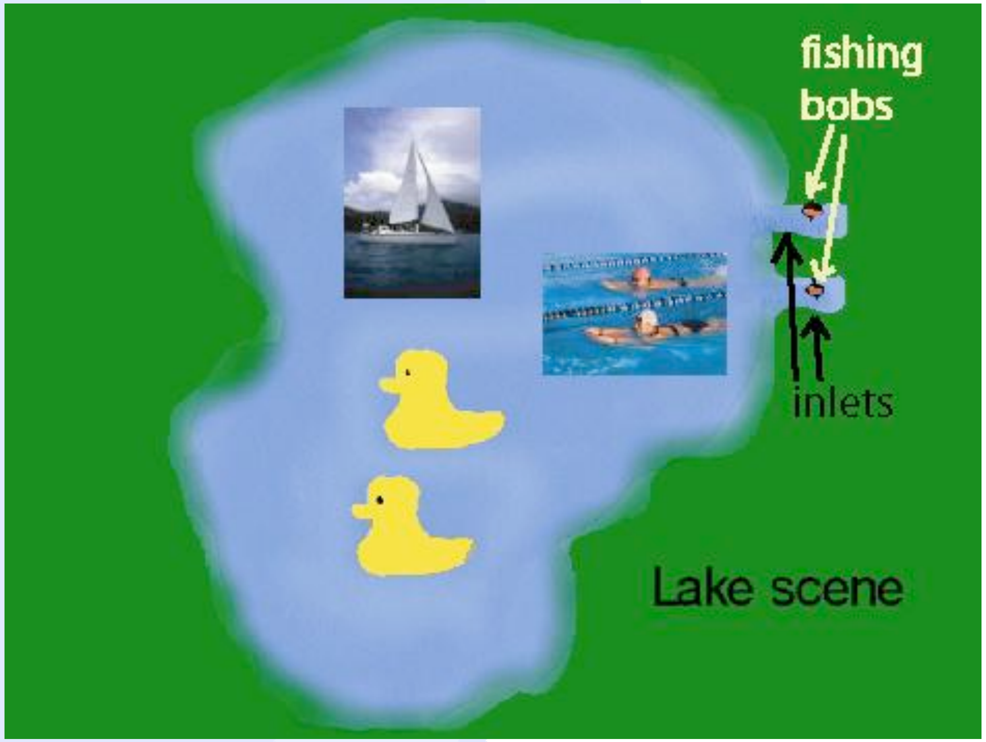
Psychoacoustics

3rd lesson

Fundamentals of Psychoacoustics

Introduction

Today's topic is the interaction between sound and the environment. How does our knowledge about the world influence the perception of sounds? This involves differentiating between bottom-up and top-down processes. Bottom-up processes involve the extraction of characteristics of the sound. such as frequency or reverberation. Also loudness and room acoustics are phenomena that depend mainly on the bottom-up processing. but also on our top-down knowledge. If both processes provide contradictory information. illusion effects. as we with the Haas and ventriloquy effects arise.



Fundamentals of Psychoacoustics

Questions of elementary psychoacoustics are:

- Perception of signals (usually simple tones) in isolation or against a background noise (signal-to-noise ratio).
- Separation of sound sources
- Localization of sounds in the room
- Pitch detection of instruments

Bottom-Up vs. Top-Down

Bottom-up:

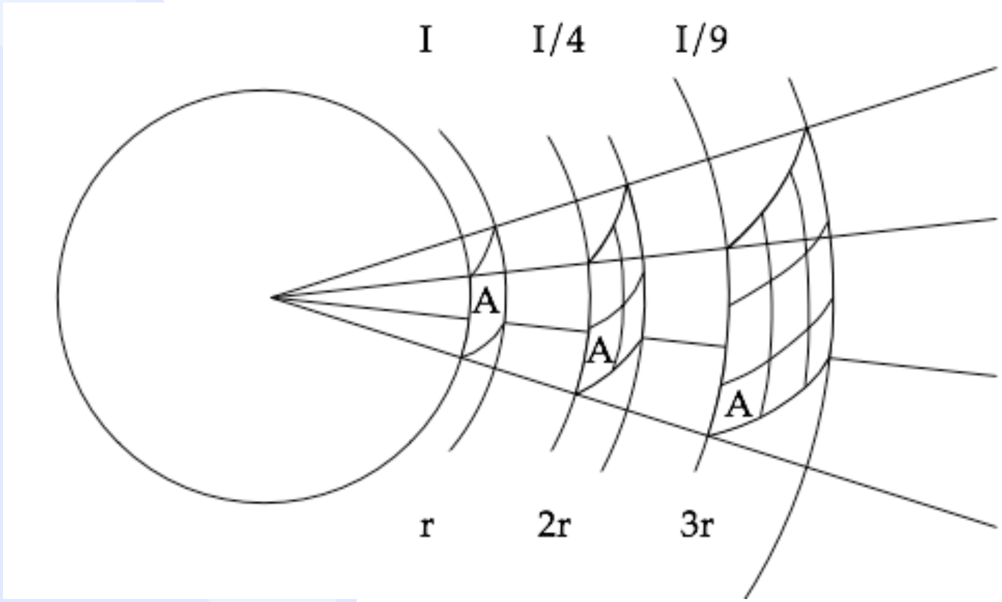
Data-based. Processing begins with the physical signal on the periphery (inner ear) and travels to higher brain regions.

Top-Down: Processing begins with mental processes that inform us about the quality of an acoustic event.

Intensity, amplitude und loudness

The intensity of a sound is measured in watts / m ^ 2. It decreases with the square to the distance of the sound source.

$$I = \frac{P}{A}$$



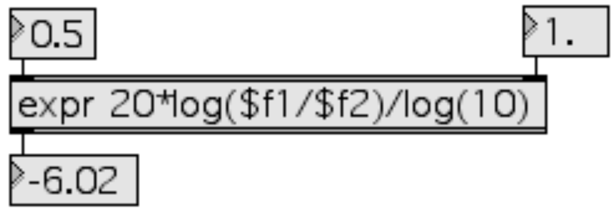
I= Intensity. P=Energy. A=Area

Intensity is the square of the amplitude

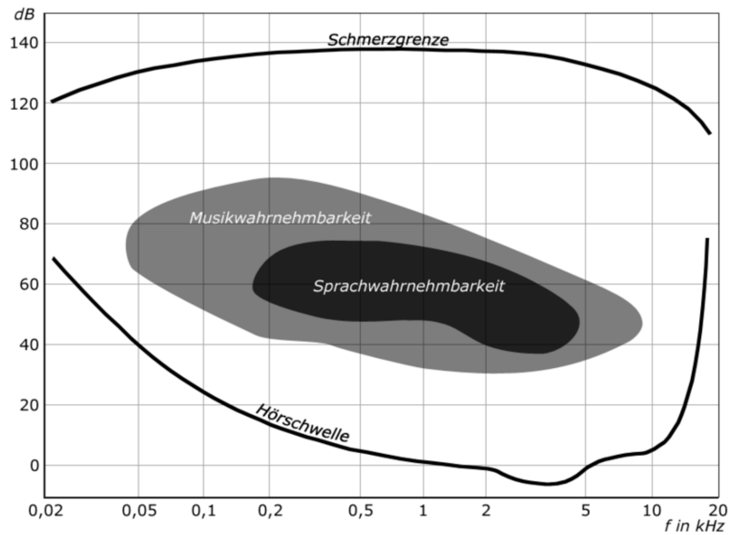
Loudness

The ratio between the amplitudes of two sinusoids is often expressed in decibels.
The formula for calculating decibels is: dB (A1 / A2) = 20 log10 (A1 / A2) = 10 log10 (I1 / I2).

The hearing threshold is the sound pressure or sound pressure level at which our ear just perceives sounds or noises. This is also referred to as the lower audible limit of the hearing range. The smallest sound pressure which is barely perceptible to the human ear is 20 µPa at a frequency of 1 kHz. This value was set as the reference for the absolute sound pressure level. (20 µPa = 0 dB SPL. SPL = Sound Pressure Level)
The term "hearing limit" refers to the limitation of the human hearing range which is represented by the hearing range. On the left are the lowest audible or perceived oscillations with the frequency of about 16 Hz and on the right the highest audible vibrations with about 19 kHz. Below you will find the hearing threshold at which the hearing begins and above the pain threshold. which marks the limit from which the volume can no longer be sustained. All four hearing limits are individual to each person and change throughout life. Basically, it can be said that the size of the hearing range gets smaller in the course of life.
The lower hearing threshold is strongly frequency-dependent. At the frequency 2 kHz it is 0 dB, at higher and lower frequencies the hearing threshold is shifted to higher levels. For example, a low sine tone of 30 Hz can only be heard when the sound pressure level exceeds 60 dB. High sine tones of 15 kHz can be perceived even for normal hearing from only about 60 dB.



Calculation of decibels in Max / MSP



Hearing range

Sound pressure level for known sound events

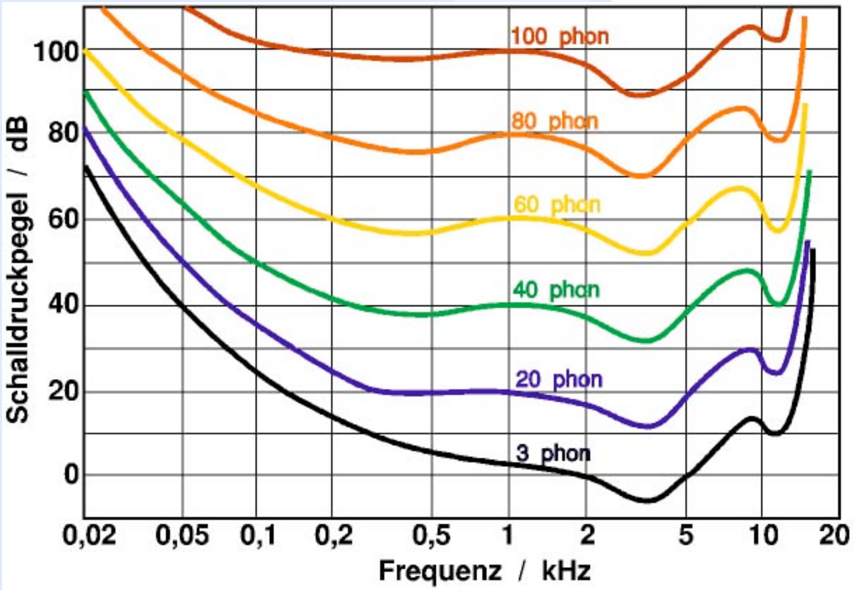
Examples	Schalldruckpegel L_p in dBSPL	Schalldruck p in N/m² = Pa als Schallfeldgröße	Schall-Intensität I in W/m² als Schallenergiegröße
Rifle being fired at 1 m	140	200	100
Pain threshold	130	63.2	10
Discomfort threshold	120	20	1
Chainsaw at 1 m distance	110	6.3	0.1
Disco. 1 m from the speaker	100	2	0.01
Diesel engine. 10 meters away	90	0.63	0.001
Edge of a traffic road 5 m	80	0.2	0.0001
Vacuum cleaner at 1 m distance	70	0.063	0.00001
Normal language at 1 m distance	60	0.02	0.000001
Normal apartment. quiet corner	50	0.0063	0.0000001
Quiet library. general	40	0.002	0.00000001
Quiet bedroom at night	30	0.00063	0.000000001
Noise in the TV studio	20	0.0002	0.0000000001
Leaf rustling in the distance	10	0.000063	0.00000000001
auditory threshold	0	0.00002	0.000000000001

dB(SPL) Quelle (mit Abstand)

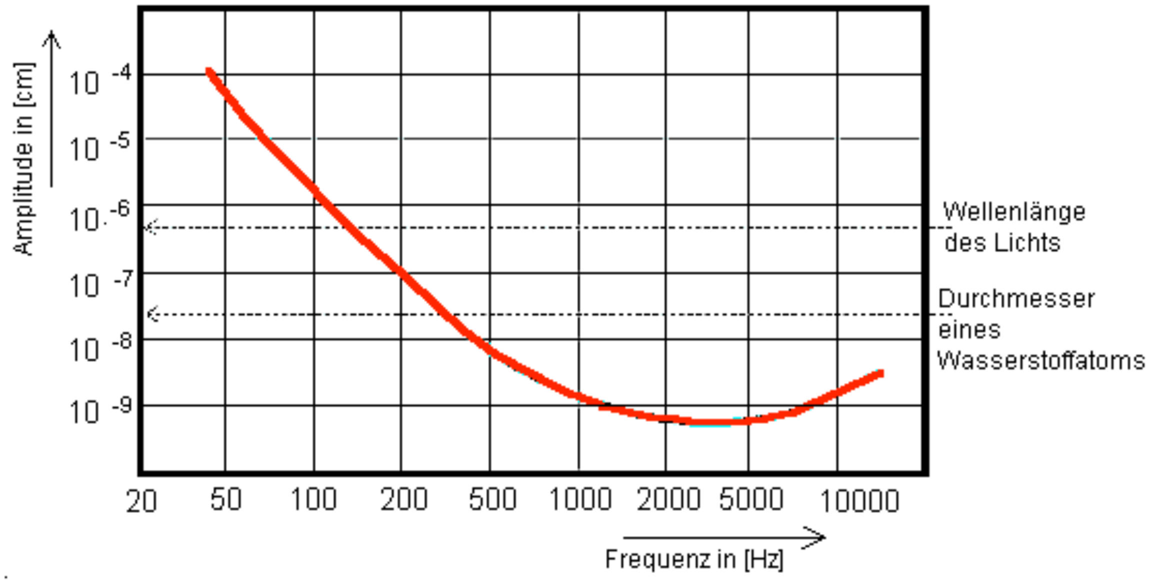
194 Theoretical limit for a sound wave at 1 atmosphere environmental pressure

Curves of equal loudness
after Fletcher and Munson

The course of the hearing threshold shows that hearing does not have the same sensitivity for all frequencies. Sine tones of different frequency, despite the same sound pressure level, are perceived differently in loudness.
This property of the hearing is described by means of the curves of equal loudness.
Depending on the frequency the sound, they give pressure levels which produces the same loudness sensation as a sine tone of the frequency 1 kHz for a given dB value (unit of measure: phon). The figures on the right show the curves of equal loudness for select sound pressure levels.



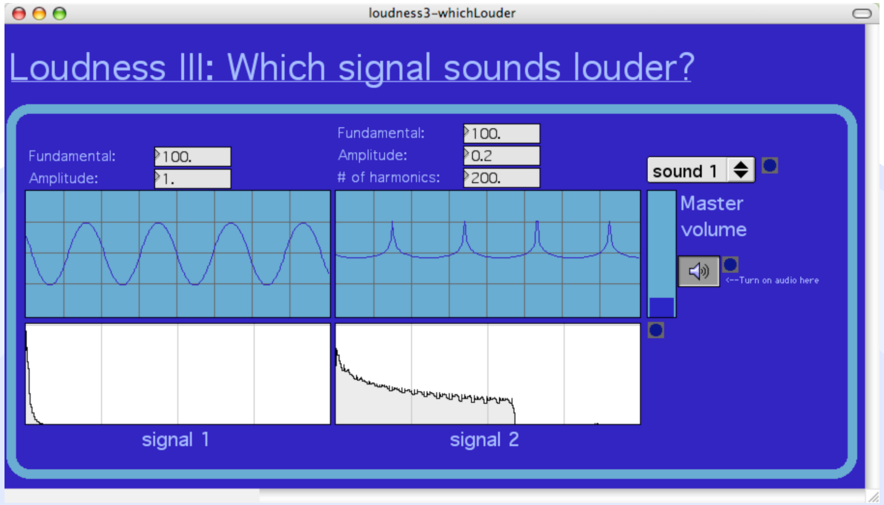
Middle ear

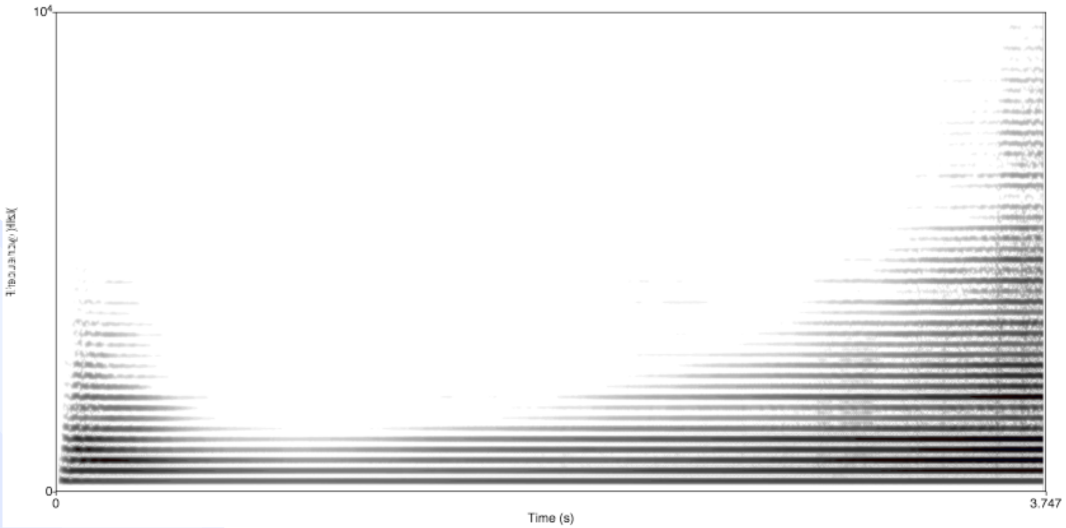


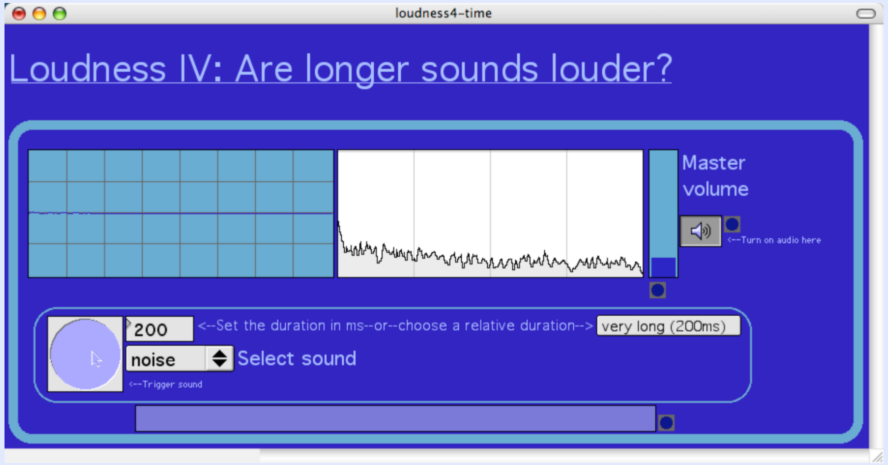
Sensitivity of the eardrum

If the eardrum is excited at the hearing threshold with a frequency of 1000 Hz, it is set in vibration whose amplitudes are below the diameter of a hydrogen atom. These unimaginable small vibrations can still be perceived as sound - a proof of how sensitive the ear is. Since the amplitude of the oscillation is below the wavelength of the visible light when excited at the threshold of hearing, the detection of eardrum vibrations is no longer possible, even with the strongest optical microscope!
The figure illustrates the relationship between the frequency and the amplitude of the eardrum within the range of the auditory threshold.

Frequency and time integration in the perception of loudness



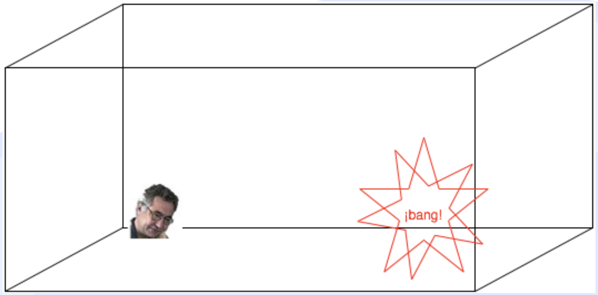




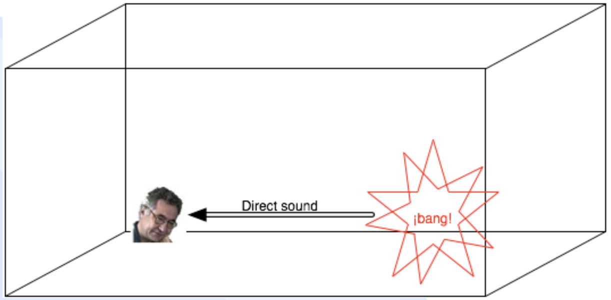
Timbre affects loudness perception

Sounds with a larger amount of higher harmonics will generally perceived as louder than tones of the same amplitude but with fewer overtones. Therefore, the musical terms like piano or forte are relative. Example: A scream will still sound loud, even when its amplitude is lowered.

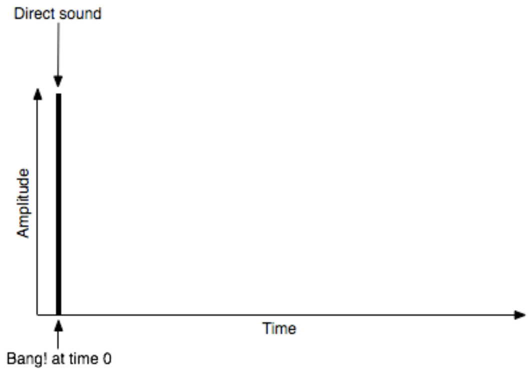
Reverb

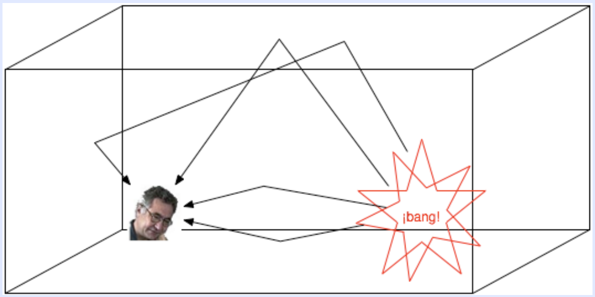


A sound event

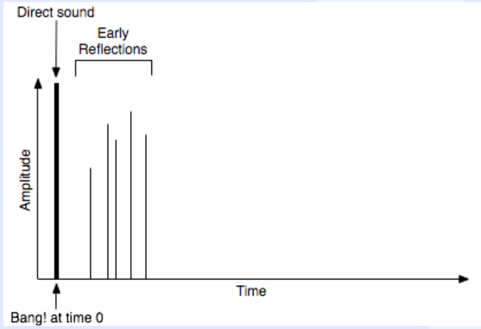


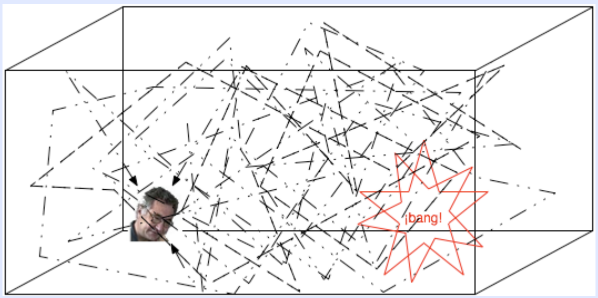
Direct sound



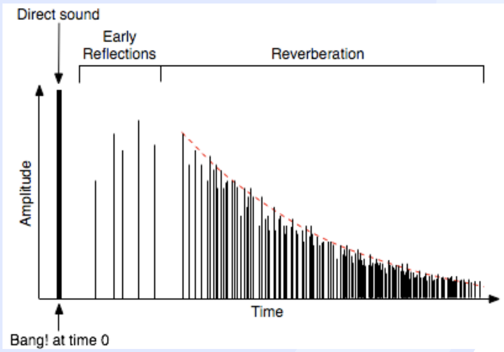


Early reflexions

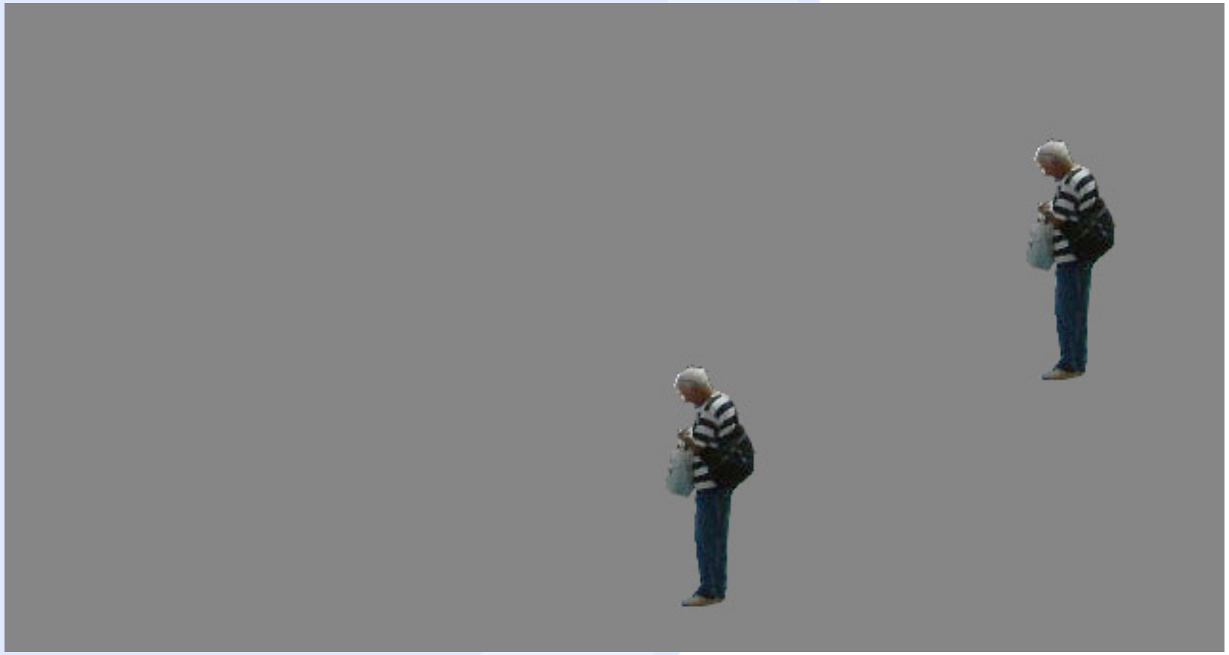




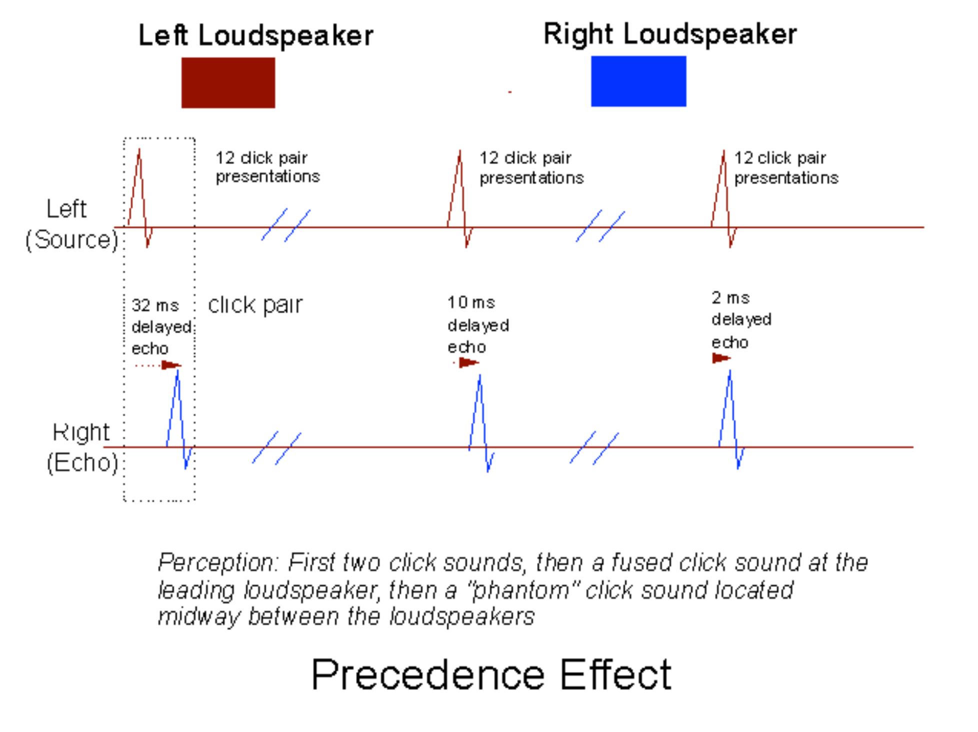
Reverb



Illusions



Precedence Effect



The **precedence effect** or **law of the first wavefront** is a binaural psychoacoustic effect. When a sound is followed by another sound separated by a sufficiently short time delay (below the listener's echo threshold), listeners perceive a single fused auditory image; its perceived spatial location is dominated by the location of the first-arriving sound (the first wave front). The lagging sound also affects the perceived location. However, its effect is suppressed by the first-arriving sound.

The precedence effect appears if the subsequent wave fronts arrive between 2 ms and about 50 ms later than the first wave front. This range is signal dependent. For speech the precedence effect disappears for delays above 50 ms, but for music the precedence effect can also appear for delays of some 100 ms.[8]
In two-click lead–lag experiments, localization effects include aspects of summing localization, localization dominance, and lag discrimination suppression. The last two are generally considered to be aspects of the precedence effect:[9]

- Summing localization: for time delays below 2 ms, listeners only perceive one sound; its direction is between the locations of the lead and lag sounds. An application for summing localization is the intensity stereophony, where two loudspeakers emit the same signal with different levels, resulting in the localized sound direction between both loudspeakers. The localized direction depends on the level difference between the loudspeakers.
- Localization dominance: for delays between 2 and 5 ms, listeners also perceive one sound; its location is determined by the location of the leading sound.
- Lag discrimination suppression: for short time delays, listeners are less capable of discriminating the location of the lagging sound.

For time delays above 50 ms (for speech) or some 100 ms (for music) the delayed sound is perceived as an echo of the first-arriving sound. Both sound directions are localized correctly. The time delay for perceiving echoes depends on the signal characteristics. For signals with impulse characteristics echoes are perceived for delays above 50 ms. For signals with a nearly constant amplitude the echo threshold can be enhanced up to time differences of 1 to 2 seconds.
A special appearance of the precedence effect is the Haas effect. Haas showed that the precedence effect appears even if the level of the delayed sound is up to 10 dB higher than the level of the first wave front. In this case the range of delays, where the precedence effect works, is reduced to delays between 10 and 30 ms.

Interaction of vision and hearing

Contradictory information through hearing and seeing gives sight the upper hand over hearing. We observe this phenomenon with the ventriloquist effect, where we perceive the sound coming from the wrong direction because of the mouth movement of the doll. In the McGurk effect, on the other hand, there is a mental interpolation between the auditory and visual impressions: we see the person speaking “ga-ga" while the audio track contains "ba-ba". However, most listeners perceive “da-da”, which is a compromise between the two percepts.