1 PA1 presentations


2 Announcement: Schlepping reminder

• Please remember if you are signed up for pre- or post-class schlepping for either recording session on Mon, 11/14, Wed, 11/16.
• Pre-class schlepping: Meet at 10 minutes before class

3 Review

3.1 Recording session 1

3.2 Ed3 assignment

• How to limit to $-3\,\text{dB}$ with ReaComp plugin
  – Large ratio
  – Small rms size
  – Short attack and release times
• Review of setting up a gate

4 Audible effects of reflections & delays

4.1 Flutter echoes & resonances

• Unpleasant *flutter echoes* tend to occur between hard, parallel walls
• Real-world examples: Killian Hall
  – Front right stage area as seen from audience (floor & ceiling)
  – Center of room with folded-in wall panels (left & right wall)
• Demo in Pd: Perceptual effect of delays
  – $\gtrsim 30\,\text{ms}$: Audible as echoes
  – $\lesssim 30\,\text{ms}$: Audible as pitched resonance – why?
4.2 Comb filters

- Result of mixing a sound with a copy of itself delayed by $\Delta t$:
  - Constructive interference if $\Delta t = T, 2T, 3T, \ldots = \frac{n}{f}$
  - Destructive interference if $\Delta t = \frac{T}{2}, \frac{3T}{2}, \frac{5T}{2}, \ldots$
- Sound example: pink noise, moving mic, reflective surface
- Can be enjoyed outdoors across MIT campus; just combine:
  - Broadband HVAC noise
  - Reflections from nearby building walls
  - Moving observer
- Other ubiquitous examples:
  - Airplane moving with respect to reflective surface on ground
  - Lavalier mic of TV weather reporters (Katz 2014, p. 29)

\[
\Delta t = \frac{\Delta d}{c} = \frac{d_2 - d_1}{c} = \frac{2h^2 + \left(\frac{d_1}{c}\right)^2 - d_1}{c}
\]
4.3 Standing waves

\[
d = \frac{n \cdot \lambda_n}{2}
\]

- Occur for any frequencies where \(\frac{\lambda}{2}\) ‘fits’ between walls
- Result: Pressure peaks and nodes remain in same location over time
- Demo: 80 Hz tone, walk around room. What happens close to walls?

4.4 Room modes

\[
f_n = \frac{c \cdot n}{2 \cdot d}
\]

- \(f_n\) modal frequencies (Hz)
- \(c\) speed of sound (m s\(^{-1}\))
- \(n\) mode number \(n \in \mathbb{N} = 1, 2, 3, \ldots\)
- \(d\) distance between walls (m)

- **Modes** … frequencies at which standing waves occur
  - First-order modes between parallel walls
  - Higher-order modes across diagonals etc.
- Spectral distribution of modes relates to quality of room acoustics:
  - Desirable: Modes evenly distributed over frequency spectrum
  - Undesirable: Accumulation of modes (e.g., in multiple dimensions)
- How to avoid multi-dimensional modes?

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**Table 1.** First-order room modes of the Sonic Arts Lab at the New Zealand School of Music in Wellington

| \(n\) | Room mode/Hz |
|---|---|---|
| 1 | 14.8 | 34.8 | 41.9 |
| 2 | 29.6 | 69.6 | 83.7 |
| 3 | 44.5 | 104.4 | 125.6 |
| 4 | 59.3 | 139.2 | 167.4 |
| 5 | 74.1 | 174.0 | 209.3 |
| 6 | 88.9 | 208.8 | 251.1 |

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**Figure 4.** Sound pressure \(p\) for a standing wave between two parallel walls.
5 Natural reverb

![Diagram](image)

5.1 Reverberation time $T_{60}$

$$T_{60} \approx 0.161 \cdot \frac{V}{S \cdot \alpha}$$

- Time it takes spl in a given room to drop by 60 dB after sound ceases
- Equation by Wallace Sabine (cf., Thompson [2002])
  - Ca. 1898, published only in 1922
  - Derived through experiments in Sanders Theatre at Harvard
  - Real-world test: design of Boston Symphony Hall (opened in 1900)

<table>
<thead>
<tr>
<th>Material</th>
<th>$\alpha$ at 125 Hz</th>
<th>$\alpha$ at 500 Hz</th>
<th>$\alpha$ at 2000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustical tile</td>
<td>0.20</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>Brick wall (unpainted)</td>
<td>0.02</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Heavy carpet on heavy pad</td>
<td>0.10</td>
<td>0.60</td>
<td>0.65</td>
</tr>
<tr>
<td>Concrete (painted)</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Heavy draperies</td>
<td>0.15</td>
<td>0.55</td>
<td>0.70</td>
</tr>
<tr>
<td>Fiberglass blanket (7.5 cm thick)</td>
<td>0.60</td>
<td>0.95</td>
<td>0.80</td>
</tr>
<tr>
<td>Glazed tile</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Paneling (0.30 cm thick)</td>
<td>0.30</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Plaster</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Vinyl floor on concrete</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Wood floor</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Table 2. Typical values for reverberation time $T_{60}$ (DPA 2015)

- Vocal booth: 0.1–0.2
- Control room: 0.2–0.3
- Living room: 0.4–0.5
- Recording studios: 0.4–0.6
- Lecture room: 0.6–0.9
- Cinema: 0.7–1.0
- Rock venue: 0.6–1.6
- Theatre: 1.1–1.4
- Opera house: $\approx$ 1.6
- Concert hall: 1.8–2.2
- Cathedral: $> 5$
- Large sports venue: 10
5.2 Critical distance $d_c$

- Distance from a sound source in a given room at which acoustic energy of direct and diffuse (reverberant) sound field are equal

- Direct vs. diffuse field ≠ near vs. field (cf., proximity effect!)
  - Near & far field can be distinguished also under free field conditions
  - Direct & diffuse field only exist in context of room acoustics

- $d_c$ useful to gauge expected reverberation level of main stereo mic for a given room and distance to ensemble

6 Artificial reverberation in hardware

6.1 Echo chambers

- Idea: Play sound into reverberant space and re-record it
- Consider $T_{60}$ equation: Cheaper to build bathroom than cathedral
- But bathroom lacks pre-delay
- Initially addressed by tape delays & delay tubes (Eargle 2003, p. 232)

6.2 Plate reverbs

Equation 3. Critical distance $d_c$

$$d_c \approx 0.057 \cdot \sqrt{\frac{V}{T_{60}}}$$

<table>
<thead>
<tr>
<th>$d_c$</th>
<th>critical distance</th>
<th>$\text{m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.057</td>
<td>magic number</td>
<td>$\sqrt{\text{s} \text{m}^{-1}}$</td>
</tr>
<tr>
<td>$V$</td>
<td>room volume</td>
<td>$\text{m}^3$</td>
</tr>
<tr>
<td>$T_{60}$</td>
<td>reverberation time</td>
<td>$\text{s}$</td>
</tr>
</tbody>
</table>

Figure 6. Principle of an echo chamber

Figure 8. Principle of a plate reverb
• Introduced by German company EMT in 1950s (originally mono)
• Famous stereo version EMT 140 followed soon (Eargle 2003, p. 233)
  – Moving-coil driving transducer toward center of 1 × 2 m plate
  – Two piezo transducers toward each end of plate
  – Adjustable damping membrane on back to tweak T60

6.3 Spring reverbs
• Same principle as plate reverb, but using a spring
• Classic example: AKG BX-20 (late 1960s)
  – Randomized spring to eliminate ‘boing’ sounds (Eargle 2003, p. 234)
  – Explicitly advertised for its 20–50 ms pre-delay (AKG 2017)

7 Digital reverberation
7.1 History
• EMT 250 (1976)1
  – First commercially available digital reverberation system
  – Introduced by EMT as alternative to their EMT 140 plate
  – Algorithm design by Barry Blesser (then professor at MIT)
• Lexicon 224 (1978)
• Lexicon 480L (1986)
• Publison Infernal Machine 90 (ca. 1987)

7.2 Algorithmic reverbs

• Generally implemented through feedback delay network (FDN) based on room model (reflections as filtered delays)
• Examples of software packages:
  – Cockos ReaVerbate (comes with Reaper)
  – Calf Reverb (LV2 and LADSPA plugins)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room size</td>
<td>Volume $V$ of simulated space (often presets)</td>
</tr>
<tr>
<td>Decay time</td>
<td>Corresponds to $T_{60}$</td>
</tr>
<tr>
<td>Wet/dry balance</td>
<td>Ratio of reverberated (‘wet’) to original (‘dry’) sound</td>
</tr>
<tr>
<td>Hr cutoff</td>
<td>Low-pass filter to dampen reflections</td>
</tr>
<tr>
<td>Stereo width</td>
<td>Decorrelation of l. &amp; r output signals</td>
</tr>
<tr>
<td>Pre-delay</td>
<td>Simulates distance to closest wall</td>
</tr>
</tbody>
</table>

Table 4. Typical software reverb control parameters (cf., Eargle[2003] P. 239)

7.3 Convolution reverbs

- Also (but rarely) referred to as “sampling reverbs” (Eargle[2003], pp. 240 f.)
- Based on convolution of dry signal with room impulse response (ir)
  1. Record a dry (close-miked) signal
  2. Acquire target room’s impulse response
  3. Convolve dry recording with ir (dsp operation)
- Sound example: Result sounds as if recorded in that room
- But sound source never has to physically be in that space ☺
- Impulse response can be thought of as room’s ‘acoustic fingerprint’
  - Originally acquired by recording a gun shot or balloon pop
  - Modern techniques based on sine sweeps (better s/n ratio)
  - Commercially (and for less prominent rooms freely) available
- Convolution reverb software:
  - [Cockos ReaVerb](http://www.cockos.com) (comes with Reaper)
  - Space Designer (comes with Logic)
  - [Altiverb](http://www.line6.com)
  - [Waves ir plugin series](http://www.waves.com)
  - [ir lv2 plugin by Tom Szilagyi](http://tom.szilagyi.de/ir-lv2)
  - [Freverb3](http://www.freesound.org插件) (library; vst plugins available)
- Demo: Record your own ir in Linux with [Aliki](http://adriaensen.com/products/aliki) (Adriaensen[2006a,b])
8 Stereo enhancing mono signals

- Idea: Provide mono signal with width (‘fake’ stereo)
- Lots of plugins available, but more fun to build your own
- Three strategies suggested by Senior (2011b)

8.1 Inverted graphic eqs

- ‘Spectral split’ of mono phantom source across stereo field
- Gives impression of source width
- Example (cf., figure 10):
  - L: boost every second frequency band; attenuate every other
  - R: boost bands attenuated on L; attenuate bands boosted on L

8.2 Delay plus mirrored panning

- Slightly delay ($\Delta t < 30$ ms) one channel against other (cf., figure 11)
- Stereo width adjustable through panpots
- But panpots should remain symmetric (same percentage on both)
- Careful – the narrower the panning, the likelier comb filtering is!

8.3 Delay plus pitch shifting

- Asymmetric delays & pitch shifts on L and R channels (cf., figure 12)
- As mix-in effect (hence delays $\Delta t$ on both channels) for vocal tracks
- Again, keep an ear on potential phase problems!
9 Preview mx2 assignment

- Another mixdown, but this time whole song and with reverb
- Consider different audio plugin families (cf., table 5)
- Reverb plugin recommendations included with instructions
- Demo: Adding a reverb plugin to a Reaper track via fx menu

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Name</th>
<th>Linux</th>
<th>Mac</th>
<th>Windows</th>
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<tbody>
<tr>
<td>LADSPA</td>
<td>Linux Audio Developer's Simple Plugin Api</td>
<td>✔</td>
<td>✘</td>
<td>✘</td>
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<tr>
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<td>LADSPA version 2</td>
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<td>✘</td>
<td>✘</td>
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<td>Au</td>
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<td>✘</td>
<td>✔</td>
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<tr>
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<td>Virtual Studio Technology</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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</tbody>
</table>

Table 5. Audio plugin families

References & further reading


