HOW DIGITAL AUDIO WORKS

"The sounds we hear are fluctuations in air pressure–tiny variations from normal atmospheric pressure—caused by vibrating objects."

"Any sound in digital form…is just a series of numbers. Any arithmetic operation performed with those numbers becomes a form of audio processing."

MSP Tutorials and Topics

Reading
Cycling '74, "How Digital Audio Works" in MSP Tutorials and Topics (Palo Alto: CA: Cycling '74, 2006).

Terms and Concepts

Sound	**Timbre**	**Physical Units**
Vibrating objects	Individual amplitude levels and trajectories	Hertz (Hz.)
Atmospheric pressure	Instrumental tone color	Decibels (*dB*)
Compression/rarefaction of air molecules	Timbral perception	**Digital representation of sound**
Momentum and inertia		Continuous vs. discrete
Simple harmonic motion	**Spectrum** (*a* vs. *f*)	Transducer
	Harmonic	ADC and DAC
Physical models	Inharmonic	Sample and hold
Pendulum		Sampling rate (44.1k, 48k, etc.)
Tuning fork	**Harmonic (overtone) series**	Low-pass filter
Plucked string	Fundamental frequency	Nyquist theorem
	Integer multiple	- Nyquist rate
Mathematical models	Partial or harmonic	- aliasing or foldover
Sine wave ($y = \sin x$)	Fusion	Instantaneous amplitude values
Complex wave	Octave	Resolution
	Fourier theory	Bit depth
Waveform (*a* vs. *t*)	As a chord/scale of nature	16-bit amplitude values
Periodic waveform		$2^{16} = 65,536$
Bipolar signal	**Inharmonic tones and noise**	Quantization
Amplitude - *a*	Non-integer multiples	- error
Frequency - *f*	Inharmonic partials	- noise
Phase - ϕ	Noise	Signal-to-Quantization Noise Ratio (SQNR)
Period - $1/f$	- white noise	Storage: 10 MB per min. for CD quality audio
Time - *t*	Randomness	Clipping
	Band-limited noise	Digital Signal Processing (DSP)
Plucked string physical model		Addition is equivalent to audio mixing
Multiple resonant modes of vibration	**Amplitude Envelope**	Multiplication is equivalent to amplification
Complex tone	Stages: Attack, Decay, Sustain and Release	
Fixed endpoints	Unipolar signal	
Nodes		
Length (*L*), density and tension	**Range of Human Hearing**	
Integer divisions of *L*	20 Hz. to 20,000 Hz.	

Reference
Curtis Roads, *The Computer Music Tutorial* (Cambridge, MA: MIT Press, 1996).

Relative Amplitude

The conversion formula for absolute amplitude (*A*) to relative amplitude (*dB*) is:

$$dB = 20\log_{10}(A / A_{ref})$$

If $A_{ref} = 1$, the maximum possible amplitude, we can express the relative intensity of this sound with an absolute amplitude $A = 0.5$ in dB, where $\log_{10}(0.5) = -0.3$:

$$dB = 20\log_{10}(0.5/1) = -6 \;\; db$$

Each having of amplitude is a difference of about -6 *dB*, each doubling is about +6 *dB*.

Quotable

"A plucked string will vibrate in all of these possible resonant modes simultaneously, creating energy at all of the corresponding frequencies. Of course each mode of vibration…will have a different amplitude."

"…in many sounds the amplitudes of the different component frequencies may vary quite separately and differently from each other. This variety seems to be one of the fundamental factors in our perception of sounds as having…*timbre*."

"…fusion is supported by the famous mathematical theorem of Jean-Baptiste Joseph Fourier, which states that any periodic wave, no matter how complex, can be demonstrated to be the sum of different harmonically-related frequencies (sinusoidal waves), each having its own amplitude and phase."

On Amplitude

"Another important factor in the nearly infinite variety of sounds is the change in over-all amplitude of a sound over the course of its duration."

"The relationship between the objectively measured amplitude of a sound and our subjective impression of its loudness is very complicated and depends on many factors."

"…our sense of the relative loudness of two sounds is related to the ratio of their intensities, rather than the mathematical difference in their intensities."

"Experiments find that for most listeners…the (extremely subjective) sensation of a sound being "twice as loud" requires a much greater than twofold increase in amplitude. Furthermore, our sense of loudness varies considerably depending on the frequency of the sounds being considered."

"The softest sound we can hear has about one millionth the amplitude of the loudest sound we can bear."

On the Nyquist Theorem

"Any frequency that exceeds the Nyquist rate is indistinguishable from a *negative* frequency the same amount less than the Nyquist rate."

On DSP

"DSP is concerned with the effects of digital filters–formulae for modifying digital signals by combinations of delay, multiplication, addition, and other numerical operations."