



# CALCULUS AND SOUND

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# Calculus and Sound

Calculus and sound are topics that may seem relatively far at first. Calculus is a study of derivatives, and integrals, ways to analyze and interpret slopes or find impossibly small or large numbers, while sound is a very physical thing. Sound is something that we interact with on a daily basis, and is even a concept that our physical bodies interpret subconsciously. However, it is due to our unconscious understanding that we misinterpret these two as unrelated fields. When we take an active approach in studying sound and use scientific tools to analyze and observe sound, we find out that sound is not only something that we can study using mathematical concepts, but it is through these concepts that we are able to create, replicate, and manipulate sound.

Sound can be interpreted with the following equations/transformations:

- **Feature Extraction:** An indispensable aspect of sound analysis involves feature extraction, where calculus assumes a central role. Features such as the rate of amplitude change over time (derivative) and the total energy in a signal (integral) are computed to characterize sound signals. These features are essential in applications like speech recognition and audio classification, where grasping the dynamics of sound is crucial.
- **Machine Learning:** The adoption of machine learning models for audio data analysis is burgeoning, with calculus concepts being integral to their training and optimization. Techniques like gradient descent, leveraging derivatives, are employed to train models to recognize patterns in audio signals. Furthermore, calculus aids in interpreting vocal commands, facilitating seamless interaction with devices and systems.

- **Spectral Analysis:** Spectral analysis involves identifying significant frequency components, patterns, and irregularities in sound signals. Calculus assists in analyzing vibrations, such as seismic activity, and in tasks like audio fingerprinting, where unique sound signal signatures are identified based on their spectral characteristics.
- **Data Visualization:** Visual representation of sound signals through data visualization techniques enriches our understanding of their underlying patterns. Calculus aids in creating graphs that depict various sound signal features, thereby enhancing interpretation and analysis.
- **Acoustic Modeling:** Acoustic modeling encompasses representing statistical properties of sound signals, pivotal in various applications. Calculus aids in identifying probabilities and parameters within sound signals, enabling accurate modeling and prediction of acoustic phenomena.
- **Fourier Transform:** The Fourier transform, a potent mathematical tool, analyzes the frequency content of sound signals by converting them from the time domain to the frequency domain. This transformation is critical for understanding sound signal composition and identifying relevant frequency components.
- **Signal Processing:** Signal processing techniques, including convolution, differentiation, and integration, are employed to analyze and manipulate sound signals. Calculus plays a crucial role in techniques like noise reduction, where differentiation and integration are utilized to modify sound signals. Additionally, differentiation aids in detecting abrupt changes or transitions in sounds.

One of the most recognizable ways that sound is used is in music. It is in music wherein sound is manipulated to its most extreme, and it is also within music that calculus and mathematical concepts are applied. One of the most common ways that musicians rely on sound to make “catchy” or “pleasing” sounding music is by incorporating music theory. This music theory in its

most basic form, is a study of ratios and how each ratio of notes sound in relation to each other.

As notes are inherently just frequencies, musicians use their understanding of these frequencies, and mix and match them, depending on how the ratios sound well together.

In the latter part of the 20th century, the instrument called a “synthesizer” was invented which allowed musicians and audio engineers to create wholly new sounds based on simple mathematical functions, running through a machine. From here, they could manipulate these functions in a simple manner by using knobs to change the slope at certain points, change the steepness of the curve, change the orientation of the function, and much much more. This instrument revolutionized the 80s and can be heard in almost every pop song since.