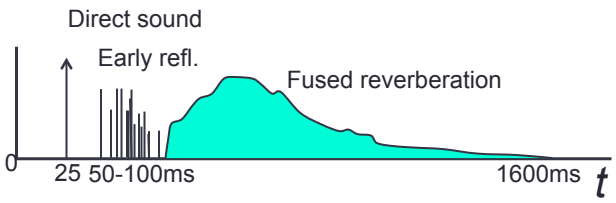
Reverberation

- Reflections in a concert hall are many
- Number increases exponentially with time
- Typically modeled in two parts:
  - Early reflections – discrete delays
  - Late reflections – generated by a network of all-pass and feedback delay filters
  - Often add low-pass filter to network because high frequencies are absorbed by air and room surfaces

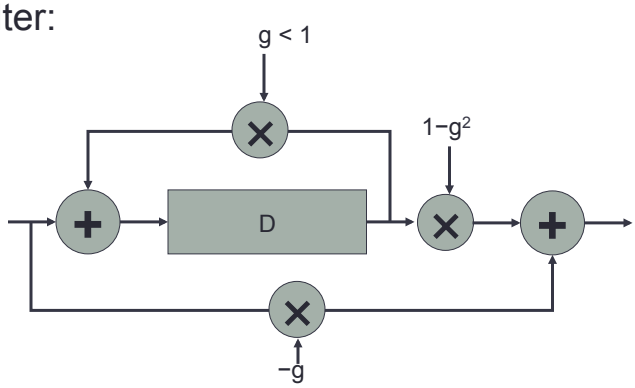
Artificial Reverberation

- RT60 – time to decay from peak amplitude to -60dB (1/1000 amplitude)
- Typical RT60 is 1.5 to 3 seconds
- Impulse response:



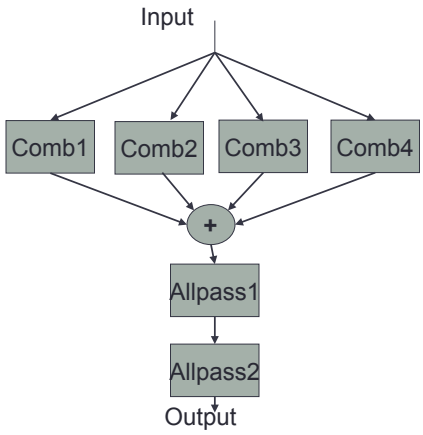
Reverberator Building Blocks

- Feedback delay (comb filter) provides decaying echo
- Allpass filter:



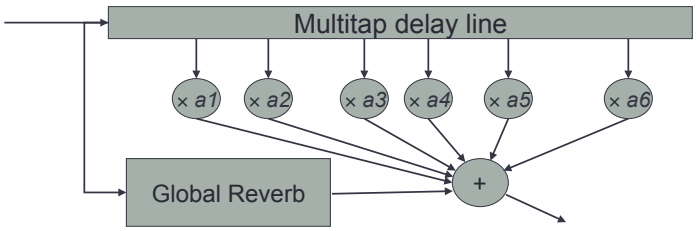
Implementations

- Schroeder



Improved Reverberators

- Add multitap delay for early reflections



- Low-pass in feedback loops
- More elaborate allpass filters
- Multichannel designs

Implementations in Nyquist

```
load "reverb.lsp"
reverb(sound, reverb-time)
```

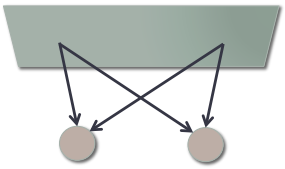
- Mix "dry" sound with reverb:

```
function reverb-mix(s, rt, wet)
  return s * (1 – wet) +
         reverb(s, rt) * wet
```

- Other reverb primitives in Nyquist:
  - nrev
  - jcrev
  - prcrev

Convolution-based Reverberators

- Reverberators can be seen as very big filters
- Long irregular impulse response
- Many modern reverbs
  - Measure impulse response of real rooms and concert halls
  - Four impulse responses for stereo
  - Apply impulse responses using fast convolution (multiplication in the frequency domain)



Summary

- Many audio effects are available
- Audio effects are crucial in modern music production
- Reverberation
  - The effect of millions of “echoes”
    - becoming denser with greater delay, and
    - generally decaying exponentially with delay

