

2. Sound Synthesis and Reproduction on Computers

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Warning:
Technical Stuff Ahead

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Overview

- Basic sound terms
- Translating sound for computers
- Sound storage and playback
- Compression and sound perception
- Digital signal processing basics
- Q & A

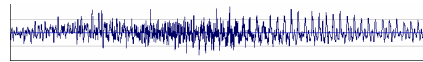
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Representing Sound

- **Waveform:** represents a sound wave
Amplitude: power – voltage, decibels [dB], sound pressure level [SPL], etc.

vs.

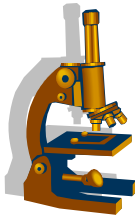
Time: Seconds



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Does Amplitude Mean Volume?

- "Loudness" is a loaded term: perception
 - An experiment



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Our Friend the Decibel

- dB = a logarithmic ratio (comparison)
 - SPL
 - Sound w/ twice amplitude of another sound:

$$\text{dB} = 20 * \log_{10} \left(\frac{2}{1} \right) \approx 6.02\text{dB}$$

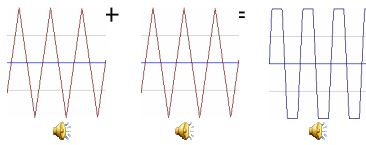
- More science experiments
- dBFS = decibels relative to full scale
 - Full scale = absolute peak amplitude a device can generate/capture (0 dBFS)



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Clipping Along...

- Trying to produce higher amplitude wave than a system can represent (0 dBFS)



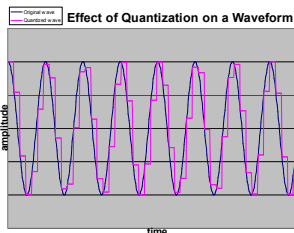
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Clipping and Games

- Commonly seen issue
 - Sounds often normalized to full scale
 - Clipping not always noticed (to a point)
 - The need for prioritization
- Monitoring for clipping
 - Multiple samples at 0 dBFS usually means clipping occurred

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Computers are from Mars, Audio is from Venus



- Sound is analog
- Computers are digital
 - Must sample (quantize) sound

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Storing Sound on Computers

- Generally captured in *time domain*
- Frequency quantization = sampling rate
- Amplitude quantization = bit-depth

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What's the Frequency, Kenneth?

- Frequency = cycles per sec (Hertz [Hz])
 - Used for sampling rate as well as pitch
 - Humans=highest sensitivity to 3-4 kHz 🦻 🦻
- How frequency relates to timbre
 - Fundamental/overtones

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Quantization

- Translation of continuous signal into discrete points of data
 - By its nature, reduces accuracy
- Can only represent frequency data at up to $\frac{1}{2}$ sampling rate (Nyquist limit)
 - Frequencies above are usually filtered out (or will be aliased) 🦻 🦻
 - Rules of thumb for sampling

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Quantization: Examples

- Frequency quantization: 44,100 Hz
 - Can represent sound frequencies of up to 22,050 kHz
- Amplitude quantization: 16 bits
 - $16 \text{ bits} = 2^{16} = 65,536$ unique levels
 - $65536 / 2 = 32768$, so full scale is $20 \log 32768 = \sim 90 \text{ dB}$ range
 - 8 bits = $\sim 42 \text{ dB}$ range

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Sound Storage and Playback



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Creating Sound in Games

- Captured/stored audio samples
 - Disk (HDD, optical, etc.)
 - Internet streaming
- Sound synthesis
 - Wavetable
 - FM/AM
 - Physical modeling
 - Real-time processing

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Storing Sounds

- Uncompressed audio data is big!
 - 16-bit 44.1 kHz stereo: 176 KB/sec (10.5 MB/min)
 - 24-bit 96 kHz 5.1: 1.7 MB/sec (103.7 MB/min)
- Helping and hurting the storage squeeze

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Playback Techniques

- Pros/cons of:
 - "In-Memory" (banks, etc.)
 - Streaming
 - Hybrid options
- Latency and audio
- Game-specific "budget" considerations

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When the sound just can't fit...

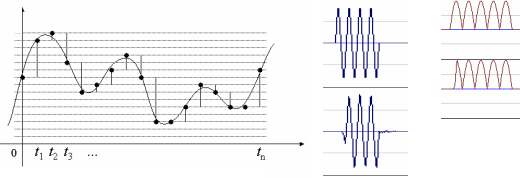
- Compression 🗂️
 - Sample rate reduction 🗂️🗂️🗂️
 - Bit-depth reduction 🗂️
 - Generic algorithms 🗂️
 - Acoustic ("perceptual") algorithms
- Tradeoffs
 - "Lossy" vs. "Lossless"



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'Cheap' Compression: ADPCM

- Adaptive Differential Pulse Code Modulation
 - Easy implementation (CPU or HW)
 - Audio waveform assumptions
- ~4:1 compression (4 bits per 16-bit sample)



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Perceptual Compression

- MP3, WMA, XMA, Ogg Vorbis, etc.
- Based on human frequency sensitivities
 - Frequency-domain compression
- Often support variable compression ratios
- Advantages and disadvantages

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Today's Lab: Understanding and Using Compression



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Lab Tasks

- Take existing high fidelity sounds
- Experiment with:
 - Sample rate reduction
 - Bit-depth reduction
 - Compression (ADPCM, MP3/WMA)
- How small can you make waves with each technique that still sound "good enough"?
- Can you mix techniques to get even better compression?

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Q & A

- Questions, comments?

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