Bel). The definition of a decibel is as follows:

$$\boxed{1\ dB = 10 \log_{10}\left(\frac{I}{I_0}\right)}$$

where I and I_0 are the intensities (also called *power* across a surface area) of two signals, which can be measured in watts. You may often see another definition for decibels, that is:

$$\boxed{1\ dB = 20 \log\left(\frac{E}{E_0}\right)}$$

where E and E_0 are amplitude, potential, or pressure, measured in volts. You can see that the two definitions for a decibel are equivalent if you consider the relationship between power I, potential E, and resistance R.

$$\boxed{I = \frac{E^2}{R}}$$

Analog to Digital Conversion – *Cont.*

- Assuming that *R* is constant for the two signals, then SNR is :

$$\boxed{\begin{aligned} 10\log_{10}\left(\frac{I}{I_0}\right) &= 10\log_{10}\left(\frac{\frac{E^2}{R}}{\frac{E_0^{\,2}}{R}}\right) = 10\log_{10}\left(\frac{E^2}{E_0^{\,2}}\right) \\ &= 10\log_{10}\left(\left(\frac{E}{E_0}\right)^2\right) = 20\log_{10}\left(\frac{E}{E_0}\right) \end{aligned}}$$

Recall that $\log_{10}(x^2) = 2\log_{10}(x)$

For a given bit-depth

$$\boxed{SNR = 20\log_{10}(2^n)}$$

- For 8-bit samples, the SNR is aprox. 48dB
- For 16-bit samples, the SNR is aprox. 96dB

Data Storage

- Working with digital media requires that you handle large amounts of data. Let's first consider the size of typical image, audio, and video files
- The examples assume that RGB color is used, with three bytes per pixel. The video example assumes a frame rate of about 30 frames/s. Each frame is like a still image

Data Storage – *Cont.*

Example Digital Image File Size (without compression):	Example Digital Audio File Size (without compression):	Example Digital Video File Size (without compression):
Resolution: 1024 pixels × 768 pixels **Total number of pixels:** 786,432 **Color mode:** RGB **Bits per pixel:** 24 (*i.e.*, 3 bytes) **Total number of bits:** 18,874,368 (= 2,359,296 bytes) **File size:** 2.25 MB	**Sampling rate:** 44.1 kHz (44,100 samples per second) **Bit depth:** 32 bits per sample (16 for each of two stereo channels) (*i.e.*, 4 bytes) **Number of minutes:** one minute **Total number of bits:** 84,672,000 (= 10,584,000 bytes) **File size:** 10.09 MB for one minute **Data rate of the file:** 1.35 Mb/s	**Frame size:** 720 pixels × 480 pixels **Bits per pixel:** 24 **Frame rate:** ~ 30 frames/s **Number of minutes:** one minute **Total image requirement:** 14,929,920,000 bits **Audio requirement:** 84,672,000 (See column 2.) **Total number of bits:** 15,014,592,000 (= 1,876,824,000 bytes) **File size:** >1.7 GB **Data rate of the file:** 238.65 Mb/s (This calculation doesn't take chrominance subsampling into account. See Chapter 6 for a discussion of subsampling.)

Data Storage

Note…

- Common abbreviations for data sizes are given in the table of next page. The prefixes *kilo-*, *mega-*, and *giga-* can lead to confusion because they are used inconsistently. You have seen that with regard to Hertz, *kilo-* means $10^3 = 1000$, *mega-* means $10^6 = 1{,}000{,}000$, and *giga-* means $10^9 = 1{,}000{,}000{,}000$. However, with regard to data storage, *kilo-* is sometimes defined as 10^3 and sometimes as 2^{10}, *mega-* is sometimes 10^6 and sometimes 2^{20}, and *giga-* is sometimes 10^9 and sometimes 2^{30}. It depends on the source. Manufacturers want to make their storage media look larger, so they generally use powers of 10. On the other hand, many computers will give file sizes defining terms with powers of 2. For example, on your computer you may be able to click on a file to see its properties, which could be listed as 3,686,456 bytes in one place, 3,600 kB in another place, and 3.52 MB in another. Clearly, powers of two are being used for the definitions, since $3{,}686{,}456/1024 \approx 3600$ and $3{,}686{,}456/1{,}048{,}576 \approx 3.52$.

Data Storage – *Side Node*

Note…

- Although usage is inconsistent in the computer industry with regard to the prefixes *kilo-*, *mega-* and *giga-*, the most common convention is to use powers of 2 for memory and file sizes and powers of 10 for data rates. We will adopt this convention in our lectures, unless indicated otherwise. You should note, however, that manufacturers sometimes use kilobyte to mean 1000 bytes, megabyte to mean 1,000,000 bytes, gigabyte to mean 1,000,000,000.

Assume the following abbreviations:

kilobyte	kB
megabyte	MB
gigabyte	GB
kilobit	kb
megabit	Mb
gigabit	Gb
terabit	Tb
terabyte	TB

For memory and file sizes, assume the following equivalences:

1 byte = 8 bits

1 kB = 2^{10} bytes = 1024 bytes

1 MB = 2^{20} bytes = 1,048,576 bytes

1 GB = 2^{30} bytes = 1,073,741,824 bytes

1 TB = 2^{40} bytes = 1,099,511,627,776 bytes

kb, Mb, Gb and Tb are defined analogously.

Data Storage – *Cont.*

- Storage media and their capacity

Storage medium	Maximum capacity
Portable Media	
CD (Compact Disk)	700 MB
DVD (Digital Versatile Disc or Digital Video Disk), standard one sided	4.7 GB standard; 8.5 GB dual-layered
DVD video or high capacity	17–27 GB
Memory stick or card	8 GB
HD-DVD (High Definition DVD), standard one-sided	15 GB standard; 30 GB dual-layered
Blu-ray Disk	25 GB standard; 50 GB dual-layered
Flash drive	64 GB
Permanent Media	
Hard disk drive	1 terabyte (1000 GB)

****Indicated capacity measures are continuously changing for some mediums..*

Data Communication

- Data communication is a broad and deep field of study that straddles the disciplines of computer science and electrical engineering. Before we begin tackling this topic, you may find it helpful to know the ways in which data communication is relevant to your study of digital media. Here are our motivations for looking at issues of data communication:
  - Digital media files are typically very large, and rarely do you keep them to yourself. You store them on CDs and DVDs, send them in email, and post them on web pages. Thus, you need to consider transmission media and communication methods for digital data.
  - Sound and video are time-based media that require large amounts of data. Both capturing and transmitting sound and video in real-time require that the data transmission keep up with the rate at which the data is played. Thus, issues of bandwidth and data rate are crucial in the capturing and transmitting of digital audio and video.

Data Communication – *Bandwidth*

- Bandwidth is important to the study of digital media because image, audio, and video files are large, and in the case of audio and video they are time-based. Thus, the rate at which these files can be created and transmitted is crucial.
- There are three definitions of bandwidth used in three different contexts
  - **Bandwidth as Maximum Rate of Change in Digital Data Communication**
  - **Bandwidth of a Signal in Terms of Frequency**
  - **Bandwidth of a Communication Channel in Terms of Frequency**

Data Communication – *Bandwidth*

- Bandwidth as Maximum Rate of Change in Digital Data Communication: the maximum rate of change of a signal, as a property of the communication system on which the signal is being sent
  - Bandwidth is measured in cycles per second or Hz. A baseband transmission system with a bandwidth of 5000 Hz can *cycle* through its signal — that is, it can change its signal from one voltage level to a different one and then back again — at a maximum rate of 5000 times per second. We can say this another way: Every 1/5000th of a second, this system can communicate two things. If one voltage represents a 0 and another represents a 1, then the system can transmit a 0 and a 1 every 1/5000th of a second. Thus, we have the following definitions:
  - Assume that a signal is sent with two possible signal levels and a bandwidth of *b* Hz. Then the data rate, *d*, in bits/s is $\boxed{d = 2b}$
  - Assume that a signal is sent with k possible signal levels and a bandwidth of *b* Hz. Then the data rate, *d*, in bits/s is $\boxed{d = 2b \log_2(k)}$

Data Communication – *Bandwidth*

- **Bandwidth of a Signal in Terms of Frequency**
  - For a signal that can be represented as a periodic waveform, let f_{max} be the frequency of the highest-frequency component and let f_{min} be the frequency of the lowest-frequency component. Then the width of the signal, *w*, is

$$\boxed{w = f_{max} - f_{min}}$$

  - For example, if a complex waveform is composed of three frequencies: 262 Hz, 330 Hz, and 392 Hz. The difference between the maximum and minimum frequency components—in this case, 130 Hz—is the width of the signal.

Data Communication – *Bandwidth*

- Bandwidth of a Communication Channel in Terms of Frequency
  - When data are communicated across the airwaves, they are sent along some particular channel, which is a band of frequencies. The sender communicates within its designated frequency band, and the receiver tunes to that band to receive the communication. The range of frequencies allocated to a band constitutes the ***bandwidth of a channel.***
  - Sample Frequency Bands for Radio and Television

Radio	Television
AM, 535 kHz to 1.7 MHz	54 to 88 MHz for channels 2 to 6
shortwave radio, 5.9 MHz to 26.1 MHz	174 to 216 MHz for channels 7 to 13
CB radio, 26.96 MHz to 27.41 MHz	470 to 890 MHz for UHF channels 14 to 83
FM radio, 88 MHz to 108 MHz, allocated in 200 kHz channels	

Data Communication – *Data Rate (Bit Rate)*

- The first definition of bandwidth: the maximum rate of change of a signal, as a property of the communication system on which the signal is being sent.
- This definition is closely related to data rate or bit rate. In fact, bandwidth is often loosely used as a synonym for data rate or bit rate, and this has become widely accepted. However, in our discussion, we distinguish between the terms.
  - Bandwidth is measured in cycles per second—Hertz
  - Data rate is measured in bits per second—more precisely, in kilobits per second (kb/s), kilobytes per second (kB/s), megabits per second (Mb/s), megabytes per second (MB/s), gigabits per second (Gb/s), or gigabytes per second (GB/s)
  - If measured in bits per second, data rate is synonymous with bit rate

Data Communication – *Data Rate (Bit Rate)*

- Recall that bandwidth and data rate are related by the equation $d = 2b \log_2(k)$. where k is the number of different signal values that can be transmitted. What we did not mention earlier is that in this equation, d is a theoretical data rate—a maximum that is not achievable in reality.
- The actual amount of data that can be sent per unit time is limited by the noise that is present in any communication system. No signal can be sent with perfect clarity over an indefinite span of space and time. Some amount of noise is introduced by electromagnetic interference. If too much noise is introduced, the receiver cannot always interpret the signal correctly. Some transmission systems are more susceptible to noise than others, and this lowers their actual achievable data rate
- A refinement of the relationship between data rate and bandwidth is given by *Shannon's theorem*, which quantifies the achievable data rate for a transmission system that introduces noise. According to Shannon's theorem, $c = b \log_2(1 + s/p)$. s is a measure of the signal power, and p is a measure of the noise power

Data Communication – *Data Rate (Bit Rate)*

- Data Transfer Rates for Common Communication Links

Wide Area Network	
Type of Data Connection	**>Data Rate**
telephone modem	28.8–56 kb/s
ISDN (Integrated Services Digital Network)	64–128 kb/s
ADSL (Asymmetric Digital Subscriber Line)	1.544–8.448 Mb/s (downstream) 16–640 kb/s (upstream)
ADSL2	0.8–3.5 Mb/s up, 5–12 Mb/s down
ADSL2+	1–3.5 Mb/s up, 24 Mb/s down
VDSL (Very High Bit DSL)	12.96–55.2 Mb/s (~ 12 Mb/s down and 52 Mb/s up, or ~ 26 Mb/s symmetrical at 1000 feet, 10 Mb/s at 4000 feet)
Cable modem	20 40 Mb/s
VDSL2	50–250 Mb/s

Data Communication – *Data Rate (Bit Rate)*

- Data Transfer Rates for Common Communication Links

Local Area Network	
Type of Data Connection	**Data Rate**
Token ring	16 Mb/s
Ethernet (10base-X)	10 Mb/s
Fast ethernet (100base-X)	100 Mb/s
FDDI	100 Mb/s
Gigabit ethernet	1 Gb/s
Wireless 802.11b	11 Mb/s
Wireless 802.11g	54 Mb/s

Data Communication – *Data Rate (Bit Rate)*

- Data Transfer Rates for Common Communication Links

Computer Interfaces	
Type of Data Connection	**Data Rate**
Serial	10–230 kb/s
Parallel	8 Mb/s
SCSI 1	12 Mb/s
SCSI 2	80 Mb/s
Fast wide SCSI	160 Mb/s
SCSI (various ultra versions)	320–2560 Mb/s
USB, USB2	12–480 Mb/s
SDI (serial digital interface)	143–360 Mb/s
Firewire (IEEE 1394)	400–800 Mb/s
DMA ATA	264–1064 Mb/s

Data Communication – *Data Rate (Bit Rate)*

- Data Transfer Rates for Common Storage Devices. (Not all generations are listed.)

CD Drives (Compact Disc)	
1X	150 kB/s (1200 kb/s or 1.2 Mb/s)
2X	300 kB/s
8X	1200 kB/s
52X	7.8 MB/s
DVD Drives (Digital Versatile Disc or Digital Video Disc)	
1X	1.32 MB/s
16X	21.09 MB/s

Data Communication – *Baud Rate*

- A term close in meaning to bandwidth and bit rate is baud rate. As is the case with bandwidth, there is some confusion—or at least lack of agreement—about the definition of *baud*.
- The most precise definition of baud rate is "the number of changes in the signal per second, as a property of sending and receiving devices."
- Under this definition, baud rate is synonymous with bandwidth, not bit rate.
- As we saw earlier in this lecture, if the sending device uses more than one signal level—say, k signal levels—then the bit rate, d, is given by the equation $d = 2b \log_2(k)$. Thus, to convert from baud rate to bit rate, you have to consider how many different signal levels are possible .

Data Communication – *Baud Rate*

- However, just like bandwidth, the term baud rate is used loosely. Baud rates for telephone modems are commonly reported in bits per second rather than cycles per second. For example, current telephone modems are often described as having a baud rate of 56 kb/s (although this is actually their bit rate). In light of this confusion, here are the main points to understand:
  - Baud rate is close in meaning to bandwidth as bandwidth relates to digital data communication. The main difference is that baud rate is usually used to refer to sending and receiving devices, whereas bandwidth has other meanings related to frequencies over the airwaves.
  - A device like a modem can have a maximum baud rate as well as an actual baud rate. The actual baud rate is the rate agreed upon between sender and receiver for a particular communication
  - What is often reported as a baud rate is really a bit rate. (But bit rate is generally what you want to know anyway, so no harm done.) To be precise, baud rate and bit rate are related by the equation $\boldsymbol{d = 2b \log_2(k)}$