21M.380 · MUSIC AND TECHNOLOGY
RECORDING TECHNIQUES & AUDIO PRODUCTION

ROOM ACOUSTICS & REVERBERATION

SESSION 18 · WEDNESDAY, NOVEMBER 9, 2016

1 PA1 presentations

- [redacted]
- Flo: Randy Newman – *A Few Words in Defense of Our Country* (2006)

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 [redacted], 10 minutes before class

3 Review

3.1 Recording session 1

3.2 ED3 assignment

- How to limit to –3 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
  - $\gtrsim 30$ ms: Audible as echoes
  - $\lesssim 30$ ms: Audible as pitched resonance – why?

4.2 Comb filters

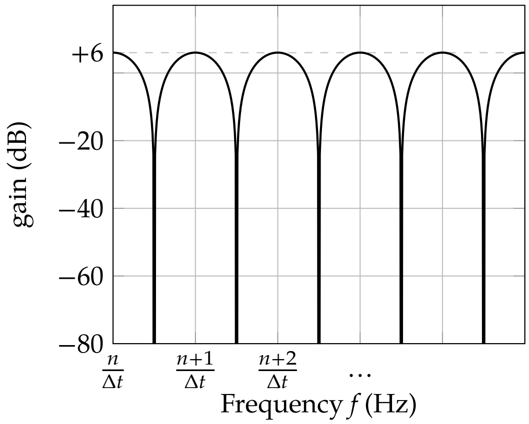

Figure 2. Comb filter frequency response (note linear x axis

- Result of mixing a sound with a copy of itself delayed by Δt:
  - Constructive interference if $\Delta t = T, 2T, 3T, \cdots = \frac{n}{f}$
  - 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)

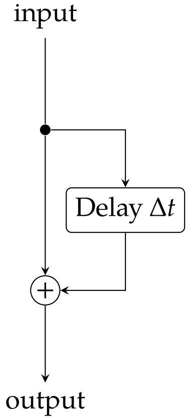

Figure 1. Comb filter flow chart

$$\Delta t = \frac{\Delta d}{c} = \frac{d_2 - d_1}{c} = \frac{2\sqrt{h^2 + \left(\frac{d_1}{2}\right)^2} - d_1}{c}$$

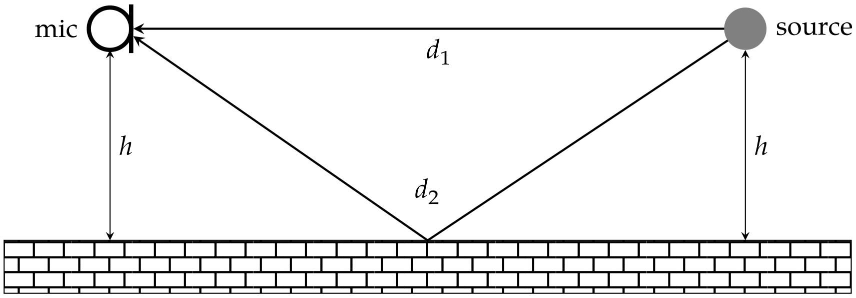

Figure 3. Comb filter effect caused by single reflection ⦿

4.3 Standing waves

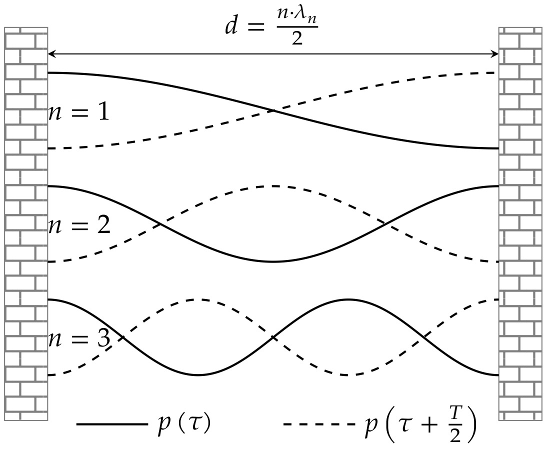

Figure 4. Sound pressure p for a standing wave between two parallel walls ▶

- 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

$$f_n = \frac{c \cdot n}{2 \cdot d}$$

Equation 1. Room modes (Rumsey and McCormick 2009, p. 24)

f_n	modal frequencies	Hz
c	speed of sound	$\mathrm{m\,s^{-1}}$
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?

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

	Length 11.57 m	Width 4.93 m	Height 4.10 m
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

5 Natural reverb

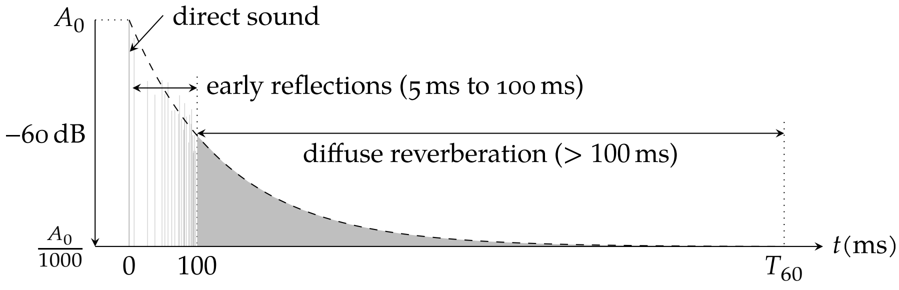

Figure 5. Typical impulse response of a room ▶

5.1 Reverberation time T_{60}

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

Equation 2. Reverberation time T_{60}

T_{60}	reverberation time	s
0.161	magic number	$\mathrm{s\,m^{-1}}$
V	total room volume	$\mathrm{m^3}$
S	total room surface	$\mathrm{m^2}$
α	average absorption coefficient	$0 \leq \alpha \leq 1$
$S \cdot \alpha$	total absorption	sabins $\equiv \mathrm{m^2}$

- 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 2. Typical values for reverberation time T_{60} (Dpa 2015) ▶

Room type	T_{60}/s
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	≈ 1.6
Concert hall	1.8–2.2
Cathedral	> 5
Large sports venue	10

Table 3. Absorption coefficient α for different materials (Hartmann 2013, p. 165)

Material	α		
	125 Hz	500 Hz	2000 Hz
Acoustical tile	0.20	0.65	0.65
Brick wall (unpainted)	0.02	0.03	0.05
Heavy carpet on heavy pad	0.10	0.60	0.65
Concrete (painted)	0.01	0.01	0.02
Heavy draperies	0.15	0.55	0.70
Fiberglass blanket (7.5 cm thick)	0.60	0.95	0.80
Glazed tile	0.01	0.01	0.02
Paneling (0.30 cm thick)	0.30	0.10	0.08
Plaster	0.04	0.05	0.05
Vinyl floor on concrete	0.02	0.03	0.04
Wood floor	0.06	0.06	0.06

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

Equation 3. Critical distance d_c

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

d_c	critical distance	m
0.057	magic number	$\sqrt{\mathrm{s}\,\mathrm{m}^{-1}}$
V	room volume	m^3
T_{60}	reverberation time	s

6 Artificial reverberation in hardware

6.1 Echo chambers

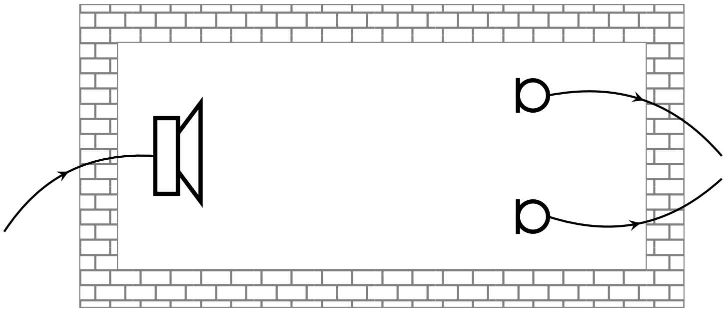

Figure 6. Principle of an echo chamber

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

6.2 Plate reverbs

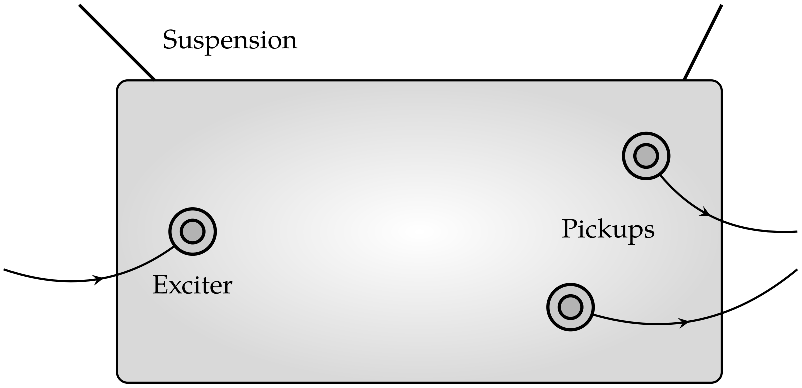

Figure 8. Principle of a plate reverb

- 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 T_{60}

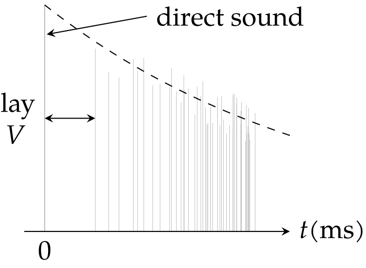

Figure 7. In artificial reverberation, *pre-delay* simulates the distance to the closest wall

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

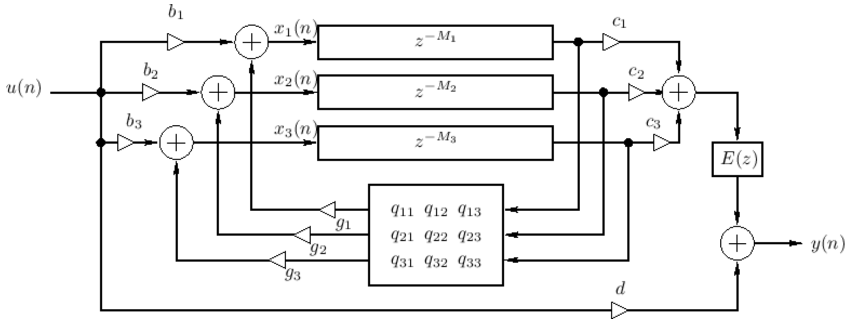

Figure 9. Feedback delay network for artificial reverberation (Smith 2010, fig. 3.10. © Julius Orion Smith. All rights reserved. This content is excluded from our Creative Commons license. For more information, see `http://ocw.mit.edu/help/faq-fair-use/`)

- 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)

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[1] cf, Shanks 2009.

Parameter	Description
Room size	Volume V of simulated space (often presets)
Decay time	Corresponds to T_{60}
Wet/dry balance	Ratio of reverberated ('wet') to original ('dry') sound
Hf cutoff	Low-pass filter to dampen reflections
Stereo width	Decorrelation of l & r output signals
Pre-delay	Simulates distance to closest wall

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 (comes with Reaper)
  - Space Designer (comes with Logic)
  - Altiverb
  - Waves ir plugin series
  - Ir lv2 plugin by Tom Szilagyi (`ir.lv2` Ubuntu/Debian package)
  - Freeverb3 (library; vst plugins available)
- Demo: Record your own ir in Linux with *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

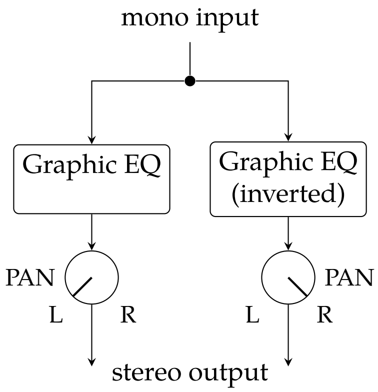

Figure 10. Stereo enhancer based on inverted EQs (after Senior 2011b, fig. 18.3)

8.2 Delay plus mirrored panning

- Slightly delay ($\Delta t < 30\,\mathrm{ms}$) 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!

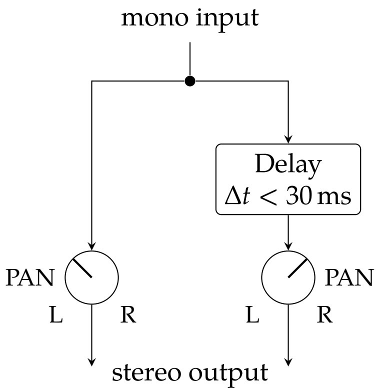

Figure 11. Stereo enhancer based on Haas delay (cf., Senior 2011b, pp. 267 f.)

8.3 Delay plus pitch shifting

- Asymmetric delays & pitch shifts on L and R channels (cf., figure 12)
- As mix-in effect (hence delays Δt on *both* channels) for vocal tracks
- Again, keep an ear on potential phase problems!

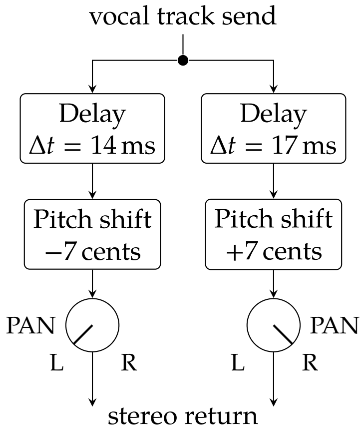

Figure 12. Stereo enhancer based on pitch shift and delay as a mix-in effect for vocal tracks (after Senior 2011b, fig. 18.4)

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

Acronym	Name	Linux	Mac	Windows
LADSPA	Linux Audio Developer's Simple Plugin API	✔	✘	✘
LV2	LADSPA version 2	✔	✘	✘
AU	Audio Units	✘	✔	✘
VST	Virtual Studio Technology	✔	✔	✔

Table 5. Audio plugin families

References & further reading

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