Physics of Musical Instruments and Computer Science in Music

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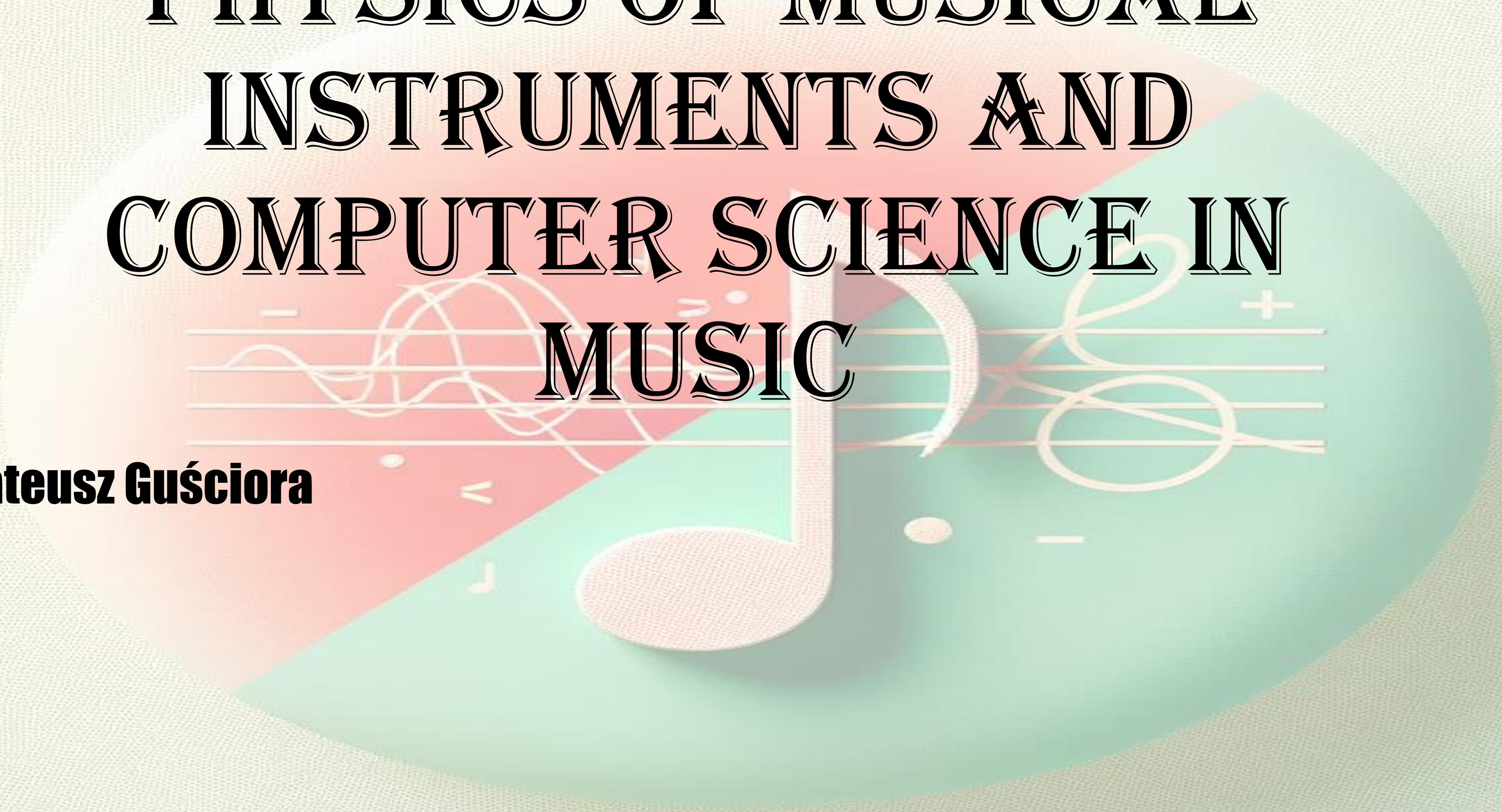


AGENDA

1. Introduction to the topic
2. Musical Instruments and Physical
3. Computer Science in Music
4. Future of Music Technology

INTRODUCTION

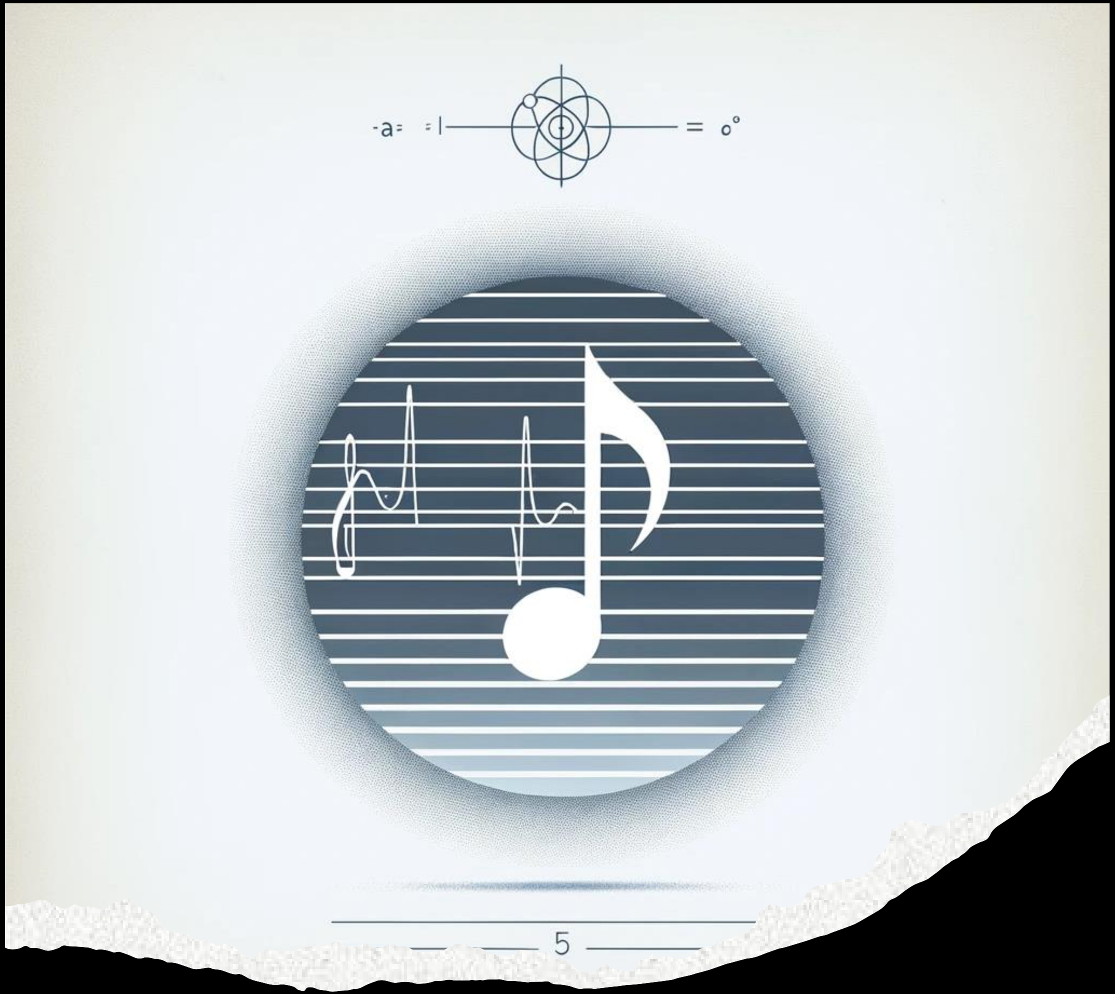
1. What is Sound

2. Relevance of Physics in Music

3. Significance of computer science in music.

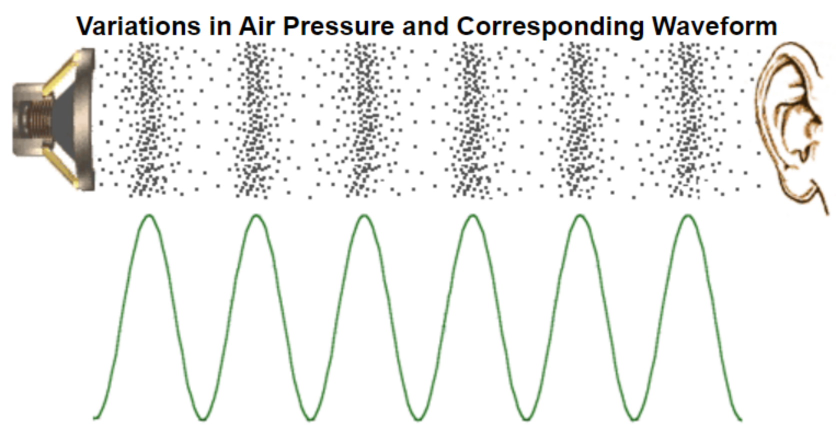
4. Aim of presentation

SOUND



Understanding Sound

- What is sound? (Mechanical Vibrations in the form of waves that propagate trhough a medium. These waves hit human ear) [1]
- How we perceive sound (Inference, Frequency, Amplitude, Timbre) [2]
- Human register frequency in range 20Hz - 20kHz

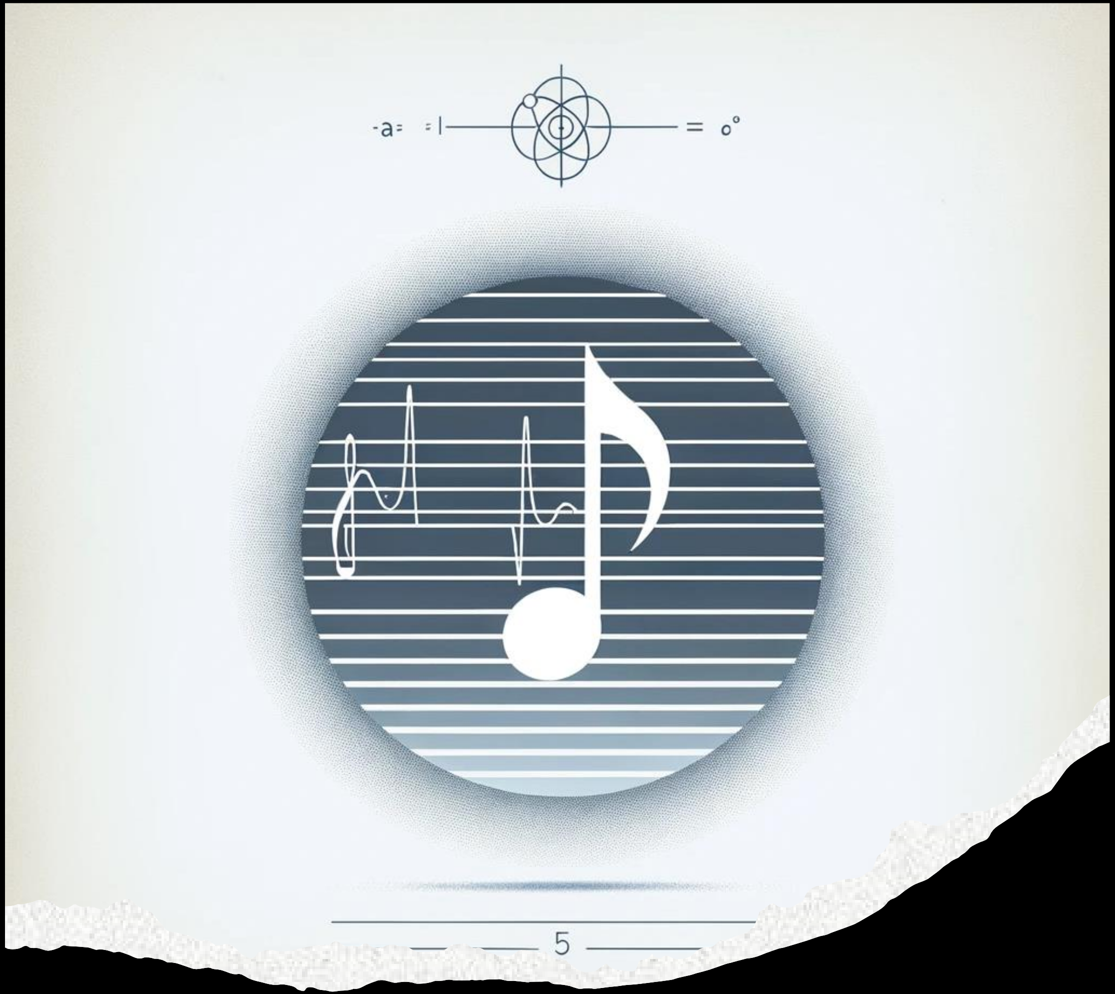


Mathematical Modeling of Sound

- Sound is mechanical wave typicaly $y(x,t)=A\sin(kx-\omega t+\varphi)$
  - A is amplitude k is wave numer ω is the angular frequency, and φ is the phase[1][2]
- Harmonics and Overtones - instruments produce sound with a fundamental frequency and overtones (harmonics) [3]
- Fourier Transform (transform from time domain to frequency domain)
- Synthesis of sound from mathematical models [4]

$$F(j\omega) = \int_{-\infty}^{\infty} f(t) \cdot e^{-j\omega t}\, dt$$

MUSICAL INSTRUMENTS



MUSICAL INSTRUMENTS – CLASSIFICATION [6]

WESTERN CLASSIFICATION

- String instruments
- Wind instruments
- Percussion instruments
- Electronic instruments

HORNBOSTEL-SACHS CLASSIFICATION

- Aerophones
- Chordophones
- Idiophones
- Membranophones
- Elektrophones

Aerophones - Wind Instrument

- Instruments that produce sound primarily by causing a **body of air** to **vibrate**, without the use of strings or membranes.
- The player's breath or an external mechanism provides the airflow

- Examples: flute, trumpet

Aerophones - Physics

- The length and shape of the air column, along with the method of tone production (mouthpiece, reed, lip vibration), determine the pitch and timbre of the sound.
- Players alter the pitch by changing the effective length of the air column (using keys or valves, or by changing lip tension).

- YouTube Video - [3:45 min]

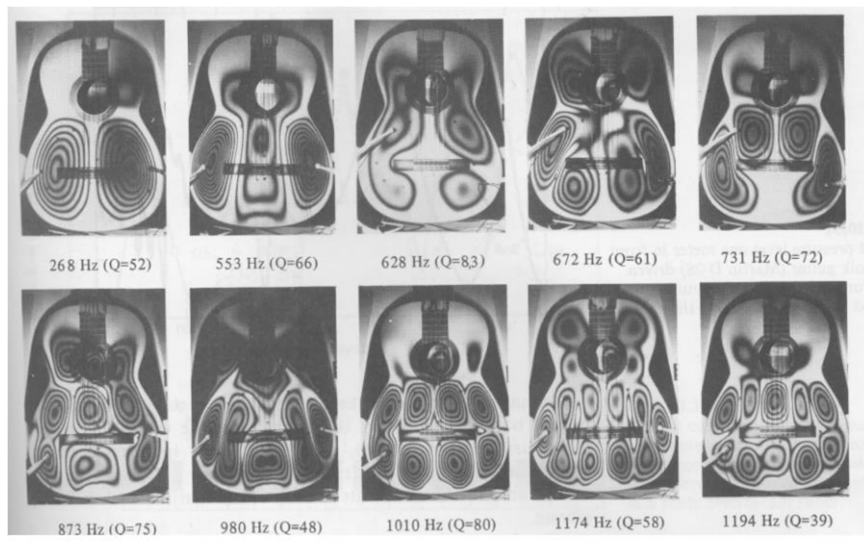
CHORDOPHONES - STRING INSTRUMENTS

- Chordophones are musical instruments that produce sound primarily through the vibration of strings.
- The strings are stretched between two points on the instrument and are set into motion through plucking, striking, or bowing.
- The material, length, tension, and thickness of the strings play a crucial role in determining the sound.

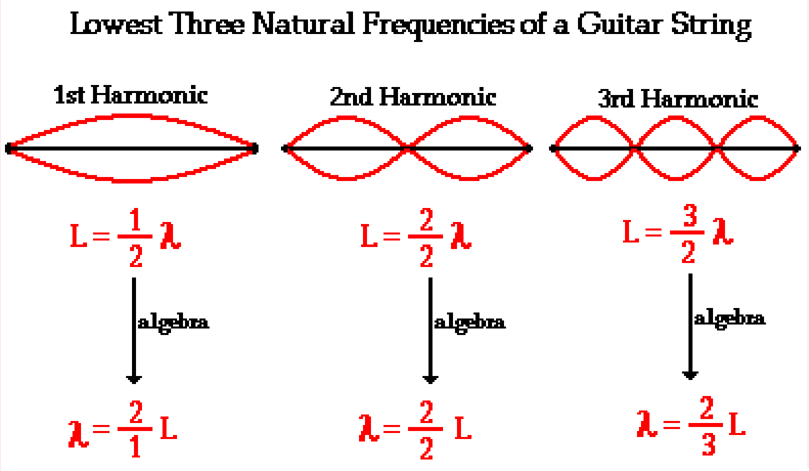
- Examples: guitar, piano, violin

CHORDOPHONES - PHYSICS

- The frequency of vibration is determined by the string's length, tension, mass, and composition.
- This frequency translates into the pitch of the note produced. The body of the instrument often acts as a resonator, amplifying the sound.
- Harmonics are also a key aspect, where fractions of the string vibrate to produce multiple pitches simultaneously.



[7] Resonating body



[8]

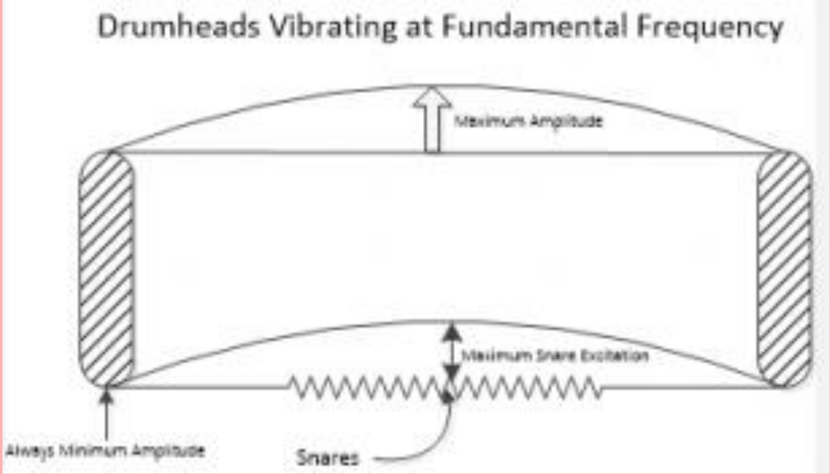
Membranophones

- Membranophones are musical instruments that produce sound primarily through the vibration of a stretched membrane.
- The sound is generated when the membrane is struck, either directly with the player's hands or with an object such as a drumstick.
- Membranophones can vary in pitch and tone, from the deep bass of a large drum to the sharp snap of a snare.

- Example: Drums, Bongos

Membranophones – Physics

- The pitch of the drum sound is influenced by the tension of the membrane and the size of the drum. Higher tension and smaller membranes typically produce higher pitched sounds.
- The body of the drum acts as a resonator, amplifying the sound and adding its own characteristics based on its material and shape.



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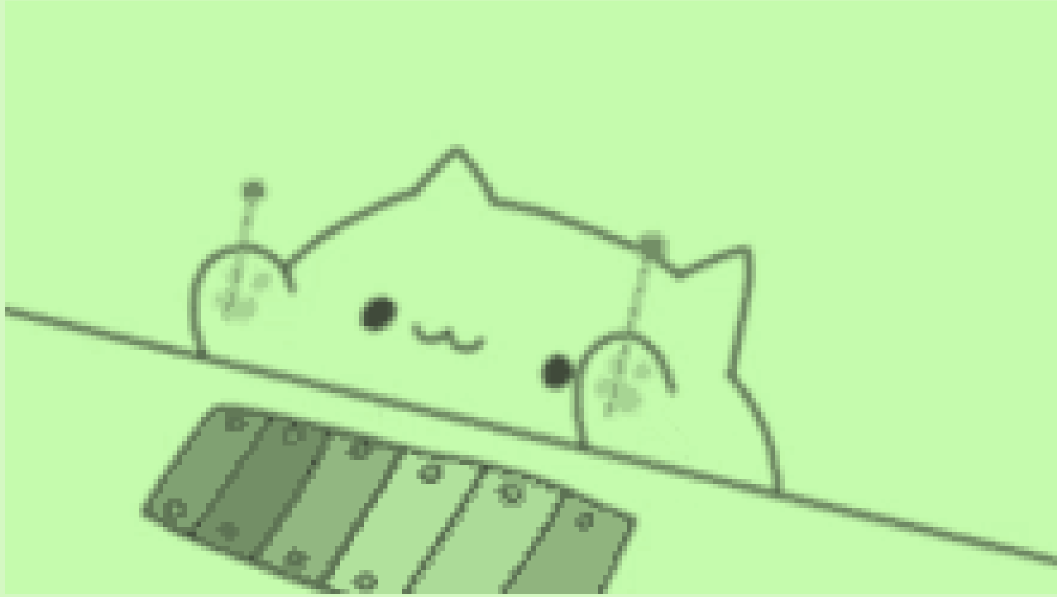
IDIOPHONES

- Idiophones are musical instruments that produce sound primarily from the material of the instrument itself.
- Sound is generated through the vibration of the body of the instrument, which can be struck, shaken, or scraped.
- They can be made from various materials including metal, wood, or stone. The physical properties of the material (density, elasticity, shape) greatly influence the sound characteristics.

- Example: xylophones, cymbals, and maracas

Idiophones - Physics

- The frequency and amplitude of these vibrations determine the pitch and volume of the sound. The sound can be modulated based on the shape of the instrument, the place where it is struck, and the hardness of the striking object.



Electrophones

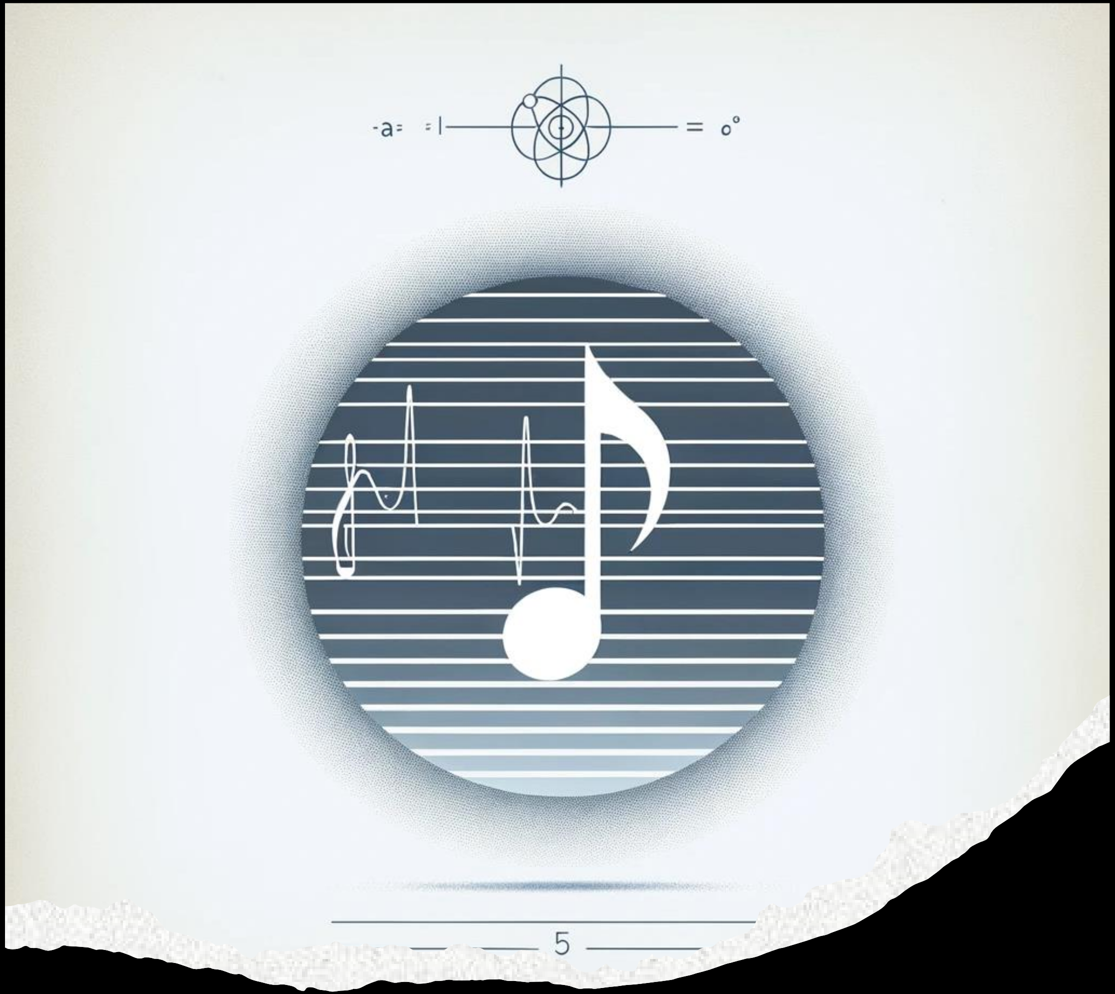
- Electrophones are musical instruments that produce sound primarily through electronic means. Unlike traditional acoustic instruments, electrophones rely on electrical circuits and components to generate, modify, and amplify sound.
- Vary greatly in their method of sound production from electronically generated tones to electrically amplified acoustic sounds.

- Examples: Keyboard, electric guitar, synthesizer

Electrophones - Physics

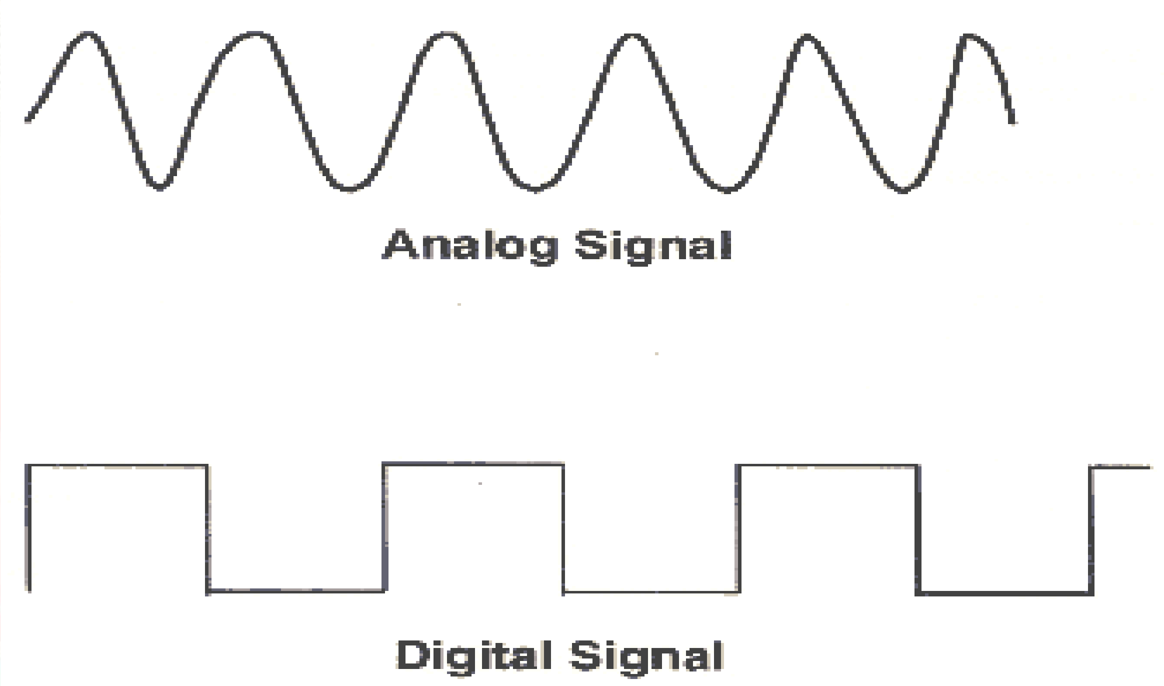
- The sound in electrophones is generated through electronic oscillators or the amplification of vibrations from electric pickups.
- The pitch, timbre, and volume can be extensively manipulated using electronic controls. This manipulation includes filters, modulators, and amplifiers, providing a vast range of sound possibilities.

PHYSICS AND MUSIC IN CONTEXT OF CS



Signal Processing

- Analog vs. Digital Signals
- Sampling, Quantization, and the Nyquist Theorem
- Digital filters and equalization
- Noise reduction techniques



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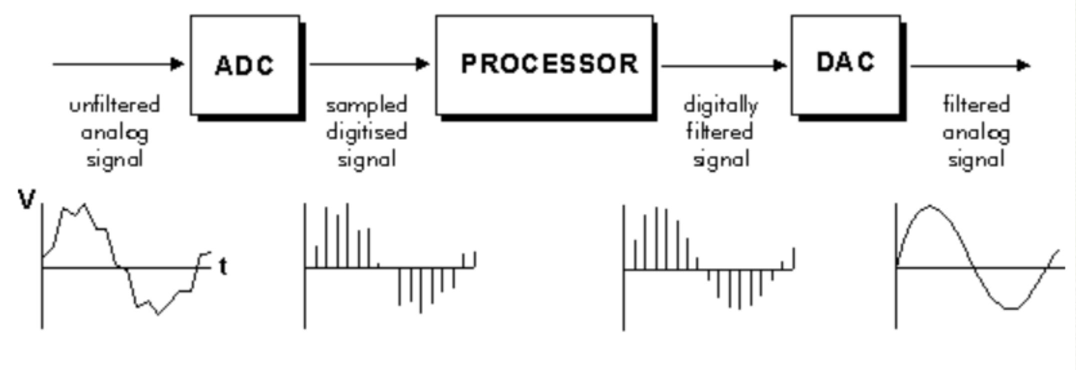

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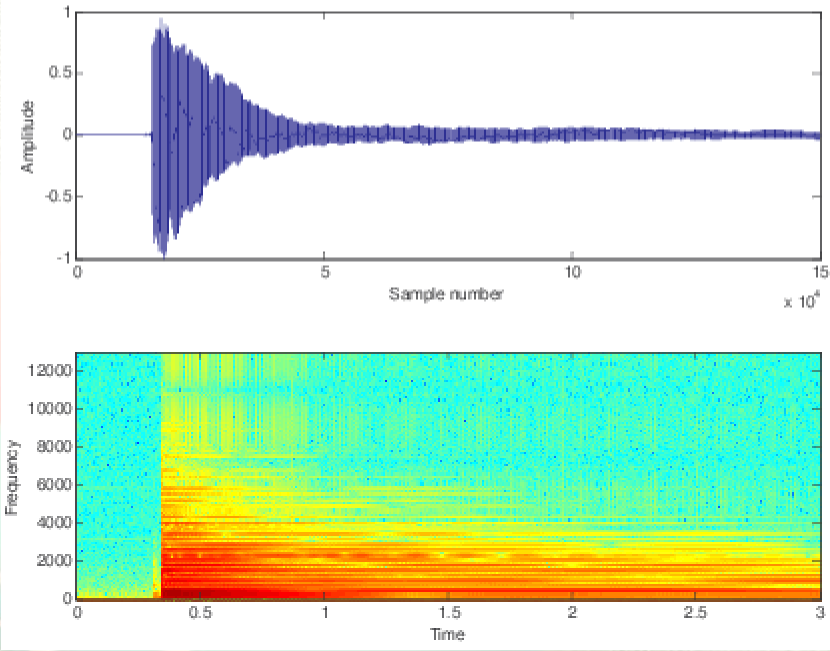
Acoustic Analysis with Software

- Wafevorm, Frequency, pitch analysis
- Visualizing sound: Oscilloscopes and Spectrogram
- Case studies:
  - Usage of such tools in Room acoustics simulation,
  - Usage of such tools in instrument design

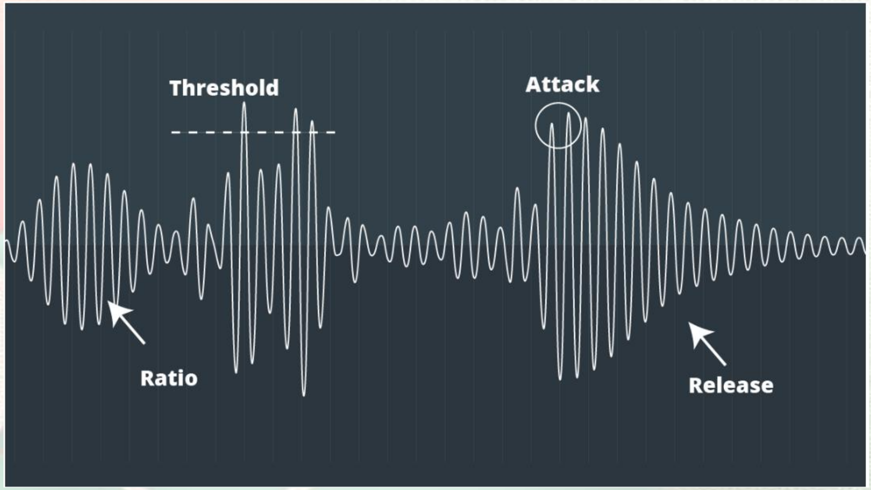


[10] Spectogram of Piano C4

[11] Electric Guitar on Oscilloscope, note E

Data Compression and Storage

- Lossy vs. Lossless audio compression
- Psychoacoustic models and MP3 encoding
- Challenges of high-fidelity audio storage
- Some popular audio format: mp3, m4a, flac, wav



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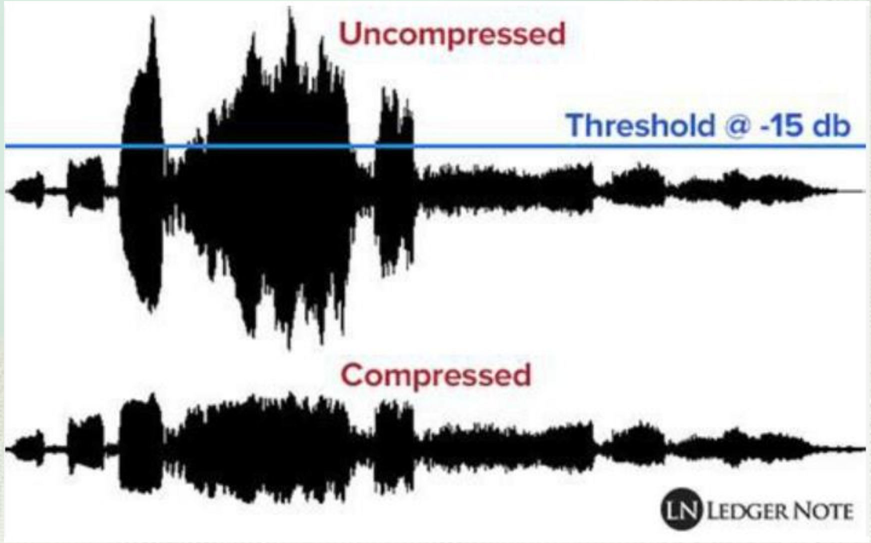

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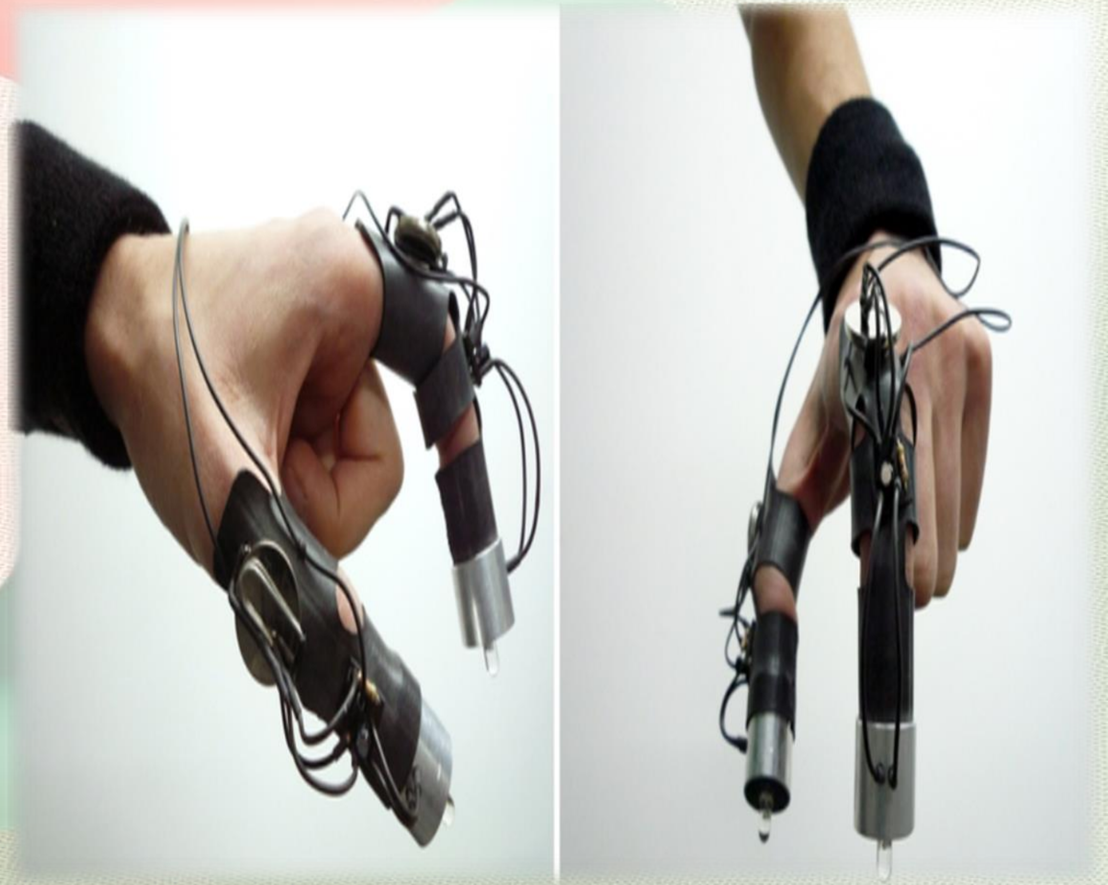
THE FUTURE OF MUSIC TECHNOLOGY

- Quantum Computing and its potential impact on music processing
- Evolution of music algorithms and computational creativity
- Ethical and Legal considerations of Generative AI in music production
- Possible rise of wearable music technology such as smart instruments



[13]

LITERATURE

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- [9] data communication & networking, november 2015 publisher: hasfem nigeria
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Other:

- [7] https://physicscourses.colorado.edu/phys1240/phys1240_sm19/L11%20-%20Vibrating%20Strings,%20Keyboard%20Instruments.pdf
- [8] https://www.physicsclassroom.com/class/sound/Lesson-5/Guitar-Strings
- [11] https://www.youtube.com/watch?app=desktop&v=Dd5dgajeIOA&ab_channel=RobRobinette
- [12] https://www.soundgym.co/blog/item?id=audio-compression-explained
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- [15] https://www.phys.unsw.edu.au/jw/pipes.html
- [16] https://physicscourses.colorado.edu/phys1240/phys1240_sm19/L11%20-%20Vibrating%20Strings,%20Keyboard%20Instruments.pdf

Q&A

THANK YOU