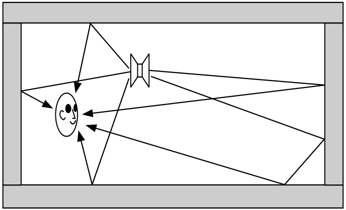
E85.2607: Lecture 4 – Reverberation

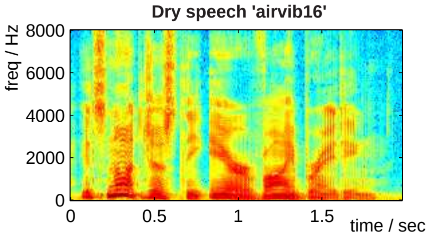
Room acoustics

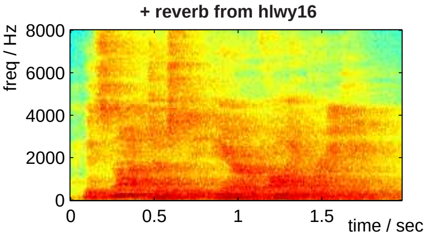


- Sound waves reflect off walls in an enclosed space
  - Different paths creates a series of echoes
- Sound scattered by different objects in the room
- Energy absorbed at walls
  - Depends on wall materials
  - Frequency dependent effects

Reverberation

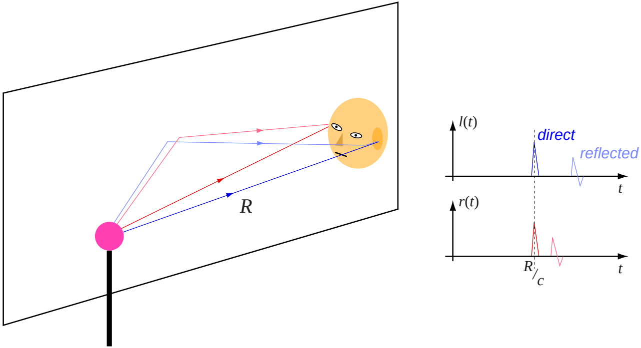
- Simulate acoustics of a particular environment
- Causes “smearing” of signal energy





Aside: The Precedence Effect (again)

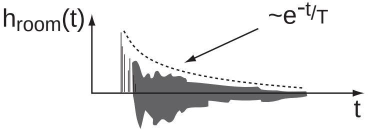
- Reflections give misleading spatial cues

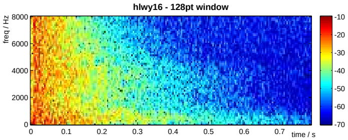


- But: Spatial impression based on 1st wavefront then 'switches off' for ~50 ms
  ... even if 'reflections' are louder
  ... leads to impression of room

Reverberation impulse response

- Room is just an LTI system
- Exponential decay of reflections:





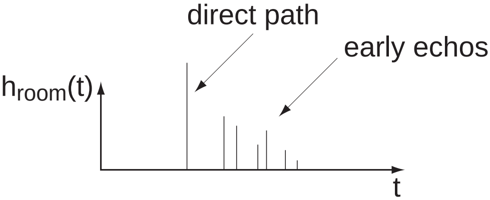
- Frequency-dependent
  - greater absorption at high frequencies → faster decay
- Size-dependent
  - larger rooms → longer delays → slower decay
- Sabine's equation (reverb time):

$$RT_{60} = \frac{0.049V}{S\bar{\alpha}}$$

V = room volume, S = surface area, $\bar{\alpha}$ = absorption coefficient

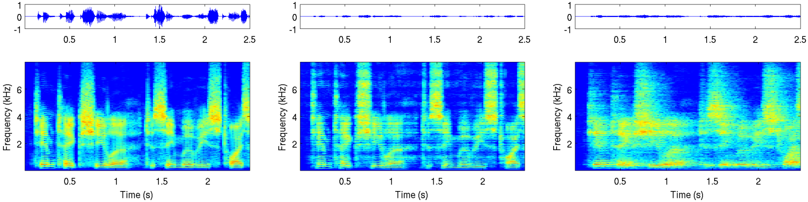
- Time constant based on room size, absorption

Anatomy of a reverberation impulse response

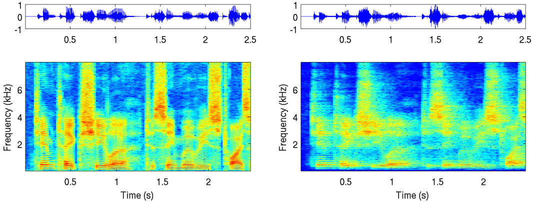


- 'Early echos' in room impulse response
- Actual reflection may be $h_{reflect}(t)$, not $\delta(t)$
- Echo density increases with time
  - Eventually everything looks like exponentially decaying noise ('reverberant tail')

Anatomy of a reverberation impulse response – example



(a) Direct-path only (b) Early echoes only (c) Late reverberation only



(a) Original (b) Combined

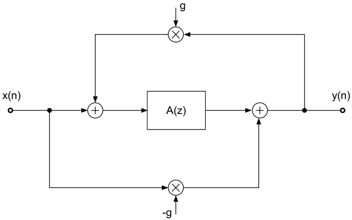
Source: Michael Mandel's Ph.D. dissertation, figure 2.2

Simulating reverb the easy way

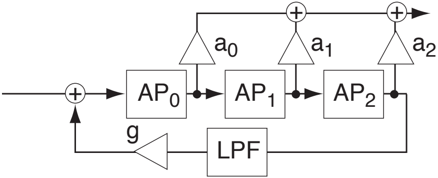
- Convolution reverb: characterize reverb by *room impulse response*
    -  $*$  $=$ 
    - If spatial cues are important, can record in stereo
    - IRs of $\sim$1 sec $\rightarrow$ very long convolution
    - Use block-based FFT convolution (`fftfilt` in Matlab)
- Can measure impulse response directly
    - Approximate impulse: clap, gunshot, ???
    - Example impulse responses: `http://www.voxengo.com/impulses/`
- Simulate sound propagation in software
    - Lots of software to do this online
        - Roomsim: `http://media.paisley.ac.uk/~campbell/Roomsim/`
        - rir.m: `http://www.2pi.us/rir.html`
- Make it up
    - Exponentially decaying noise...

Simulating reverb the old fashioned way

- Reproduce perceptually salient aspects
  - early echo pattern (→ room size impression)
  - overall decay tail (→ wall materials. . .)
  - interaural coherence (→ spaciousness)
- Nested allpass filters [Gardner, 1992]

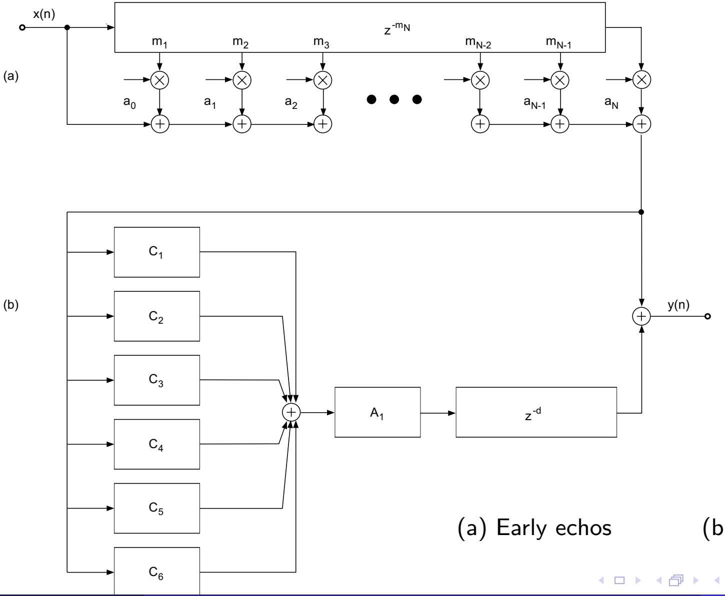


Schroeder allpass section



- Use $g \sim 0.7$, mutually prime $M > 50$ms
- Don't allpass filters have flat frequency response?

Moorer Reverberator [Moorer, 79]



(a) Early echos (b) Reverberant tail

The End

Reading *DAFX*, Section 6.5

Credits Some slides borrowed from the EE6280 lecture on spatial sound by Dan Ellis and Michael Mandel