the gamedesigninitiative at cornell university

Lecture 12

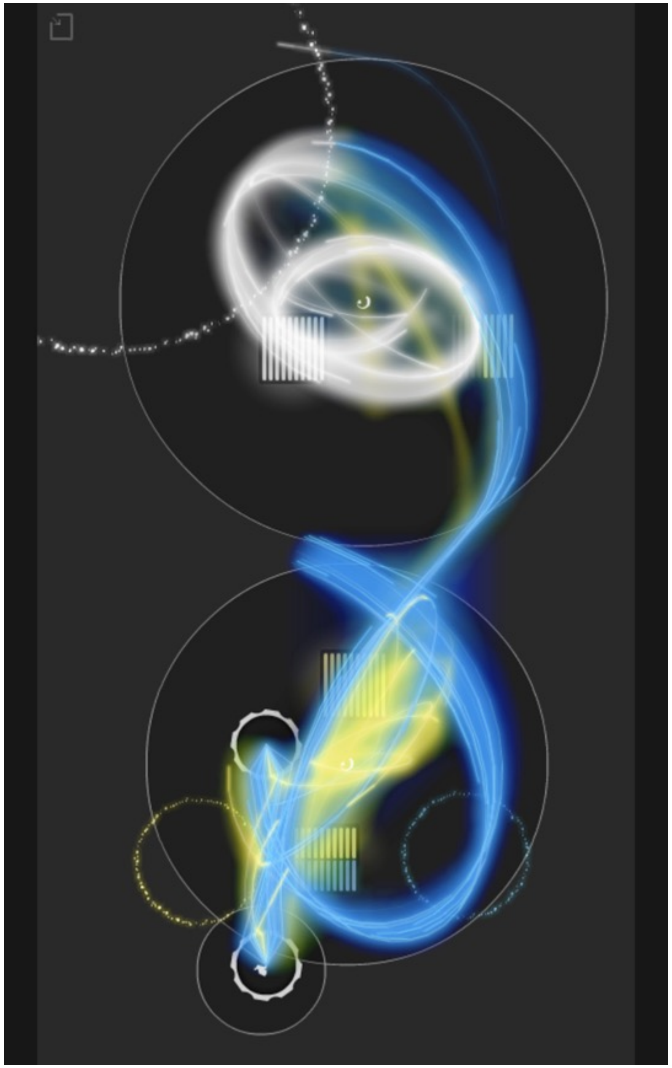
Game Audio

The Role of Audio in Games

Engagement

- **Entertains** the player
  - Music/Soundtrack
- Enhances the **realism**
  - Sound effects
- Establishes **atmosphere**
  - Ambient sounds

The Role of Audio in Games



Feedback

- **Indicate** off-screen action
  - Hint for player action
- **Highlight** on-screen action
  - Call attention to an NPC
- Increase **reaction** time
  - Players react to sound faster

History of Sound in Games

Basic Sounds

- Arcade games
- Early handhelds
- Early consoles

Early Sounds: *Wizard of Wor*

History of Sound in Games

Basic Sounds → Recorded Sound Samples

Sample = pre-recorded audio

- Arcade games
- Early handhelds
- Early consoles

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

History of Sound in Games

Basic Sounds → Recorded Sound Samples → Some Variability of Samples

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- Sample selection
- Volume
- Pitch
- Stereo pan

History of Sound in Games

Basic Sounds → Recorded Sound Samples → Some Variability of Samples → More Variability of Samples

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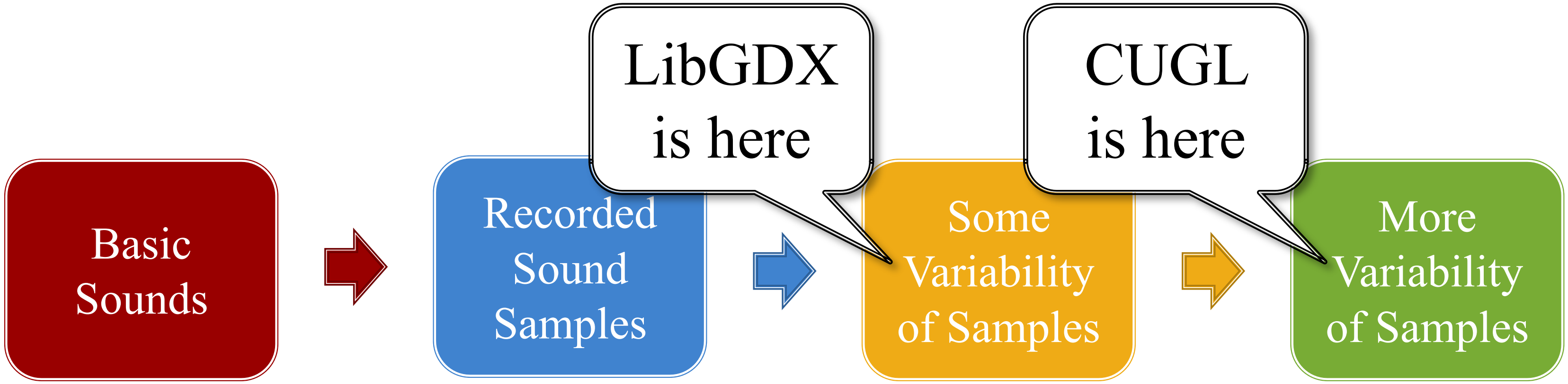
Recorded Sound Samples
- Starts w/ MIDI
- 5th generation (Playstation)
- Early PCs

Some Variability of Samples
- Sample selection
- Volume
- Pitch
- Stereo pan

More Variability of Samples
- Multiple samples
- Reverb models
- Sound filters
- Surround sound

History of Sound in Games



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- Multiple samples
- Reverb models
- Sound filters
- Surround sound

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

Format	Description	File Formats
Linear PCM	Completely uncompressed sound	.wav, .aiff
MP3	A popular compressed, lossy codec	.mp3, .wav
Vorbis	Xiph.org's alternative to MP3	.ogg
FLAC	Xiph.org's compressed, lossless codec	.flac, .ogg
MIDI	**NOT SOUND**; Data for an instrument	.midi
(HE-)AAC	A lossy codec, Apple's MP3 alternative	.aac, .mp4, .m4a
ALAC	Apple's lossless codec (but compressed)	.alac, .mp4, .m4a

MP3 largely avoided due to patent issues.

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Supported in LibGDX

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Supported in CUGL

MP3 largely 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?

- **Question 1:** Streaming or no streaming?
  - Audio gets large fast; music often streamed
  - But
  - Fe

Sound FX: Linear PCM/WAV

Music: OGG Vorbis

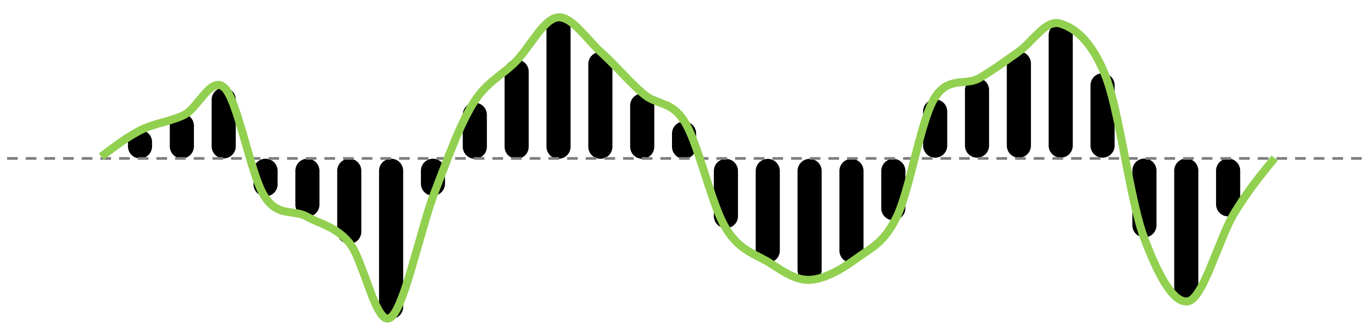
- **Ques**
  - Mu
  - On
- **Question 3:** How many channels (speakers) needed?
  - MP3 channel is *stereo only*
  - Others support many channels (e.g. 7.1 surround)

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

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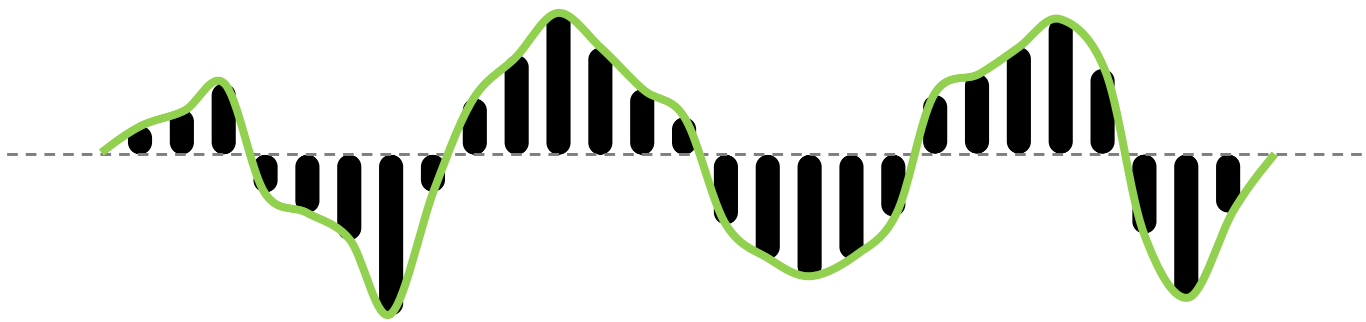
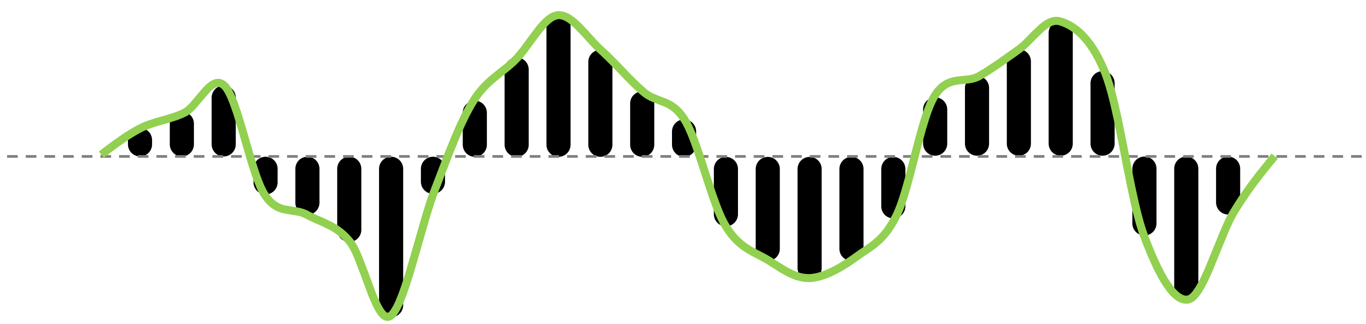


- Sometimes encoded as shorts or bytes MIN to MAX

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

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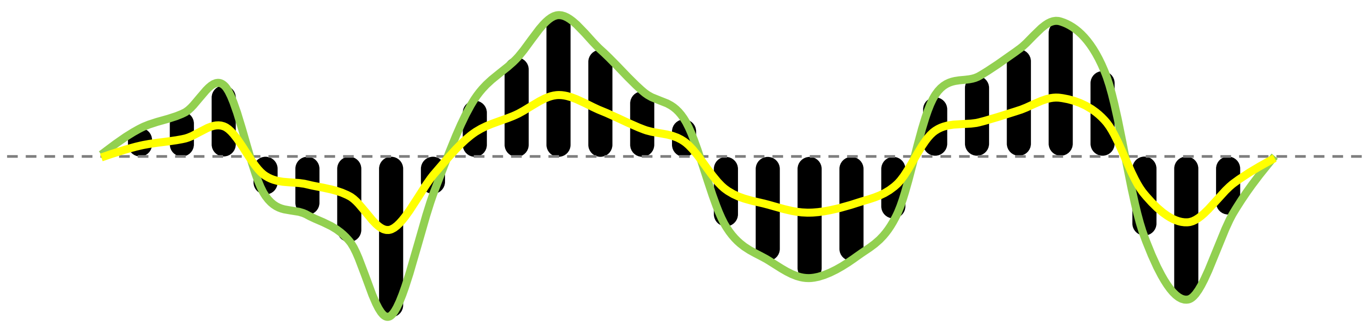


- Magnitude of the amplitude is the volume
  - 0 is lowest volume (silence)
  - 1 is maximum volume of sound card
  - Multiply by number 0 to 1 to change global volume

Linear PCM Format

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

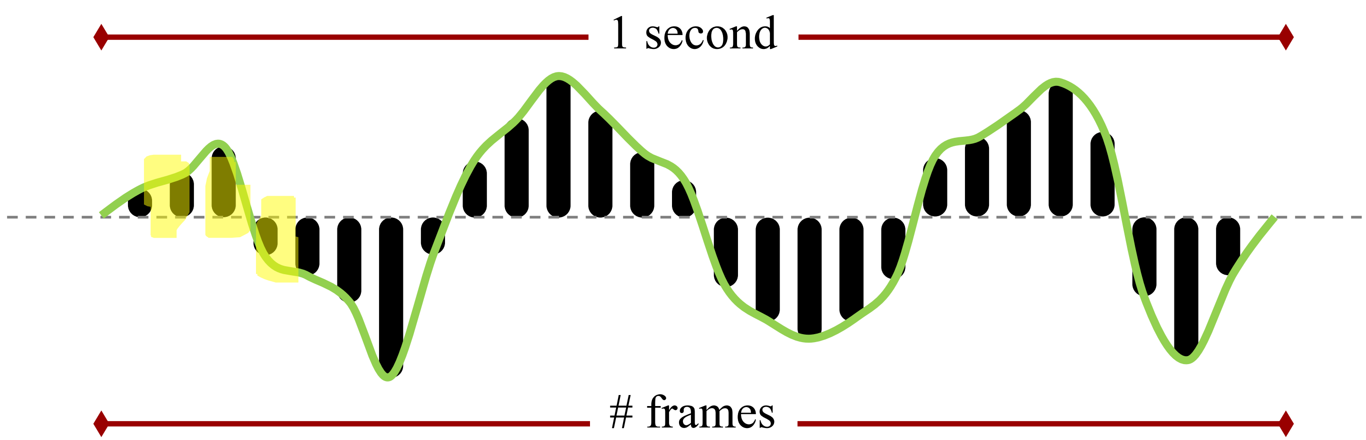
0.5	0.2	-0.1	0.3	-0.5	0.0	-0.2	-0.2	0.0	-0.6	0.2	-0.3	0.4	0.0

frame

- 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

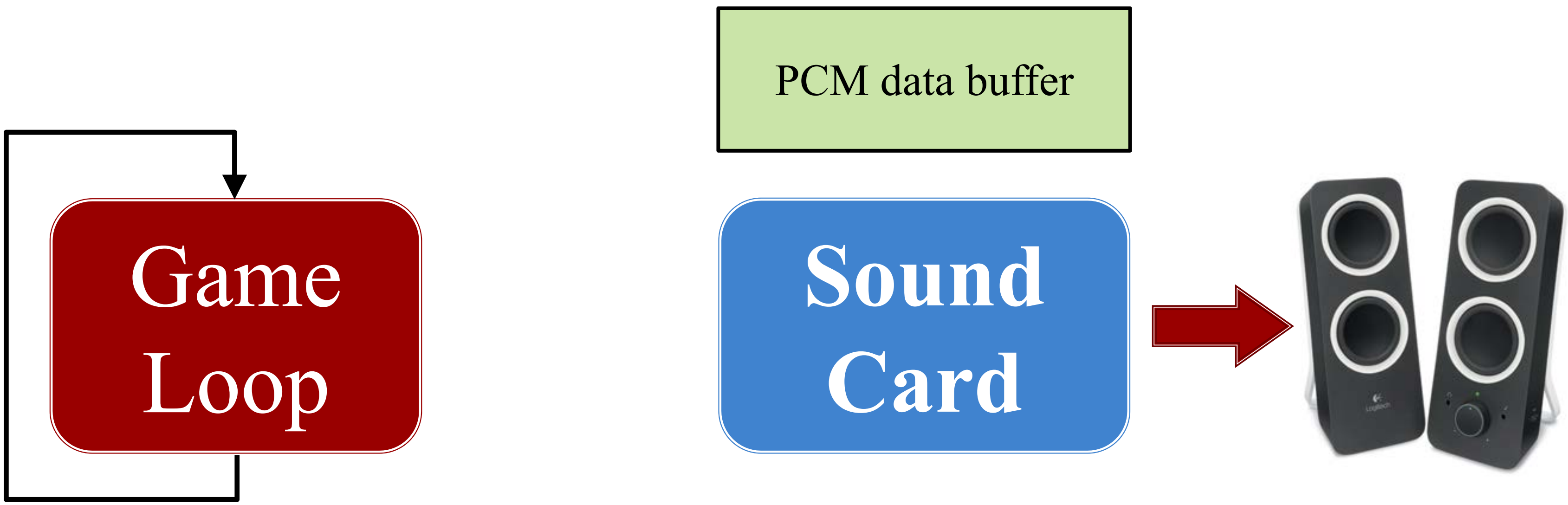
Linear PCM Format

- The sample rate is frames per second



- **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



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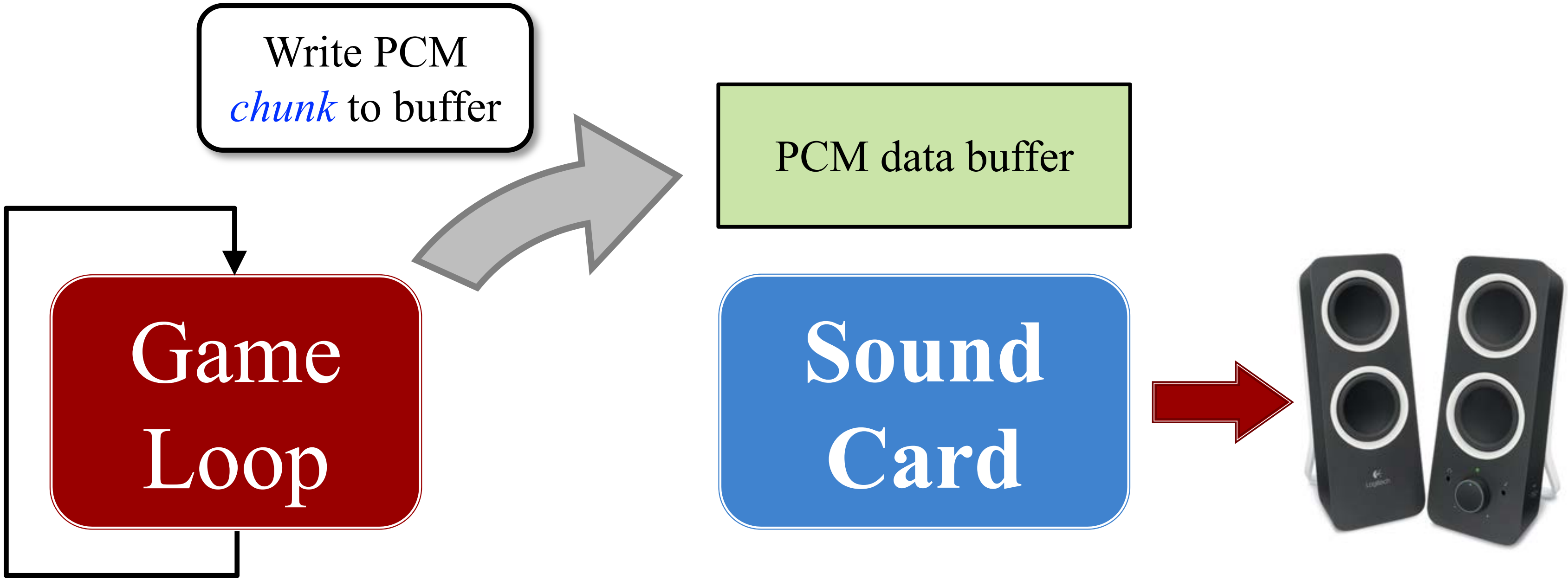

Direct Sound in CUGL: AudioNode

- Class representing an audio **source instance**
  - Not the same as Sound, which is an *asset*
  - sound->createNode() returns an instance node
  - Plug node into an AudioOutput (device)
- Data is read from method

```
/**
 * Reads up to the specified number of frames into the given buffer
 *
 * @param buffer      The read buffer to store the results
 * @param frames      The maximum number of frames to read
 */
Uint32 AudioNode::read(float* buffer, Uint32 frames);
```

Direct Sound in CUGL: AudioNode

- Class representing an audio **source instance**
  - Not the same as Sound, which is an *asset*
  - sound->createNode() returns an
  - Plug node into an AudioOutput

Called in separate *audio thread*

- Data is read from method

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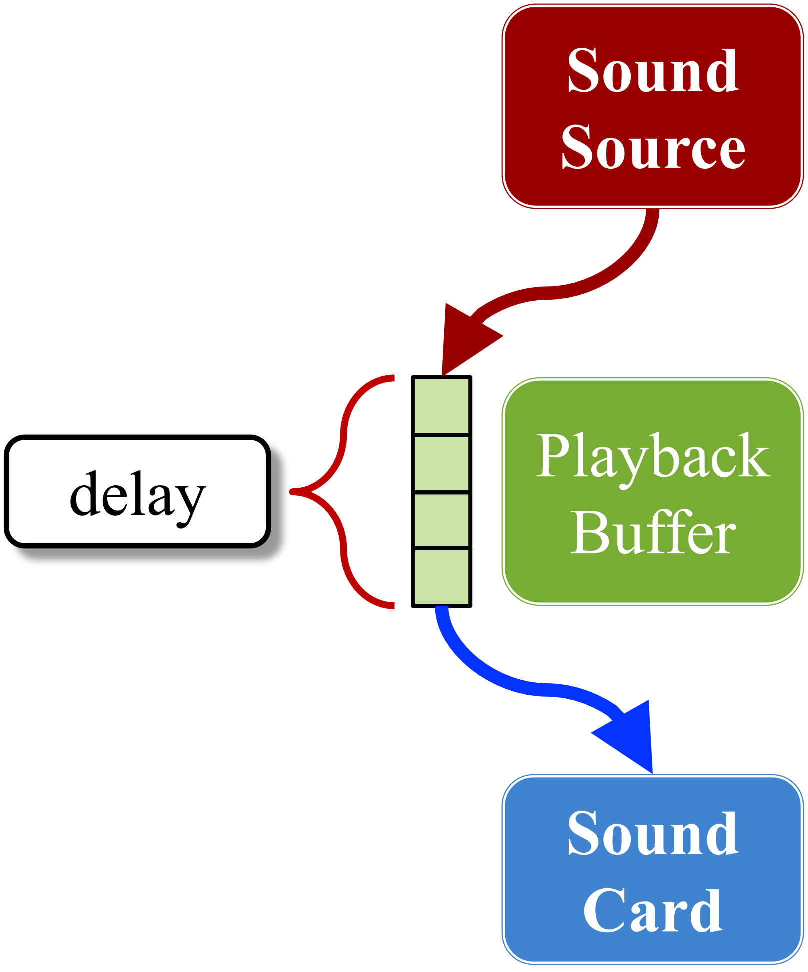
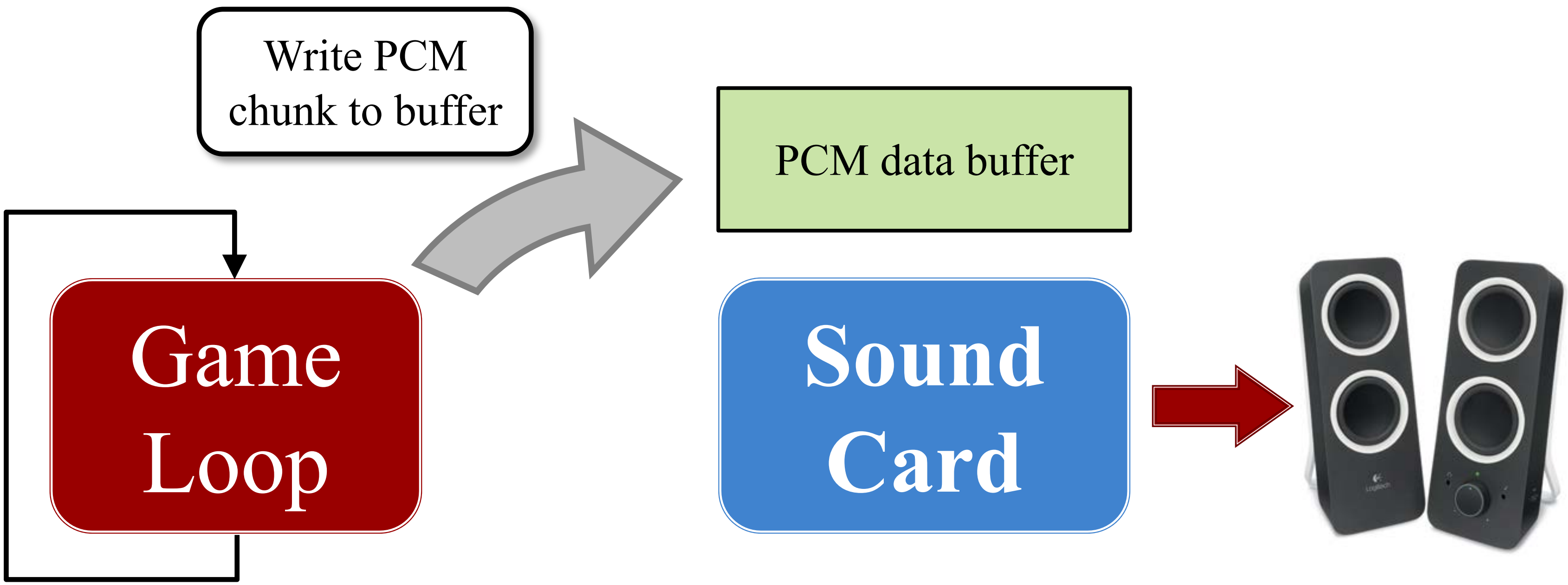
The Latency Problem

- 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 ≤ framerate
  - **Android latency is ~90 ms!**
- Buffering is a necessary evil
  - Keeps playback smooth
  - Allows real-time *effects*



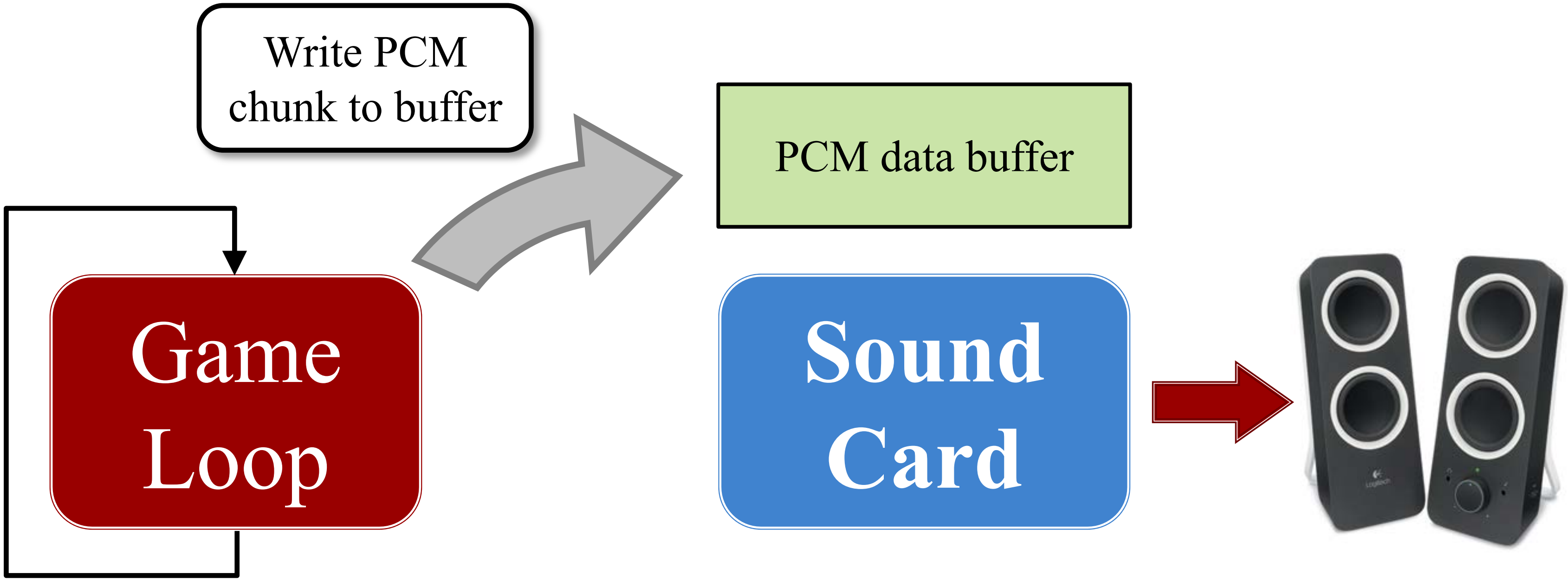
Playing Sound Directly



Choice of buffer size is important!

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

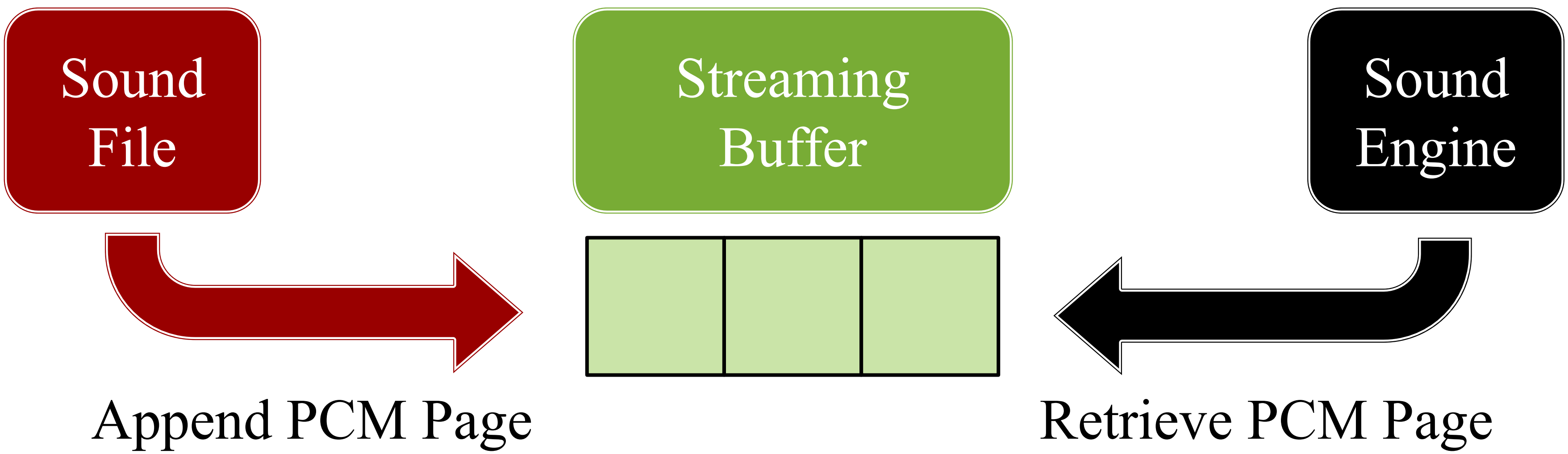
Playing Sound Directly



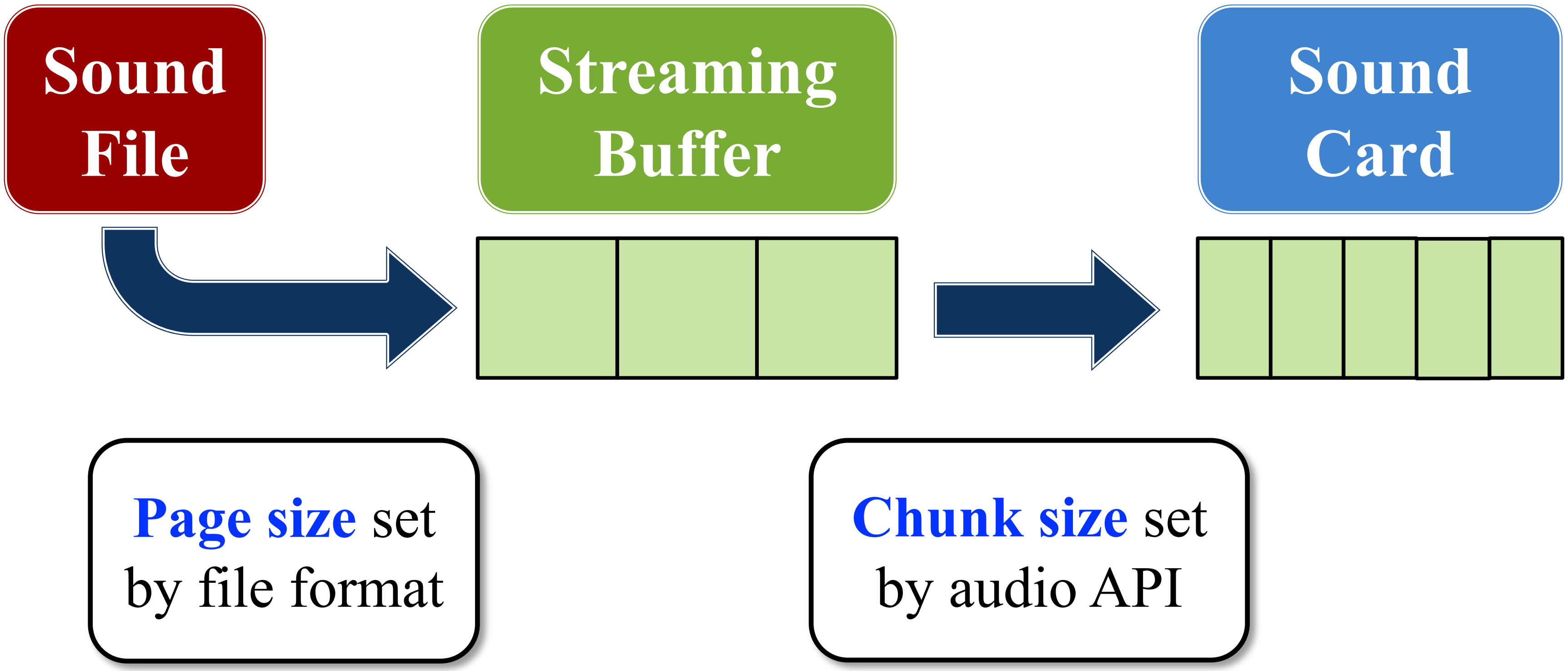
- Windows: 528 bytes (even if you ask for larger)
- MacOS, iOS: 512-1024 bytes (hardware varies)
- Android: 2048-4096 bytes (hardware varies)

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!

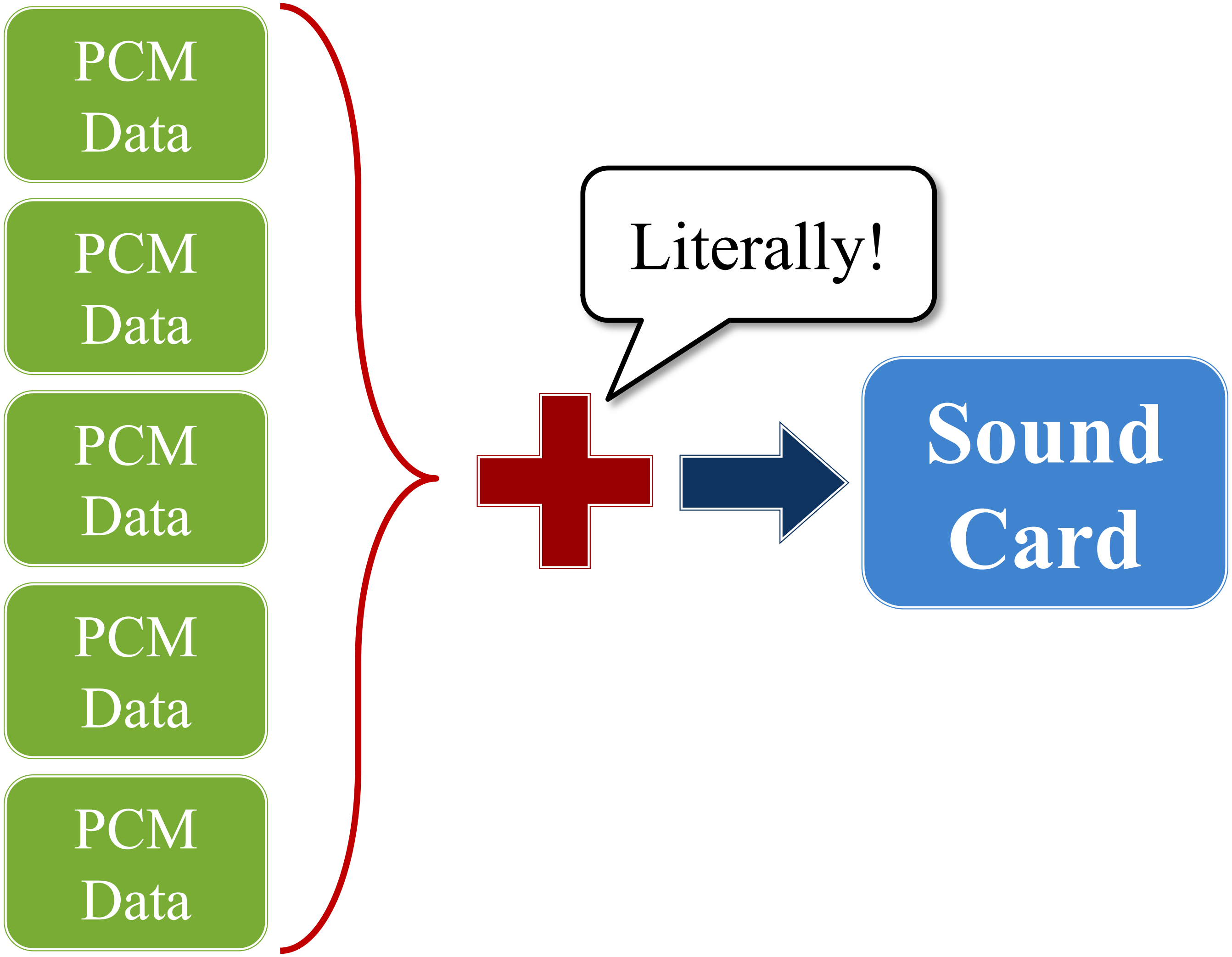


How Streaming Works

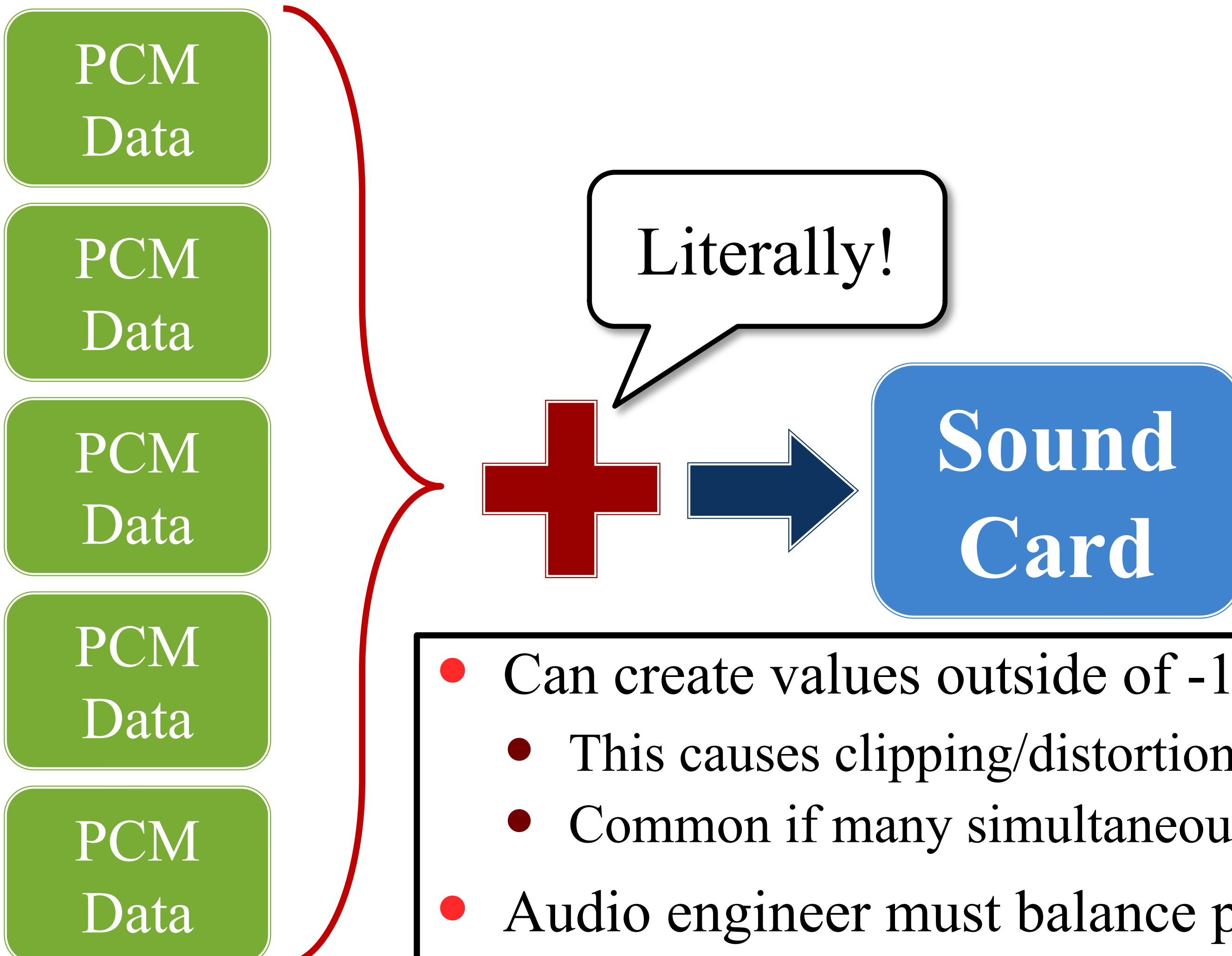


- **Sound**: Sound asset that is *preloaded* as full PCM
- **Music**: Sound asset that is *streamed* as PCM pages

Handling Multiple Sounds



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

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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  - Fu…
  - …ers)
  - …pause, resume, or loop sound

This is the purpose of a **sound engine**

- Want ability to **mix** sounds together
  - Functions to add together sound data quickly
  - Background process for dynamic volume adjustment

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 is deprecating in 2022

Proprietary Sound Engines

- **Apple AVFoundation**
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  - B

And many competing 3rd party solutions

- **Ope**
  - Directed by Khronos Group (OpenGL)
  - Substantially less advanced than other APIs
  - Really only has support in Android space
  - Google is deprecating in 2022

What about SDL?

- CUGL is on top of SDL
  - SDL has its own audio API
  - Works on all platforms
- But it is a **extremely** low-level API
  - Fill the buffer with linear PCM data
  - Either pull (callback) or push (queue)
  - No support for non-WAV audio formats
  - No support for mixing, pausing, or **anything**

Solution: CUGL Audio Classes

- **AudioEngine:** Playing sound effects
  - Built on the the OpenAL model
  - Very easy to use and understand
  - Designed for simultaneous sounds
- **AudioQueue:** Playing music sequences
  - Accessed from the `AudioEngine`
  - Creates seamless playback queues
  - Ideal for long-running music loops

Solution: CUGL Audio Classes

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Modern version of OpenAL model

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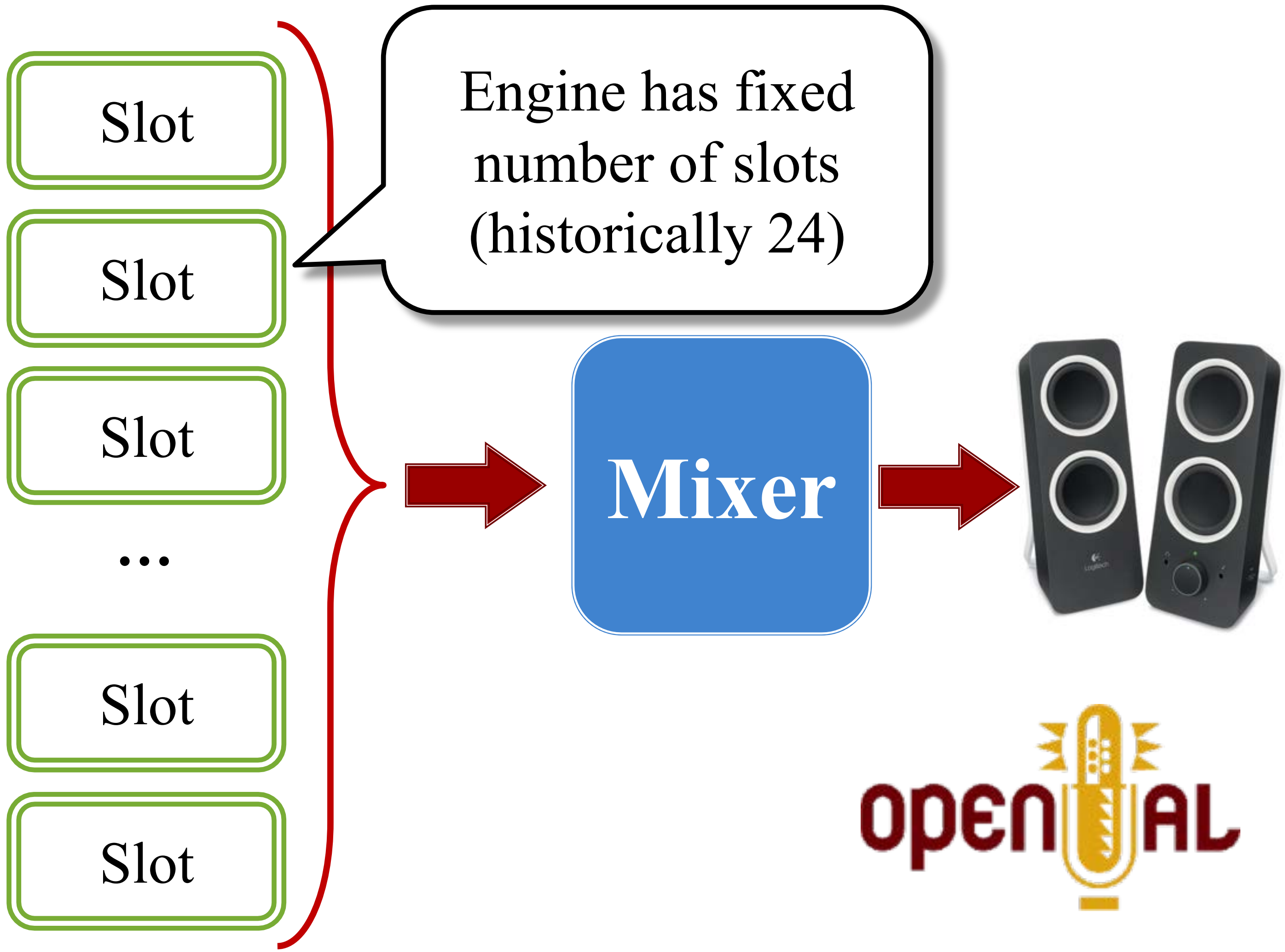
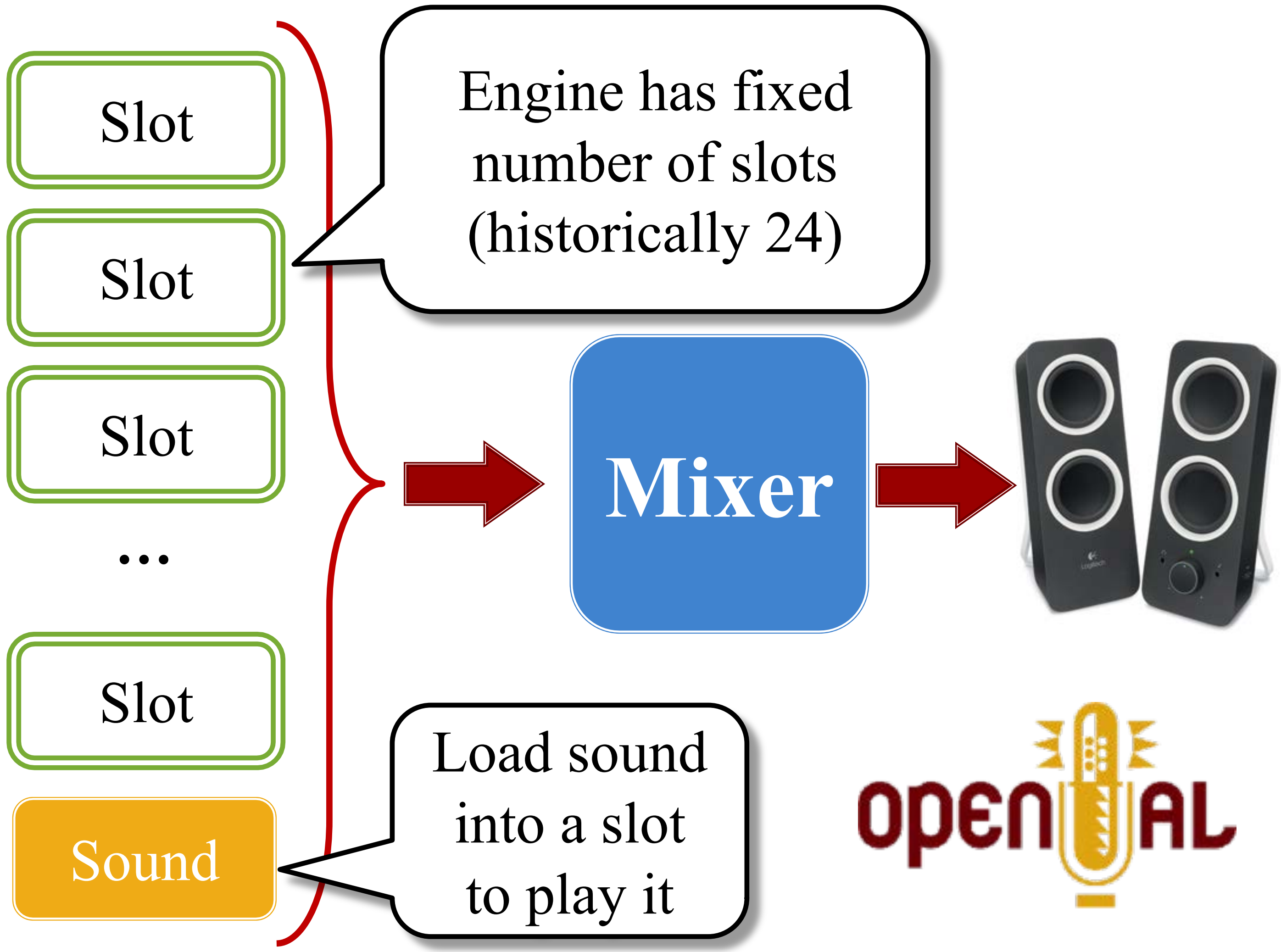
Classic Model: Playback Slots



Classic Model: Playback Slots



openAL

Classic Model: Playback Slots

Slot

Slot

Slot

…

Slot

Engine has fixed number of slots (historically 24)

Mixer

Queue to follow after

Sound

Sound

Load sound into a slot to play it

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

Sound

Mixer

Need to remember the slot id

Volume is property of a slot!

Why This is Undesirable

- Tightly couples architecture to sound engine
  - All controllers need to know this playback slot id
  - Playback must communicate id to all controllers
- Instances usually have a *semantic meaning*
  - **Example**: Torpedo #3, Ship/crate collision
  - Meaning is independent of the slot assigned
  - Would prefer to represent them by this meaning
- **Solution**: Refer to instances by *keys*

Application Design

Slot

Slot

Slot

...

Slot

Sound

How AudioEngine works!

Mixer

Assign this a **key** identifier

The AudioEngine API

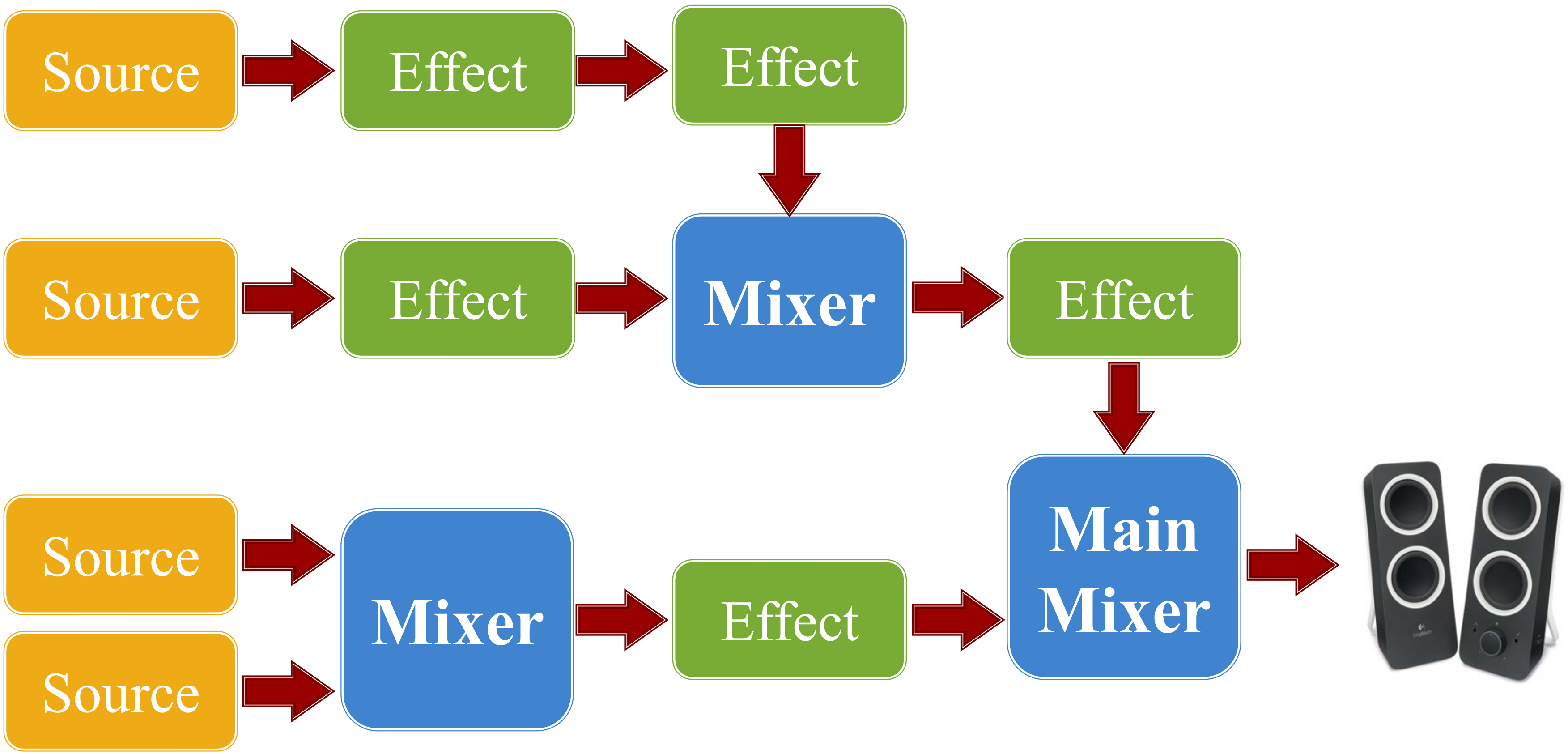
- ```
  /**
   * Plays the given sound, and associates it with the specified key.
   *
   * @param  key     the reference key for the sound effect
   * @param  sound   the sound effect file to play
   * @param  loop    whether to loop indefinitely
   * @param  volume  the sound volume
   */
  void play(const string key, const std::shared_ptr<Sound>& sound);
  ```
- `void stop(const string key);`
- `void setVolume(const string key, float volume);`
- `void getState(const string key);`

Refer to instance logically
  ```

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/function
  - **Callback**: Pass a listener to the engine
- `AudioEngine` allows both approaches

Gapless Playback

- Gapless playback requires a **queue**
  - Queue immediately plays next sound on completion
  - Ideally with some **crossfade** to prevent pops
- Supported by class `AudioQueue`
  - Built on top of `AudioEngine`; use `allocQueue()` method
  - Permanently takes over a slot for the queue
  - Can have multiple queues – as many as there are slots
  - But no simultaneity guarantee between queues
- `AudioQueue` is *kind of* similar to `AudioEngine`
  - But no need for keys, as there is only one slot

The AudioQueue API

- ```
  /**
   * Adds the given sound to the queue, to play when possible.
   *
   * @param  sound   the sound effect file to play
   * @param  loop    whether to loop indefinitely
   * @param  volume  the sound volume
   * @param  fade    number of seconds to fade in
   */
  void enqueue(const std::shared_ptr<Sound>& sound);
  ```
- `void advance(usigned int steps);`
- `void setVolume(float volume);`
- `void getState();`

No need for a key
  ```

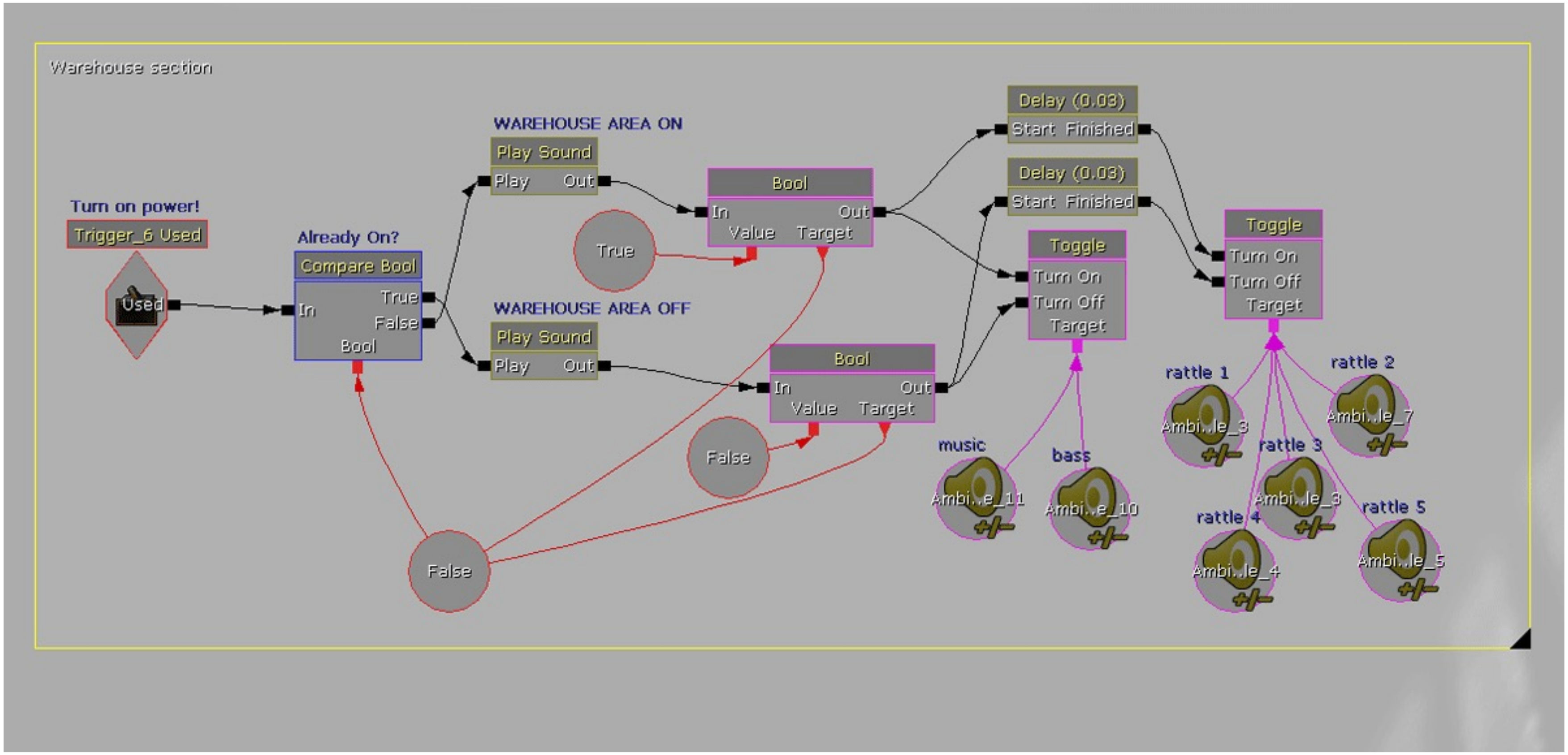
Problem with the Slots Model

- 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

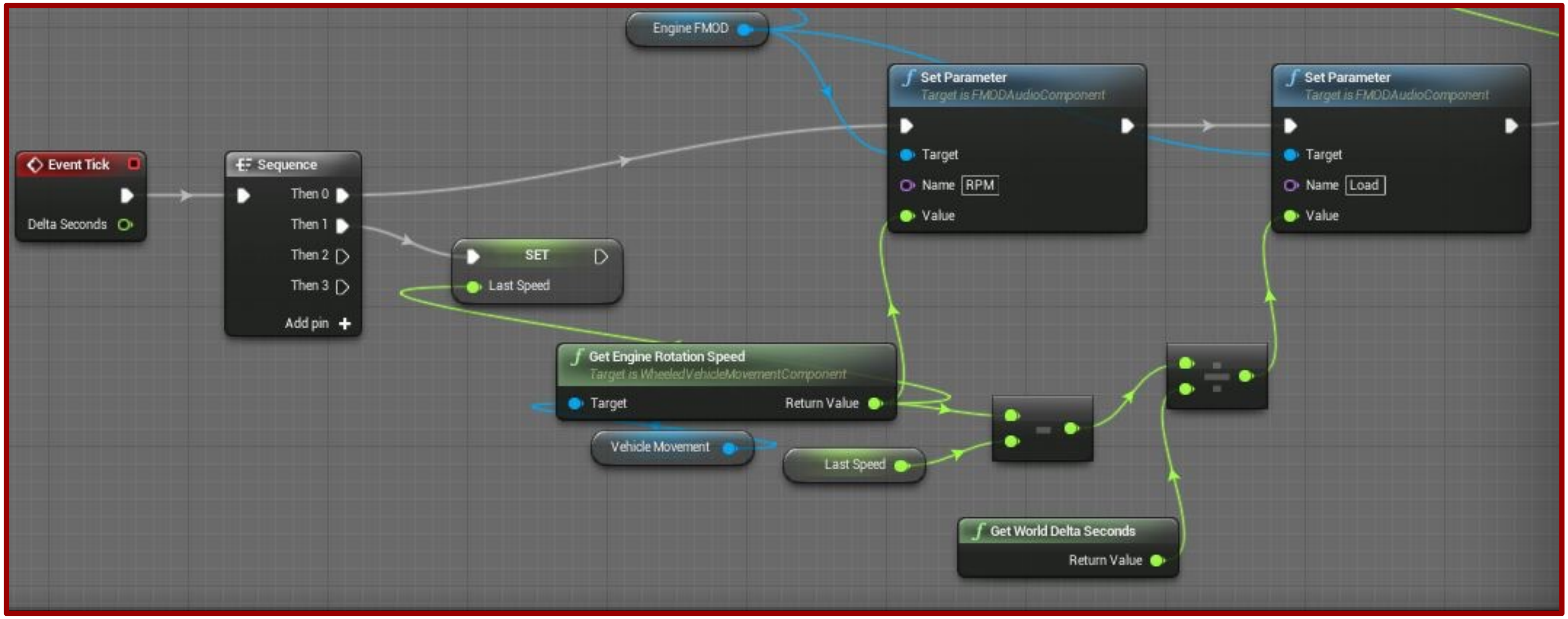
DSP Processing: The Mixer DAG



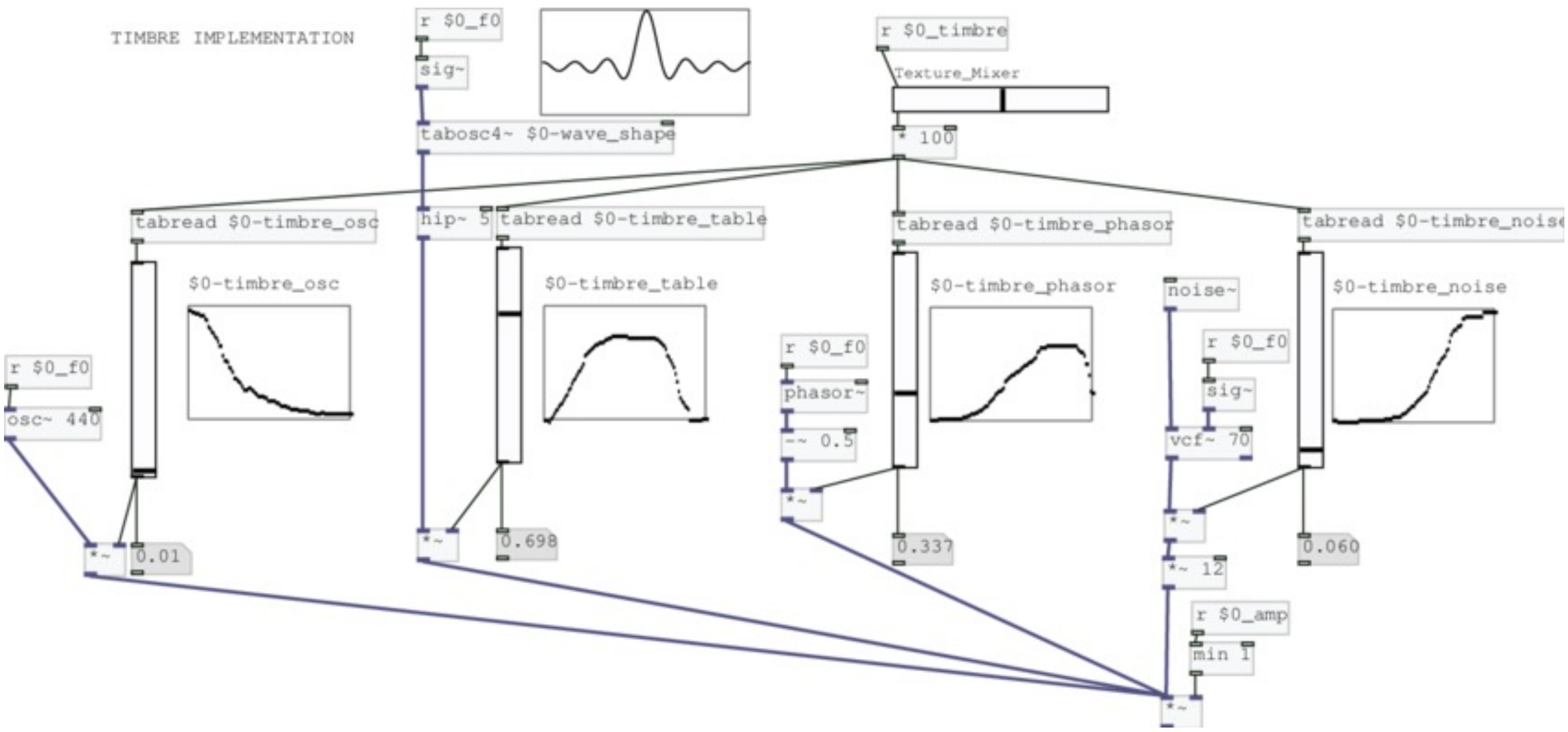
Example: UDK Kismet



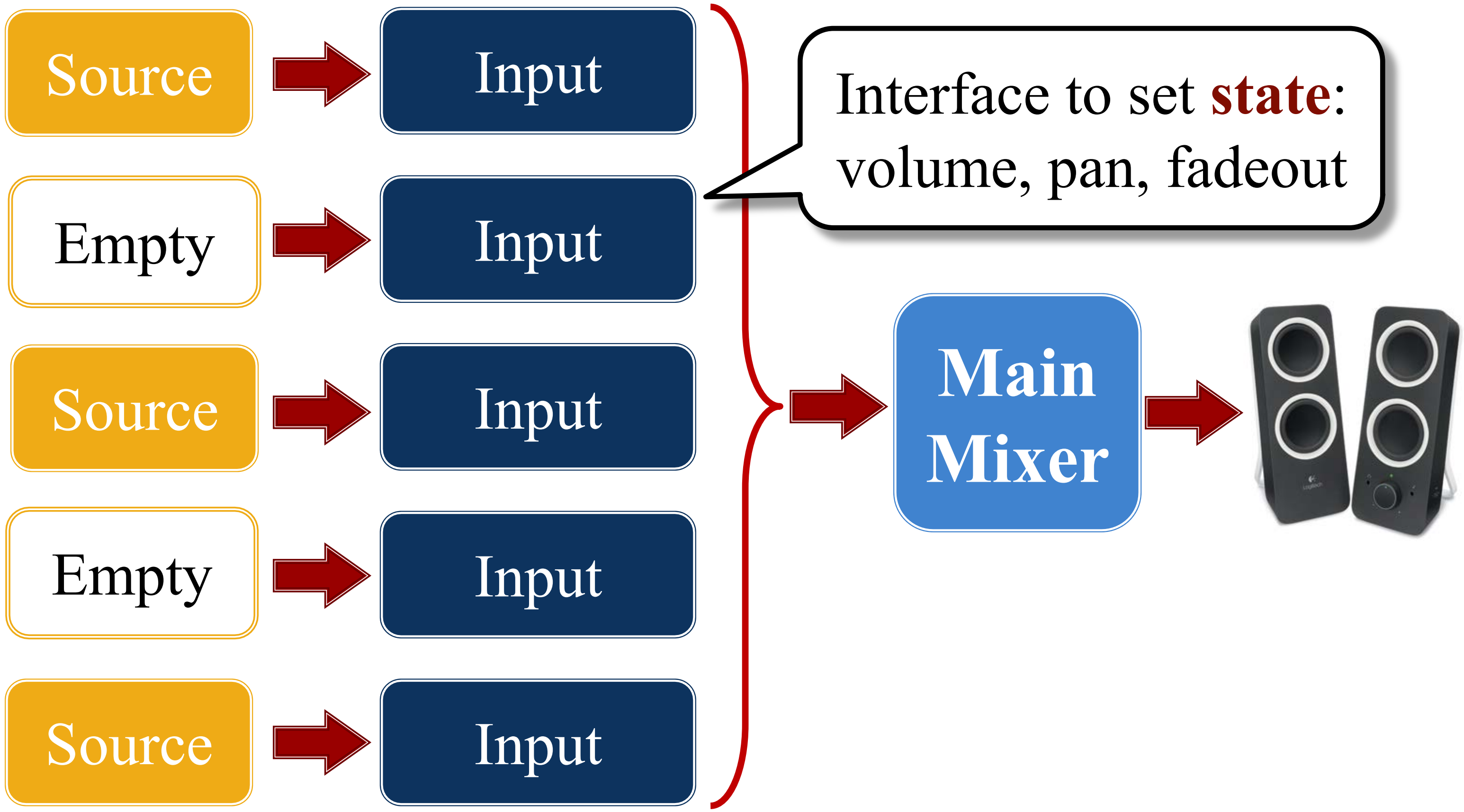
Example: FMOD



Example: Pure Data



The Slot Model is a Special Case



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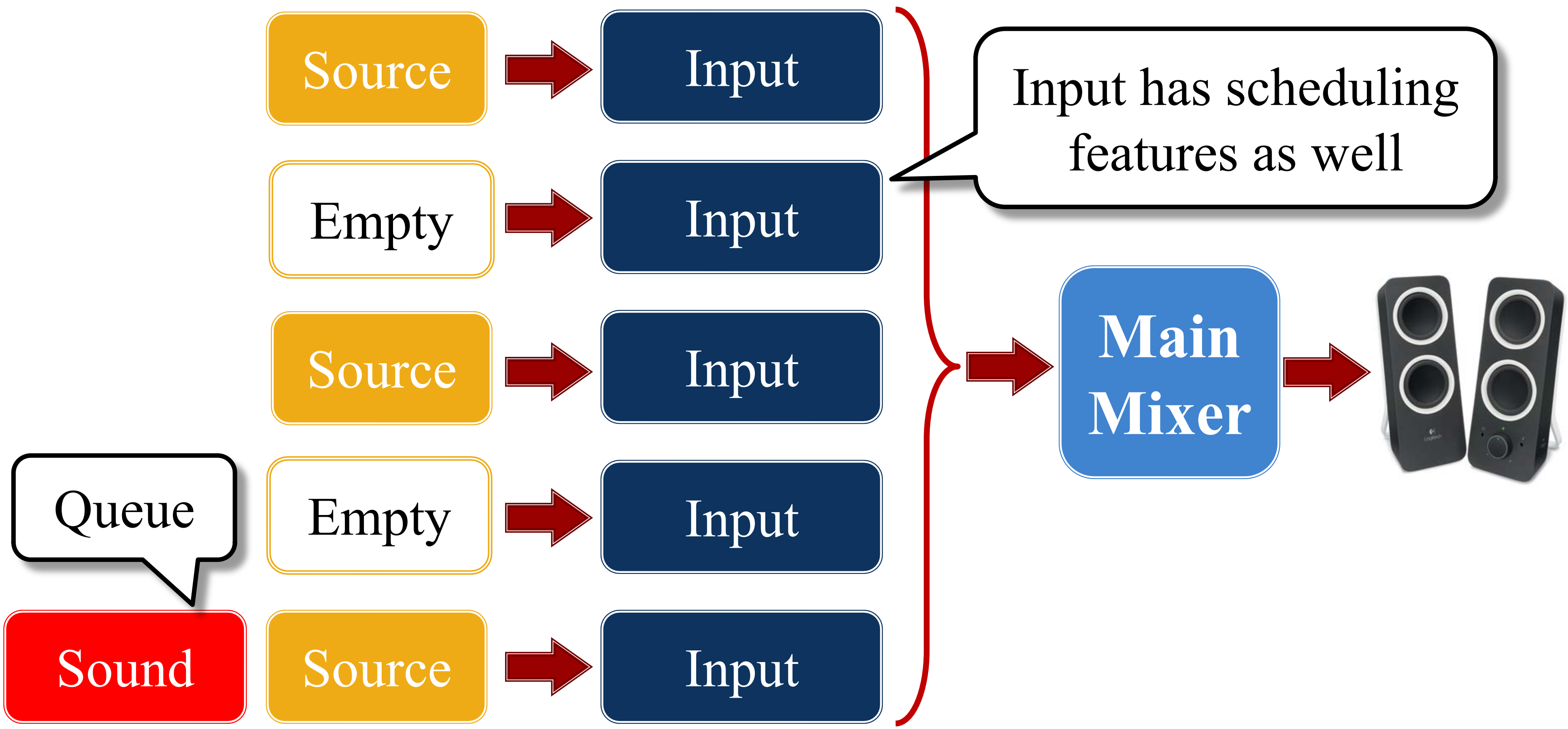
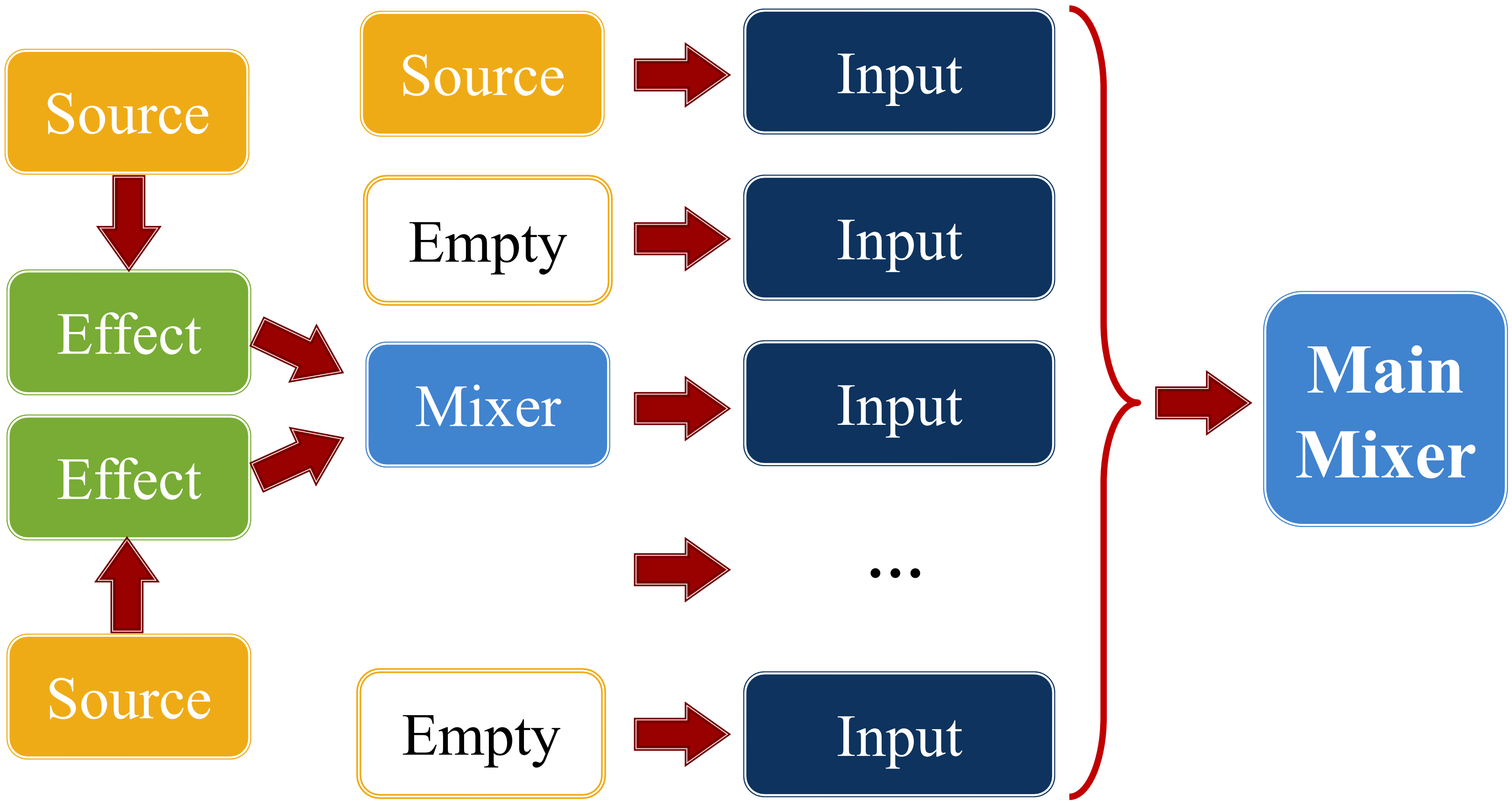


All happens behind scenes of `AudioEngine` interface.

The Slot Model is a Special Case



Theoretically input should accept any **audio subgraph**

The AudioEngine Revisited

- ```
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Refer to instance logically
  ```

The AudioEngine Revisited

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   * @pa
   *
   */
  voi                                                    & node);
  ```

Also supported by AudioQueue

- `void` `key);`
- `void setVolume(const string key, float volume);`
- `void getState(const string key);`

Refer to instance logically
  ```

Using AudioNode in AudioEngine

- Normal playback is **built on top of it**
  - Uses `sound->getInstance()` to get your node
  - So just as fully featured as normal playback
- But the node must implement `completed()`
  - This is optional method for `AudioNode` subclasses
  - The default implementation always returns `false`
  - But that means the sound never finished playing
  - So the scheduler cannot free slot for new sound

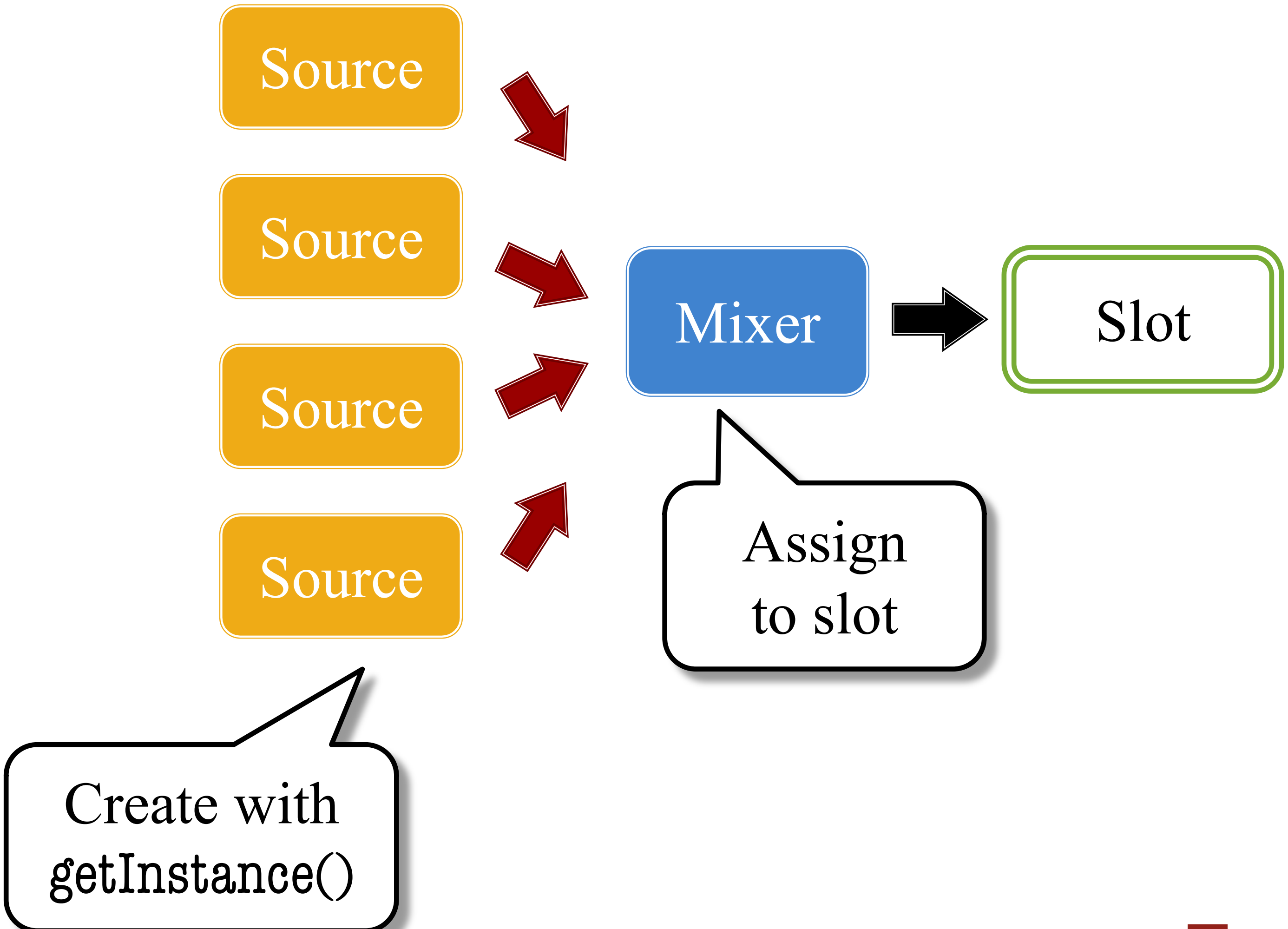
AudioNode Classes in CUGL

- **AudioPlayer**
  - Single playable instance for a sound asset
- **AudioFader**
  - Fade-in, fade-out and cross-fade effects
- **AudioMixer**
  - Group several **simultaneous** nodes together
- **AudioScheduler**
  - Used to queue up sounds in a **sequence**

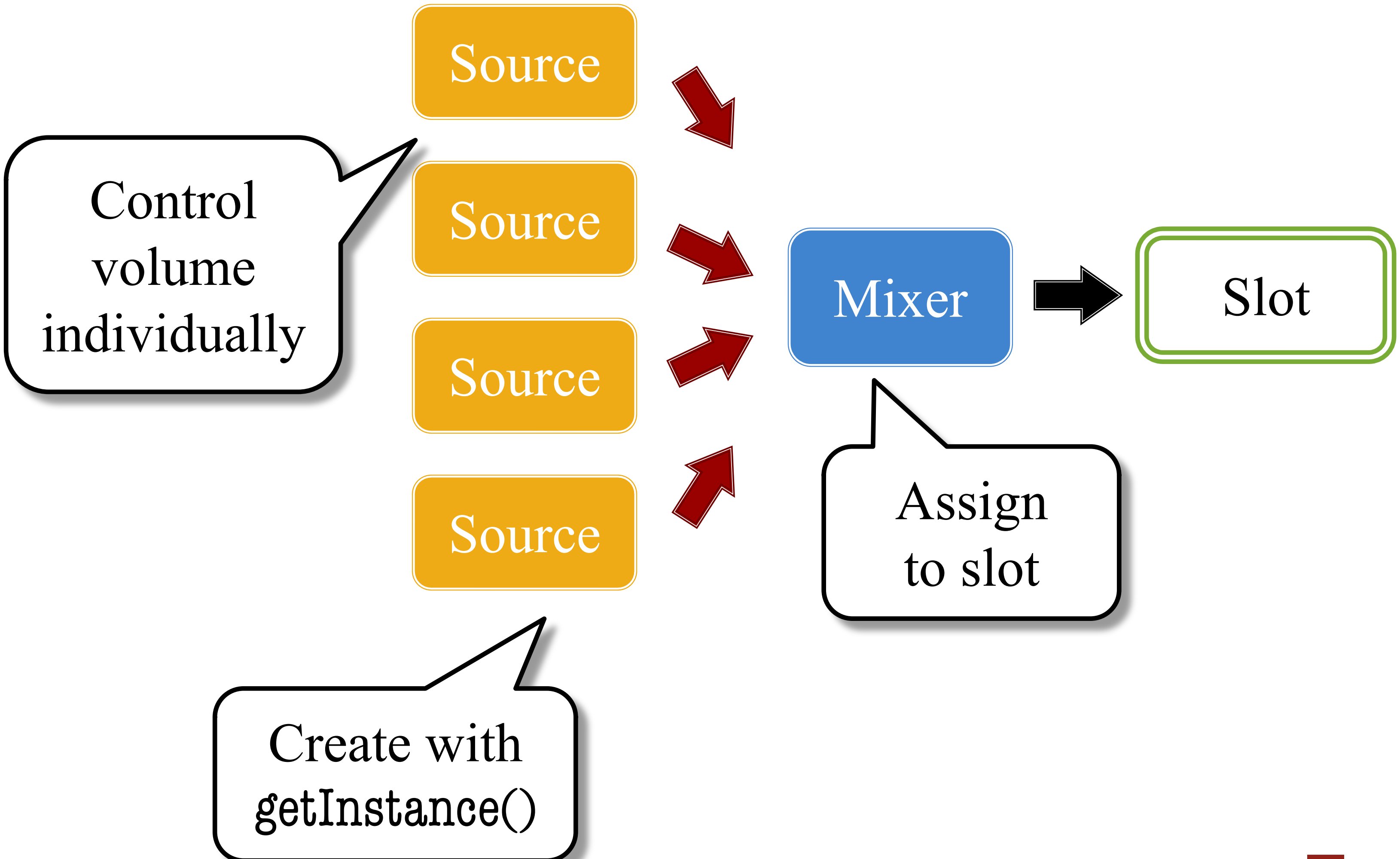
AudioNode Classes in CUGL

- **AudioPanner**
  - Simple stereo channel panning
- **AudioSpinner**
  - Like panner but works on 7.1 sound fields
- **AudioResampler**
  - Converts audio to different sample rate
- **AudioSynchronizer**
  - **Experimental** beat detection for rhythm games

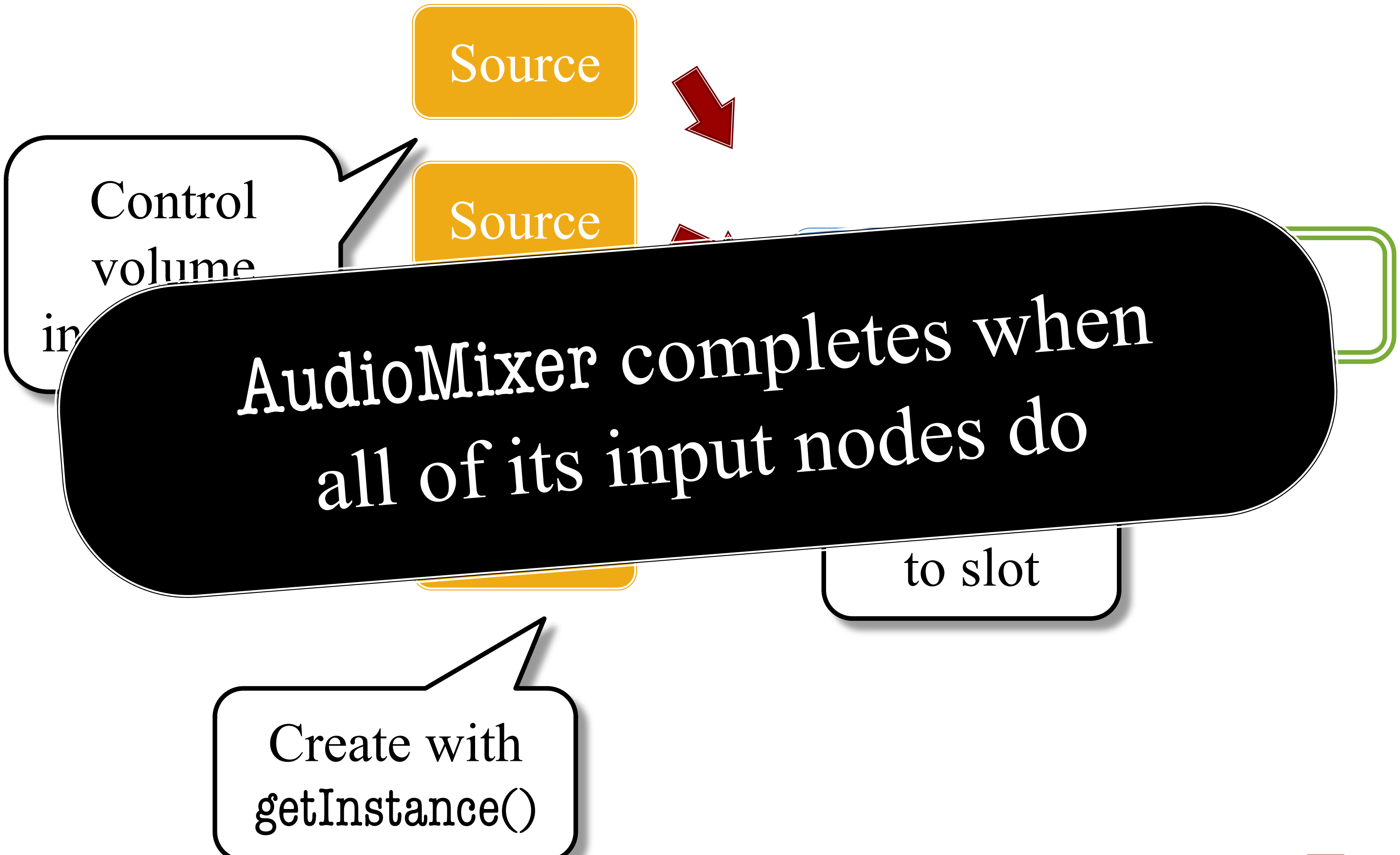
Application: Vertical Layering



Application: Vertical Layering



Application: Vertical Layering



Two Special AudioNodes

- Class AudioOutput
  - Terminal node of the graph
  - Represents output device
  - Can be *named* or *default*
  - Defines channels, sample rate
- Class AudioInput
  - Initial node of the graph
  - Represents input device
  - Can be *named* or *default*
  - May or may not match ouput

AudioOutput

AudioOutput

AudioOutput

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AudioInput

AudioInput

AudioInput

BlackHole

Two Special AudioNodes

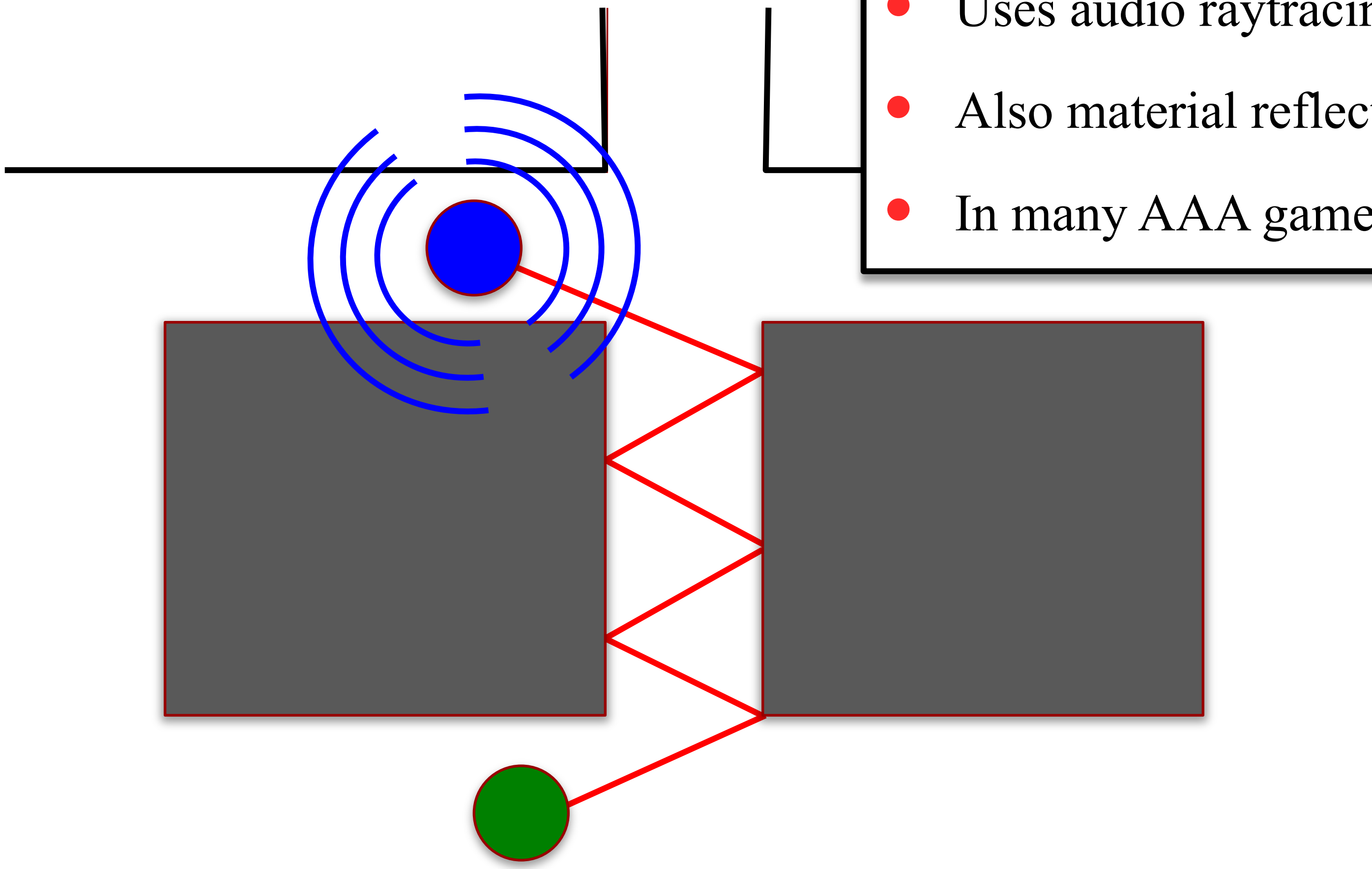
- Class `AudioOutput`
  - Terminal node of the graph
  - Represents output device
  - Can be
- These are all managed by the AudioDevices singleton
  - Represents input device
  - Can be *named* or *default*
  - May or may not match ouput

AudioInput

AudioInput

BlackHole

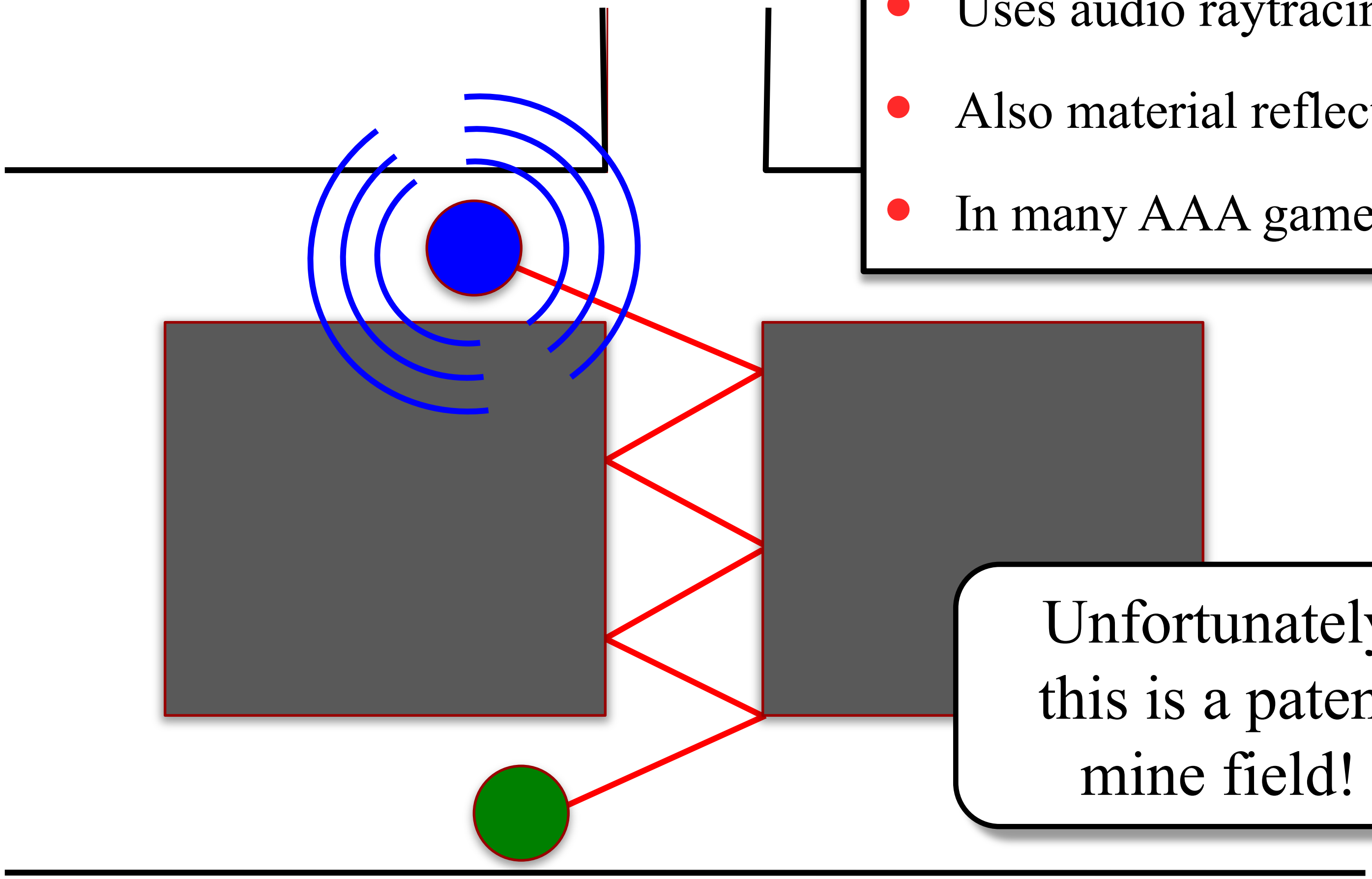
Advanced: Reverb Calculations



- Uses audio raytracing
- Also material reflection
- In many AAA games

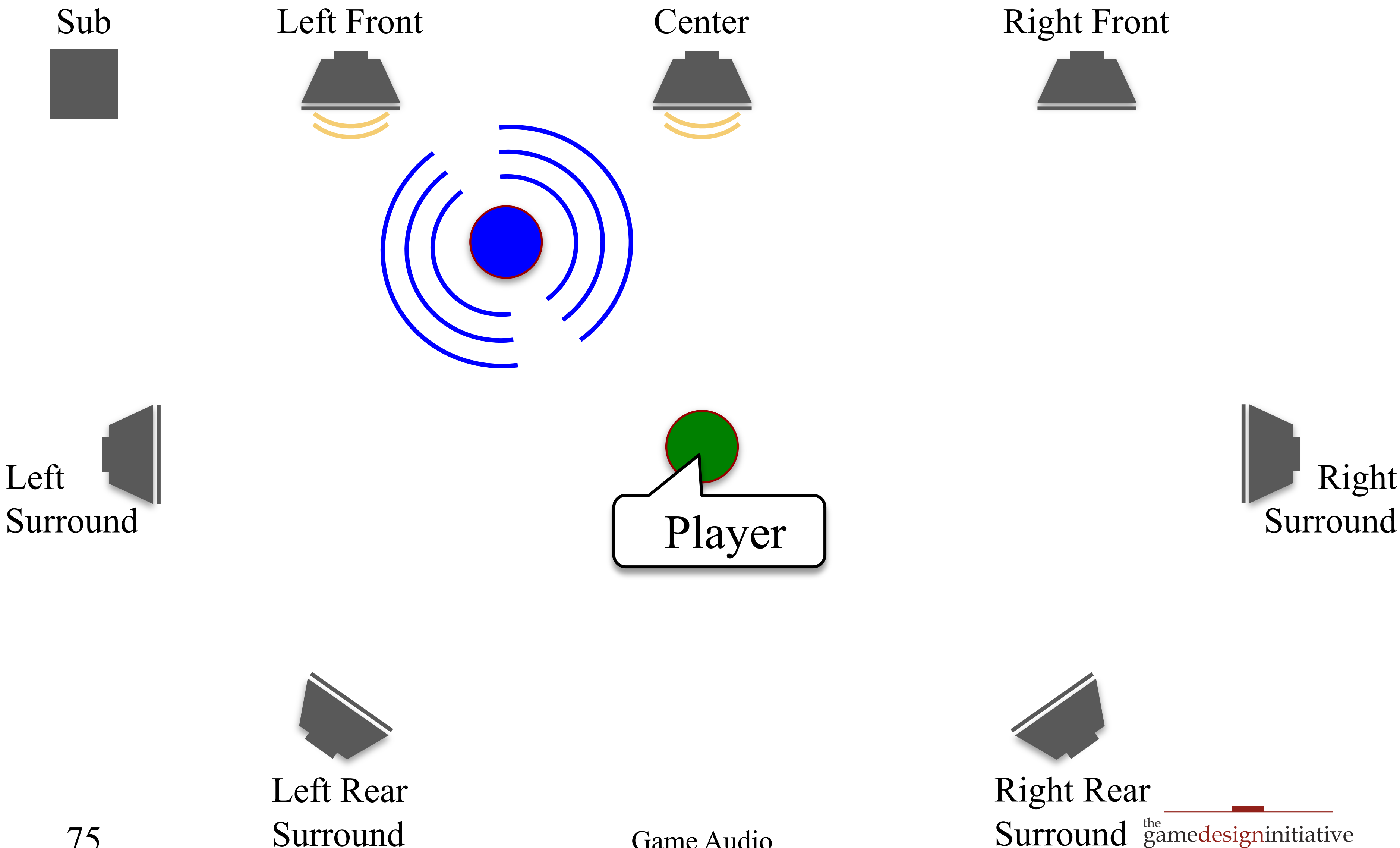
Advanced: Reverb Calculations

- Uses audio raytracing
- Also material reflection
- In many AAA games

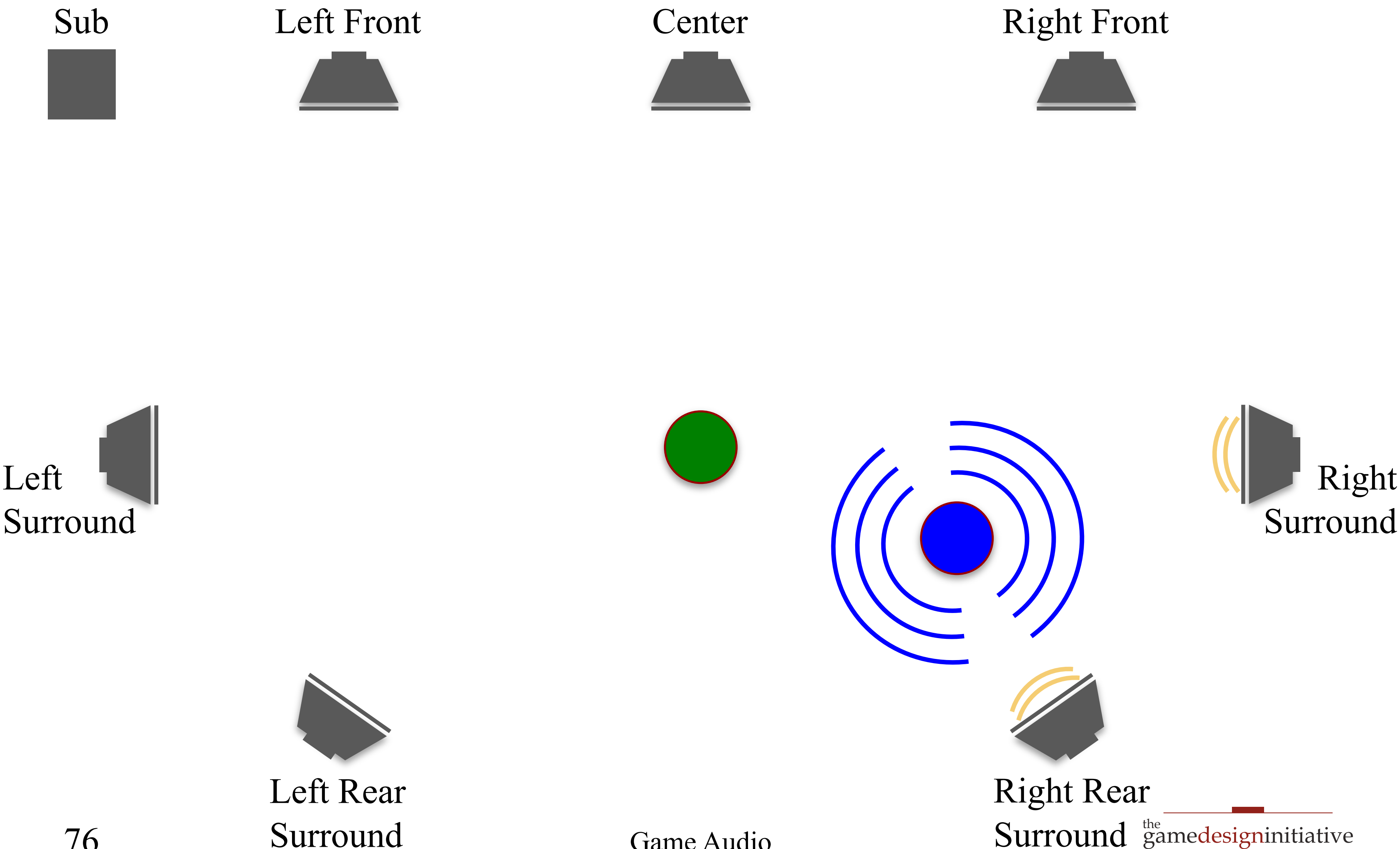


Unfortunately this is a patent mine field!

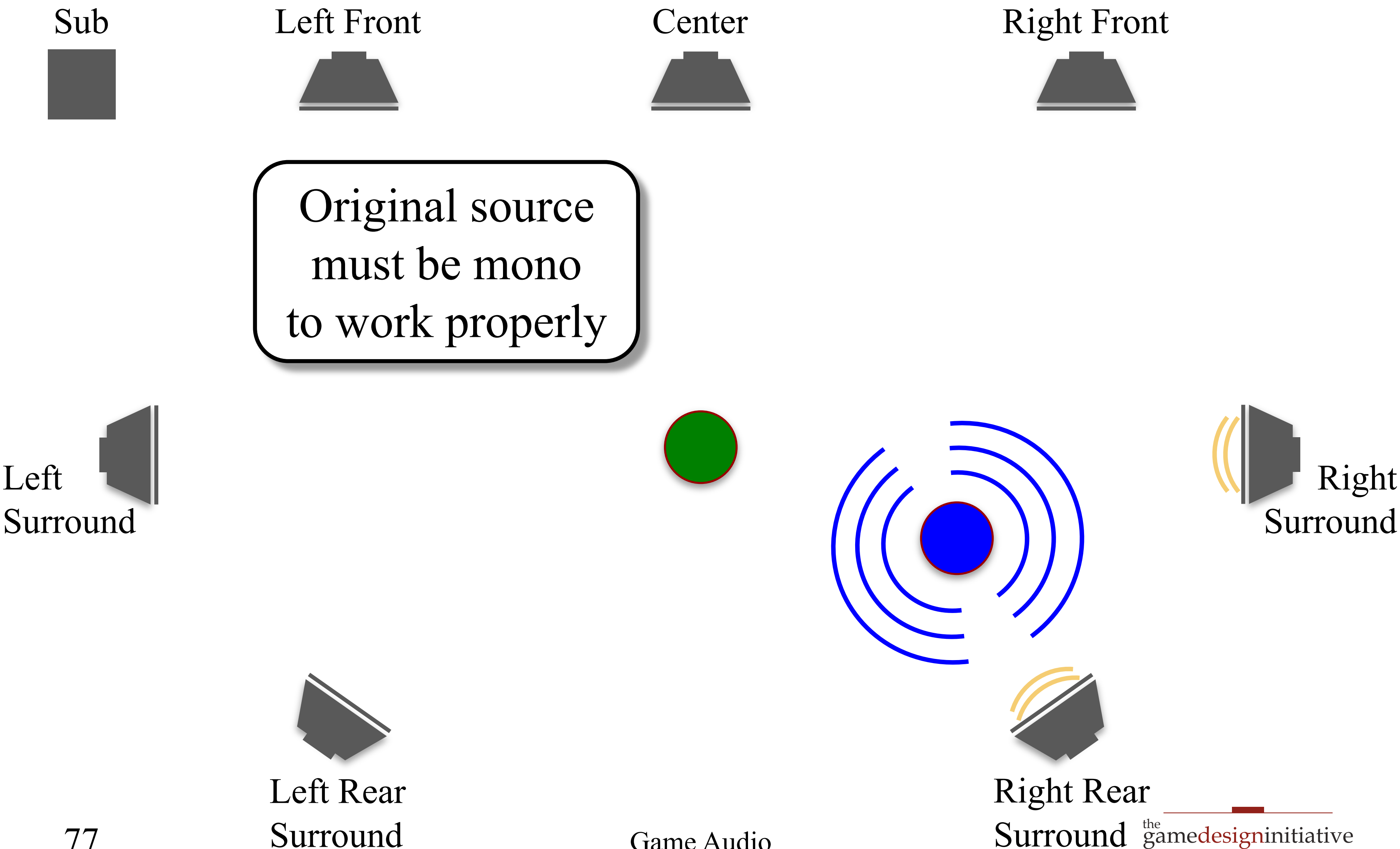
Advanced: Surround Sound



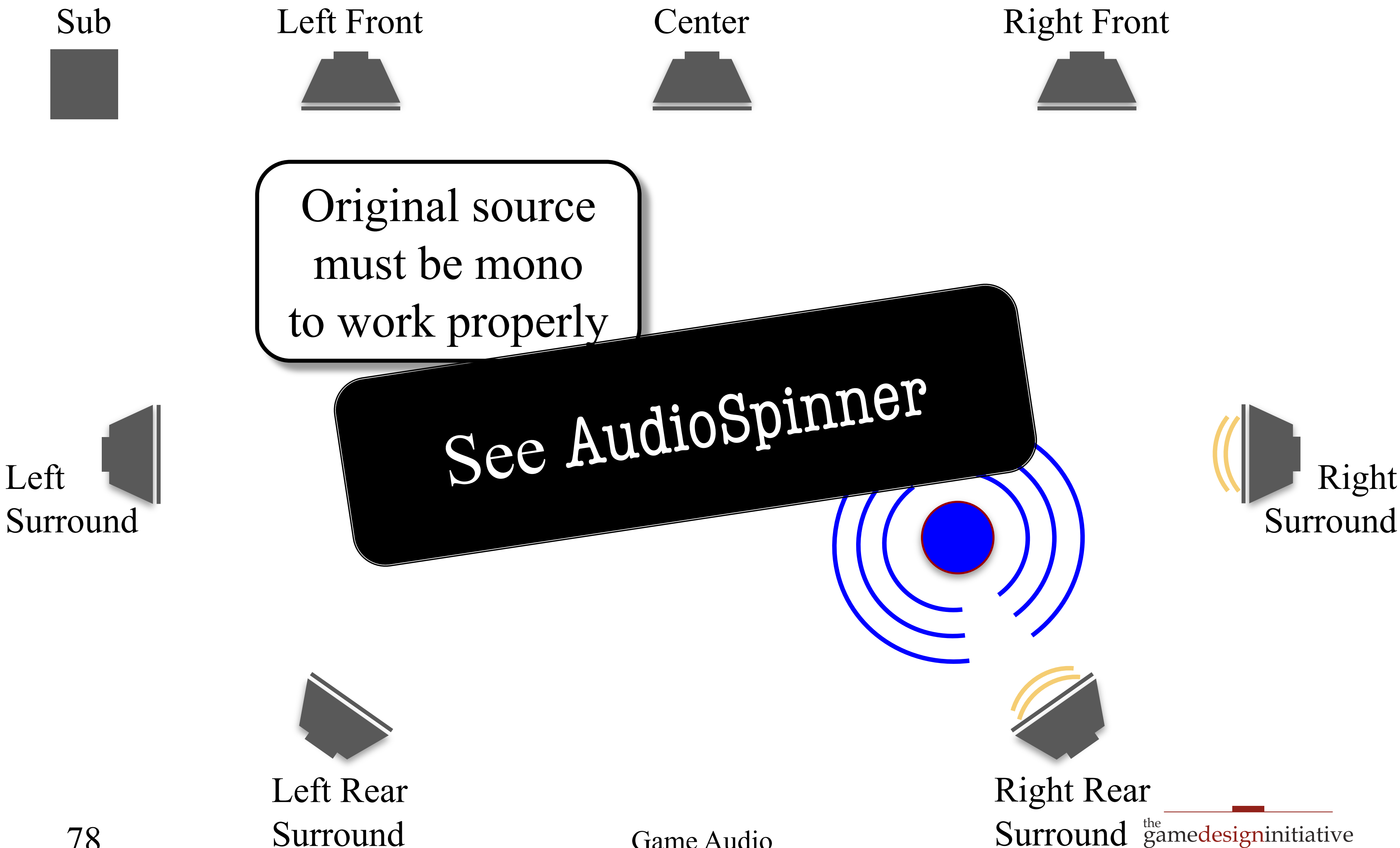
Advanced: Surround Sound



Advanced: Surround Sound



Advanced: Surround Sound

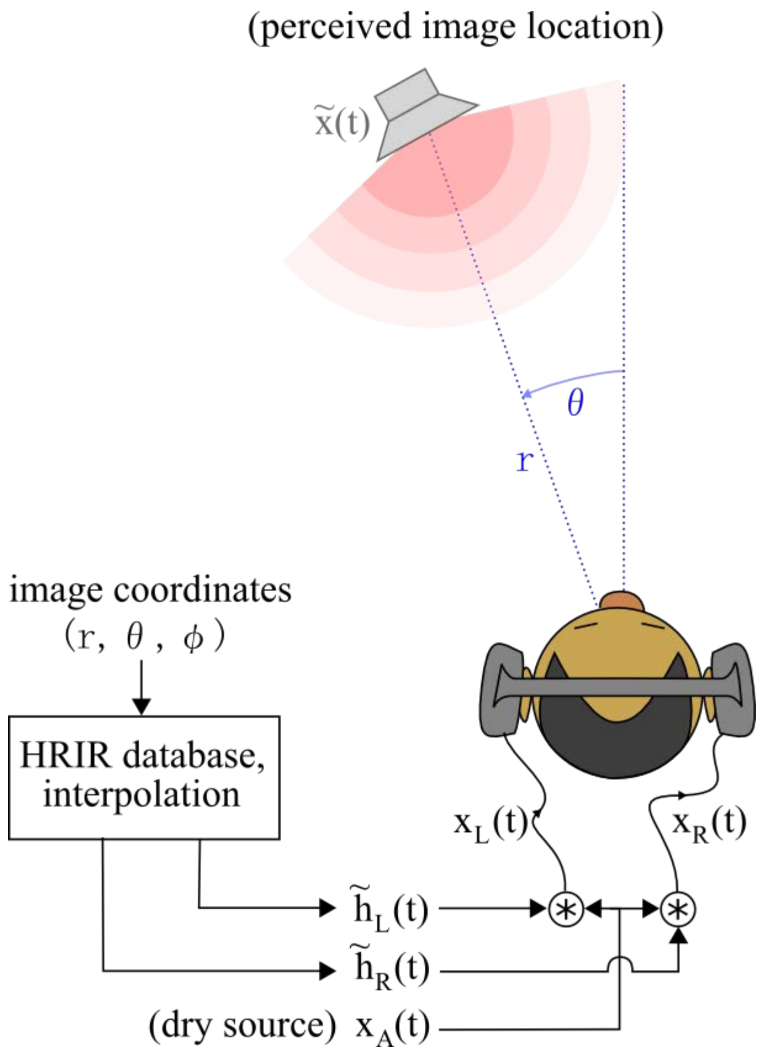


Original source must be mono to work properly

See AudioSpinner

Advanced: Binarual Synthesis

- Mobile positional sound?
  - Only stereo: left/right
  - Cannot pinpoint source
- **Goal**: realistic perception
  - Track the sound parallax
  - Account for shape of head
- Not (yet) in CUGL
  - In experimental branch
  - Will merge in summer



Example: *Papa Sangre*

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
  - CUGL has some early support for all this