140

Sonic College 2020
Jakob Schmid

140

Jeppe Carlsen (design, programming)

Niels Fyrst, Andreas Peitersen (visual design)

Jakob Schmid (audio)

Developed as hobby project over 3 years

NINTENDO SWITCH

PSN

STEAM

Wii U

Humble Bundle

XBOX ONE

gog.com

140

IGF award 2013

Excellence in Audio

Honorable mention: Technical Excellence

Spilprisen 2014

Sound of the Year

Nordic Game Award 2014

Artistic Achievement

140 Soundtrack

Vinyl

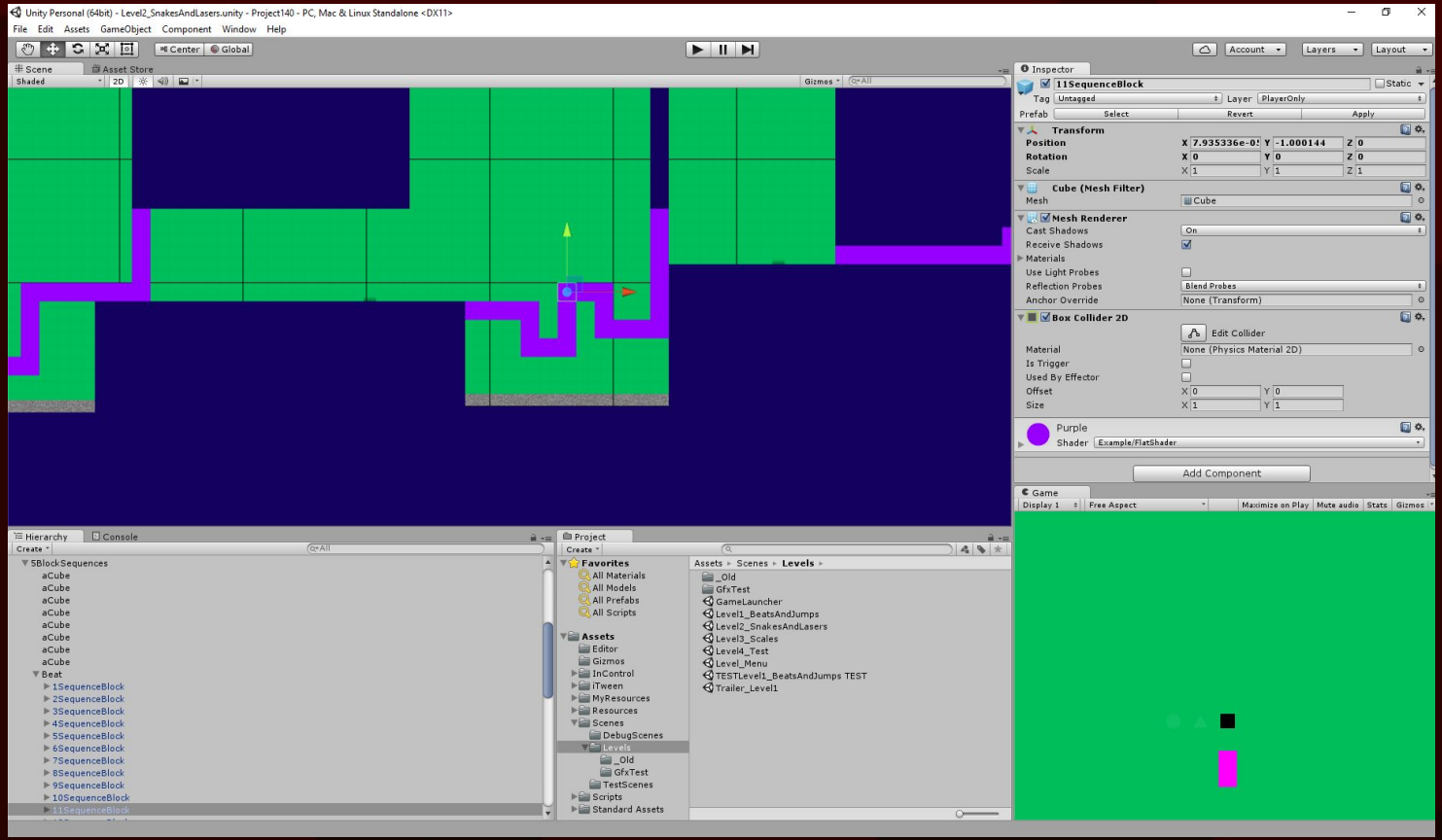
- iam8bit

Digital

- Steam
- GOG.com
- Spotify
- iTunes
- Amazon

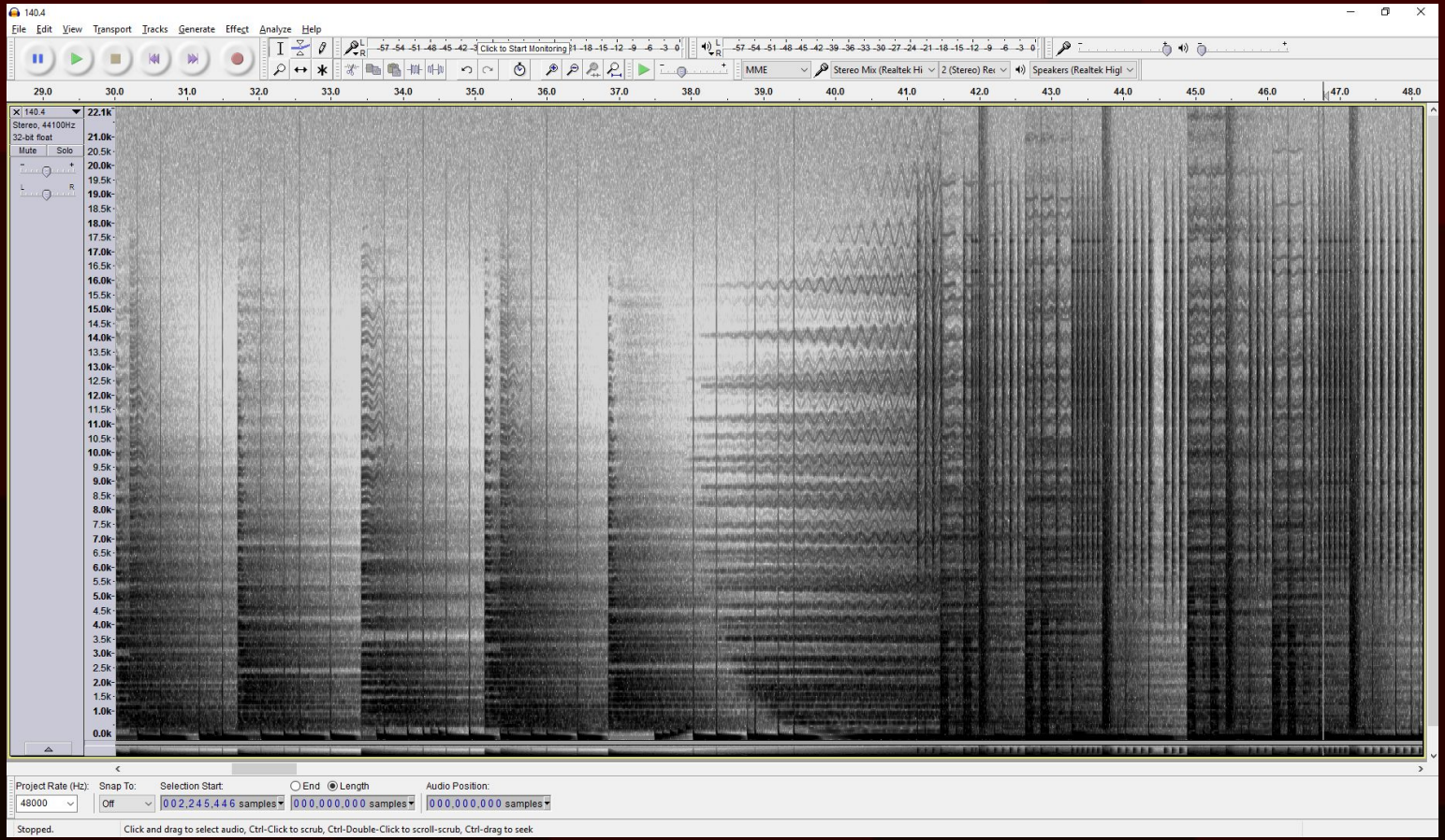
https://schmid.dk/games/140/soundtrack/

Developed in Unity 3



Ableton Live

Audacity


140.4
File Edit View Transport Tracks Generate Effect Analyze Help
Click to Start Monitoring
MME
Stereo Mix (Realtek Hi
2 (Stereo) Rec
Speakers (Realtek High
140.4
Stereo, 44100Hz
32-bit float
Mute Solo
Project Rate (Hz):
Snap To:
Selection Start:
End Length
Audio Position:
48000
Off
002,245,446 samples
000,000,000 samples
000,000,000 samples
Stopped.
Click and drag to select audio, Ctrl-Click to scrub, Ctrl-Double-Click to scroll-scrub, Ctrl-drag to seek


Audio in 140

Audio in 140

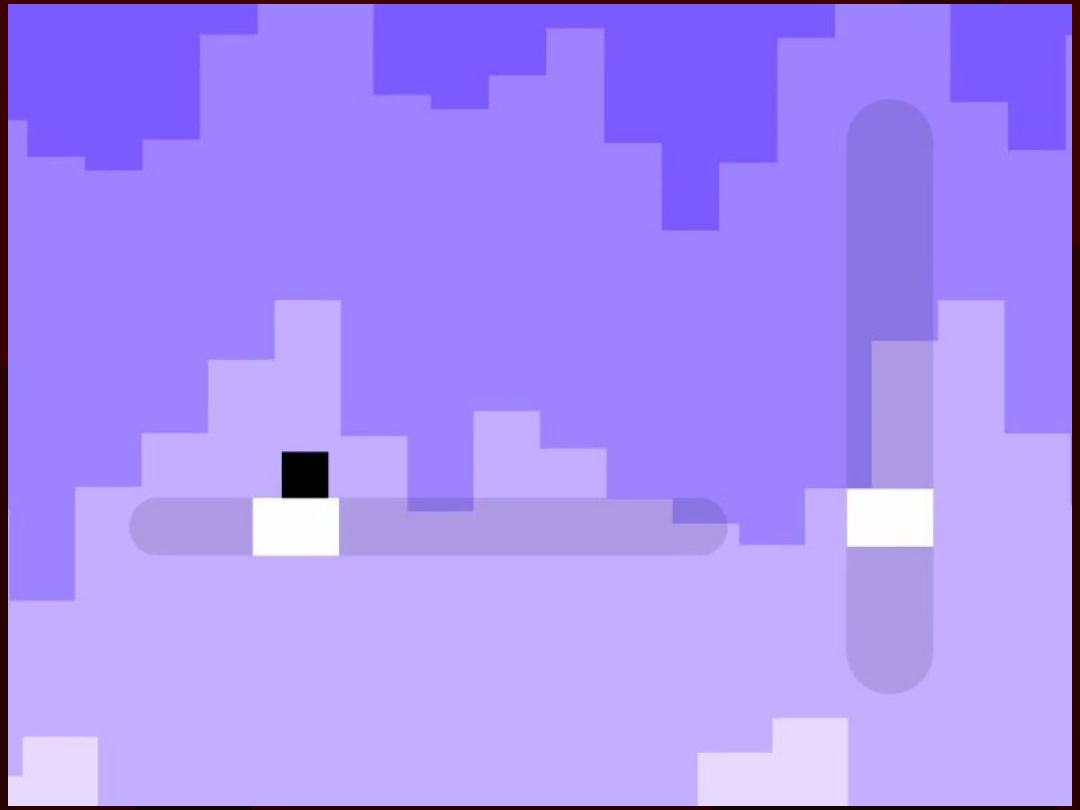
Overview

- Control game from music
- Interactive music
- Music timing in 140
- Fun audio tricks

140 demo


Control Game from Music

Moving a Platform



Moving a Platform

1. 
wait for 16th note #1

2. 
start moving

3. 
wait for 16th note #8

4. 
start moving

Basic Approach

- Play music loop
- Use audio time from loop to control game elements (instead of game time)

Unity built-in audio:

```
AudioSource.time                (seconds)
AudioSource.timeSamples         (samples)
```

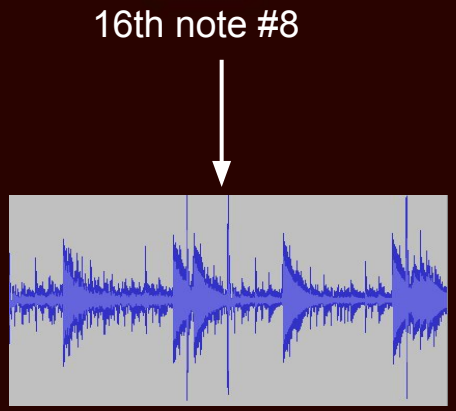
FMOD Unity Integration:

```
EventInstance.getTimelinePosition    (milliseconds)
```

Music Events

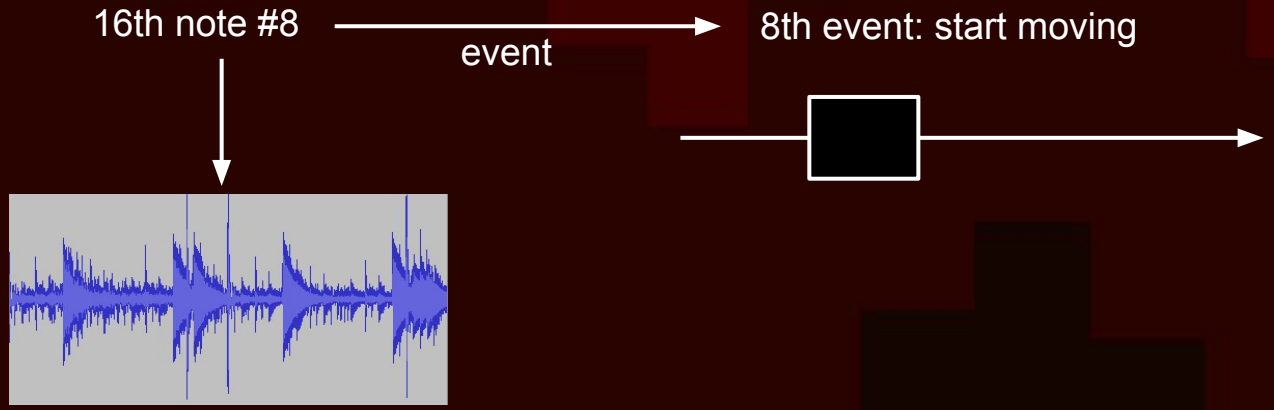
‘Waiting for 16th note #8’ means:

- Get audio time from playing loop
- When next musical beat reached, raise event
- On the 8th event, do something



Music Events

Game elements listen for events and trigger animation on beats



Music Events

- When next musical beat reached, raise event

  - And when is that, exactly?

Useful Calculations

For a given tempo, how long is a note in seconds?

Tempo

How long is a 140 BPM 16th note in seconds?

Tempo

How long is a 140 BPM 16th note in seconds?

```
140 beat/m
```

Tempo

How long is a 140 BPM 16th note in seconds?

```
140 beat/m * 4 note/beat = 560 note/m
```

Tempo

How long is a 140 BPM 16th note in seconds?

```
140 beat/m * 4 note/beat = 560 note/m
                         = 560/60 note/s
```

Tempo

How long is a 140 BPM 16th note in seconds?

```
140 beat/m * 4 note/beat = 560 note/m
                         = 560/60 note/s
```

This means that we have:

```
                           60/560 s/note
```

Tempo

How long is a 140 BPM 16th note in seconds?

```
140 beat/m * 4 note/beat = 560 note/m
                         = 560/60 note/s
```

This means that we have:

```
                           60/560 s/note
                        ~= 0.10714 s/note
```

Moving a Platform

1. 
wait for 16th note #0

2. 
start moving

3. 
wait for 16th note #8

4. 
start moving

Moving a Platform

1.

2.

3.

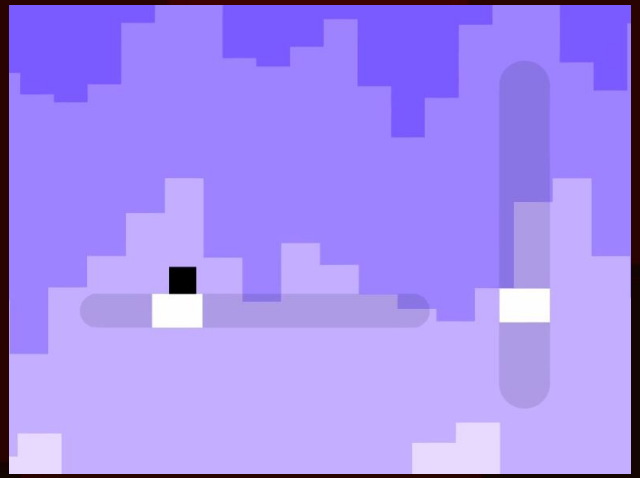
4.

wait for 16th note #0,
time = 0 s

wait for 16th note #8,
time = 8 * 0.10714 s
= 0.857 s

Summary

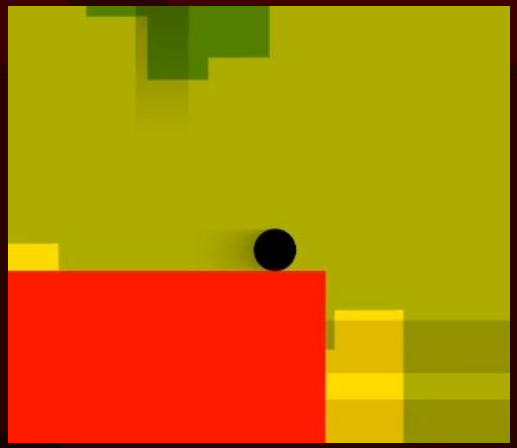
- Game elements wait for music events to control animation
- Music system observes `AudioSource.time` (Unity built-in)
- ... or `EventInstance.getTimelinePosition` (FMOD Unity)
- Tempo can be converted to seconds
- Music events are triggered when a given time has been reached

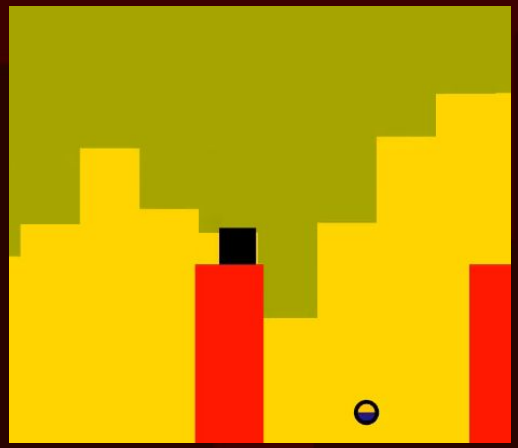


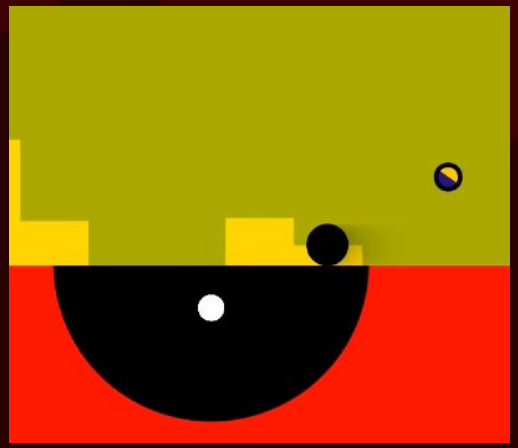

Interactive Music

Interactive Music Mixing

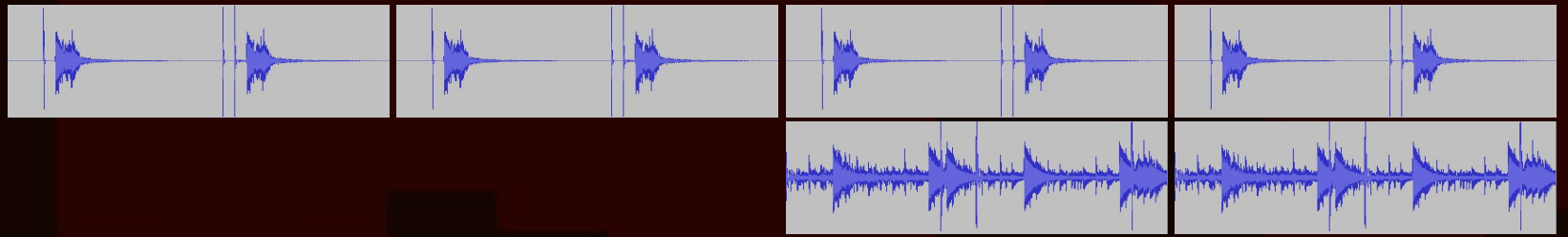
We wanted to mix music interactively in Unity.







time



The Music Timing Problem

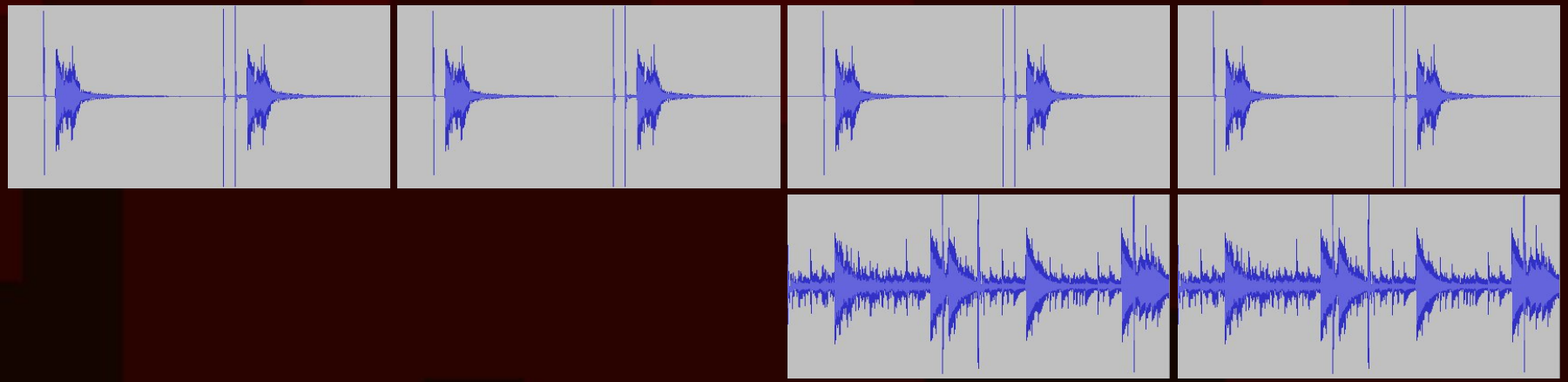
For beat-oriented music, loops should be synchronized with sample accuracy.

- That means a precision of 0.00002 s

Loop Transition

Goal:

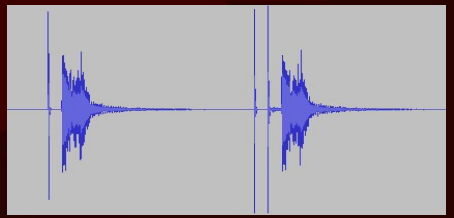
- Start loop A and let it run for a while.
- Then start loop B.
- B should be sample-accurately synchronized with loop A.



Loop Transition Problem

Start loop A:

```
audioSourceA.Play()
```



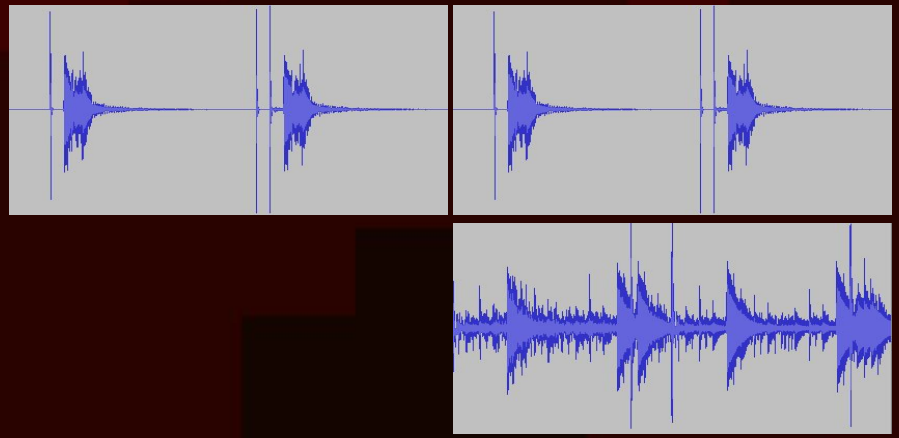
Loop Transition Problem

Start loop A:

```
audioSourceA.Play()
```

Exactly when A loops, start loop B:

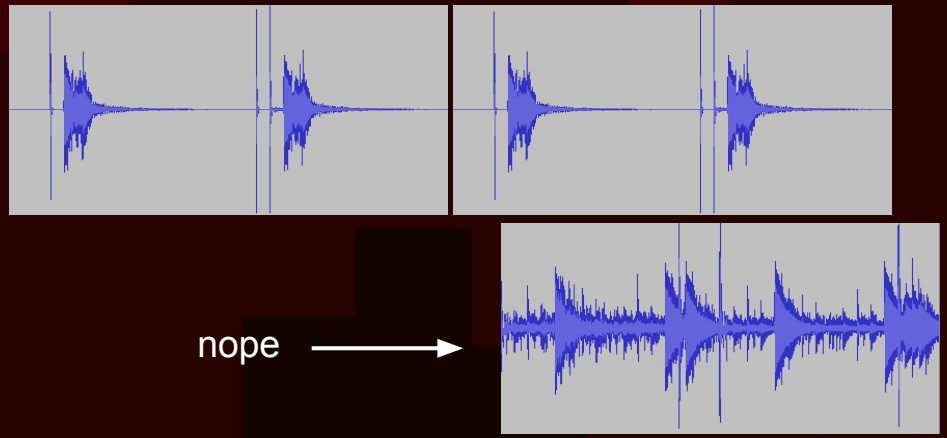
```
Wait for A to loop, then:
  audioSourceB.Play()
```



Loop Transition Problem

It doesn’t work!

New sound is out of sync.

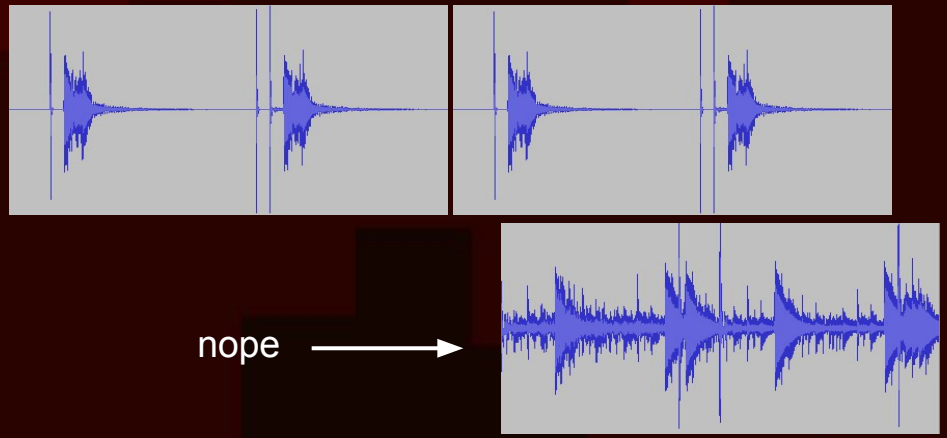


Loop Transition Problem

It doesn’t work!

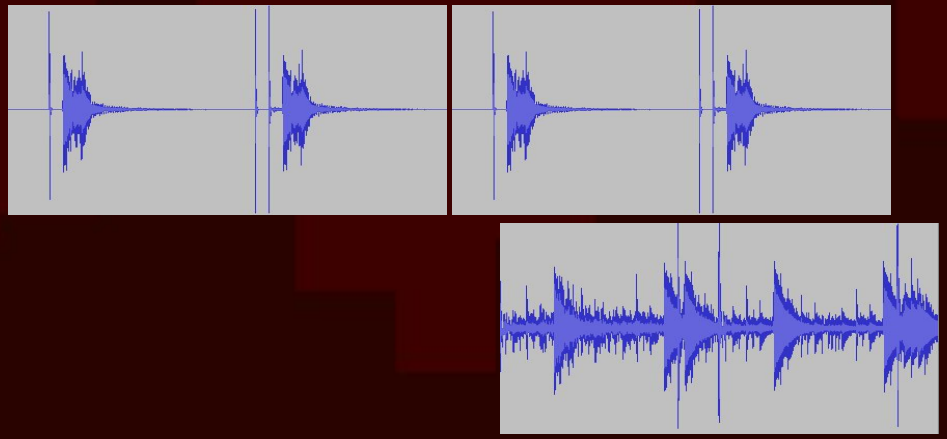
New sound is out of sync.

The problem exists in every sound engine.



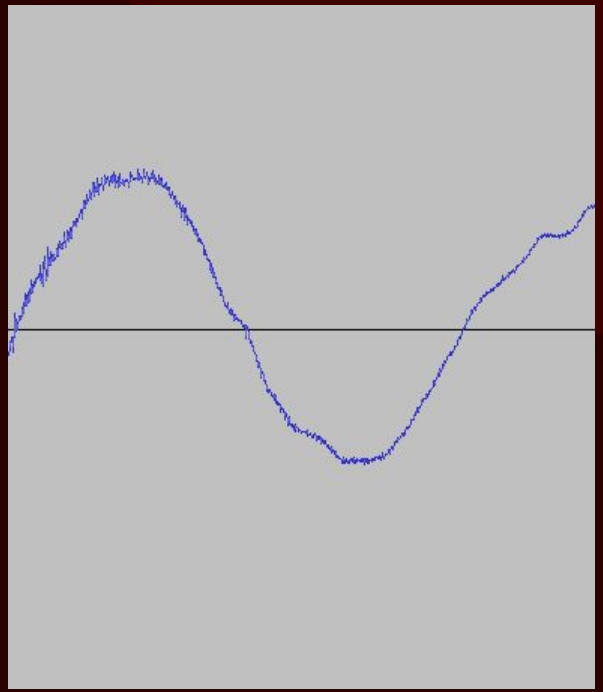
Loop Transition Problem

Why?



Audio Rendering

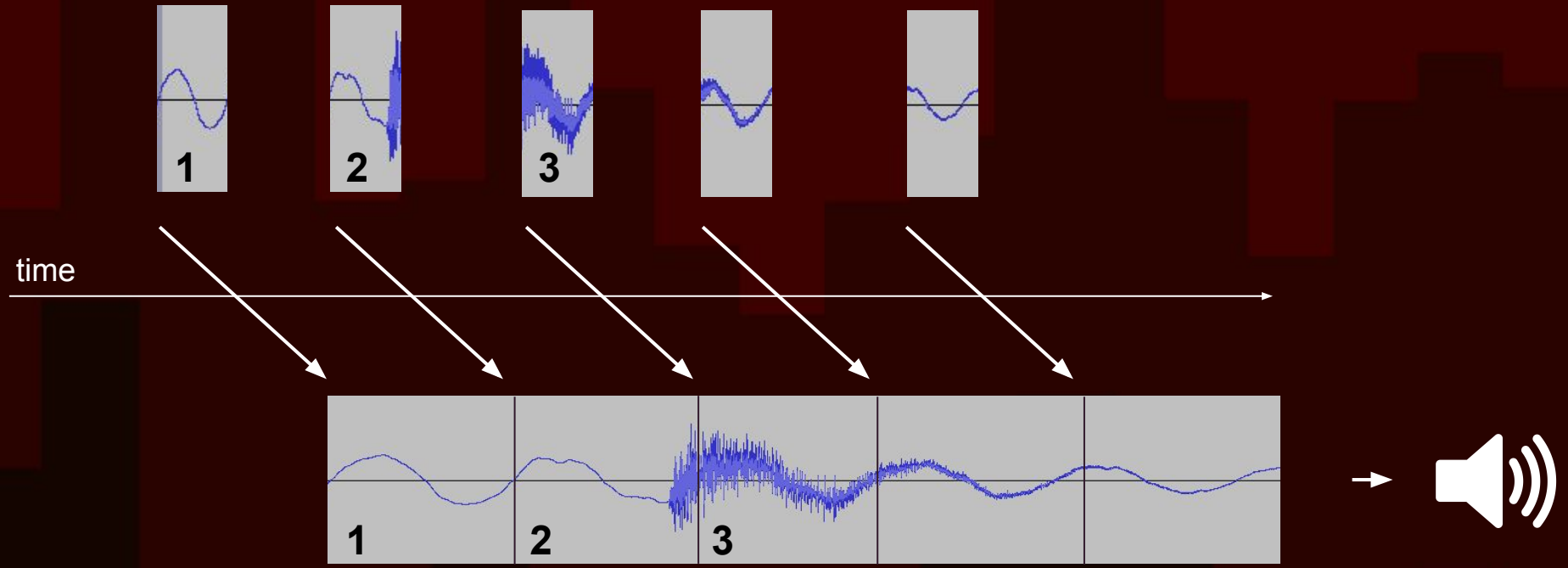
Audio is rendered a fixed number of samples at a time:



1024 sample buffer, 21 ms

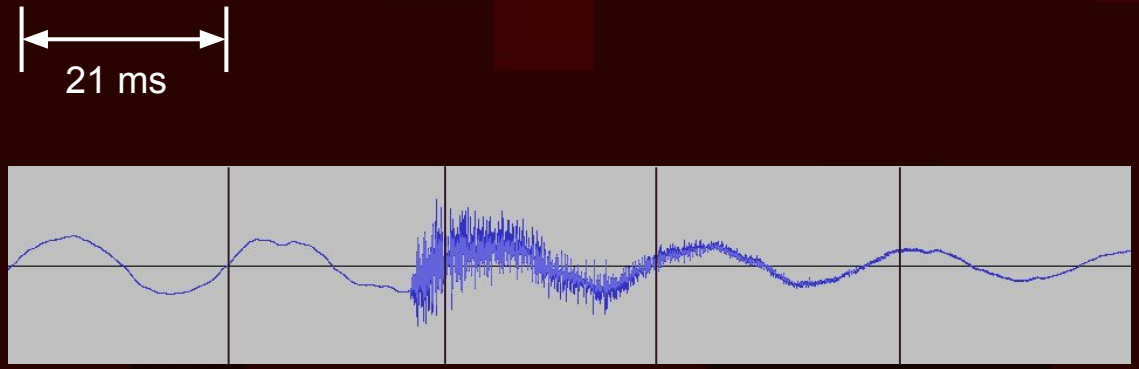
Audio Rendering

The sound card plays a buffer while the next one is being rendered:



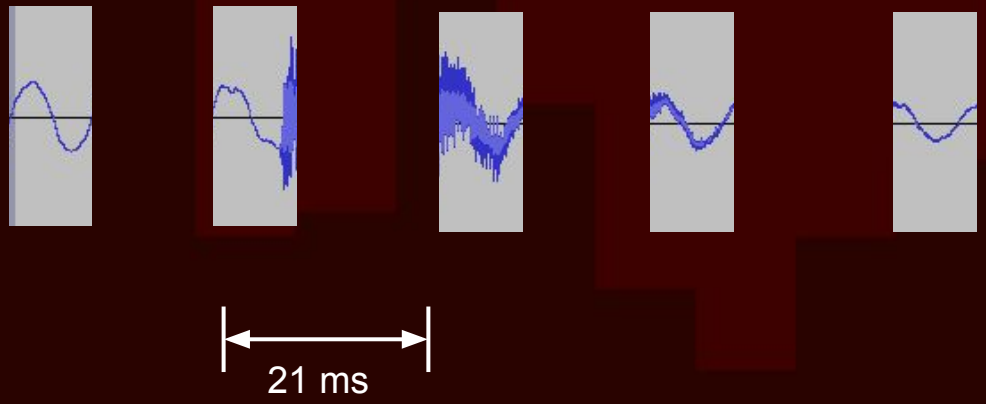
Audio Rendering

If buffers are e.g. 1024 samples long, we need a new one every 21 ms.



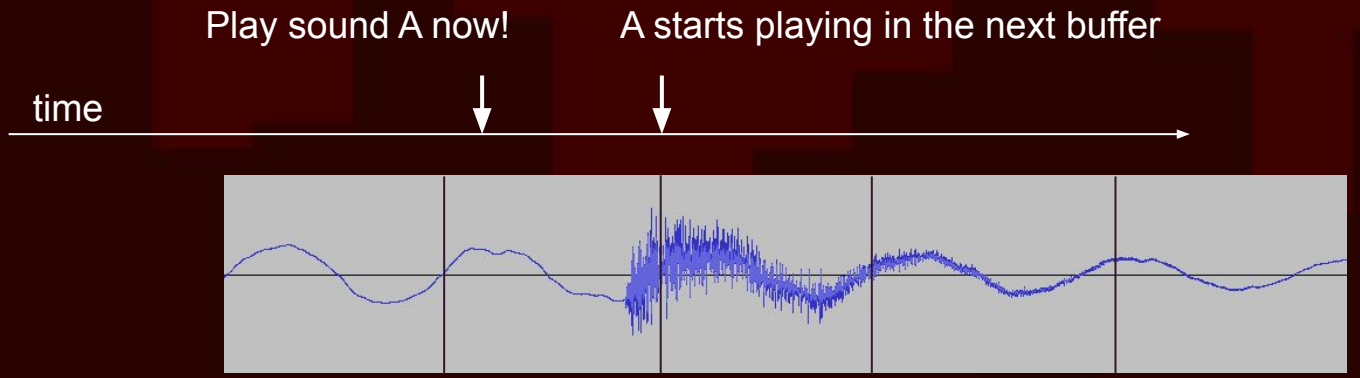
Audio Rendering

In this case, a new buffer is rendered every 21 ms:



Audio Rendering

- New sounds won’t start immediately, but earliest in the next audio buffer
- Their start time will also be quantized to buffer start times, e.g. 21 ms



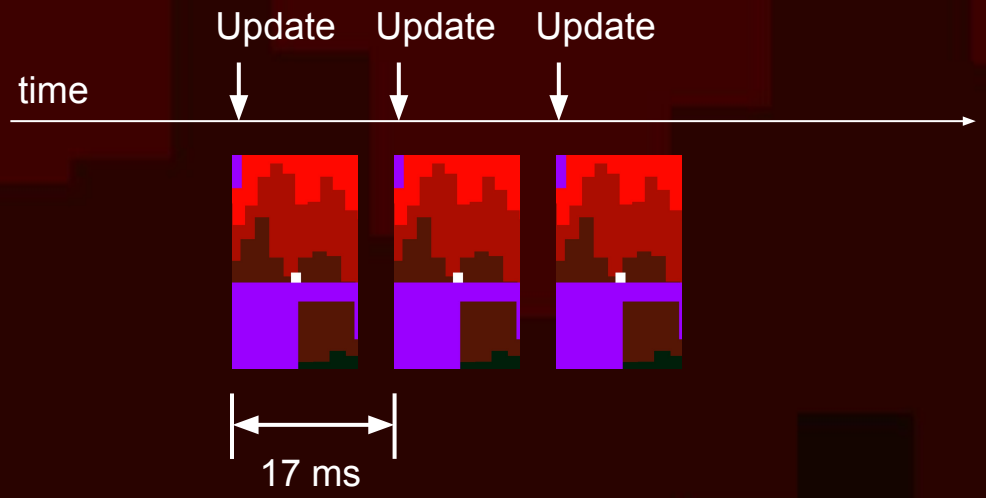
Audio Rendering

In Unity, our audio code will probably be in an Update method

```
using UnityEngine;

public class MyAwesomeScript : MonoBehaviour
{
    public AudioSource mySound;

    // Use this for initialization
    void Start()
    {
    }

    // Update is called once per frame
    void Update()
    {
        mySound.Play();
    }
}
```

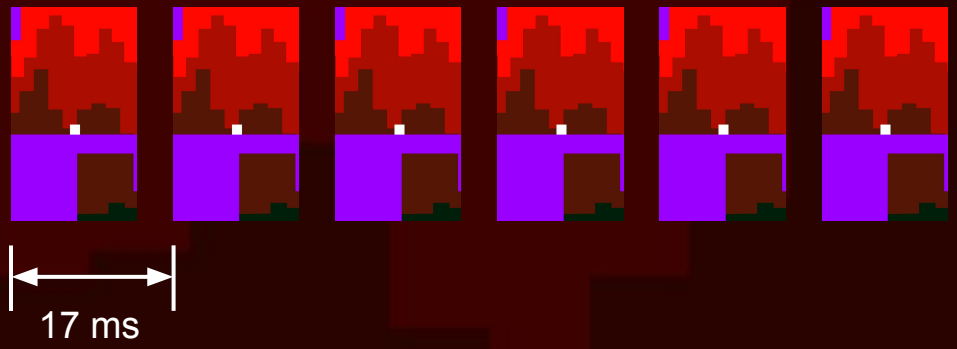
Audio Rendering

Unity Update methods are called for every video frame
(e.g. 17 ms at 60 FPS)



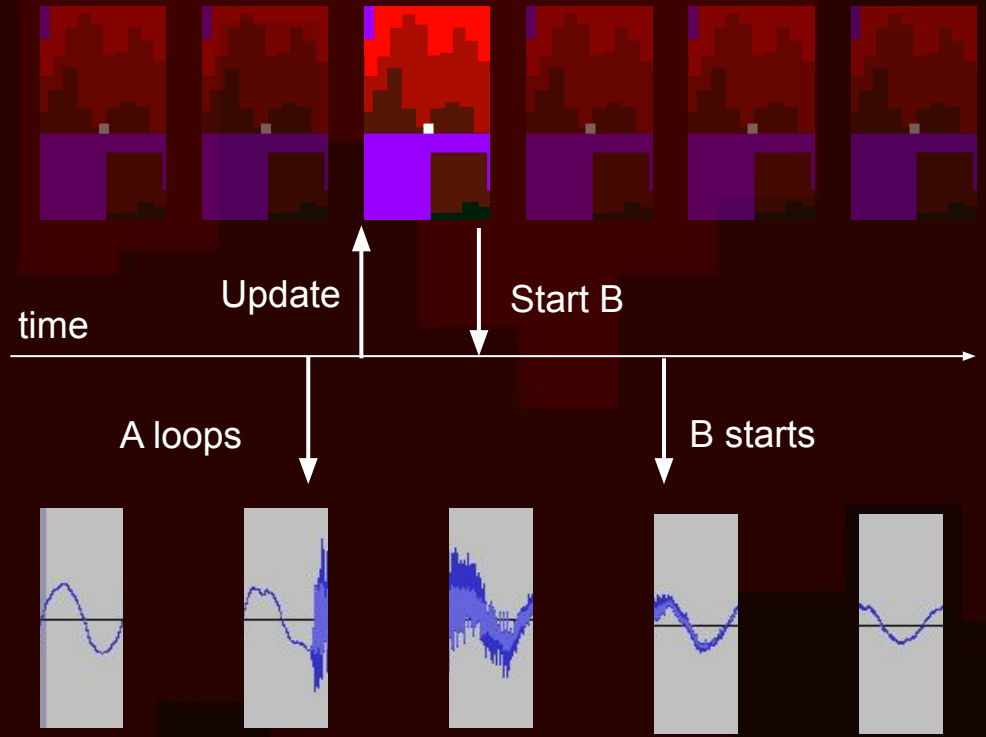
Audio Rendering

Audio buffers and video frames are not synchronized:



Audio Rendering

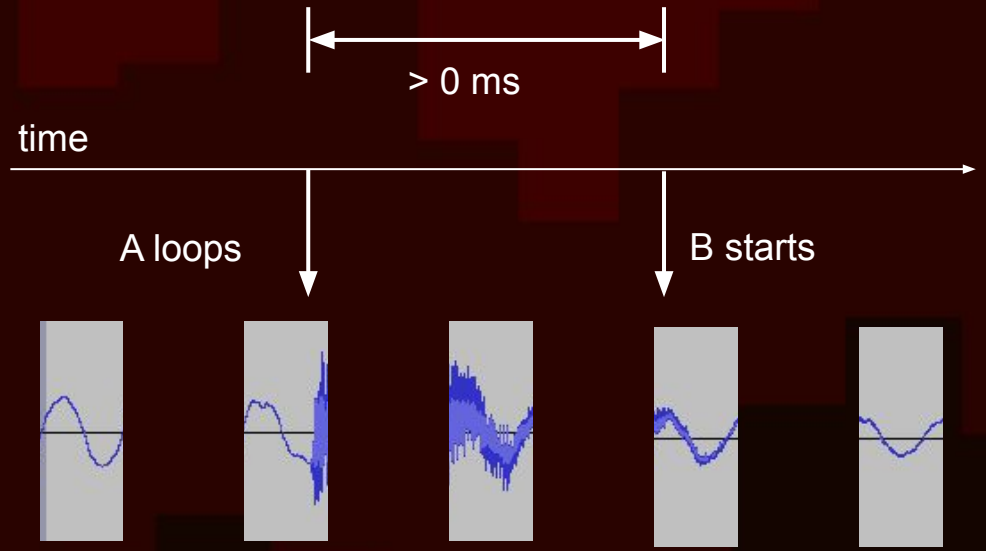
So, if we want to start a sound B exactly when another sound A loops...



Immediately is Too Late

So, if we want to start a sound B exactly when another sound A loops...

Detecting it in Update and playing B immediately is too late!



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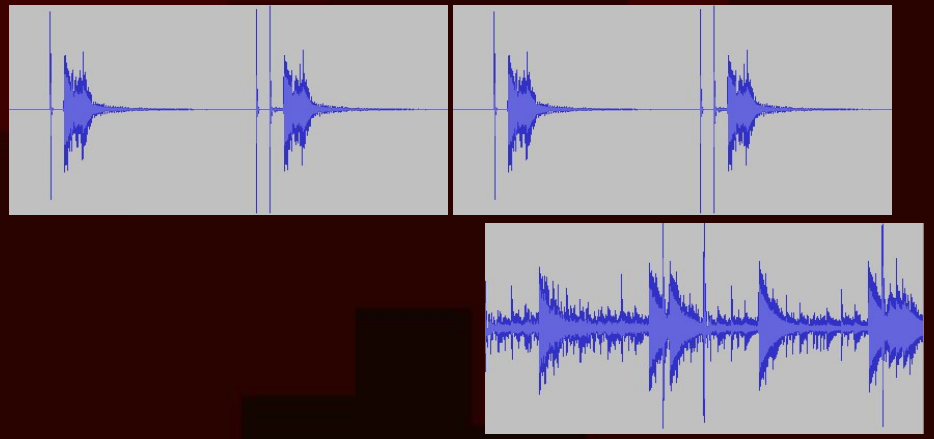
Detecting it in Update and playing B immediately is too late!

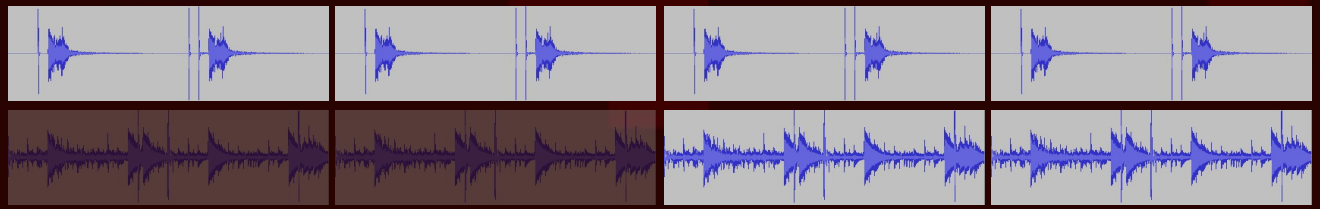


Interactive Music Solutions

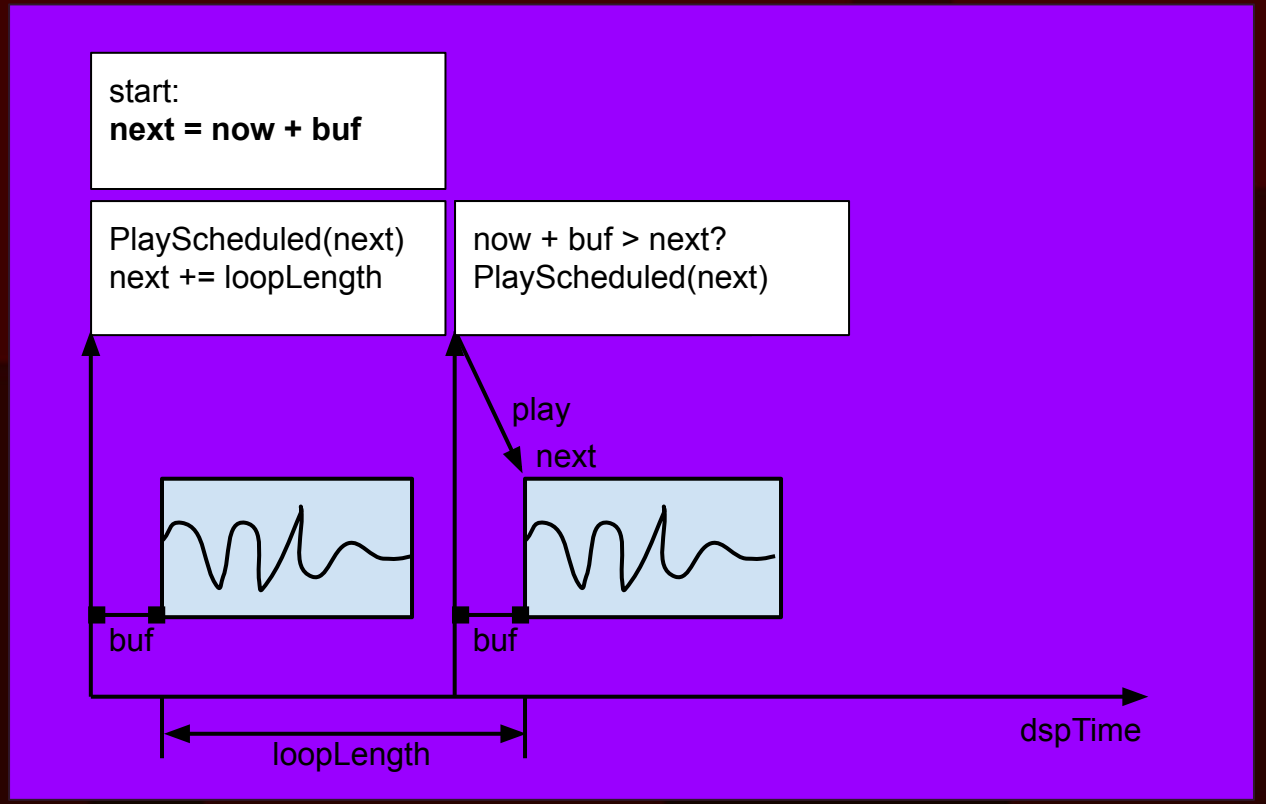
- Synchronized Loops
- PlayScheduled

Solution A: Synchronized Loops

- All loops should be exactly same length, or integer multiples
- All loops should be started in the same frame, possibly muted
- New loops cannot be started
- Never change pitch



Solution B: PlayScheduled



Solution B: PlayScheduled

```
Start:
    buf = 0.1 // as low as possible
    next = AudioSettings.dspTime + buf
Update:
    now = AudioSettings.dspTime
    if(now + buf > next)
        audio.PlayScheduled( next )
        next += loopLength
```

- see http://www.schmid.dk/gallery/play_scheduled/ for C# code

Solution Comparison

Solution A: Synchronized Loops

- Very simple to implement
- Requires a loop for every single independent musical element
- Loops must be same length or integer multiple
- Pitch cannot be changed

Solution Comparison

Solution A: Synchronized Loops

- Very simple to implement
- Requires a loop for every single independent musical element
- Loops must be same length or integer multiple
- Pitch cannot be changed

Solution B: PlayScheduled

- Non-trivial implementation
- Flexible: Individual notes can be sequenced
- No length requirement for music sounds
- Pitch can be changed

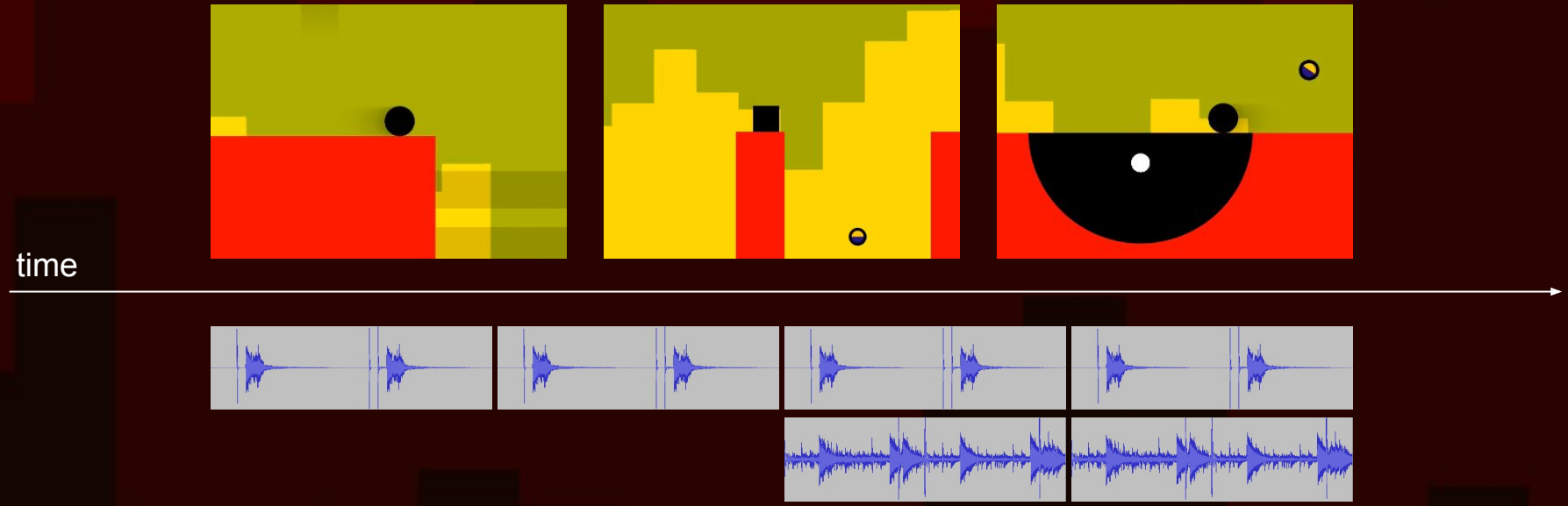
Summary

- Synchronizing loops with sample accuracy is tricky
- Audio is rendered in buffers, delaying and quantizing sounds
- Unity Update calls correspond to video frames, not audio buffers
- Immediately is too late: detecting loop and reacting in Update results in a delay
- Solution A: Synchronized Loops
- Solution B: PlayScheduled

Music Timing in 140

Music Timing in 140

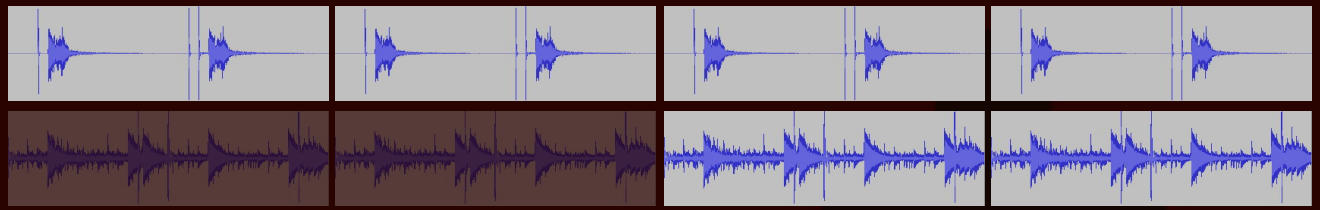
- We wanted the music to be mixed interactively with the gameplay.
- Loops should be sample-accurate.
- We were using Unity 3 at the time, which limited our options (no PlayScheduled)



Music Requirements

Simple solution with sample-accurate timing:

- All music must be loops of a fixed length, or multiples of that length.
- Start all loops in same frame, possibly muted.



Music Requirements

Simple solution with sample-accurate timing:

- All music must be loops of a fixed length, or multiples of that length.
- Start all loops in same frame, possibly muted.

During game progression:

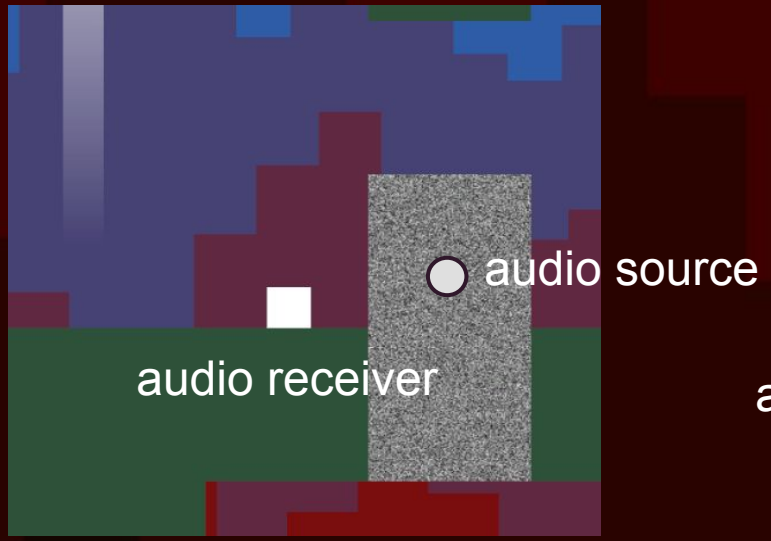
- Control volume/muting and pan.
- Never change pitch unless just before stopping a loop.

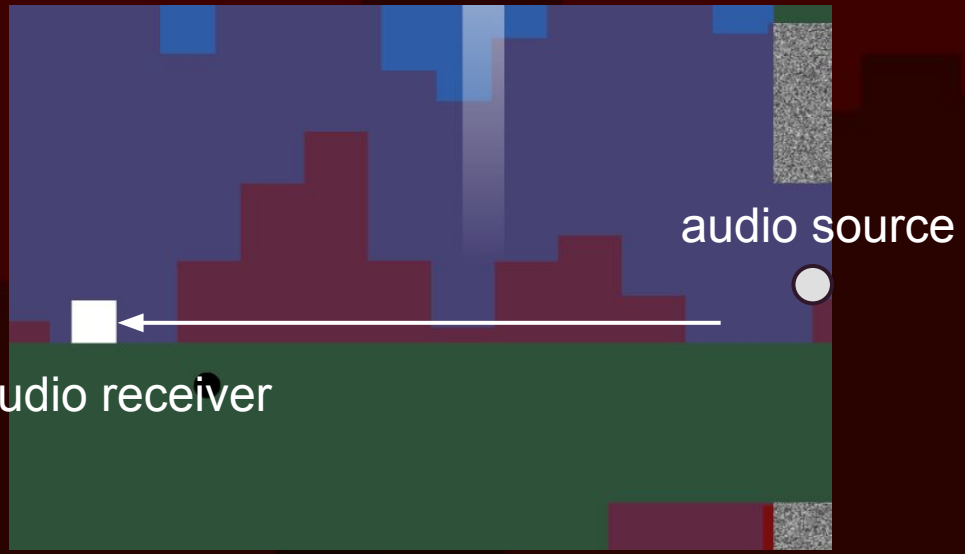
Localized Music Loops

- Music loops are “physically” placed in level geometry
- Dynamic mixing occurs as player moves around
- Certain areas can gain unique atmosphere based on music

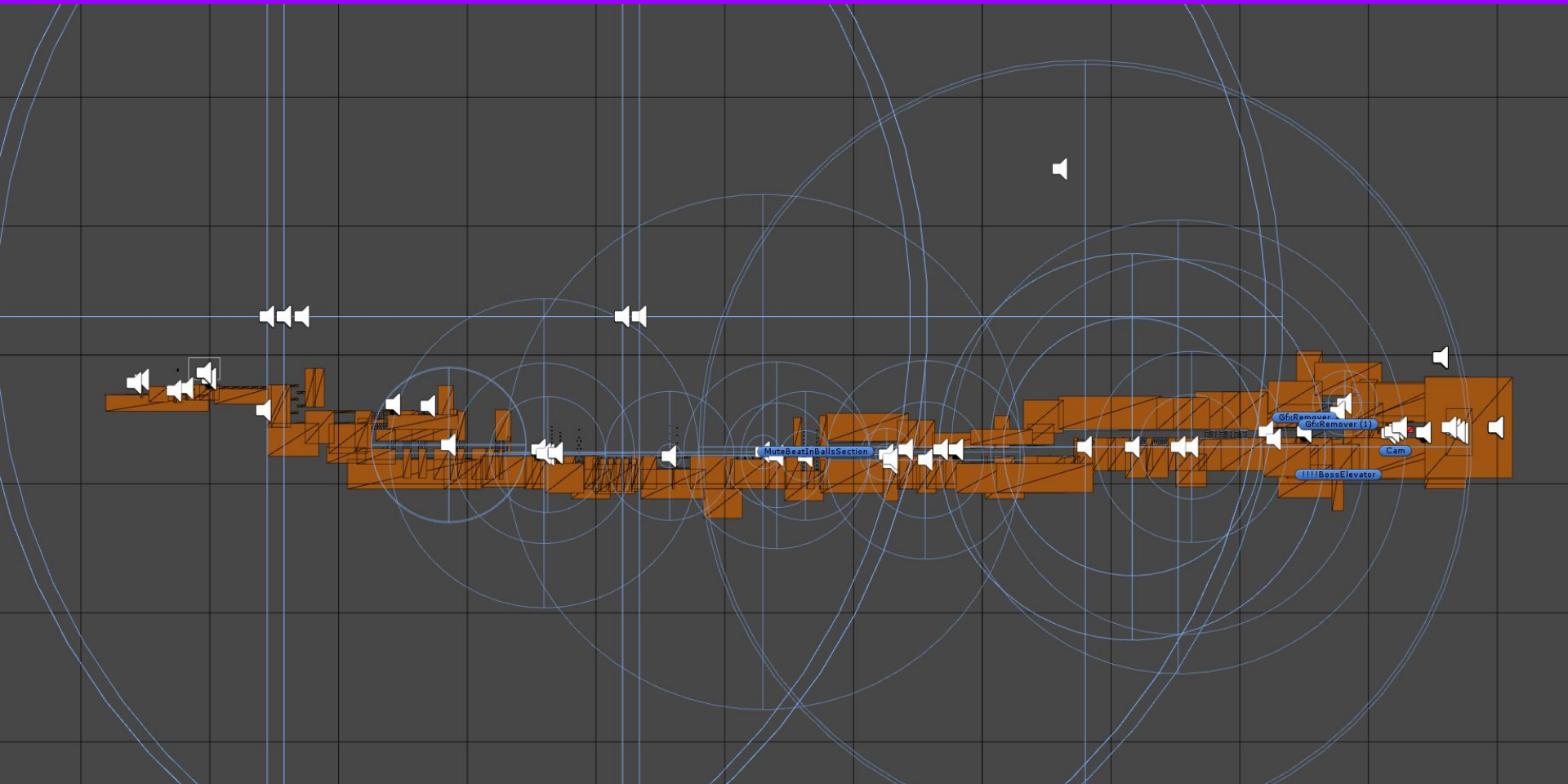
Localized Music Loops

Simple attenuation and panning for music loops using the built-in audio system



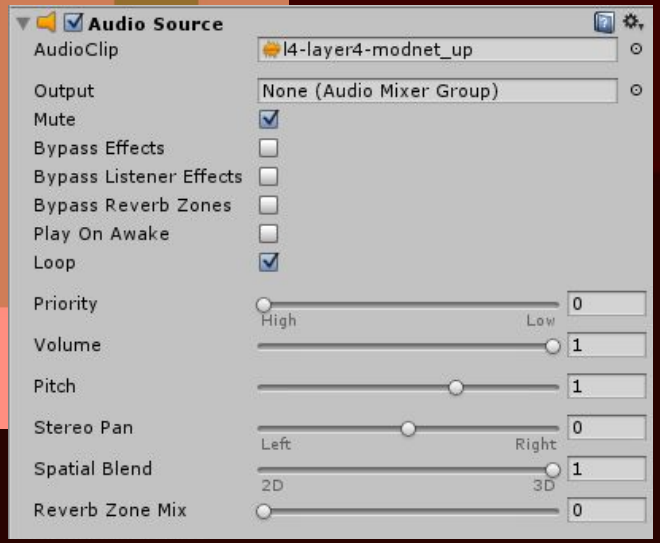


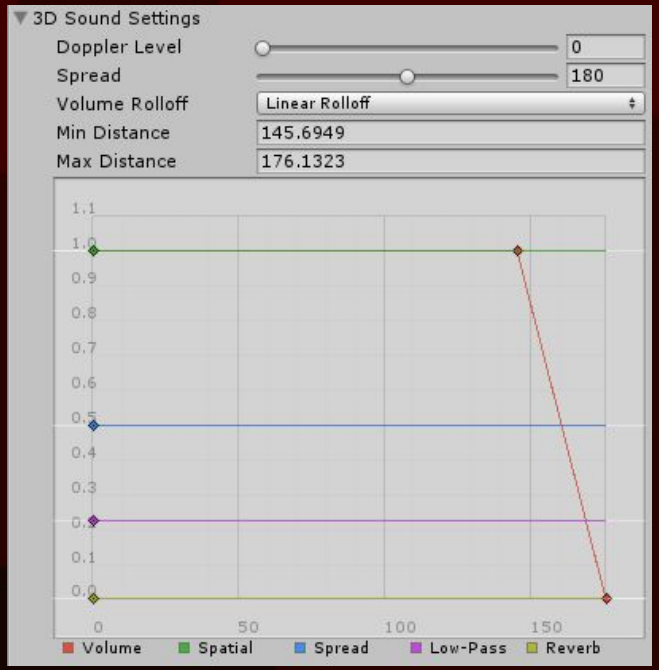
Localized Music Loops - Level 4



140 demo

Example Audio Loop

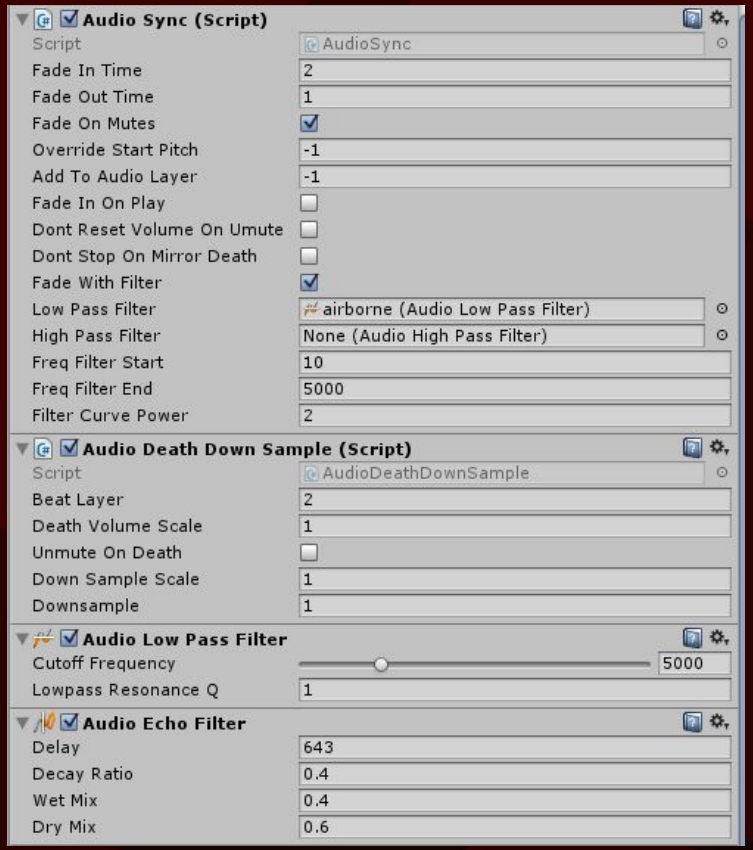




Example Audio Loop Components

AudioSync component: handles all loops

- Handles fade in/out
- Controls filters
- Adds loop to ‘layer’ (group)



Example Audio Loop Components

AudioSync component: handles all loops

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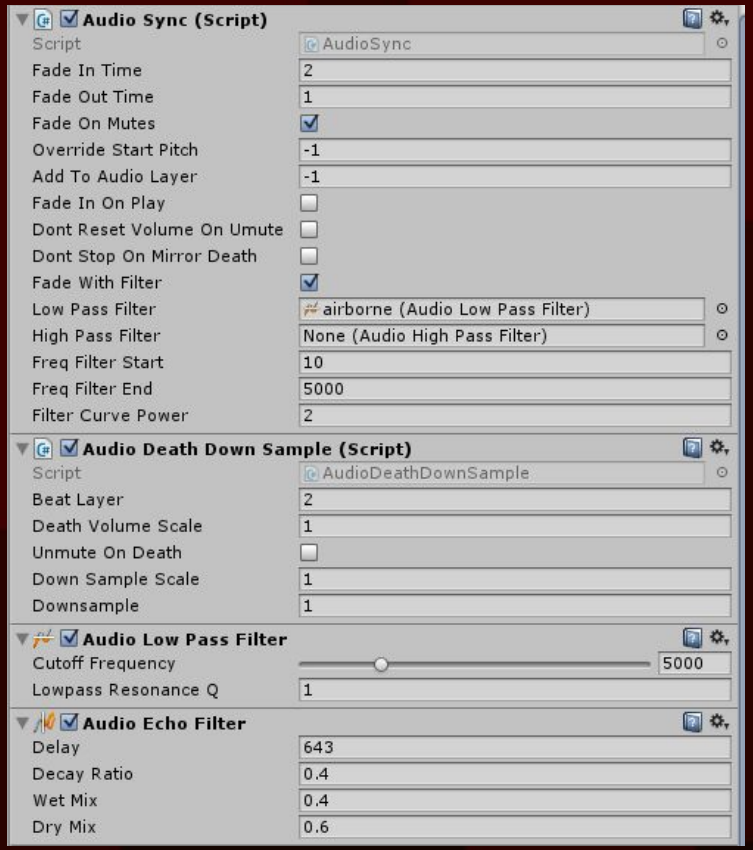
AudioDeathDownSample:

downsample filter (more on this later)



Example Audio Loop Components

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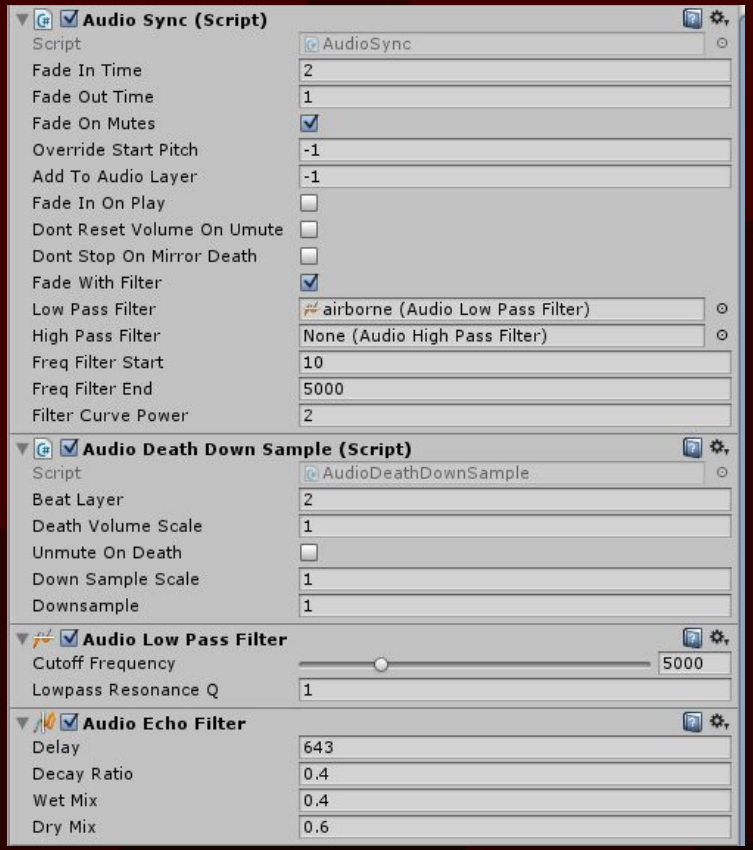
AudioDeathDownSample:

downsample filter

AudioLowPassFilter: built-in Unity LPF



Example Audio Loop Components

AudioSync component: handles all loops

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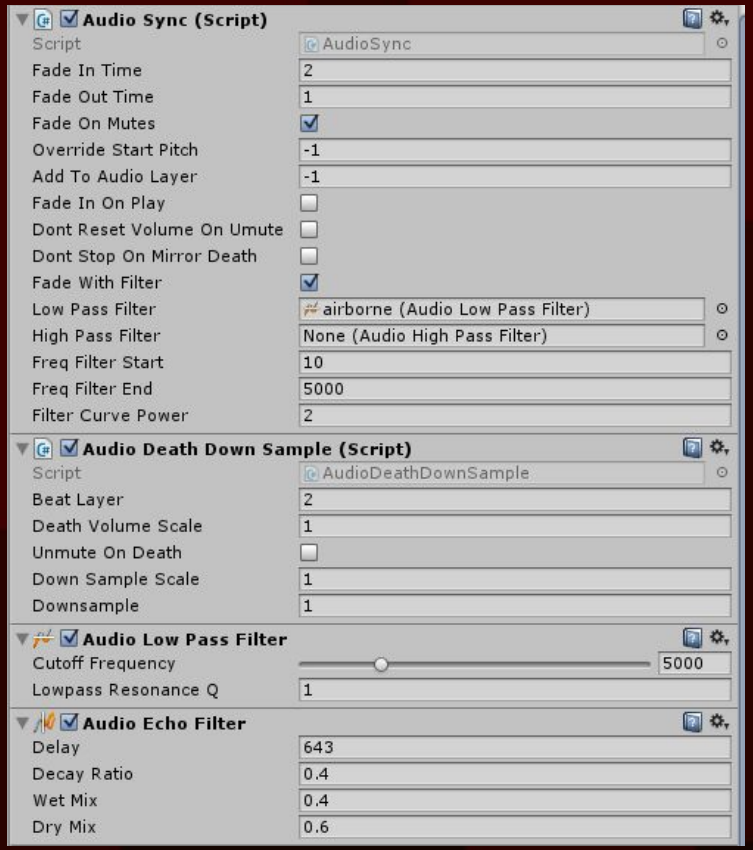
AudioDeathDownSample:

downsample filter

AudioLowPassFilter: built-in Unity LPF

AudioEchoFilter: built-in Unity delay

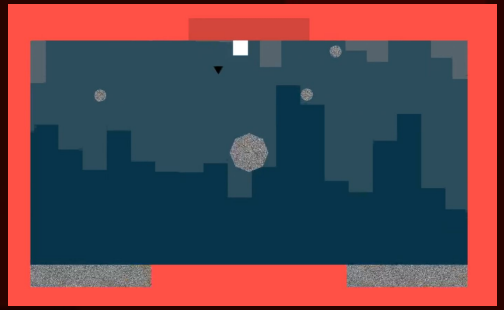


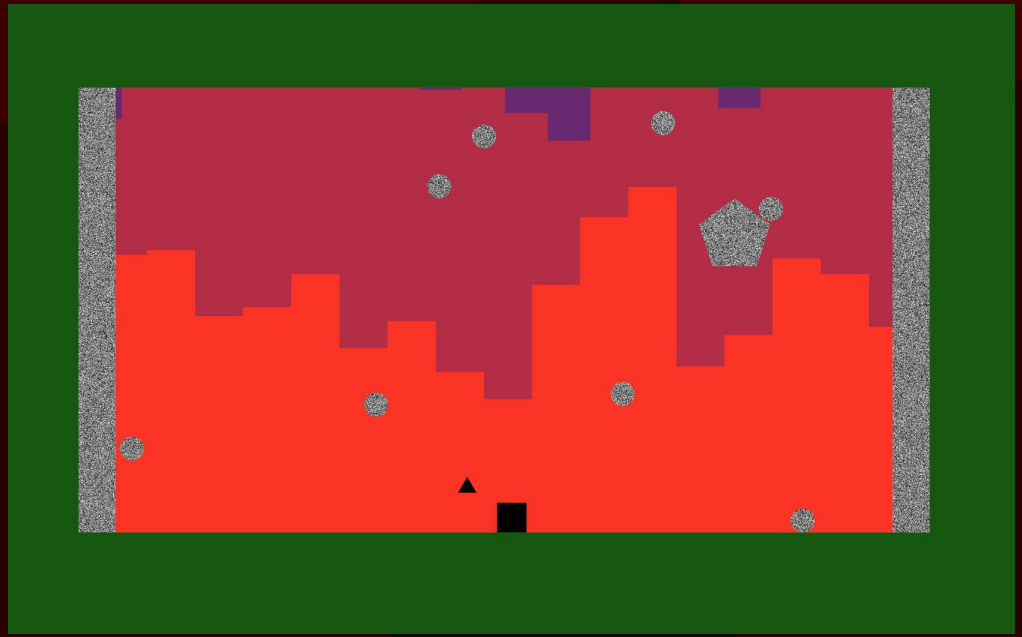
Masking Loops

Music loops can be masked:

- Fade using filters
- Delay
- Unmuting at specific beats

Level 4 Boss



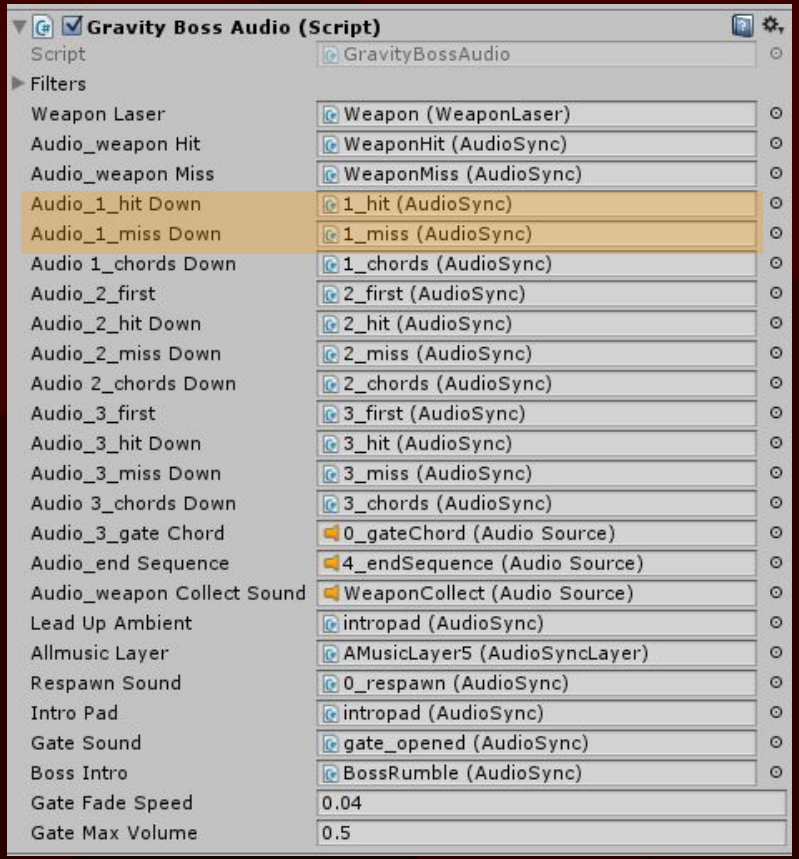


Level 4 Boss

- Over 20 loops running simultaneously

Level 4 Boss

- Separate loops for hit and miss
- Muted / unmuted when hit or miss is determined

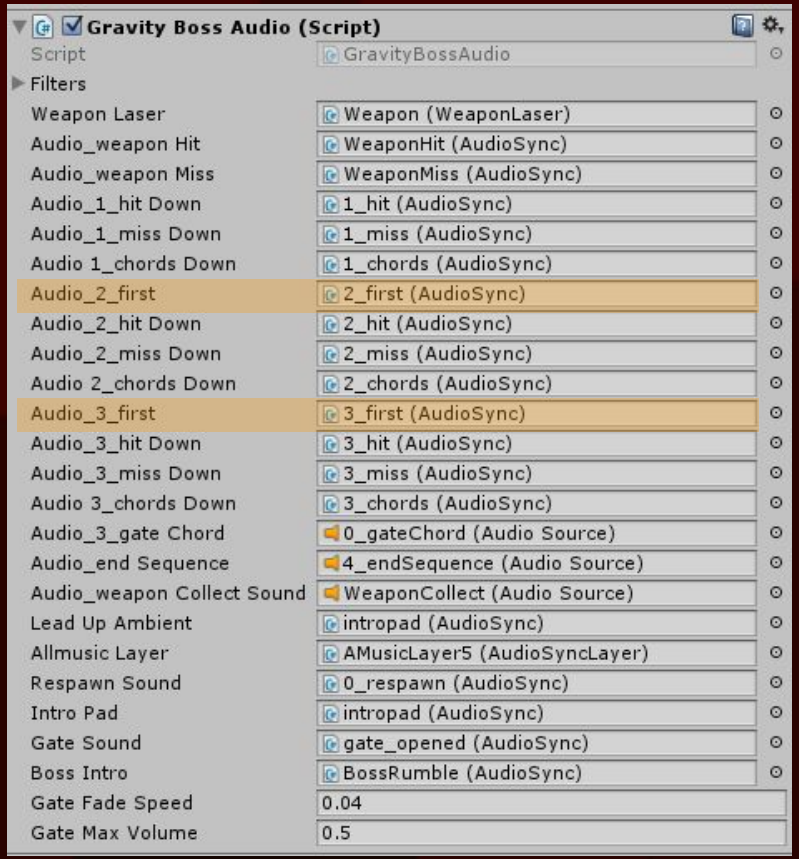


Level 4 Boss

- Each stage has its own set of loops

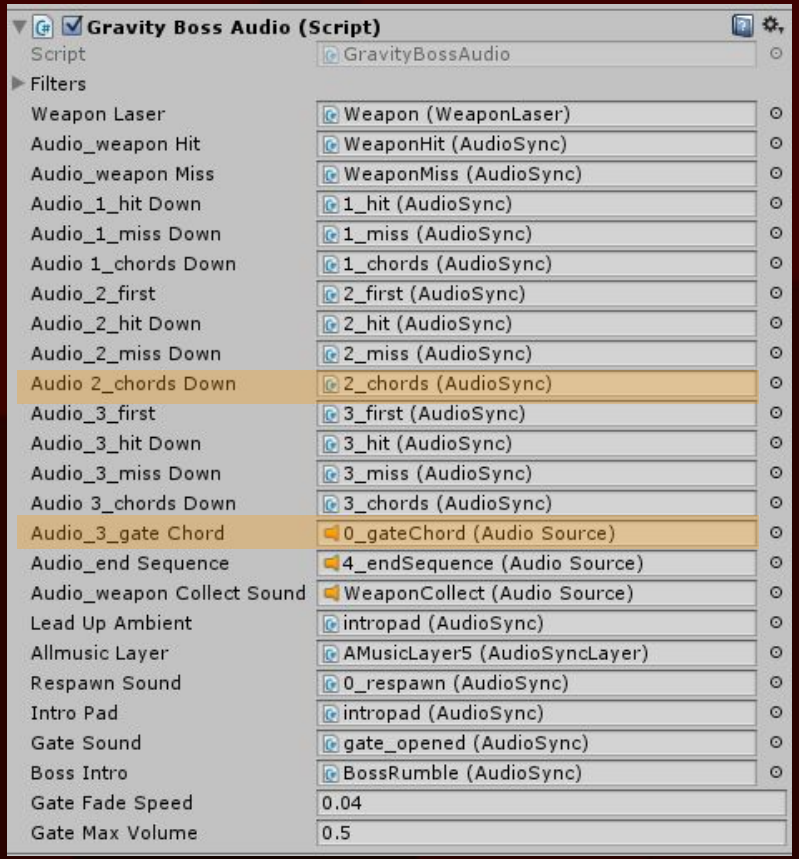
Level 4 Boss

- Each stage is in a different key
- Loops have long Ableton Reverb tails
- Reverb tails and key change requires special transitional first loop



Level 4 Boss

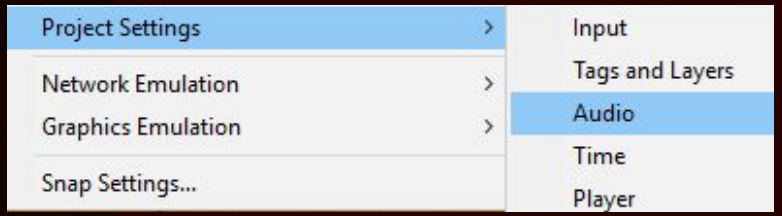
- House chords are faded in using filter between hits to create tension
- Final chord is faded in, anticipating end sequence

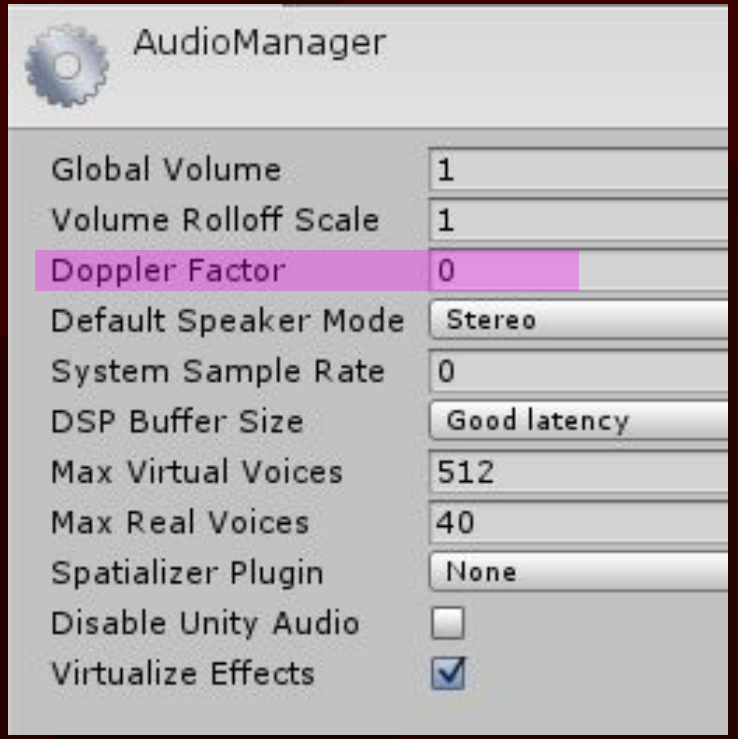


140 demo

Doppler Effect

- Disable Doppler effect to avoid drifting loops!



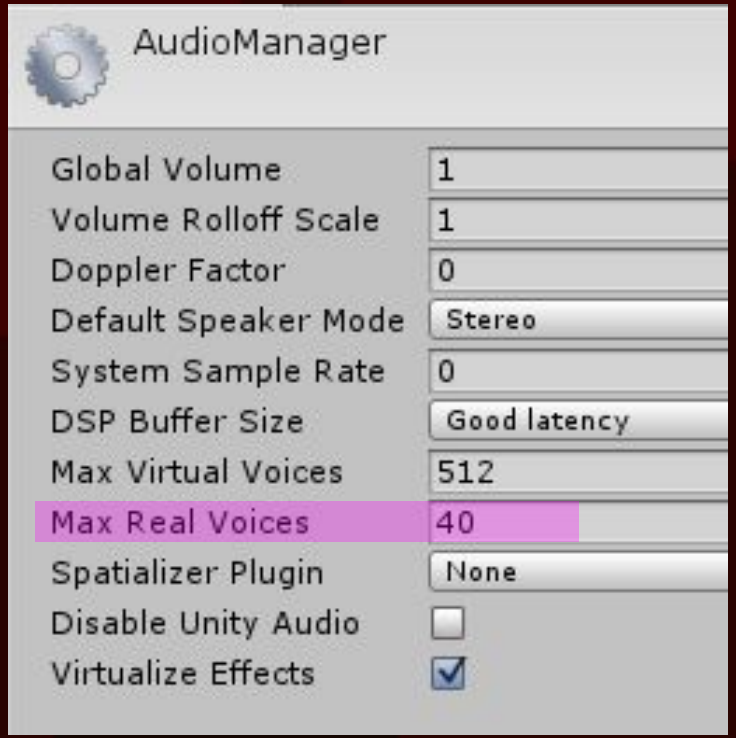


Max Real Voices

In Unity 3, if more than 32 sounds are playing at once, we lose sample accuracy!

Same limitation in Unity 2017, but the number can be increased.

140 currently uses 40 voices.



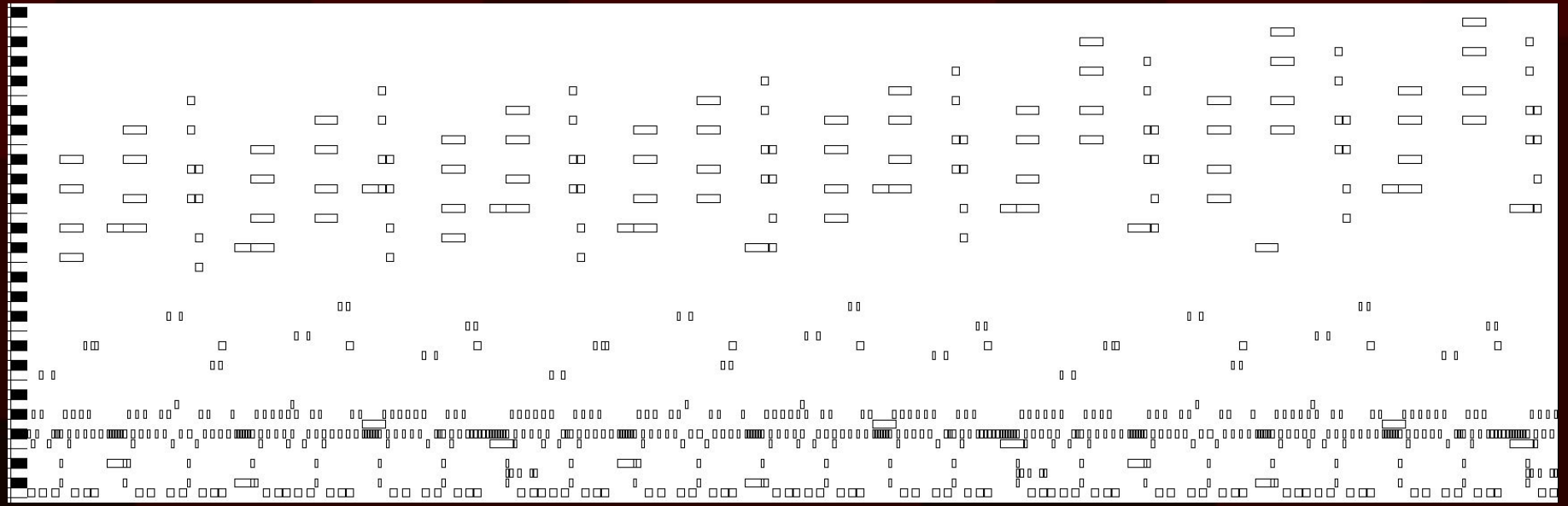
Summary

- In 140, we start all loops at once and control their volume
- Localized music loops: volume and pan using built-in audio system
- Use filters and effects to mask loops
- Level 4 boss music uses muting, fading, and filtering of 20 loops
- Disable Doppler effect
- Check that ‘Max Real Voices’ is enough

140 Music Production

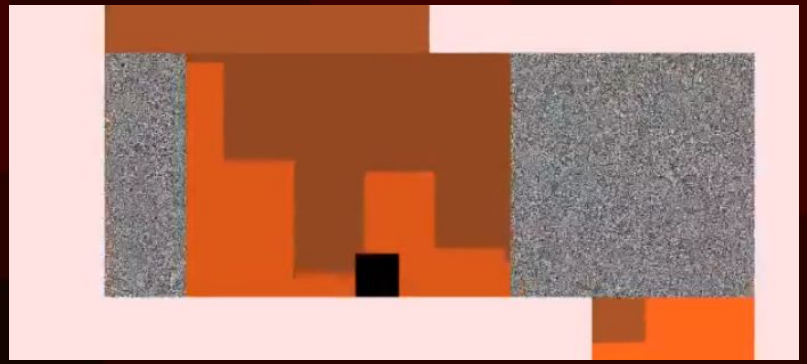
The Puzzle of Music

Making music for a *music game* can be like solving a puzzle

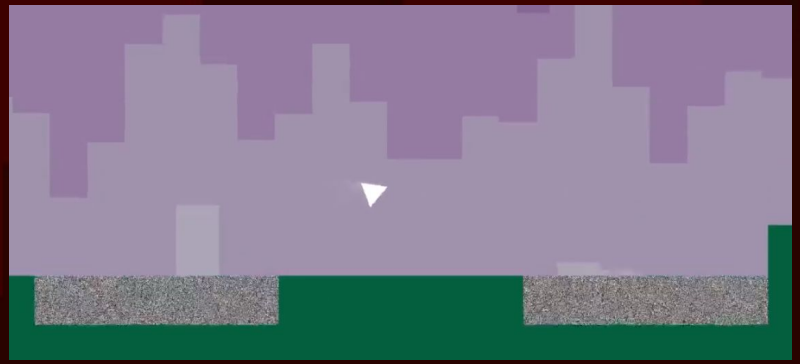


KillBlocks and Togglers

Two example game mechanics

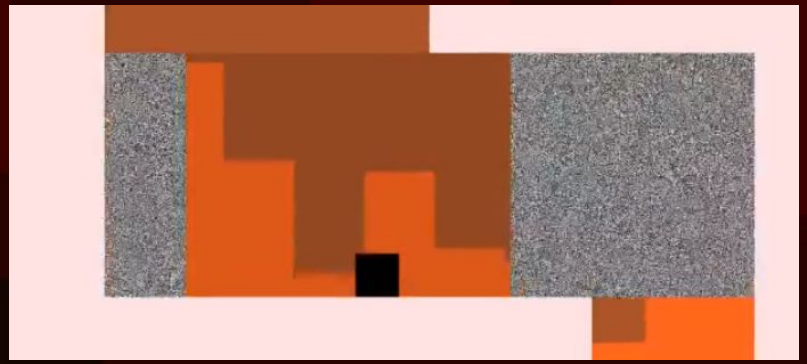


KillBlock



Toggler

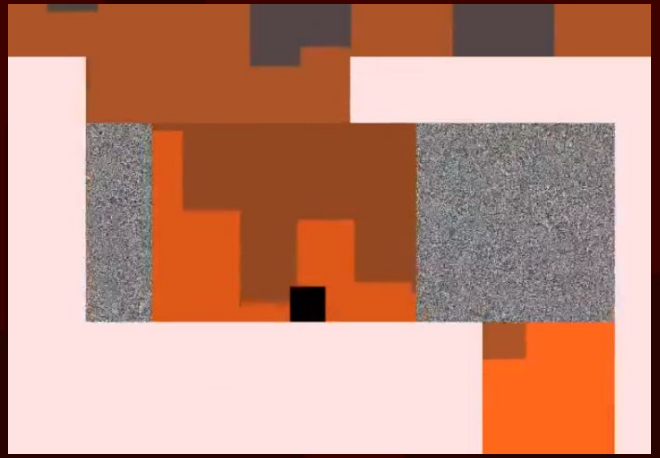
KillBlocks



KillBlock

KillBlock Rhythm Pattern

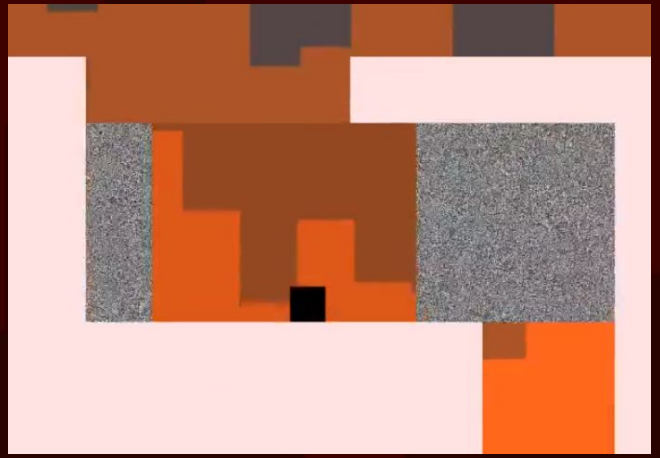
- Communicates to player exactly when certain game areas are either safe or lethal
- Must correspond exactly to game logic timing



```
time ──────────────────────────►

   >  >        > >   x


   >  MOVE blocks right
   x  TOGGLE all blocks
```

KillBlock Rhythm Pattern

- Music runs at 140 beats/minute
- A 'bar' is 4 beats ~ 1.7 seconds
- Our KillBlock rhythm is exactly 2 bars



```
time (bars) ──────────────────►
1 . . . : . . . 2 . . . : . . .
  >   >       > >   x
```

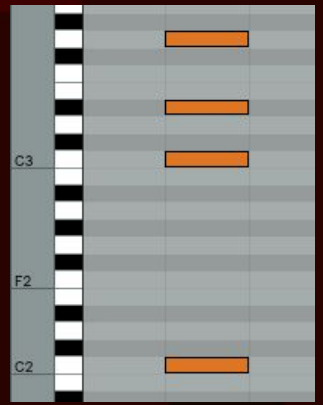
KillBlock Sounds

- > MOVE sound is a 'Landlord stab'
- x TOGGLE sound is a 808 cowbell

> MOVE Sound

- 'Landlord' stab
- Classic house sample
- Sampled minor chord played on piano-like FM synth
- Origin of sample seems to be 1984 Linndrum demo tape
- Made famous by Landlord's 'I Like It (blow out dub)' (1989)

sounds like



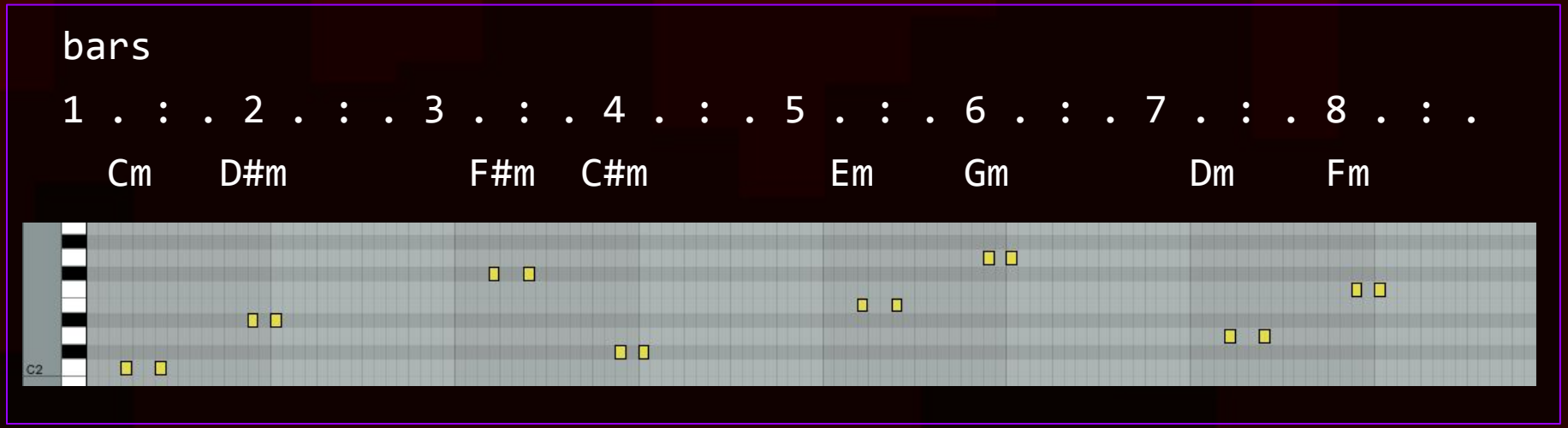
Sampled Chords

- Sampled chord is played back at different sample rates
- Resulting output is the same chord with new base notes

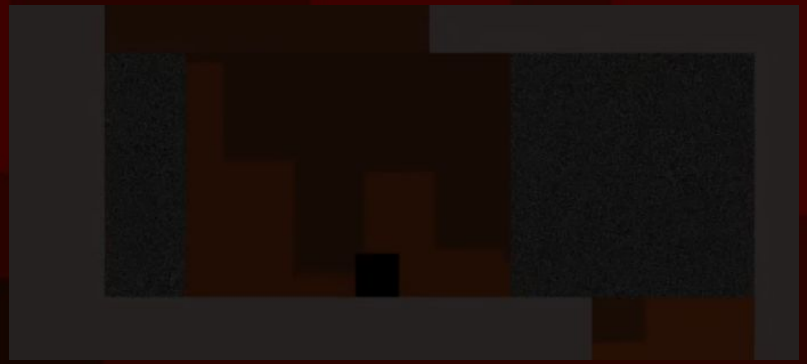
(foundational for all sampler-based music)

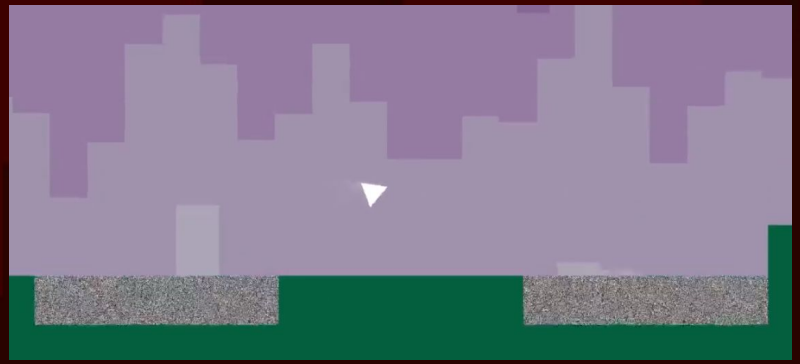
KillBlock Harmony

- The result can be heard in the KillBlock loop
- 2-bar rhythmic loop
- 8-bar harmonic loop



KillBlocks and Togglers





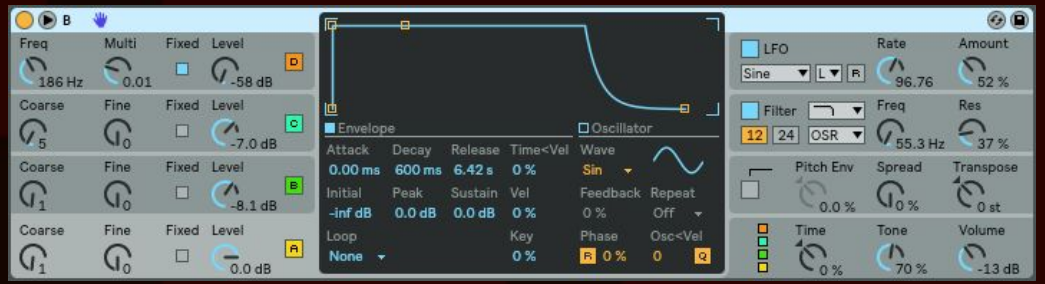
Toggler

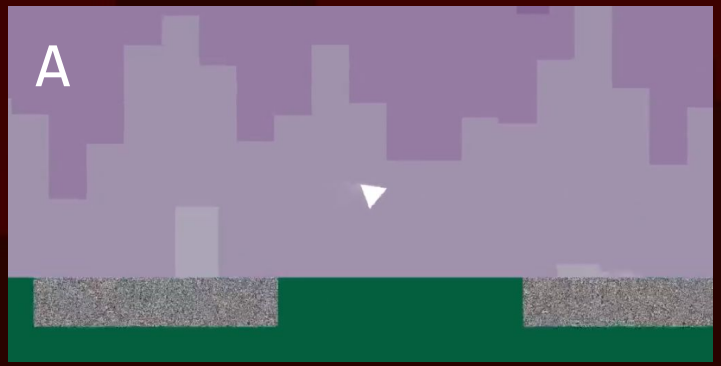
Toggler Sound

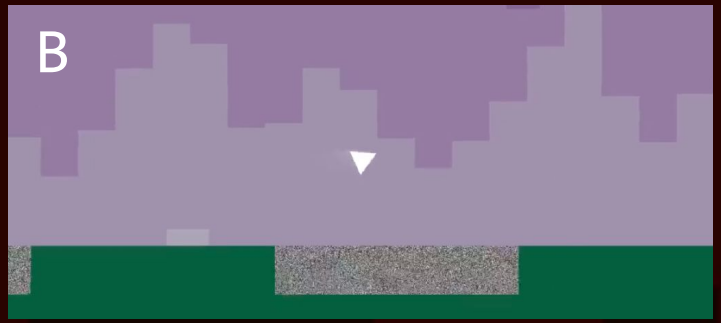
The toggler loop alternates between two different Operator patches

State A Sound

State B Sound



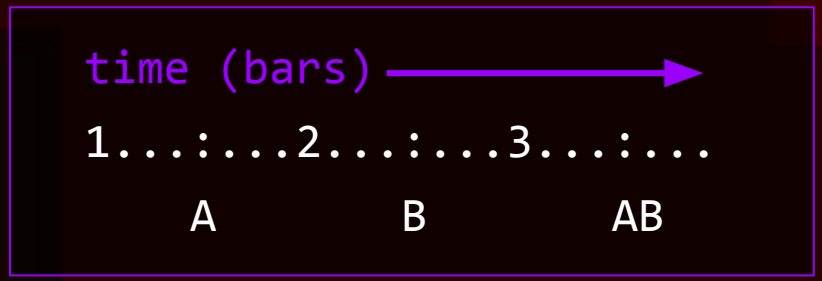


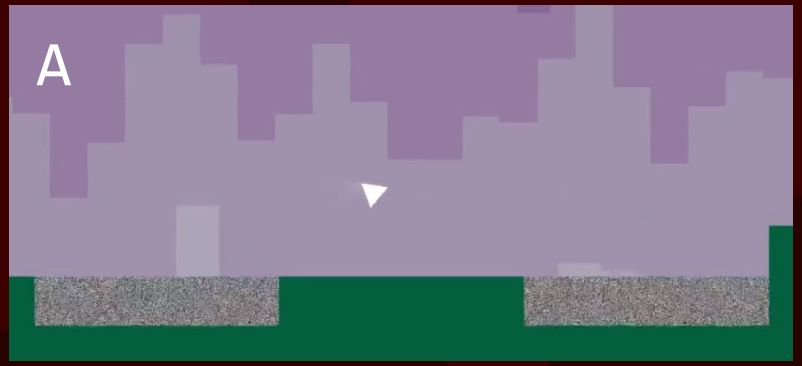


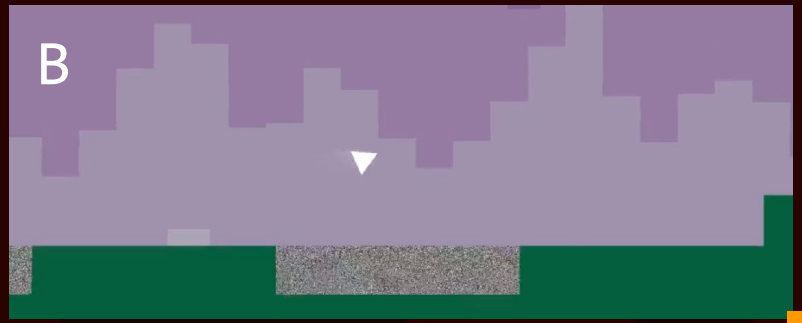
Toggler Rhythm Pattern

The toggler loop:

- 3-bar rhythmic loop
- Game logic toggle floors between lethal and non-lethal
- Two states: A and B

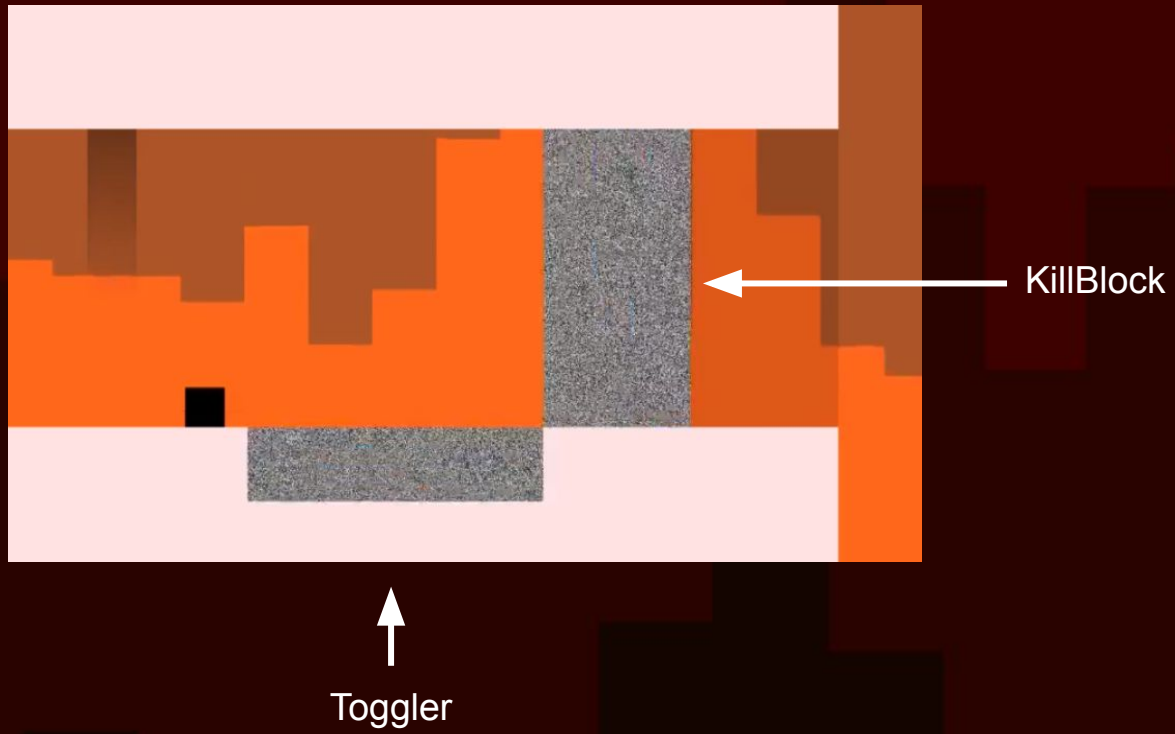






Toggler and KillBlock

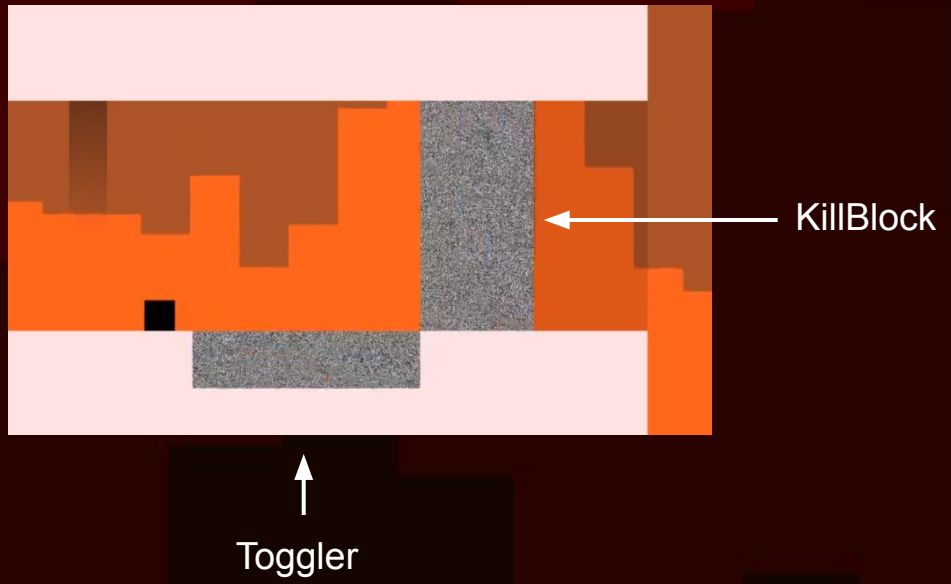
Both play at once in this jump puzzle!



Toggler and KillBlock Rhythms

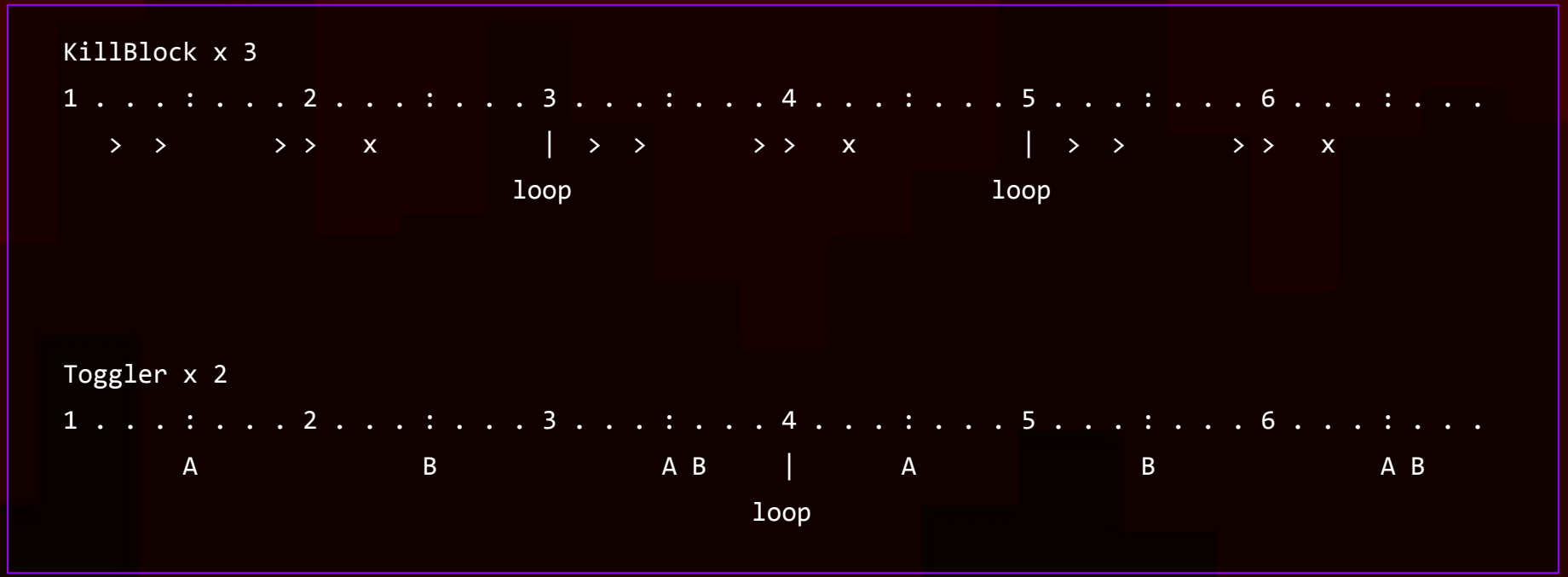
- KillBlock loop is 2 bars
- Toggler loop is 3 bars

```
KillBlock
 1 . . . : . . . 2 . . . : . . .
    >  >        > >   x

Toggler
 1 . . . : . . . 2 . . . : . . . 3 . . . : . . .
         A               B               A B
```



Toggler and KillBlock Looped

Loop simultaneously after 2 x 3 = 6 bars

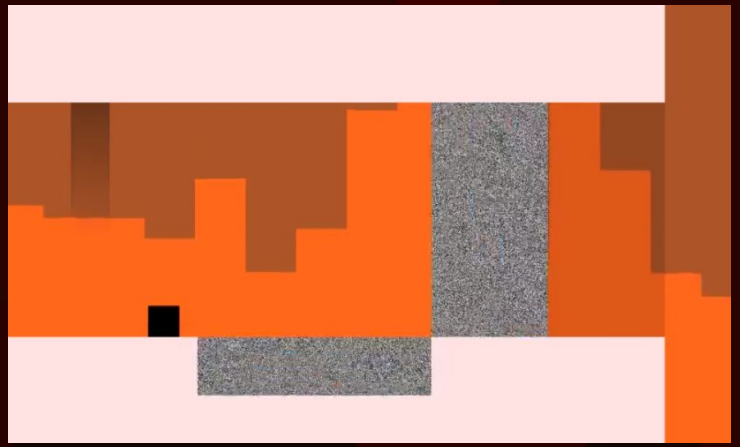


Toggler and KillBlock Combined

The combined 6-bar loop of Toggler and KillBlock:

```
Combined 6-bar loop
1 . . . : . . . 2 . . . : . . . 3 . . . : . . . 4 . . . : . . . 5 . . . : . . . 6 . . . : . . .
   > > .     > > x .         > > .     > > x .         > > .     > > x .
       A             B             A B           A             B             A B
```

This pattern is what the player must grasp to pass the jump puzzle



Toggler Harmony

- Toggler loop must be in harmony with KillBlock loop
- 8-bar harmonic loop

KillBlock:	Cm	D#m	F#m	C#m	Em	Gm	Dm	Fm
Toggler:	Cm7	D#m7	Bm11	C#m7	Em7	Cm11	Dm7	Fm7

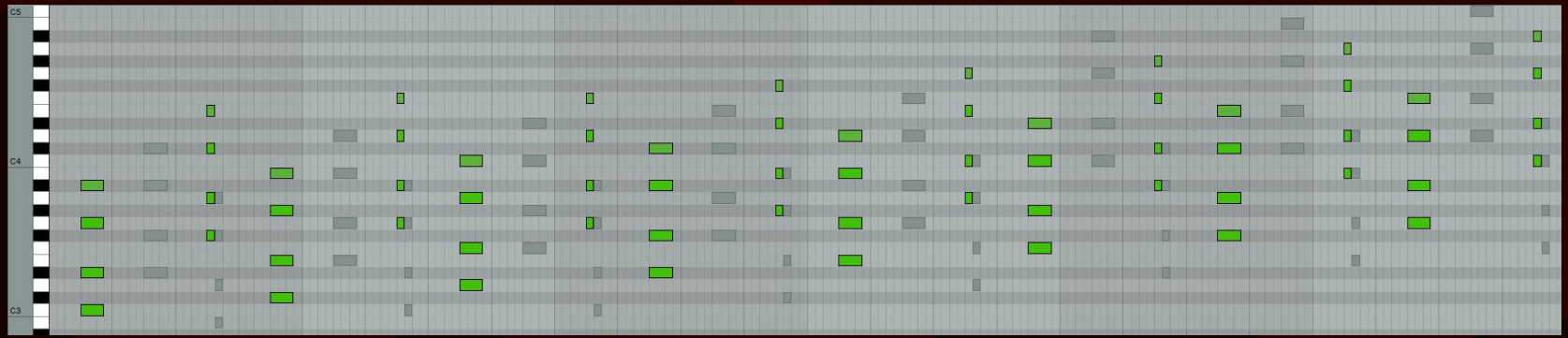
Toggler Full Loop

- 3-bar rhythmic loop
- 8-bar harmonic loop
- Full loop: 3 x 8 = 24 bars

```
1...:...2...:...3...:...4...:...5...:...6...:...7...:...8...:...9...:...10..:...11..:...12..:...
    A       B       AB  |   A       B       AB  |   A       B       AB  |   A       B       AB
    Cm7     D#m7    Bm11    C#m7    Em7     Cm11    Dm7     Fm7 |   Cm11    D#m7    F#m7    C#m11

13..:...14..:...15..:...16..:...17..:...18..:...19..:...20..:...21..:...22..:...23..:...24..:...
    A       B       AB  |   A       B       AB  |   A       B       AB  |   A       B       AB
    Em7     Gm7     Dm11    Fm7 |   Cm7     D#m11   F#m7    C#m7    Em11    Gm7     Dm7     Fm11
```

Toggler Full Loop

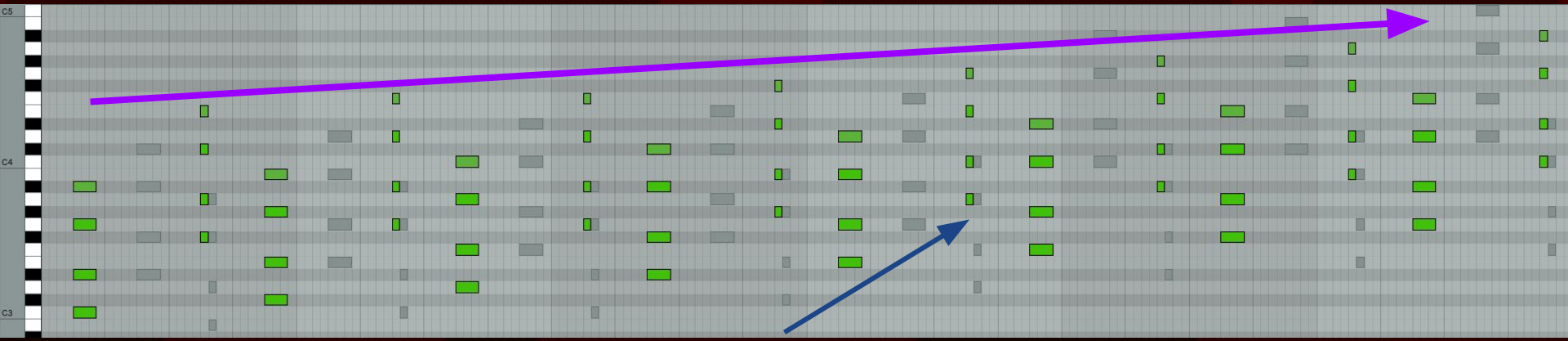
```
1...:...2...:...3...:...4...:...5...:...6...:...7...:...8...:...9...:...10..:...11..:...12..:...
    A       B       AB      A       B       AB      A       B       AB      A       B       AB
    Cm7     D#m7    Bm11    C#m7    Em7     Cm11    Dm7     Fm7     Cm11    D#m7    F#m7    C#m11

13..:...14..:...15..:...16..:...17..:...18..:...19..:...20..:...21..:...22..:...23..:...24..:...
    A       B       AB      A       B       AB      A       B       AB      A       B       AB
    Em7     Gm7     Dm11    Fm7     Cm7     D#m11   F#m7    C#m7    Em11    Gm7     Dm7     Fm11
```



Rising Pattern

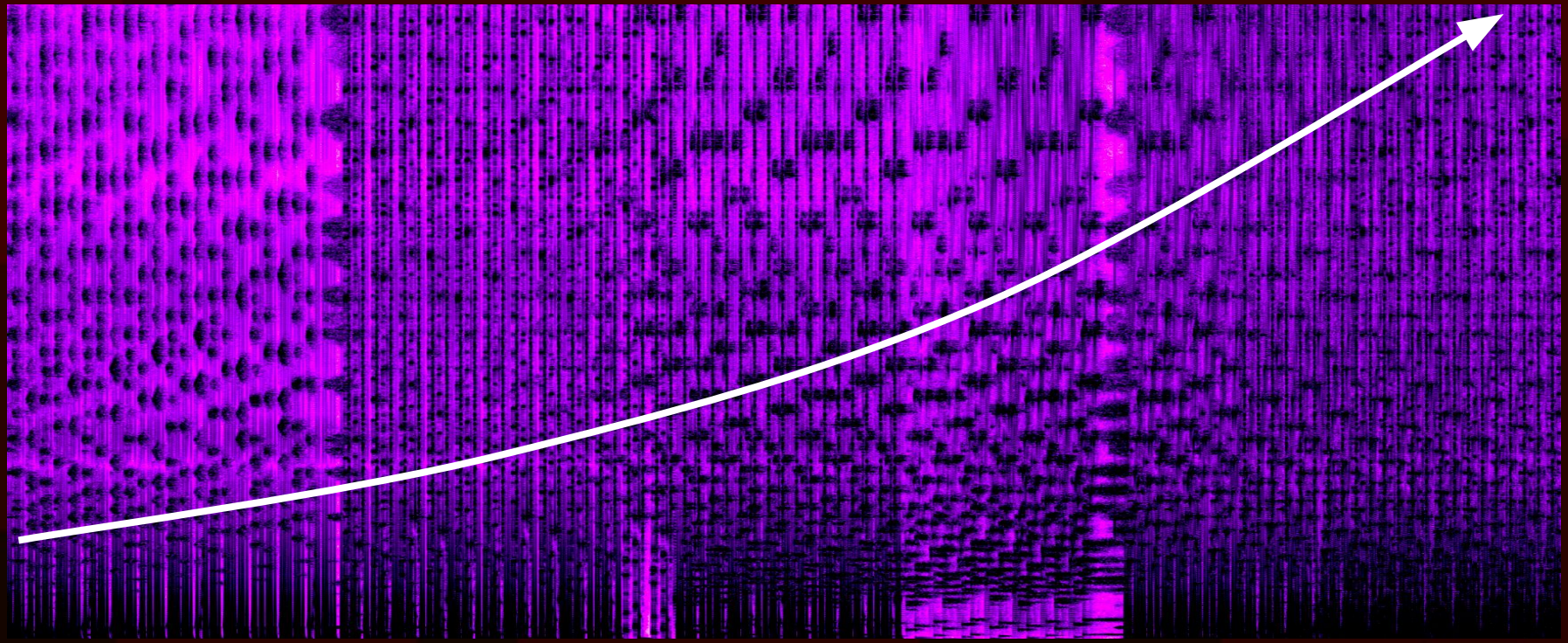
Level 4 is composed to emulate frequency continuously rising:

- Uses chord inversions to create 4-chord rising sequences
- Chord notes generally ascend over full 24-bar loop



Rising Pattern

Spectral analysis of soundtrack version shows rising frequency pattern



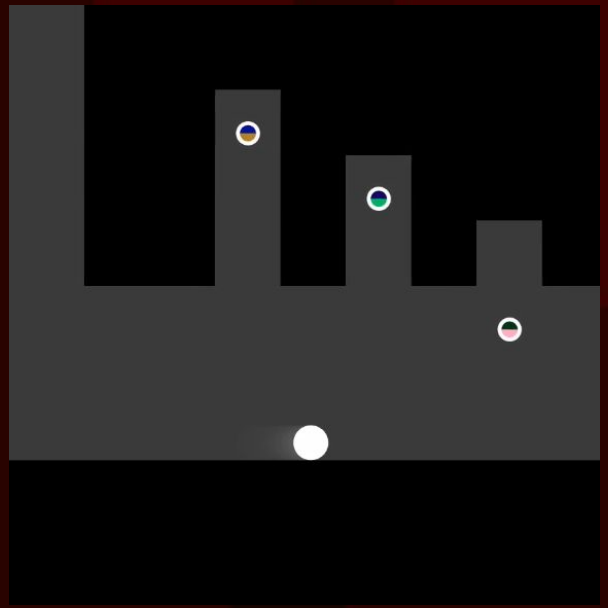
Fun Audio Tricks

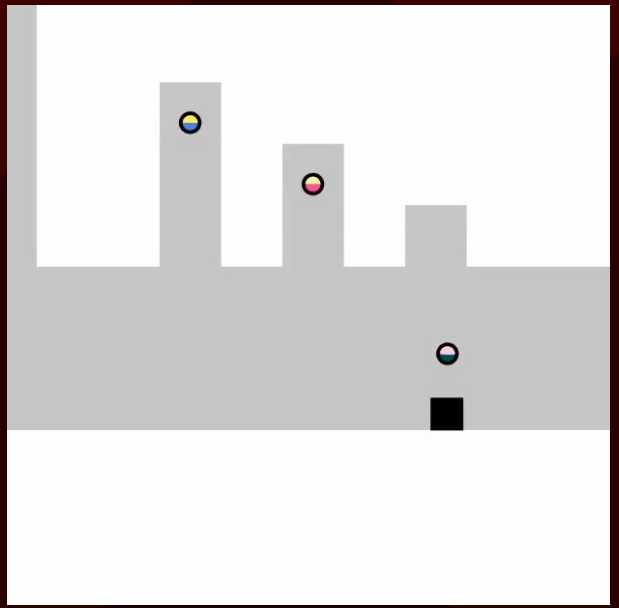
Fun Audio Tricks

- Modulation
- Cassette tape jam
- Downsampling
- Fake crash

Menu Modulation

- When picking up a mirror mode key, modulate ambient track from Cm to Dm.
- Track contains no rhythmic elements, so loop synchronization is not an issue.





From Semitones to Frequency

Modulate ambient track from Cm to Dm:

Frequency of D relative to C (+2 semitones, well-tempered):

$$2^{2/12} \sim 1.12246204830937$$

From Semitones to Frequency

Modulate ambient track from Cm to Dm:

Frequency of D relative to C (+2 semitones, well-tempered):

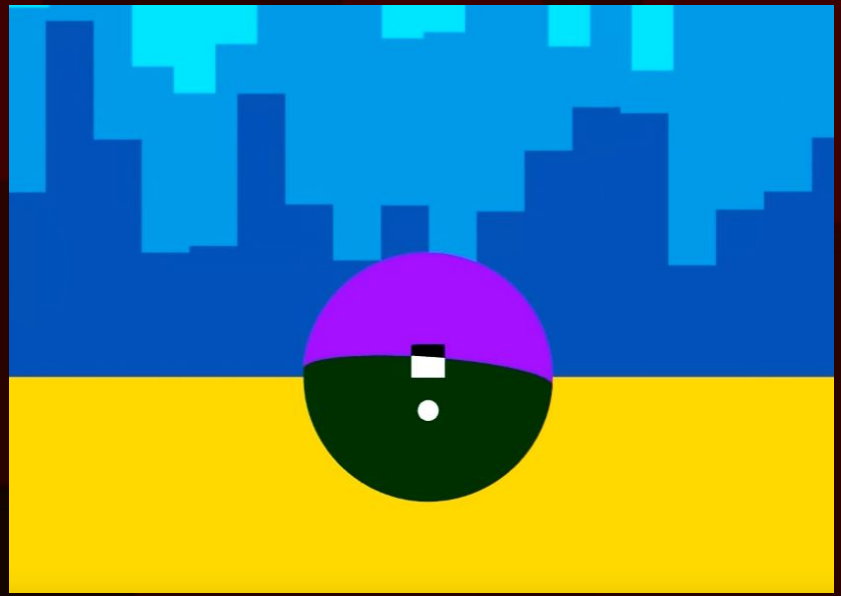
$$2^{2/12} \sim 1.12246204830937$$

Gradual pitch change code, as f goes from 0 to 1:

```
relativePitch = pow(2.0, 2.0 / 12.0)
source.pitch = lerp(1.0, relativePitch, f)
```

Cassette Tape Jam

When a key is delivered, the playing music is stopped with a cassette tape jam-inspired effect.



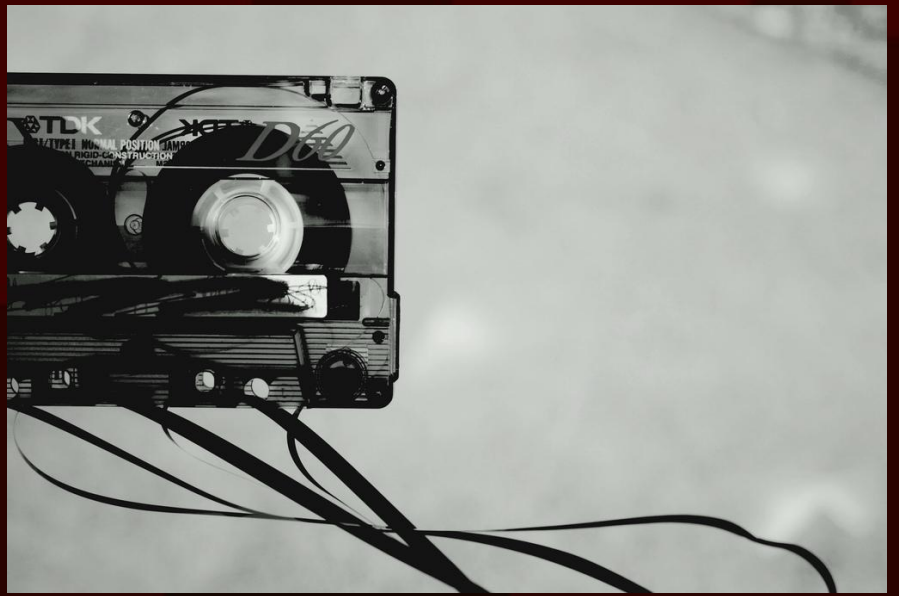


Image credit: Kristi Bogel

Cassette Tape Jam

The tape jam effect is achieved with:

- applying strong vibrato to all music tracks,
- enveloping pitch towards 0 and volume towards silence.

Cassette Tape Jam Code

The tape jam effect is achieved with:

- applying strong vibrato to all music tracks,
- enveloping pitch towards 0 and volume towards silence.

As f goes from 0 to 1:

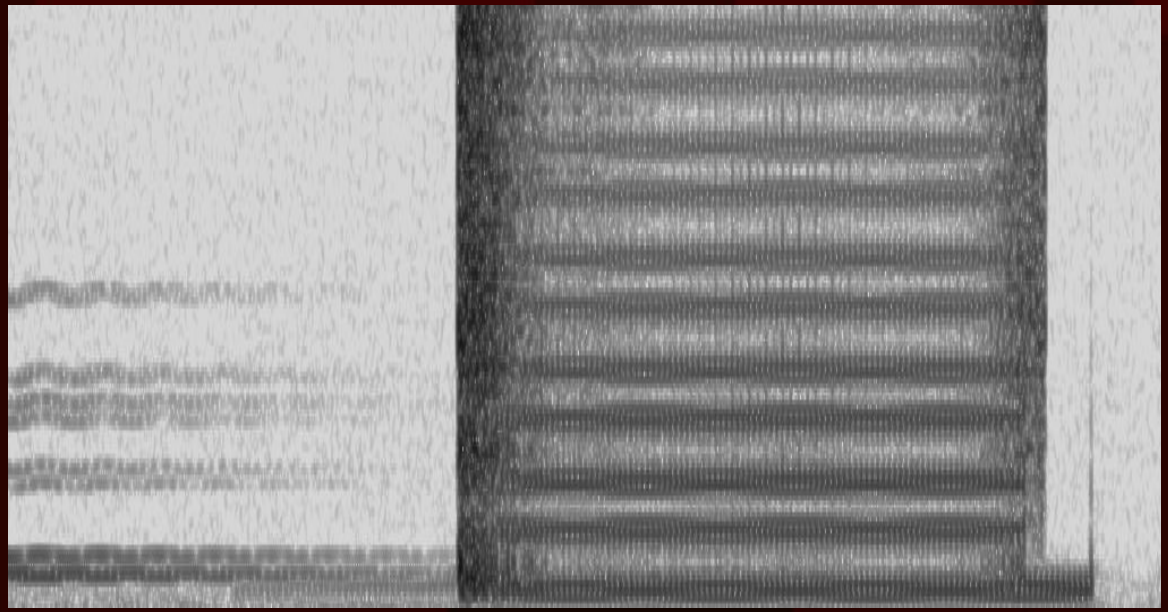
```
source.pitch = (1-f)                          // pitch envelope
             + sin(time * FREQ) * STRENGTH    // vibrato
source.volume = lerp(maxVolume, 0, f)         // amp envelope
```

Downsampling

When the player dies, the visuals turn black and white, and the audio is brutally distorted.

Downsampling

- The death audio effect is a simple variable downsampling filter.
- It sounds ugly on purpose.



Downsampling Filter Code

The simplest variable downsampling filter:

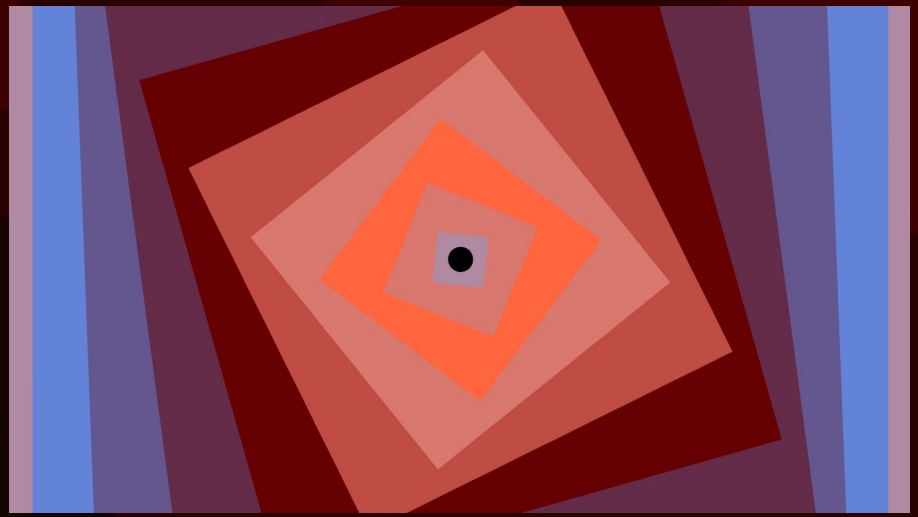
repeat every D’th sample D times.

```
void OnAudioFilterRead(float[] data, int channels) {
  if (D > 1) {                                  // if filter active
    for (int s = 0; s < data.Length; s+=2) {    // for all samples
      data[s]   = data[s / D * D];              // left channel
      data[s+1] = data[s / D * D + 1];          // right channel
    }
}
```

Fake crash

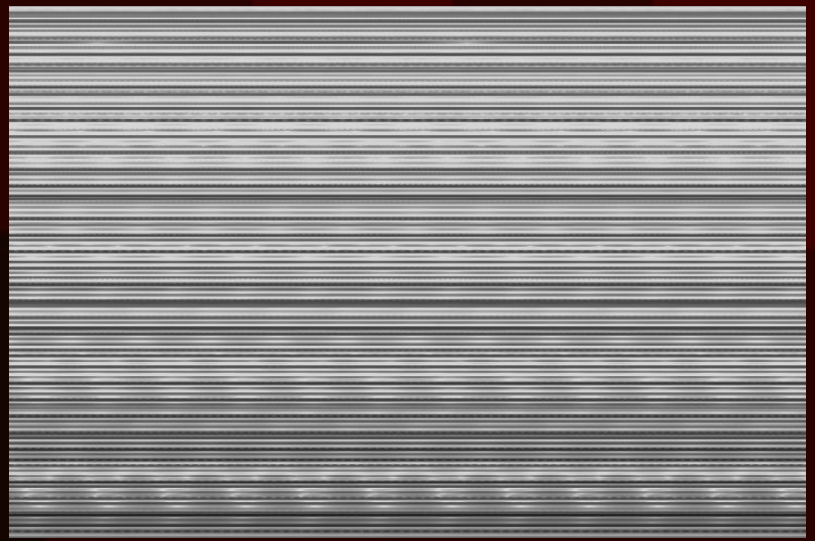
When the final boss is beaten, the game simulates the game crashing.

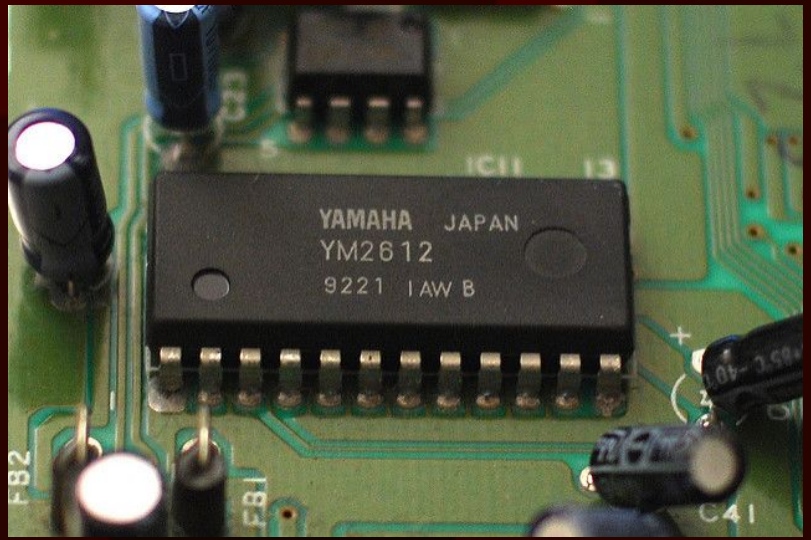
Or rather, how the game *would* crash if it was running on a SEGA Genesis.



Fake crash

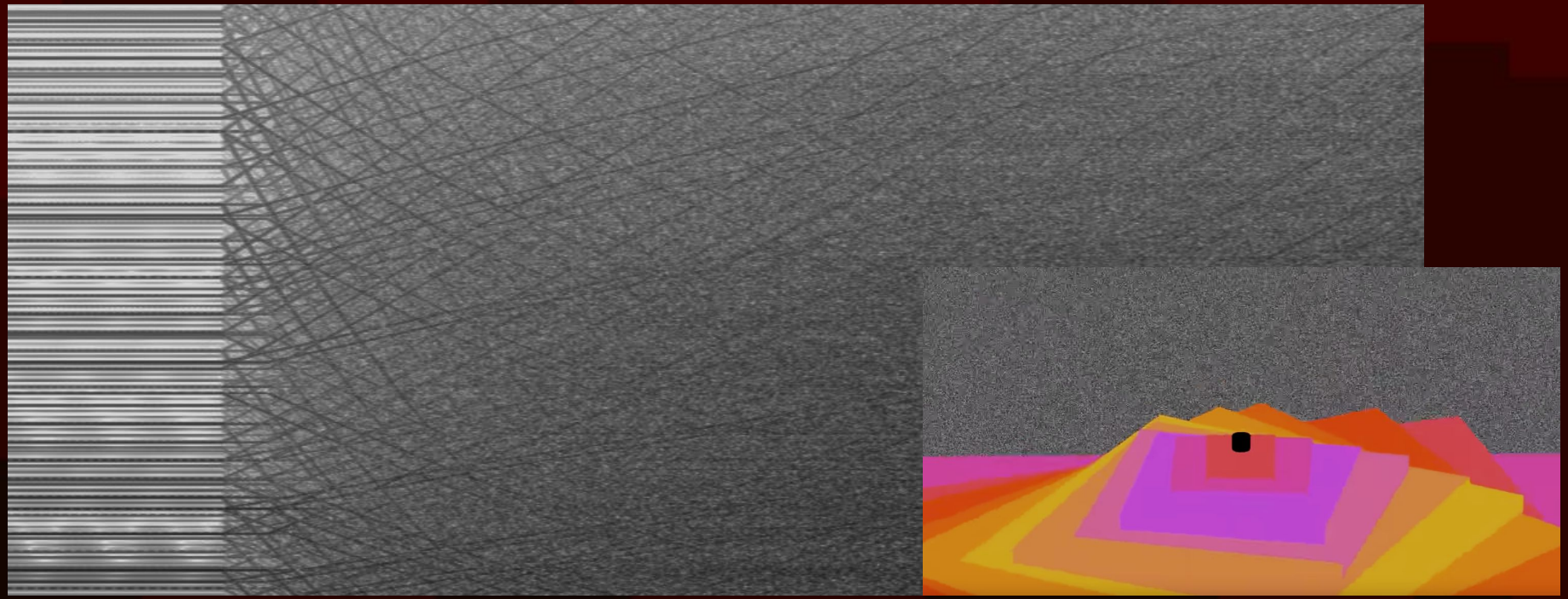
- The final chord of the boss fight and the screen is unchanged for 9 seconds, leaving at least one YouTuber very nervous.
- Crashes on old oscillator-based systems would have similar behaviour.





Glissando and 3D Rotation

- The oscillators slowly starts individually wandering towards a final chord.
- The game rotates the view, for the first time exposing a 3D world.



Summary

- Pitch change on playing track works for ambient music.
- Vibrato and amplitude and pitch envelopes simulate cassette tape jam.
- Downsampling filter is implemented `OnAudioFilterRead` method.
- Game ends with fake crash sound with hanging oscillators.
- Fake crash is resolved with oscillators gliding towards final chord.

Questions?