Lecture 25

Game Audio
The Role of Audio in Games

Engagement

- **Entertains** the player
  - Music/Soundtrack
- **Enhances the realism**
  - Sound effects
- **Establishes atmosphere**
  - Ambient sounds
- **Other reasons?**
The Role of Audio in Games

Feedback

- **Indicate** off-screen action
  - Indicate player should move
- **Highlight** on-screen action
  - Call attention to an NPC
- **Increase** reaction time
  - Players react to sound faster
- **Other reasons?**
History of Sound in Games

• Arcade games
• Early handhelds
• Early consoles
Early Sounds: *Wizard of Wor*
History of Sound in Games

- Arcade games
- Early handhelds
- Early consoles

- Starts w/ MIDI
- 5th generation (Playstation)
- Early PCs

Sample = pre-recorded audio
Samples: Sinistar
History of Sound in Games

- Arcade games
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Basic Sounds → Recorded Sound Samples → Some Variability of Samples

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- Sample selection
- Volume
- Pitch
- Stereo pan

Game Audio
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Some Variability of Samples
- Sample selection
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More Variability of Samples
- Multiple samples
- Reverb models
- Sound filters
- Surround sound
History of Sound in Games

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Recorded Sound Samples

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Some Variability of Samples

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More Variability of Samples

LibGDX is here

CUGL is here

LibGDX is here

CUGL is here
The Technical Challenges

- Sound **formats** are not (really) cross-platform
  - It is not as easy as choosing MP3
  - Different platforms favor different formats

- Sound playback **APIs** are not standardized
  - LibGDX & CUGL are layered over many APIs
  - Behavior is not the same on all platforms

- Sound playback crosses **frame boundaries**
  - Mixing sound with animation has challenges
### File Format vs Data Format

#### File Format
- The data storage format
  - Has data other than audio
- Many have many encodings
  - *caf* holds MP3 *and* PCM
- **Examples:**
  - .mp3, .wav, .aiff
  - .aac, .mp4, .m4a (Apple)
  - .flac, .ogg (Linux)

#### Data Format
- The actual audio encoding
  - Basic audio codec
  - Bit rate (# of bits/unit time)
  - Sample rate (digitizes an analog signal)
- **Examples:**
  - MP3, Linear PCM
  - AAC, HE-AAC, ALAC
  - FLAC, Vorbis
## Game Audio Formats

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**MP3 historically avoided due to patent issues**
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**Supported in LibGDX**

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MP3 historically avoided due to patent issues
Which Formats Should You Choose?

• **Question 1:** Streaming or no streaming?
  - Audio gets large fast; music often streamed
  - But streaming creates overhead; bad for sound fx
  - Few engines support WAV streams (LibGDX & CUGL do)

• **Question 2:** Lossy or lossless compression?
  - Music can by lossy; sound fx not so much
  - Only FLAC and WAV are standard lossless

• **Question 3:** How many channels (speakers) needed?
  - MP3 channel is *stereo only*
  - Others support many channels (e.g. 7.1 surround)
Which Formats Should You Choose?

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  • Others support many channels (e.g. 7.1 surround)

Sound FX: Linear PCM/WAV
Music: OGG Vorbis
Linear PCM Format

- Sound data is an array of **sample** values

| 0.5 | 0.2 | -0.1 | 0.3 | -0.5 | 0.0 | -0.2 | -0.2 | 0.0 | -0.6 | 0.2 | -0.3 | 0.4 | 0.0 |

- A sample is an **amplitude** of a sound wave

- Values are normalized -1.0 to 1.0 (so they are floats)
Linear PCM Format

- Sound data is an array of **sample** values

| 0.5 | 0.2 | -0.1 | 0.3 | -0.5 | 0.0 | -0.2 | -0.2 | 0.0 | -0.6 | 0.2 | -0.3 | 0.4 | 0.0 |

- A sample is an **amplitude** of a sound wave

- Sometimes encoded as shorts or bytes MIN to MAX
**Linear PCM Format**

- Sound data is an array of *sample* values

| 0.5 | 0.2 | -0.1 | 0.3 | -0.5 | 0.0 | -0.2 | -0.2 | 0.0 | -0.6 | 0.2 | -0.3 | 0.4 | 0.0 |

- Magnitude of the amplitude is the volume
  - 0 is lowest volume (silence)
  - 1 is maximum volume of sound card
  - Multiply by number 0 to 1 to change global volume
Linear PCM Format

- Sound data is an array of **sample** values

| 0.5 | 0.2 | -0.1 | 0.3 | -0.5 | 0.0 | -0.2 | -0.2 | 0.0 | -0.6 | 0.2 | -0.3 | 0.4 | 0.0 |

- Magnitude of the amplitude is the volume
  - 0 is lowest volume (silence)
  - 1 is maximum volume of sound card
  - Multiply by number 0 to 1 to change global volume
Linear PCM Format

- Samples are organized into (interleaved) **channels**

- Each channel is essentially a **speaker**
  - Mono sound has one channel
  - Stereo sound has two channels
  - 7.1 surround sound is **eight** channels

- A **frame** is set of simultaneous samples
  - Each sample is in a separate frame
Linear PCM Format

- The sample rate is frames per second

  1 second

  # frames

- **Example:** 0.5 seconds of stereo at 44.1 kHZ
  - 0.5 s * 44100 f/s = 22050 frames
  - 2 samples/frame * 22050 frames = 44100 samples
  - 4 bytes/sample * 44100 samples = 176.4 kBytes

- 1 minute of stereo CD sound is 21 MB!
Playing Sound Directly

Game Loop

PCM data buffer

Sound Card
Playing Sound Directly

Write PCM chunk to buffer

Game Loop

PCM data buffer

Sound Card

Game Audio
Direct Sound in LibGDX: AudioDevice

- /**
  * Writes the array of float PCM samples to the audio device.
  *
  * This method blocks until they have been processed.
  */
  
  void writeSamples(float[] samples, int offset, int numSamples)

- /**
  * Writes array of 16-bit signed PCM samples to the audio device.
  *
  * This method blocks until they have been processed.
  */
  
  void writeSamples(short[] samples, int offset, int numSamples)
Direct Sound in LibGDX: AudioDevice

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Requires separate audio thread

Game Audio
The Latency Problem

- Buffer is really a *queue*
  - Output from queue front
  - Playback writes to end
  - Creates a *playback delay*

- **Latency**: amount of delay
  - Some latency must exist
  - Okay if latency $\leq$ framerate
  - **Android latency is $\sim$90 ms!**

- Buffering is a necessary evil
  - Keeps playback smooth
  - Allows real-time *effects*
Playing Sound Directly

Choice of buffer size is important!

- **Too large**: long latency until next sound plays
- **Too small**: buffers swap too fast, causing audible pops
Playing Sound Directly

- **Windows**: 528 bytes *(even if you ask for larger)*
- **MacOS, iOS**: 512-1024 bytes *(hardware varies)*
- **Android**: 2048-4096 bytes *(hardware varies)*
How Streaming Works

- All sound cards **only** play PCM data
  - Other files (MP3 etc.) are decoded into PCM data
  - But the data is **paged-in** like memory in an OS

- Why LibGDX/CUGL can stream WAV files too!
How Streaming Works

**Sound**: Sound asset that is *preloaded* as full PCM

**Music**: Sound asset that is *streamed* as PCM pages
Handling Multiple Sounds

Literally!

Sound Card

PCM Data

PCM Data

PCM Data

PCM Data
Handling Multiple Sounds

- Can create values outside of -1 to 1
  - This causes clipping/distortion
  - Common if many simultaneous sounds
- Audio engineer must balance properly

```
Literally!
```

PCMs

Sound Card

Game Audio
Why is Mixing Hard?

- Playback may include **multiple sounds**
  - Sounds may play simultaneously (offset)
  - Simultaneous sounds may be same asset
  - **Asset** (source) vs. **Instance** (playback)

- Playback crosses **frame boundaries**
  - It may span multiple animation frames
  - Need to know when it stops playing
  - May need to stop (or pause) it early
We Want Something Simpler!

- Want ability to **play** and **track** sounds
  - Functions to load sound into card buffer
  - Functions to detect if sound has finished

- Want ability to **modify** active sounds
  - Functions for volume and pitch adjustment
  - Functions for stereo panning (e.g. left/right channels)
  - Functions to pause, resume, or loop sound

- Want ability to **mix** sounds together
  - Functions to add together sound data quickly
  - Background process for dynamic volume adjustment
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This is the purpose of a **sound engine**
Cross-Platform Sound Engines

- **OpenAL**
  - Created in 2000 by Loki Software for Linux
  - Was an attempt to make a sound standard
  - Loki went under; last stable release in 2005
  - Apple supported, but HARD deprecated in iOS 9

- **FMOD/WWISE**
  - Industry standard for game development
  - Mobile support is possible but not easy
  - Not free; but no cost for low-volume sales
Proprietary Sound Engines

- **Apple AVFoundation**
  - API to support modern sound processing
  - Mainly designed for music/audio creation apps
  - But very useful for games and playback apps

- **OpenSL ES**
  - Directed by Khronos Group (OpenGL)
  - Substantially less advanced than other APIs
  - Really only has support in Android space
  - Google deprecated in 2022 (it was BAD!)
Proprietary Sound Engines

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What Does LibGDX Use?

- LibGDX support is actually OS specific
  - Recall the core/desktop package distinction
  - Because LibGDX supports mobile and computer
- Different platforms have different backends
  - All desktop platforms are built on OpenAL
  - The android backend uses android.media
- Needs an abstraction bringing all together
  - This is done with the Audio interface
The LibGDX Audio Interface

- LibGDX provides an audio **singleton**
  - One global object referencing audio device
  - Access via GDX.audio (static field of GDX)
  - Same principle as System.out

- Singleton implements the **Audio** interface
  - Use it to access AudioDevice for direct sound
  - Use it to allocate new Sound, Music instances
  - But do not use it for much sound manipulation
The LibGDX Audio Interface

- LibGDX provides an audio **singleton**
  - One global object referencing audio device
  - Access via `GDX.audio` (static field of `GDX`)
  - Same principle as `System.out`

- Singleton implements the **Audio** interface
  - Use it to interact with `AudioDevice` for sound
  - Use it to allocate new `Sound`, `Music` instances
  - But do not use it for much sound manipulation

**Essentially a factory for other classes**
## The LibGDX Sound Classes

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<tr>
<td>• Returns a long integer</td>
<td>• This is a <code>void</code> method</td>
</tr>
<tr>
<td>• Represents sound <em>instance</em></td>
<td>• Only allows <em>one instance</em></td>
</tr>
<tr>
<td>• <code>loop()</code> is a separate method</td>
<td>• <code>loop</code> is an attribute of music</td>
</tr>
<tr>
<td>• Has no public constructor</td>
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<tr>
<td>• Use <code>Audio.newSound(f)</code></td>
<td>• Use <code>Audio.newMusic(f)</code></td>
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<td>• Audio can cache/preload</td>
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<td>• Must dispose when done</td>
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Playing a Sound

- Playback may include **multiple sounds**
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  - **Asset (source) vs. Instance (playback)**

- Playback crosses **frame boundaries**
  - It may span multiple animation frames
  - Need to know when it stops playing
  - May need to stop (or pause) it early
Playing a Sound

- Playback may include **multiple sounds**
  - Sounds may play simultaneously (offset)
  - Simultaneous sounds may be same asset
- Requires an understanding of OpenAL
- Playback crosses timing boundaries
  - It may span multiple animation frames
  - Need to know when it stops playing
  - May need to stop (or pause) it early
Classic Model: Playback Slots

Engine has fixed number of slots (historically 24)

Slot
Slot
Slot
...
Slot
Slot

Mixer
**Classic Model: Playback Slots**

- **Engine has fixed number of slots (historically 24)**
- **Load sound into a slot to play it**

---

48 Game Audio
Classic Model: Playback Slots

Engine has fixed number of slots (historically 24)

Queue to follow after

Load sound into a slot to play it

Sound

Sound
Playing a Sound with Slots

- **Request** a playback slot for your asset
  - If none is available, sound fails to play
  - Otherwise, it gives you an id for the slot

- **Load** asset into the slot (but might stream)

- **Play** the playback slot
  - Playing is a property of the slot, not asset
  - Playback slot has other properties, like volume

- **Release** the slot when the sound is done
  - This is usually done automatically
Application Design

Slot
Slot
Slot
...
Slot

Need to remember the slot id

Mixer

Volume is property of a slot!

Sound
The Sound API

- /**
   * @return channel id for sound playback
   *
   * If no channel is available, returns -1
   * @param volume The sound volume
   * @param pitch The pitch multiplier (>1 faster, <1 slower)
   * @param pan The speaker pan (-1 full left, 1 full right)
   */
   public long play(float volume, float pitch, float pan);

- public void stop(long audioID);

- public void resume(long audioID);

- public void setLooping(long audioID, boolean loop);

- Public void setVolume(long audioID, float volume);
The Sound API

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- public void setLooping(long audioID, boolean loop);

- Public void setVolume(long audioID, float volume);

- Returns available slot id

- Need to remember slot id

Game Audio
Why This is Undesirable

- Tightly couples architecture to sound engine
  - All controllers need to know this channel id
  - Playback must communicate the id to all controllers

- Instances usually have a semantic meaning
  - **Example**: Torpedo #3, Ship/crate collision
  - Meaning is independent of the channel assigned
  - Would prefer to represent them by this meaning

- **Solution**: Refer to instances by *keys*
Idea: SoundManager Class

- A **SoundManager** is essentially a hashmap
  - Map strings (keys) to integers (slot ids)
  - Only stores a key when instance is playing

- This class needs to be a **singleton**
  - So we can access this anywhere at all time
  - Demo: See the class provided with this lecture

- To work, the map must be **up-to-date** at all times
  - We use this controller to play the sounds
  - And it must be notified when a sound is done
Stopping Sounds

• Would like to know when a sound is finished
  • To free up the slot (if not automatic)
  • To stop any associated animation
  • To start a follow-up sound

• Two main approaches
  • Polling: Call an isPlaying() method
  • Callback: Pass a function when play

• Default LibGDX cannot do either of these
Stopping Sounds

- Would like to know when a sound is finished
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- Two main approaches
  - **Polling**: Call an `isPlaying()` method
  - **Callback**: Pass a function when play

- Default LibGDX cannot do *either* of these
Solution: **AudioEngine**

• You are all making **desktop games**
  • This means you are always using OpenAL
  • Just need a way to expose OpenAL features
  • This is the purpose of GDIAC audio backend

• **Basic interface is** AudioEngine
  • Upcast GDX.audio to this interface
  • Now have access to SoundEffect, MusicQueue
  • These classes give extra features you need

• **Note:** AssetDirectory handles this automatically
The **GDIAC Sound Classes**

### SoundEffect
- Works just like Sound
  - Primary method is `play()`
  - Returns a long integer
- But has **playback control**
  - Can poll if still playing
  - Can add listener to monitor
- Exposes **OpenAL features**
  - Elapsed playback time
  - Panning between speakers
  - Sound pitch control

### MusicQueue
- Works just like Music
  - Primary method is `play()`
  - This is a `void` method
- But has a **playback queue**
  - Can add `AudioSource` to it
  - Provides gapless playback
- Methods **manage the queue**
  - Add or remove music
  - Swap out music at position
  - Skip over current music
Problem with the Slots Model

• All controls are embedded in the slot
  • Example: Volume, looping, play position
  • Restricted to a predetermined set of controls

• Modern games want custom sound-processing
  • User defined sound filters (low pass, reverb)
  • Advanced equalizer support
  • Support for surround and 3D sound
  • Procedural sound generation
DSP Processing: The Mixer DAG

Source → Effect → Effect

Source → Effect → Mixer → Effect

Source → Mixer → Effect → Main Mixer

Source → Mixer → Effect → Main Mixer
Example: UDK Kismet
Example: FMOD
Example: Pure Data
The Slot Model is a Special Case

Interface to set **state**:
volume, pan, pitch

Calling `play()` assigns an input slot behind the scenes
The Slot Model is a Special Case

Theoretically input should accept any audio subgraph
The Slot Model is a Special Case

Even OpenAL cannot do this.
The Slot Model is a Special Case

Feature in engine for 4152!

Even OpenAL cannot do this.
Summary

- Audio design is about creating soundscapes
  - Music, sound effects, and dialogue
  - Combining sounds requires a sound engine

- Cross-platform support is a problem
  - Licensing issues prevent a cross-platform format
  - Very little standardization in sound APIs

- Best engines use digital signal processing (DSP)
  - Mixer graph is a DAG supporting sound effects
  - Unfortunately, we cannot do this in LibGDX