Vibration, Sound, and Music

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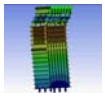
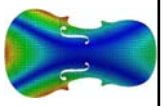
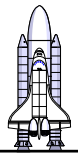
Vibration, Sound and Music

Where do the topics of vibration, sound and music lie within the fields of engineering?

Civil	Computer	Electrical	Mechanical
			
•Dynamics of Structures	•Music Software •Music on the Web	•Circuit Design •Consumer Electronics •Signal Processing •Speech Synthesis •Analog Recording •Digital Recording •Ultrasound Imaging	•Design of Sound Systems •Design of Acoustic Enclosures •Vibration in Machines •Recording technology •Design of musical instruments •Acoustic diagnosis •Aerodynamic stablity

Why seek to understand vibration and sound?

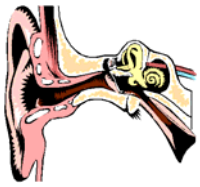


- Sound is important for communication and can be a source of pleasure and enjoyment (as in the case of music).
- Sound and vibration can be annoying and even harmful if they are too intense.
- Vibration can lead to instability and failure of complex structures and systems.

In this presentation:

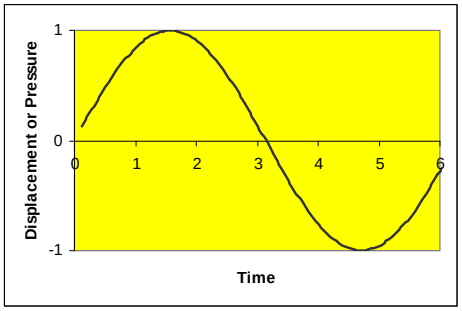
- A discussion of the fundamentals of sound/vibration and human hearing.
- A discussion of the concept of resonance and natural frequency.
- A discussion of the concept of sound filtering.
- A discussion of digital sound.
- A discussion of tone and the spectral analysis of sound/vibration signals.
- A short workshop on jazz music and how it is influenced by technology.

What is sound and vibration?



- Sound waves are pressure vibrations in the air. Vibration is cyclic motion of an object. Vibration travels in solids as structural borne waves. Sound waves are generated by anything that vibrates — a vibrating object causes the air next to it to vibrate, and the vibration is passed along through the air in all directions.
- When the vibrating air enters your ear, it makes your eardrum vibrate, and three bones in your inner ear convert this motion into a signal that your brain can interpret.

The nature of sound:



Sounds may be made up combinations of waves containing more than one frequency and more than one amplitude.

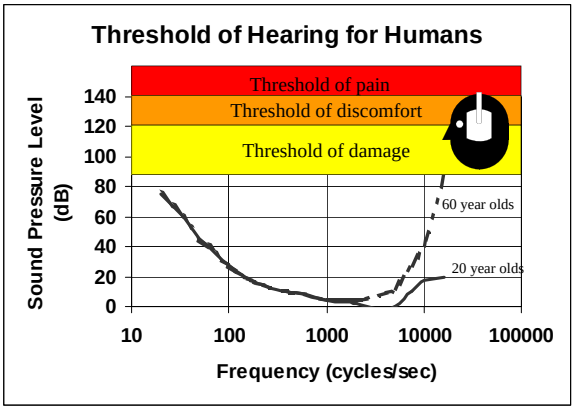
What do Sounds Look Like?

A demonstration of the use of an oscilloscope and speaker to show different sounds at different frequencies.

Human Hearing

- **Frequency: The slowest vibration frequency you can hear is about 20 vibrations per second, and the fastest is around 16,000 to 20,000 vibrations per second.**
- **Pressure amplitude: The human ear can detect sounds over a very large range of amplitudes. The human ear can detect sounds as low as 0.0002 microbars to 2,000 microbars (7 orders of magnitude). This range is so large that we generally reference the range using a logarithmic scale to denote sound pressure level:**

$$Sound\quad pressure\quad level\,(dB) = 20\log\left[\frac{pressure(microbars)}{0.0002(microbars)}\right]$$



But what sound level is 90 dB?

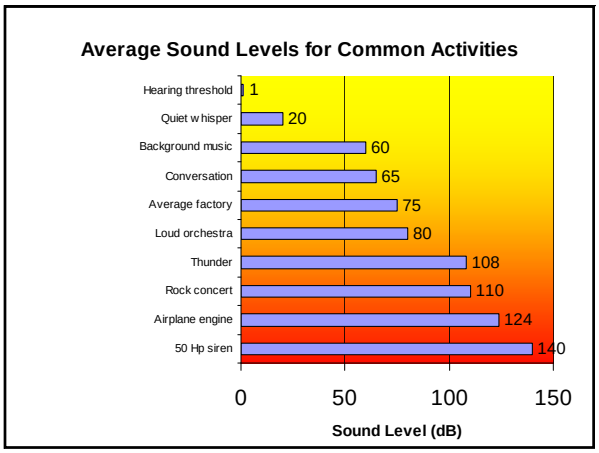
- **How would I know if I am being subjected to damaging levels of sound?**
- **How do experts measure sound levels?**
- **What does dBA and dBC mean?**
- **Does the sound level fall off as I get further away from the source, or off-axis from the source?**

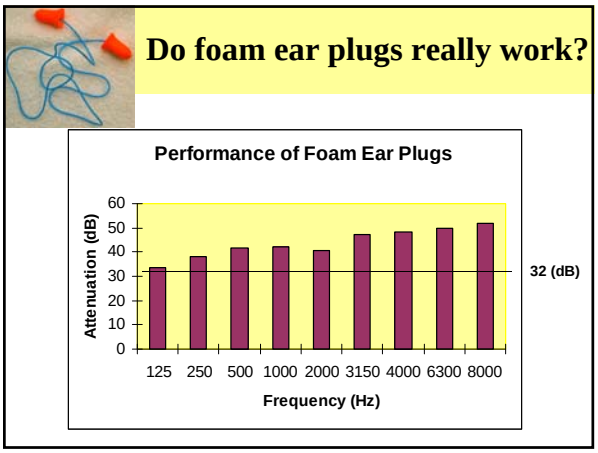
Measuring Sound Levels

- **A sound level meter is the way that professionals measure sounds. This device provides output in db.**
- **The "A" filter or "weighting" scale is sensitive in the range 500-10,000 Hz. This is the range of normal speech.**
- **The "C" filter is over the range 32 - 10,000 Hz. This is often used for music.**

How much sound is allowable by the U.S. Dept of Labor?

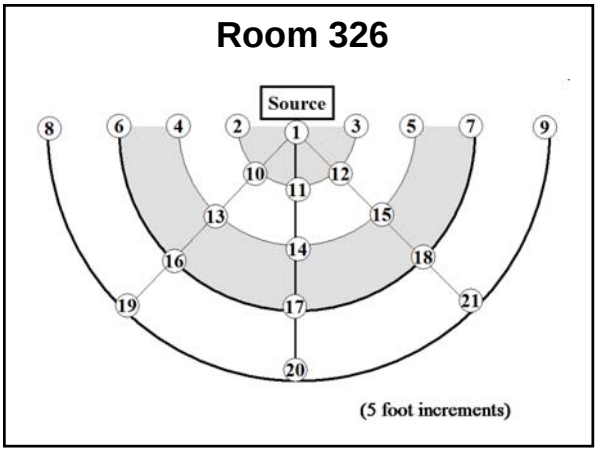
Sound Level (dB)	Maximum Duration per Day (hours)
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
110	0.5
115	< 0.5





How does sound change as we move away from the source?

An experiment to see if sound level falls off as the distance from the source is increased and as the orientation relative to the source is changed.



The Concept of Natural Frequency

- **Many objects in nature have one or more natural frequencies at which they vibrate if plucked or struck.**
- **This frequency can be troublesome if we excite the object with an energy that reinforces this frequency.**
- **Most systems have some damping in them that limits the vibration if they are excited at their natural frequencies. A damper is much like the dashpot on a door closing mechanism. If the damping is not large enough, the resulting vibration can still be damaging.**

What is the natural frequency of a structure and why is it important?

Demonstration of forced vibration of a cantilever beam with resonance.
(walk to lab)

The basis for acoustic musical instruments

- **All acoustical music instruments are based on the fundamentals of mechanical vibration. Examples are: The vibration of a string or strings, the vibration of a flow of air, the vibration of a reed, the vibration of the human lip, the vibration of a membrane, etc.**
- **The natural frequency of a musical instrument can usually be adjusted to play different notes of a scale.**

The basis for design of acoustic musical instruments

- **What we want for an ideal musical instrument is:**

1) a way to adjust the natural frequency of vibration in discrete steps to give desired pitches.

2) a way to make the vibration change into sound with as much volume as possible.

How does the Equal Temperament Chromatic scale work?

- The chromatic scale is composed of twelve semitone steps each satisfying the criteria that the frequency ratio of their tones be a constant value. Mathematically this is:

$$\frac{f(note2)}{f(note1)} = \frac{f(note3)}{f(note2)} = \frac{f(note4)}{f(note3)} \ldots\ldots = \frac{f(note13)}{f(note12)} = a$$

- The 13th note must be the octave. This means:

$$f(note13) = 2 f(note1)$$

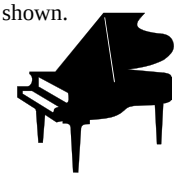
- Thus we conclude:

$$f(note13) = a^{12} f(note1)$$

What is the chromatic scale based on Equal Temperament?

Thus: $a^{12} = 2$ and $a = \sqrt[12]{2} = 1.059463094$

Using A4=440 Hz, we can construct the chromatic scale as shown.



Note		Ratio	Frequency (Hz)
A4	a^0=	1.000000000	440.00
Bb4	a^1=	1.059463094	466.16
B4	a^2=	1.122462048	493.88
C5	a^3=	1.189207115	523.25
C#5	a^4=	1.259921050	554.37
D5	a^5=	1.334839854	587.33
Eb5	a^6=	1.414213562	622.25
E5	a^7=	1.498307077	659.26
F5	a^8=	1.587401052	698.46
F#5	a^9=	1.681792831	739.99
G5	a^{10}=	1.781797436	783.99
Ab5	a^{11}=	1.887748625	830.61
A5	a^{12}=	2.000000000	880.00

Consider the vibration of a string under tension:

The fundamental frequency of vibration of a string under tension is:

$$f = \frac{2}{L}\sqrt{\frac{T}{m}}$$

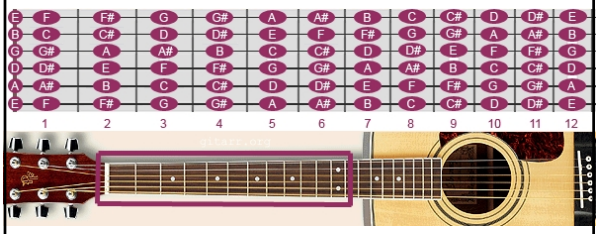
where:

f = frequency
L = length
m = mass per unit length
T = Tension in the string

How do frets work on a stringed instrument?

Demonstration of the octave change using a bass string that is half length.

This is why the frets on a guitar are spaced closer together as we go higher in pitch.



The sounds of instruments are made up of the combination of sine waves.

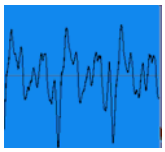
- The sine waves add together to give the unique sound that we recognize as the sound of a particular instrument.
- In most cases the sound is pleasing to the ear.
- Our mind is able to discern what type of instrument we are hearing by analyzing the combination of these sounds.
- As we look at the components, what we are doing is analyzing the spectra of the sounds. This means that we look at the frequencies and the amplitudes of the various components.

Consider the cello:

Yo-Yo Ma

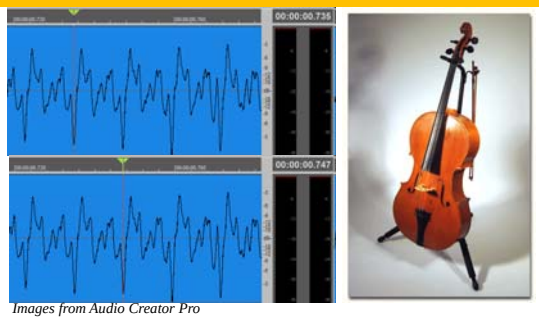
- The cello sounds as follows:
- If we play a low "E" (i.e. E_2 = 82.4) the sound is as follows:

About this cello sound:



- This sound will have slight changes in amplitude and frequency as a result of the movement of the player's hand on the fretboard. This distinctive sound is characteristic of a professional cello player and is called vibrato.
- This sound does have a repeating form but it is not exactly a pure sine wave.
- It is actually a sum of several pure sine waves that blend together to give the unique sound we recognize as a cello.
- These pure sine waves are actually multiples of the fundamental frequency.

The cello wave form for E_2 = 82.4 Hz. with vibrato



Images from Audio Creator Pro

$0.747 - 0.735 = 0.012$ sec/*cycle*

$1 / 0.012 = 83$ *cycles* / sec .

To help us to see the various frequencies and amplitudes, of the pure sine waves that make up the sound we can use a spectrum analyzer.

The Spectra of Sounds

Sound spectra can be classified as being of one of two types:

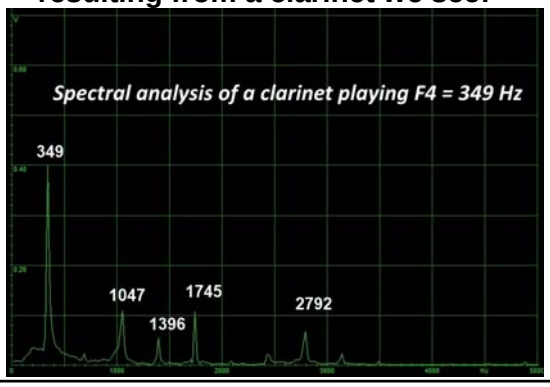
(1) ***Harmonic,*** in which the spectral components (different frequencies) are mostly whole number multiples of the lowest, and most often loudest, frequency. The lowest tone is called the fundamental and the higher (i.e. in frequency) spectral components are called overtones, or harmonics. The cello falls into this category.

(2) ***Inharmonic,*** in which the criteria in (1) are not met i.e in which the spectral components are mostly NOT whole number multiples of the lowest frequency, which is often NOT the loudest tone. Many percussion instruments fall into this category.

See if you can identify the following musical instruments:

Sound	Name of Instrument	Playing note Continuous	Sound
1.		F = 349 Hz	
2.		Bb = 466 Hz	
3.		A = 440 Hz	
4.			

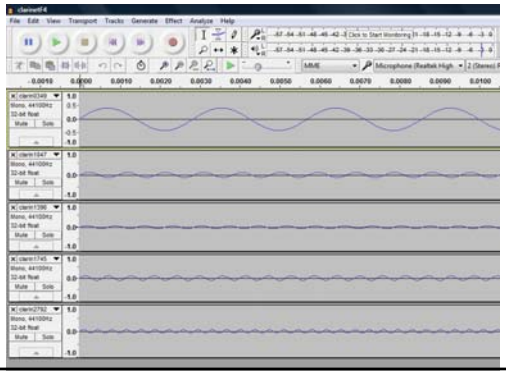
If we look at the spectrum of sounds resulting from a clarinet we see:



Here is what we can get from the spectrum analysis:

Frequency	Harmonic	Amplitude
1*349 = 349 Hz	Fundamental	0.42
3*349 = 1,047 Hz	3rd harmonic	0.10
4*349 = 1,396 Hz	4th harmonic	0.05
5*349 = 1,745 Hz	5th harmonic	0.10
8*349 = 2,792 Hz	8th harmonic	0.06

Now, let's put together some of the components to make a Clarinet sound:



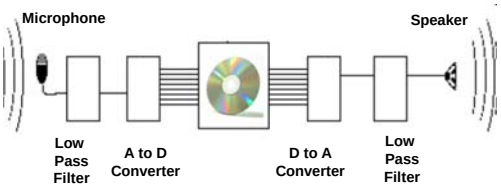
Sound Filtering

- **There are times when we want to design a system that will pass certain frequencies of sound and reject others. For example an equalizing circuit on a home stereo system can be used to enhance bass and diminish treble or visa versa.**
- **A filter that rejects high frequencies and passes low frequencies is known as a "low pass filter."**
- **A filter that rejects low frequencies and passes high frequencies is know as a "high pass filter."**

How do we create an equalizer circuit for our stereo system?

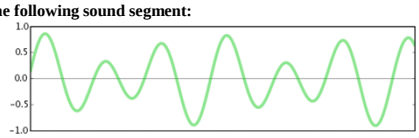
Demonstration of the use of a low pass filter.

How does a computer record sound?

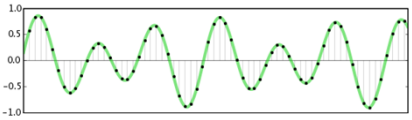


How does the A to D converter work?

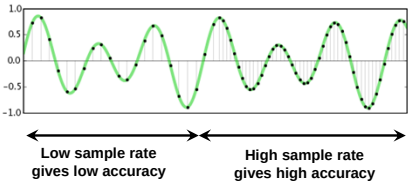
Consider the following sound segment:



At equal intervals of time the computer measures and saves the strength of the electrical signal from the microphone.

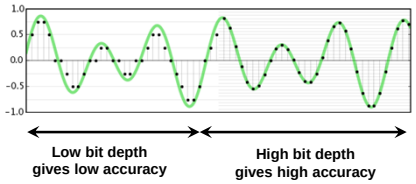


- **Thus the digital audio data is just a long series of numbers that are stored on a CD or in computer memory.**
- **There are two parameters that are important. The first is how often the data is sampled (the sample rate).**



- **For CD quality sound, we use a sampling rate of 44,100 times per second. It can be shown that the minimum sample rate necessary to reproduce a sound is twice the frequency of that sound. Thus if the human ear can hear up to 20,000 Hz, the sampling rate for digital sound must be 40,000 Hz.**

- **The second parameter of importance is how accurately the points are measured vertically (the bit depth).**



- **For CD quality sound, the bit depth is 16 bits. Since 2^{16} = 65,536 this gives considerable room for accurate measurement.**

- **The main drawback of digital audio is that it takes up a lot of disk space.**
- **To determine the size of a CD quality digital audio file, multiply:**
  - **the sample rate (e.g. 44,100 Hz)**
  - **times the bit depth (e.g. 16 bit)**
  - **times 2 for stereo and then**
  - **times the number of seconds to be recorded.**
- **This value for a 74 minute CD is over 6 billion bits which is 800 megabytes for 8 bits per byte.**

Digital Compression

- **The solution is to use a compression scheme to reduce the size of the data. This requires some compromises.**
- **MP3 is a compression technique that can dramatically reduce the file size of a digital audio file with surprisingly little effect on the quality.**
- **One second of CD-quality audio takes up 1.4 megabits per second, while a common bitrate for MP3 files is 128 kilobits per second, which is a compression factor of more than 10!**
- **MP3 works by cleverly "throwing away" details about the audio waveform that humans are not very sensitive to, based on a psychoacoustic model of how our ears and brains process sounds.**

Can you tell the difference?

Sound clip	Bit rate	File Size
	Wav file uncompressed at 1,400 kilobits/sec	15.10 MB
	MP3 compression at 128 kilobits/sec	1.37 MB
	MP3 compression at 32 kilobits/sec	0.35 MB

"Allegro from Appalacian Spring" by Aaron Copeland

Let's take a few minutes and look at one of the unique music forms in the U.S. Jazz

Jazz and the Blues

- **The blues genre is a uniquely American form of folk music and is the fundamental form in jazz.**
- **Jazz and the blues date back into the 1800's in the U.S. and have become timeless forms of musical expression.**
- **Jazz and the blues are characterized by polyrhythms, syncopation, and improvisation.**

A timeline of Jazz

Pre-jazz (pre-blues) era:

- **During the 1800s in America's south, music was an important part of the life of plantation. Plantation songs, spirituals, and field hollers were a part of everyday life. This music of the plantations blended with the European-American musical tradition to create the basis for blues, ragtime, and other musical forms from which jazz evolved.**
- **Early jazz and early blues music were based on African polyrhythms.**
- **Some of the early forms of pre-jazz included antebellum cakewalks which were dances done to the accompaniment of a banjo and bones.**
- **In the 1840's traveling minstrel shows became a popular music form and a precursor to jazz.**

What is a polyrhythm?

- **A polyrhythm is two different rhythms being played at the same time.**
- **The most common polyrhythm is the three against two rhythm shown below:**

	1	2	3	4	5	6
"3"	x	.	x	.	x	.
"2"	x	.	.	x	.	.

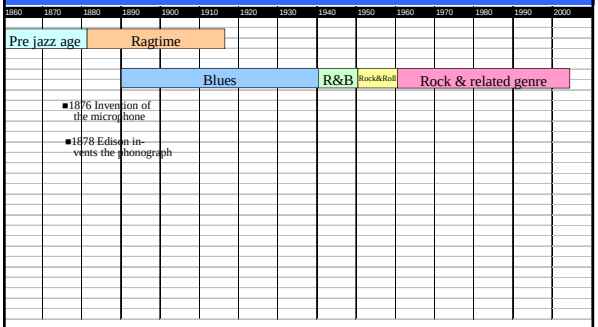
- **There are many other polyrhythms.**

A timeline of Jazz

Ragtime Era

- **Ragtime was one of the earliest forms of jazz. It was composed primarily for the piano.**
- **Ragtime combined a sixteenth-note-based syncopated melody with the form and feel of a march. It was usually written in 2/4 or 4/4 time with a predominant left hand pattern of bass notes on odd-numbered beats and chords on even-numbered beats accompanying a syncopated melody in the right hand.**
- **In 1893 Scott Joplin, a classically trained musician, heard ragtime musicians at the Chicago World's Fair and was inspired to write this type of music.**
- **Ragtime had syncopation but very little improvisation.**
- **The dissemination of ragtime was by sheet music.**

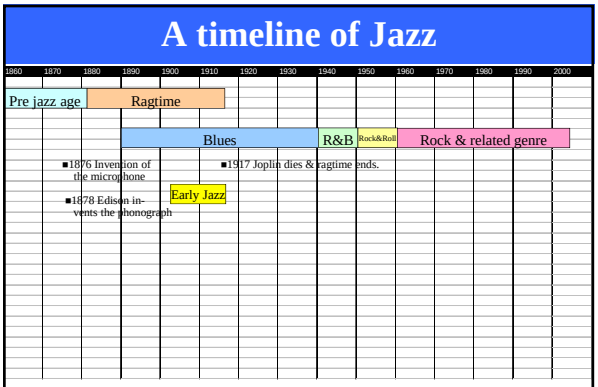
A timeline of Jazz



The Blues

- **Like ragtime, the blues was an important influence on the development of later jazz.**
- **A highly expressive, predominantly vocal tradition, blues songs are characterized by a slow, mournful lament about love and about life in general.**
- **A blues songs usually includes words which form a three-line stanza. The first line is sung twice, the third rhymes with the first two (aab form).**
- **Most experts agree that the blues were the root of Rhythm & Blues, which ultimately lead to Rock & Roll.**

A timeline of Jazz



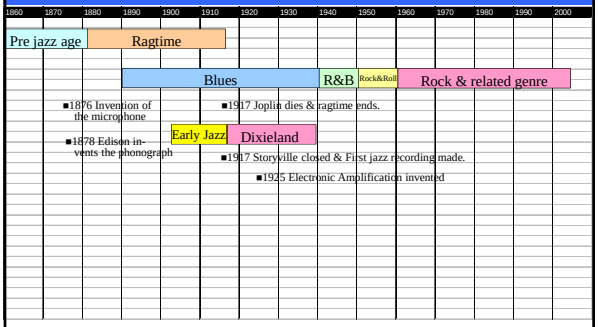
Early (New Orleans) Jazz

- The first New Orleans Jazz groups were people who had picked up abandoned instruments on the battlefields after the Civil War.
- These groups were more like marching bands, and often played at funerals. Their sound was polymelodic.

Early (New Orleans) Jazz

- The region in New Orleans in which the early jazz bands played was called Storyville. It was not a particularly desirable neighborhood.
- Storyville was closed down by the U.S. Navy in 1917 and this caused jazz to migrate to many other places such as New York and Chicago.

A timeline of Jazz



Dixieland Jazz

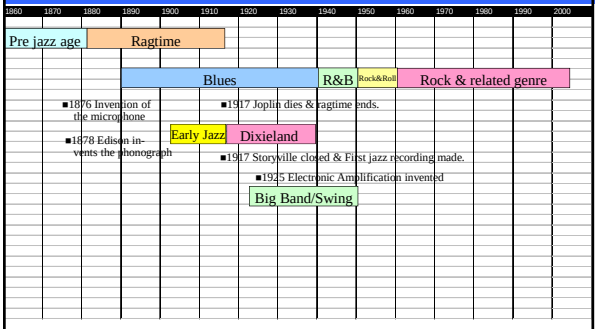
King Oliver's Creole Band
Chicago - about 1922.

- It was not until 1917 that jazz was recorded effectively.
- It was not until 1925 that electronic amplification made it possible for the guitar and the bass to be heard. At this time the string bass slowly replaced the tuba, the guitar slowly replaced the banjo and a whole new style of music was born.

Dixieland Jazz

- Electronic amplification also made it possible to hear vocalists.
- These technological developments greatly shaped the future of jazz music.
- Dixeland jazz often features a clarinet doing a counter melody over the other instruments.

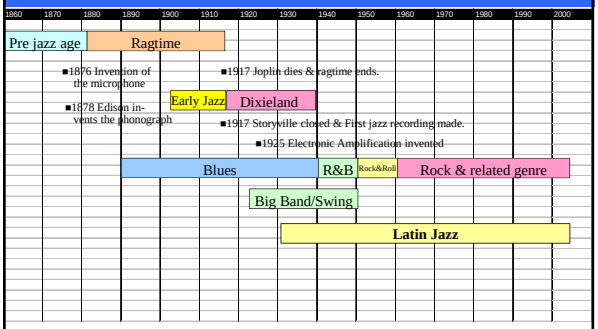
A timeline of Jazz



The Big Band Sound & Swing

- Following the rise of Dixieland jazz in the 1920s was a new style performed by a large ensemble usually consisting of 10 players or more. This music was more sophisticated, more organized and less improvised.
- These bands, called big bands, relied increasingly on saxophones instead of clarinets and emphasized sectional playing.
- The music performed by big bands was called swing, a type of music that people could dance to easily. This energetic dance music was wildly popular for almost two decades, with the swing era extending through the late-1940s.

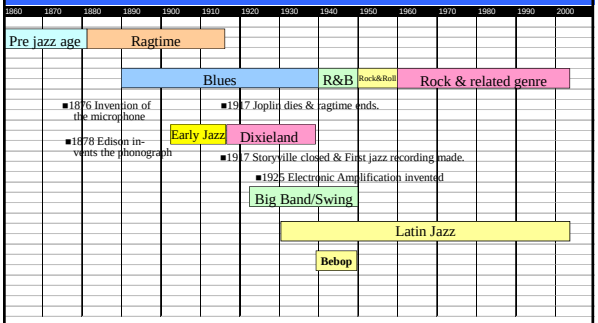
A timeline of Jazz



Latin Jazz

- **Latin-influenced jazz is characterized by Latin dance rhythms combined with jazz melodies and chord progressions.**
- **Latin influences began to enter mainstream American popular music in the 1930's. During the 1950's and 1960's these influences became particularly strong, with Latin dances such as the mambo, cha-cha-cha, samba, and bossa nova becoming extremely popular in the United States.**
- **Other Latin dances such as the salsa and merengue continue to be an influence today.**

A timeline of Jazz



Bebop

- Bebop emerged in the 1940s a as a style of jazz in great contrast to the music of the big bands. It featured a small group of musicians -- four to six players -- rather than the 10 or more associated with the big bands. The smaller size allowed more solo opportunities for the players.
- Bebop itself was characterized by more complex melodies and chord progressions, as well as more emphasis on the role of the rhythm section. Furthermore, phrases within the music were often irregular in length, making bebop interesting to listen to, but in contrast to music of the big bands, unsuitable for dancing.
- Bebop led the way to other genres of jazz.
- You can identify Bebop by its fast rhythm, regular walking bass lines, and its improvised instrumental solos.

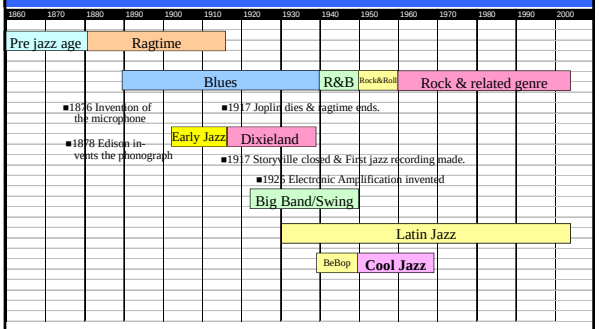
Influential Artists of Bebop

Dizzy Gillespie

Charlie Parker

Theolonius Monk

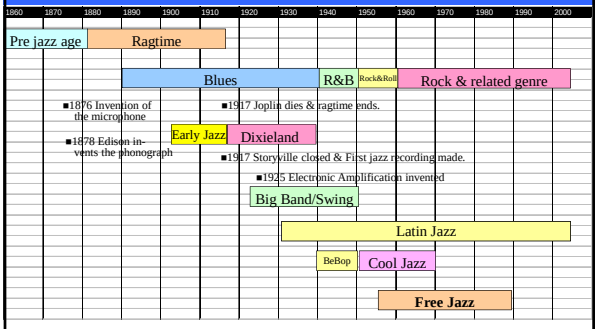
A timeline of Jazz



Cool Jazz

- **Cool jazz developed during the late 1940's in New York and California and remained popular for several decades.**
- **Cool jazz was more subtle, moody, muted, and restrained than bebop, and may have been influenced by the harmonies of 20th-century art music composers like Stravinsky and Debussy.**
- **Two of the most important contributors to the cool jazz style were trumpeter Miles Davis and pianist, bandleader, and composer-arranger Gil Evans.**
- **One of the best known cool jazz players/composers is Dave Brubeck.**

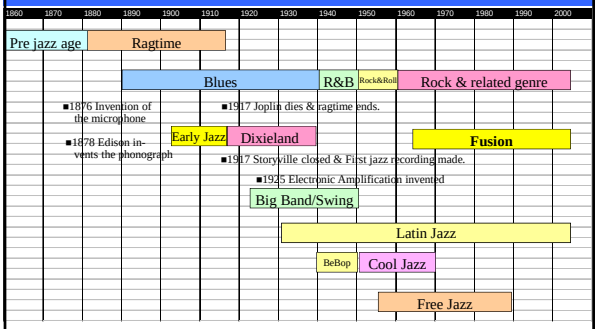
A timeline of Jazz



Free Jazz

- **Experimental, provocative, and challenging for many listeners, free jazz was characterized by a high degree of dissonance. Pitch and tone quality were manipulated by players on their instruments to produce squeaks, shrieks, and wails.**
- **Two of the major contributors to the evolution of free jazz were alto saxophonist Ornette Coleman and pianist Cecil Taylor. Some of the best known examples of free jazz are the later works of John Coltrane.**
- **Free jazz evolved because there was a dissatisfaction among musicians with the expressive possibilities of bebop, hard bop, and modal jazz.**

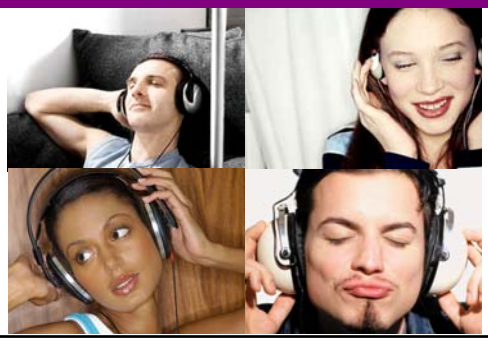
A timeline of Jazz



Fusion Jazz

- **Jazz fusion (or "jazz-rock fusion" or "fusion") is a musical genre that merges elements of jazz with other styles of music, particularly pop, rock, folk, reggae, funk, R&B, and hip hop.**
- **Fusion Jazz is characterized by a rock beat under an improvised jazz melody.**
- **Fusion jazz is more electronic than acoustic, featuring synthesizer, electric bass, electric guitar, electronically-processed woodwind and brass instruments, and a great deal of percussion.**

If given the correct algorithm rules, the human ear coupled with the human mind is a system that is able to identify patterns and recognize musical styles with ease.



We can identify the different types of jazz by their unique characteristics

Era/Genre	Tuba and/or Banjo	March-like on piano	Multiple melodies at the same time with clarinet.	Slow mournful, first line repeated	Moderate to rapid regular rhythm plus improvised melody line.
Early New Orleans Jazz	*				
Ragtime		*			
Dixieland			*		
Blues				*	
Bebop					*

We can identify the different types of jazz by their unique characteristics

Era/Genre	Large orchestra – dance music, highly arranged.	Latin rhythm with jazz melody – often Latin rhythm instruments.	Dissonance and free form.	Smooth, mellow sound. Very pleasant to hear.	Blend of rock beat with jazz melody often on synthesized instruments.
Big Band/Swing	*				
Latin Jazz		*			
Free Jazz			*		
Cool Jazz				*	
Fusion					*