AVAudioEngine in Practice

Session 502
Kapil Krishnamurthy
Core Audio Rock Star

Overview

Core Audio overview

AVAudioEngine

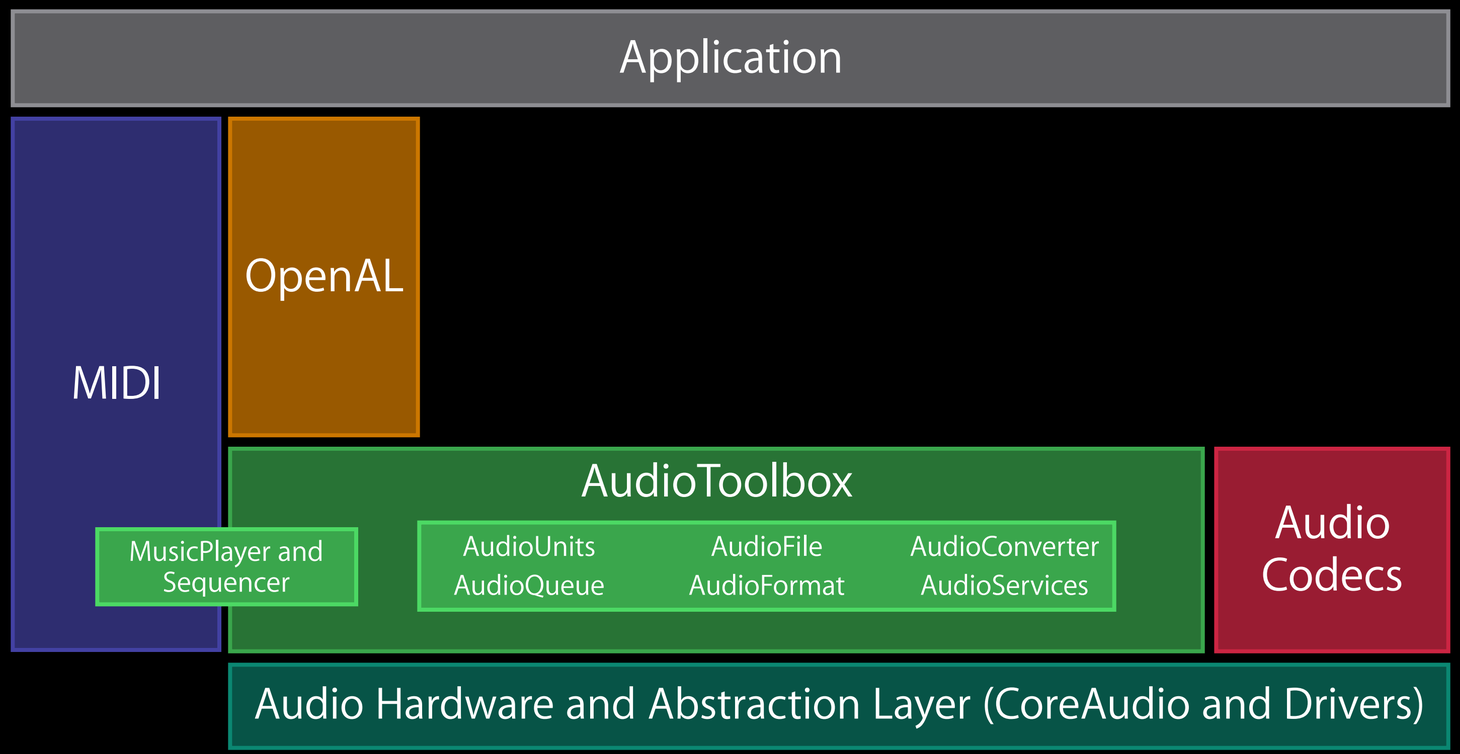
- Goals
- Features
- Building blocks
- Gaming and 3D audio

Core Audio Overview

iOS and Mac OS X Audio Stack

Multiple APIs for implementing audio features

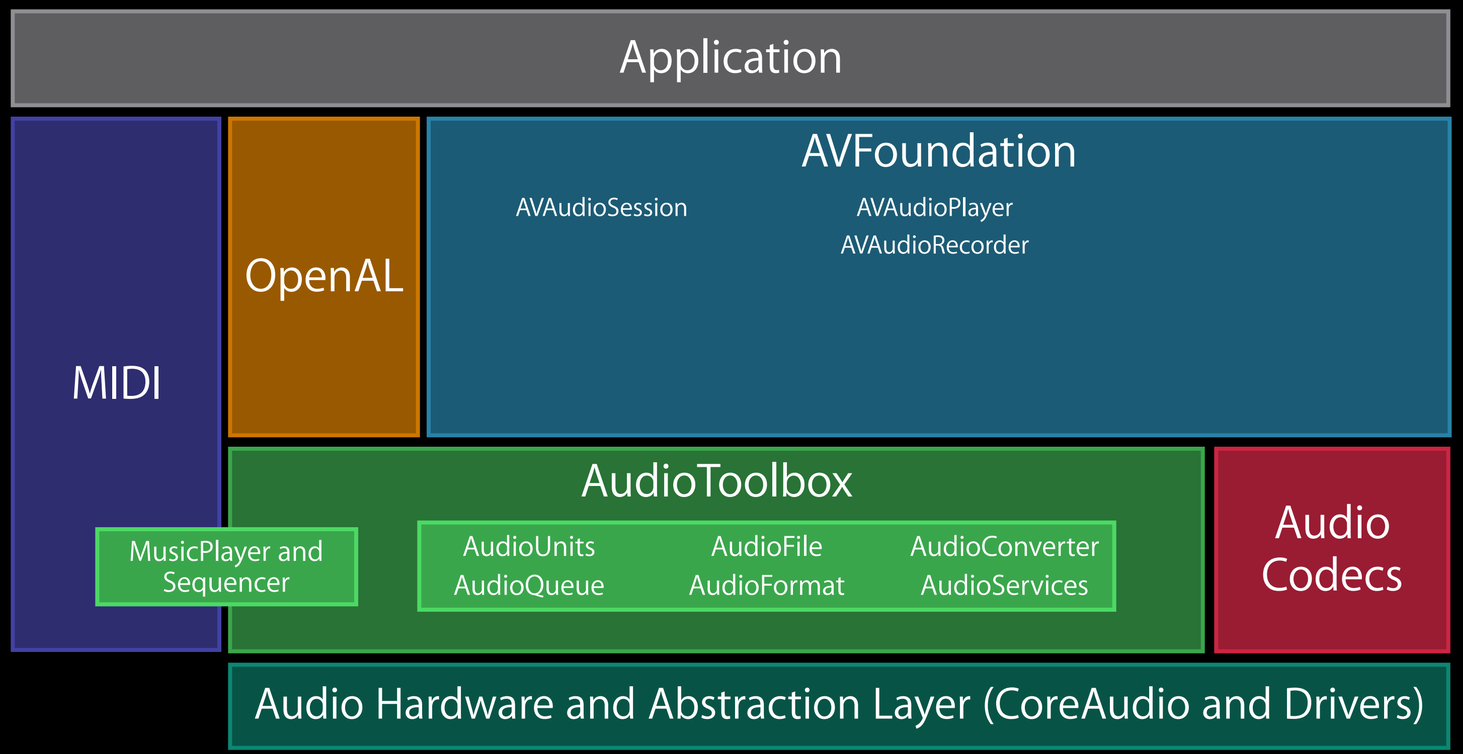
Low latency, real-time audio



iOS and Mac OS X Audio Stack

Multiple APIs for implementing audio features

Low latency, real-time audio



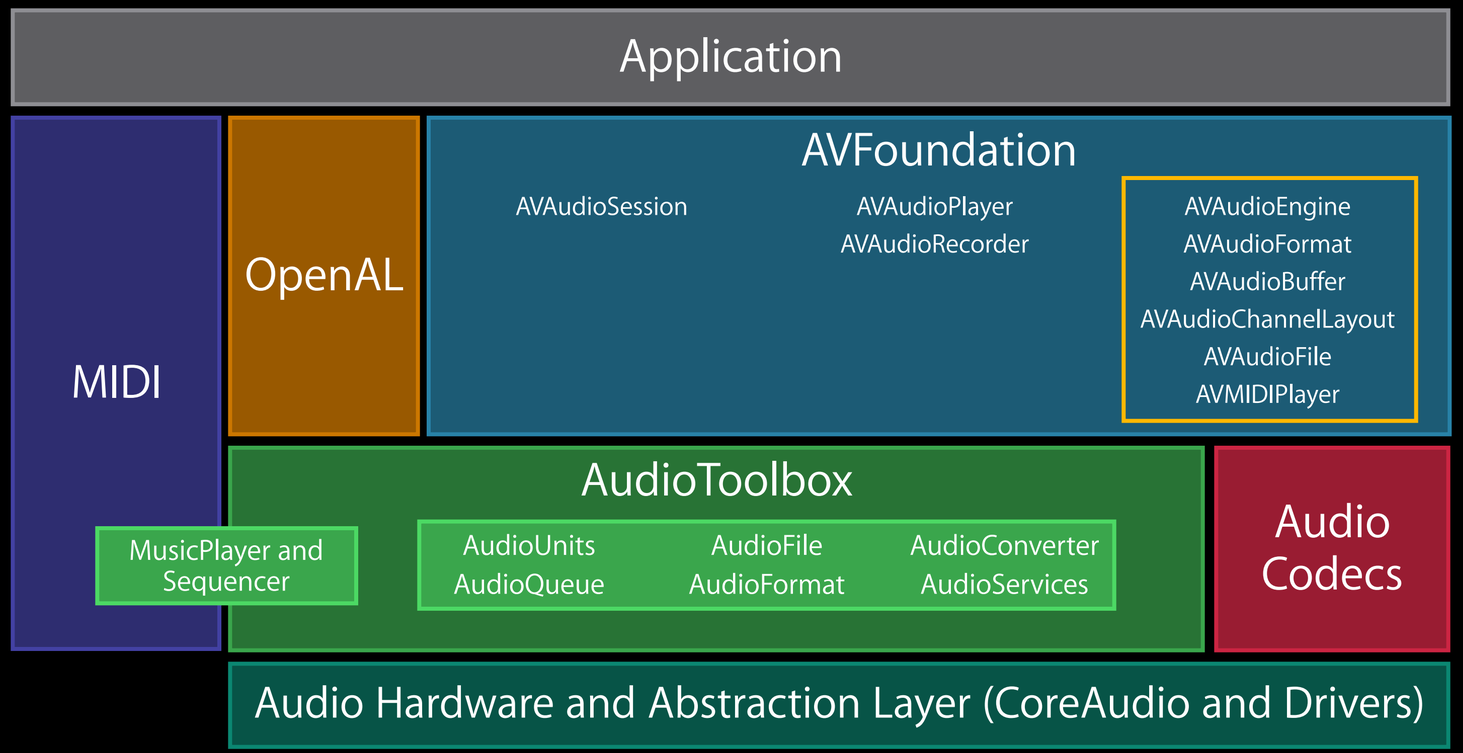
iOS and Mac OS X Audio Stack

Multiple APIs for implementing audio features

Low latency, real-time audio

AVAudioEngine—New to Mac OS X 10.10, iOS 8.0

AV Audio Utility classes—Refer to session 501 (What's new in Core Audio)



AVAudioEngine

Goals and features

Goals

Provide powerful, feature-rich API set

Achieve simple as well as complex tasks

Simplify real-time audio

Features

Objective-C API set

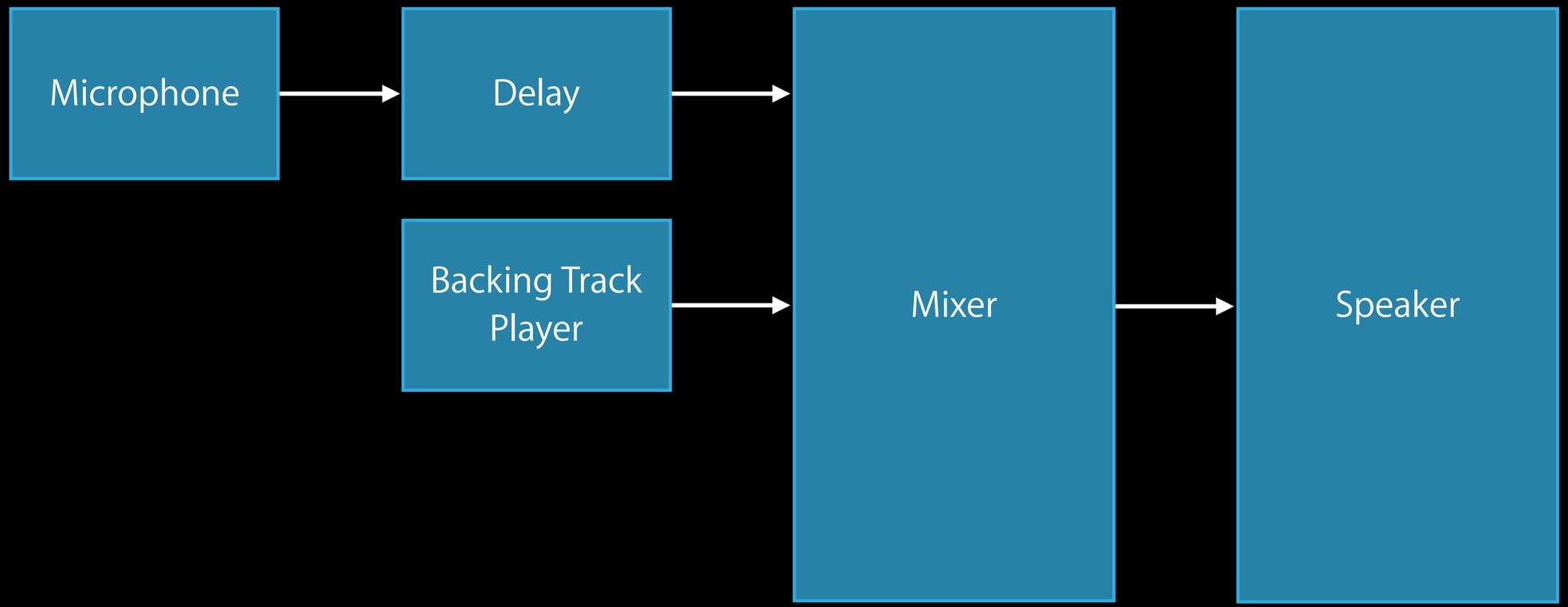
Low latency, real-time audio

Features

- Read and write audio files
- Play audio using files and buffers
- Record audio
- Connect audio processing blocks
- Capture audio at any point in the processing chain
- Implement 3D audio for games

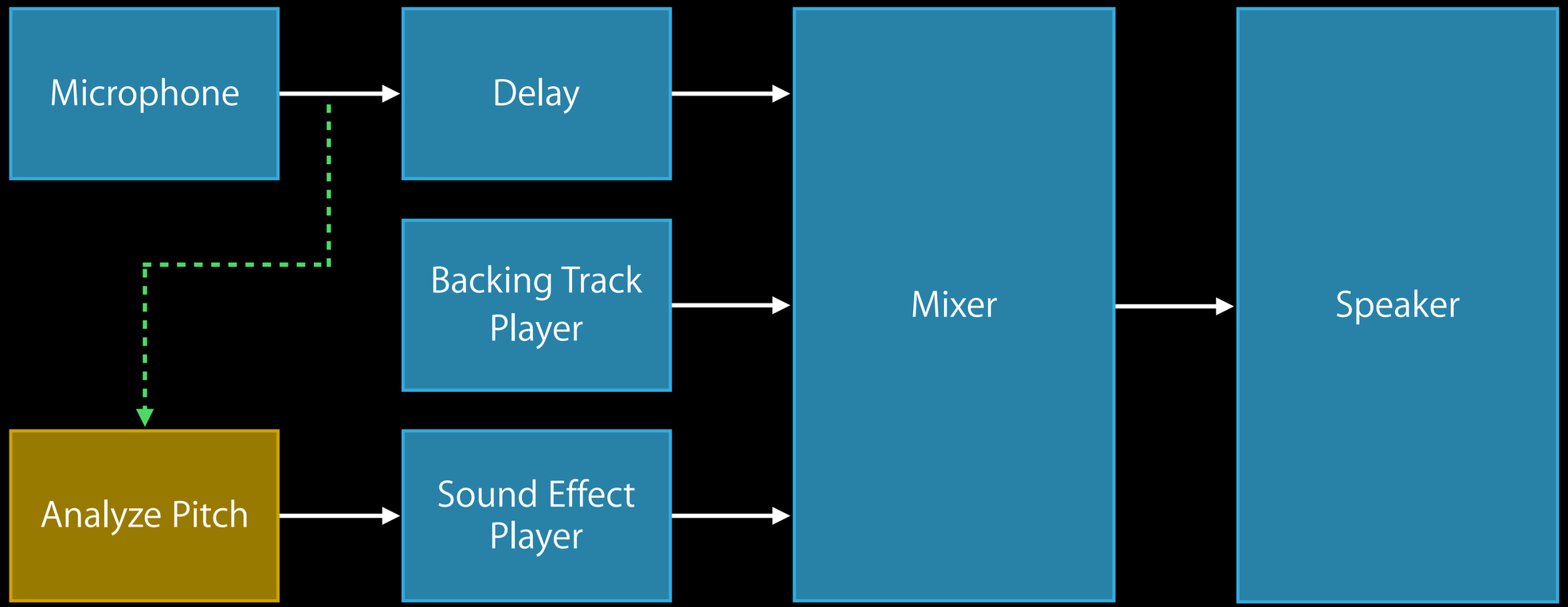
Sample Use Case One

Karaoke



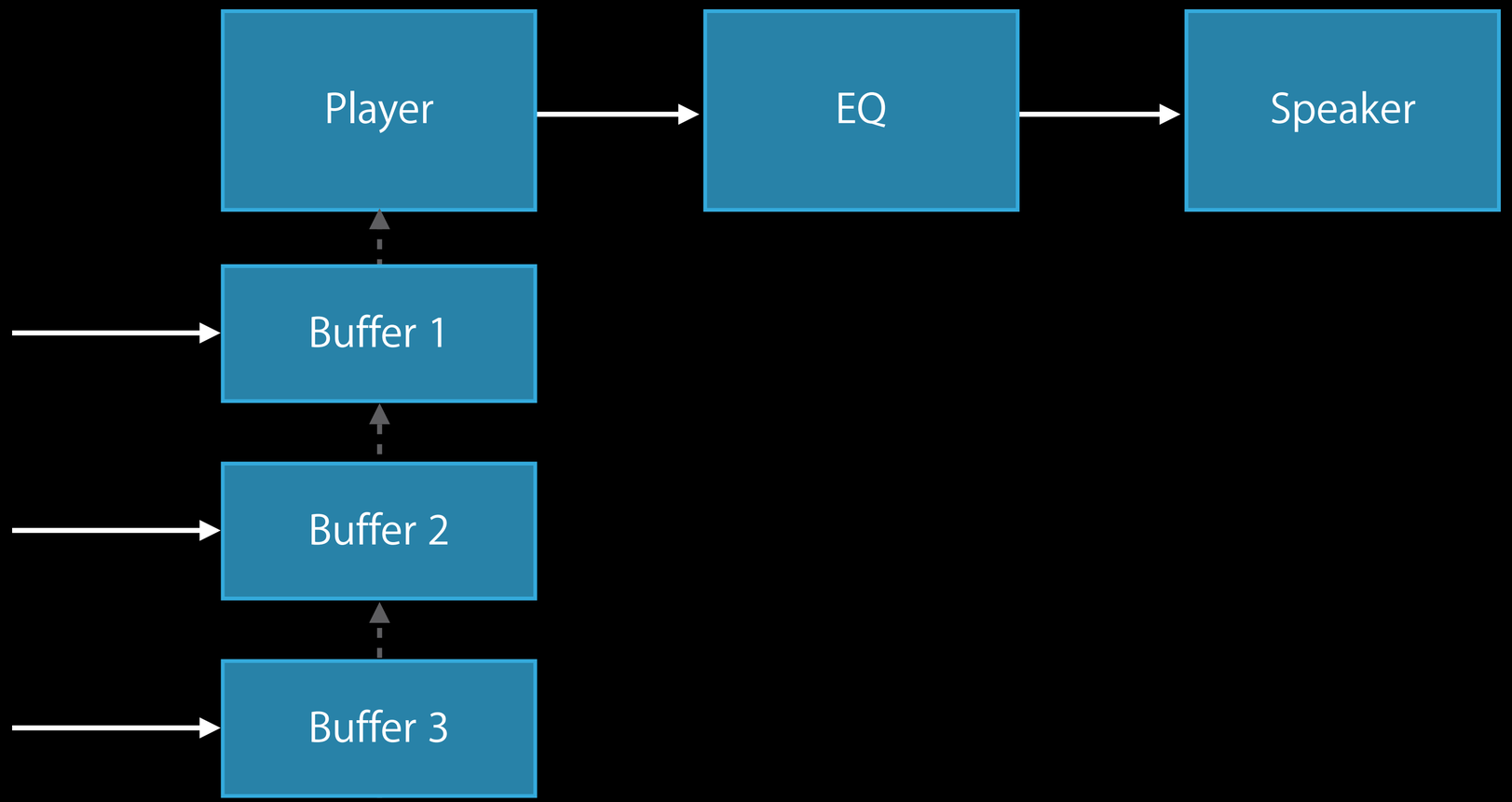
Sample Use Case One

Karaoke



Sample Use Case Two

Streaming audio



AVAudioEngine

Building blocks

Building Blocks

Engine (AVAudioEngine)

Node (AVAudioNode)

- Output node (AVAudioOutputNode)
- Mixer node (AVAudioMixerNode)
- Player node (AVAudioPlayerNode)

Engine

AVAudioEngine class

Engine manages graph of audio nodes

Use the engine to set up connections between nodes

Start/stop the engine

Allows dynamic node configuration

Engine Workflow

AVAudioEngine class

Create an engine

Create nodes

Attach nodes to the engine

Connect the nodes together

Start the engine

Node

AVAudioNode class

Nodes are audio blocks

- Source—Player, microphone
- Process—Mixer, effect
- Destination—Speaker

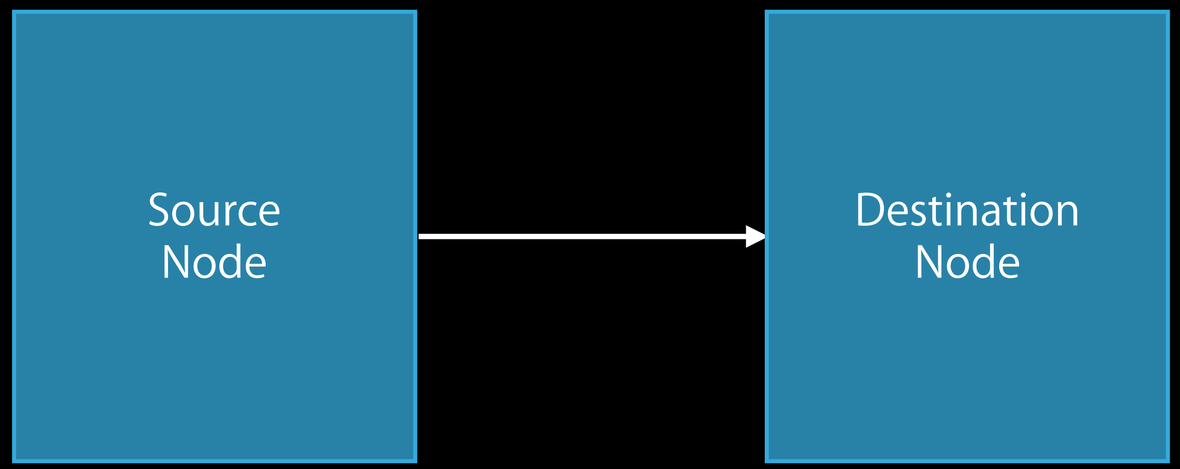
N inputs/M outputs, specified as busses

Every bus has an audio data format

Active Chain

Node connections

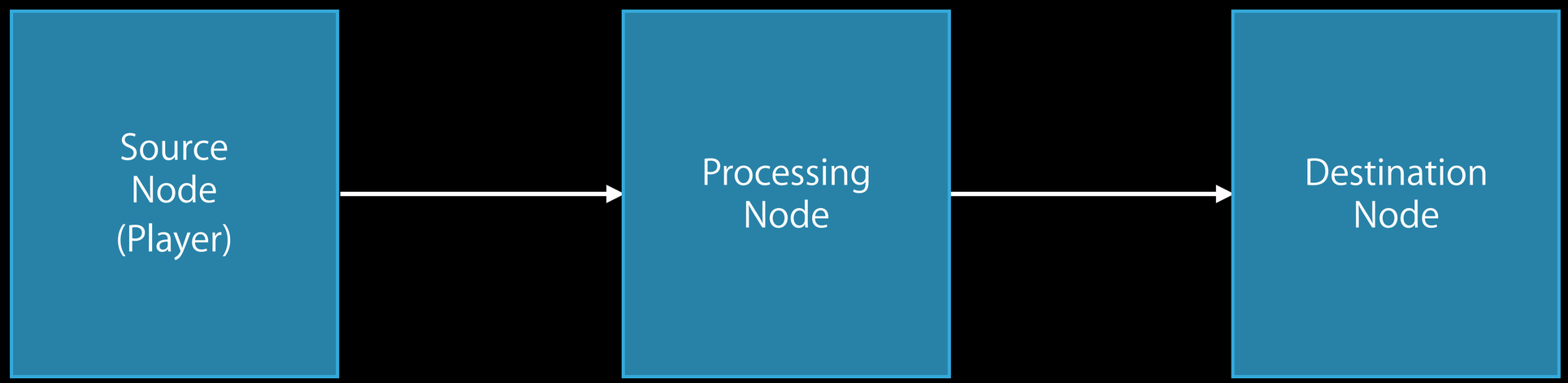
Active chain => Source node to destination node



Active Chain

Node connections

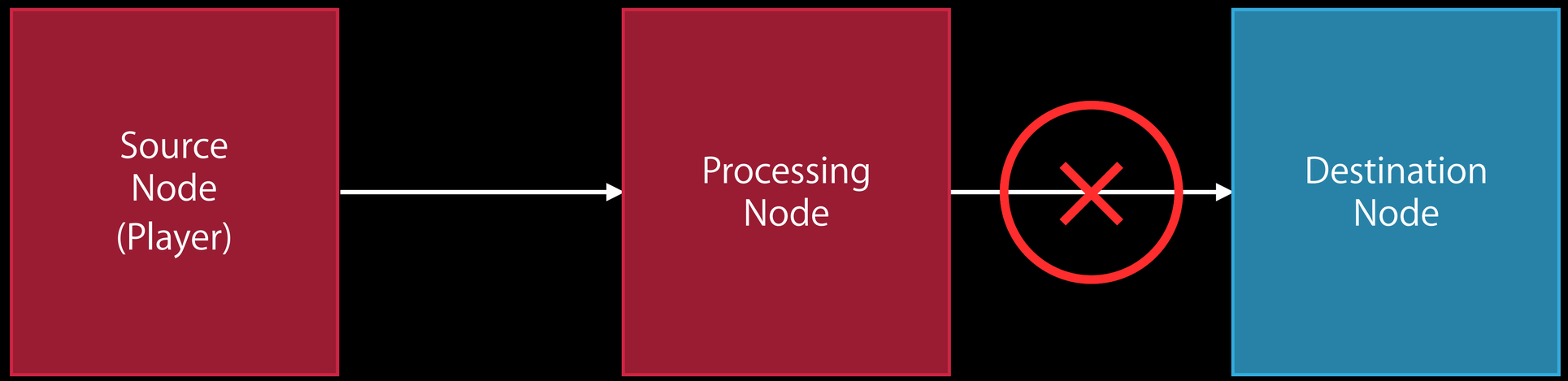
Active chain => Source node to destination node



Inactive Chain

Node connections

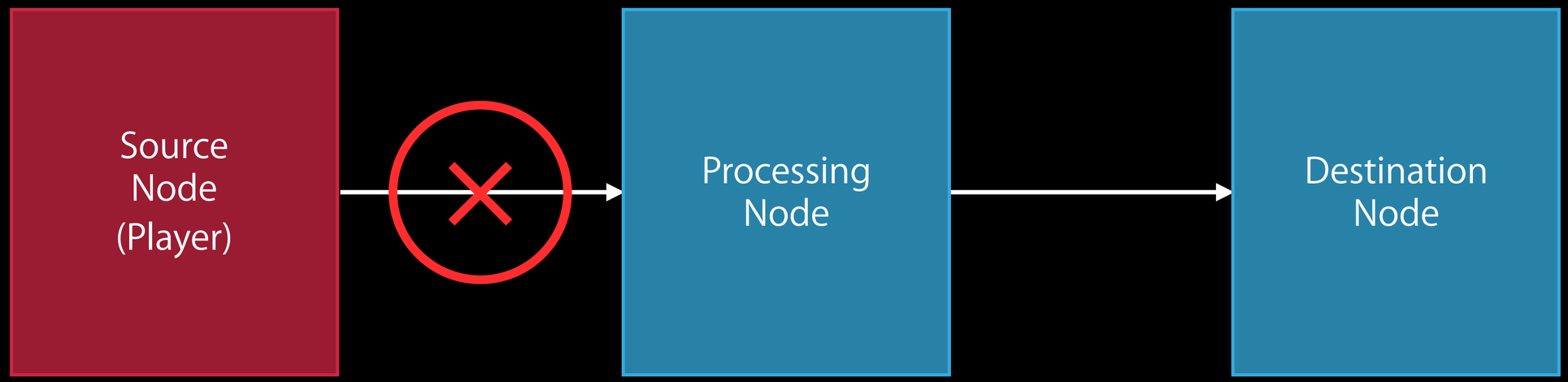
Disconnected nodes are in an inactive state



Inactive Chain

Node connections

Disconnected nodes are in an inactive state



Output Node

AVAudioOutputNode class

Engine has an implicit destination node called output node

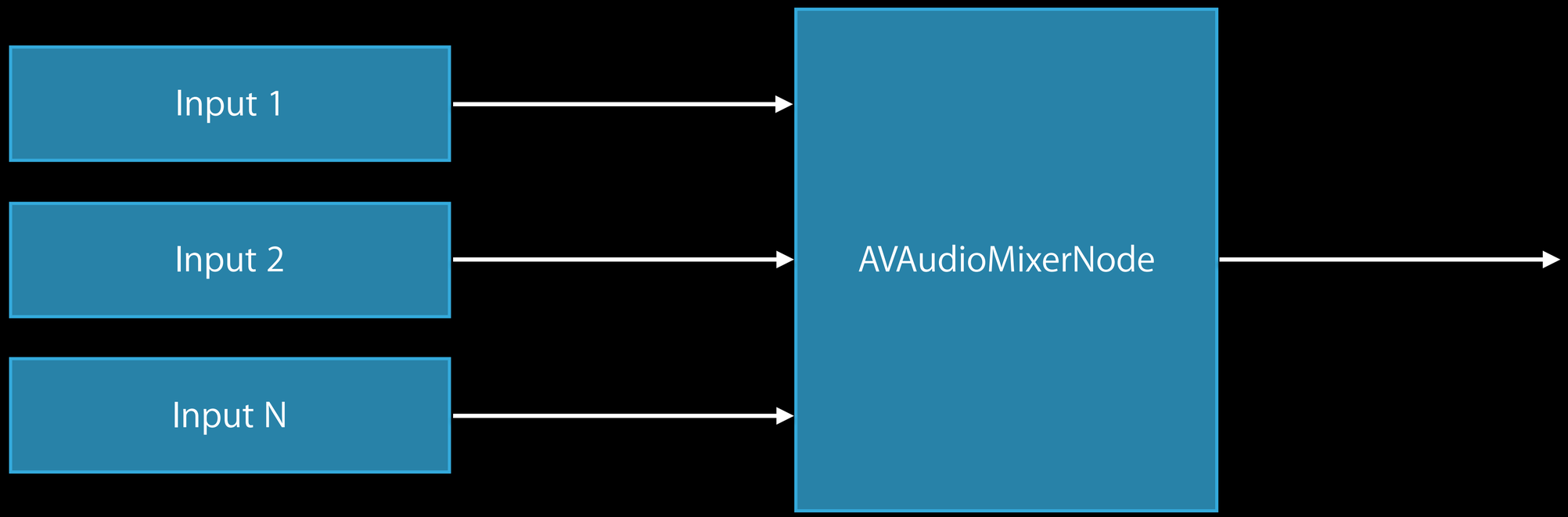
Output node provides audio data to the output hardware

Standalone instance cannot be created

Mixer Node

AVAudioMixerNode class

Processing node that mixes N inputs to a single output

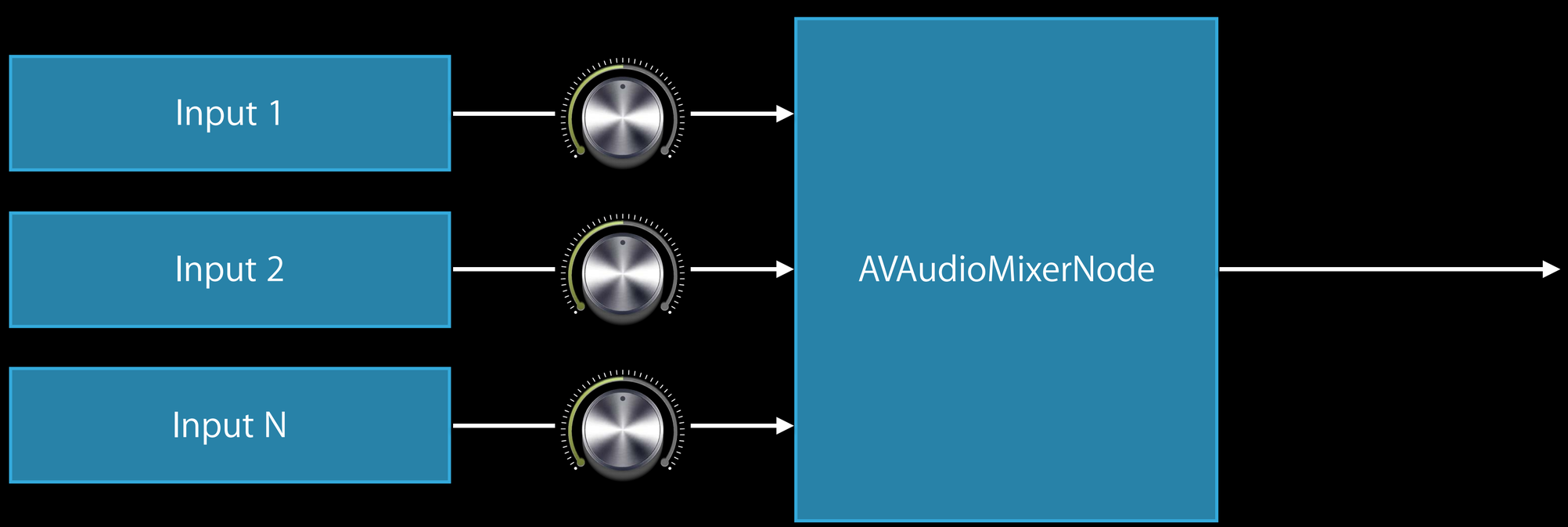


Mixer Node

AVAudioMixerNode class

Processing node that mixes N inputs to a single output

Volume control over each input bus



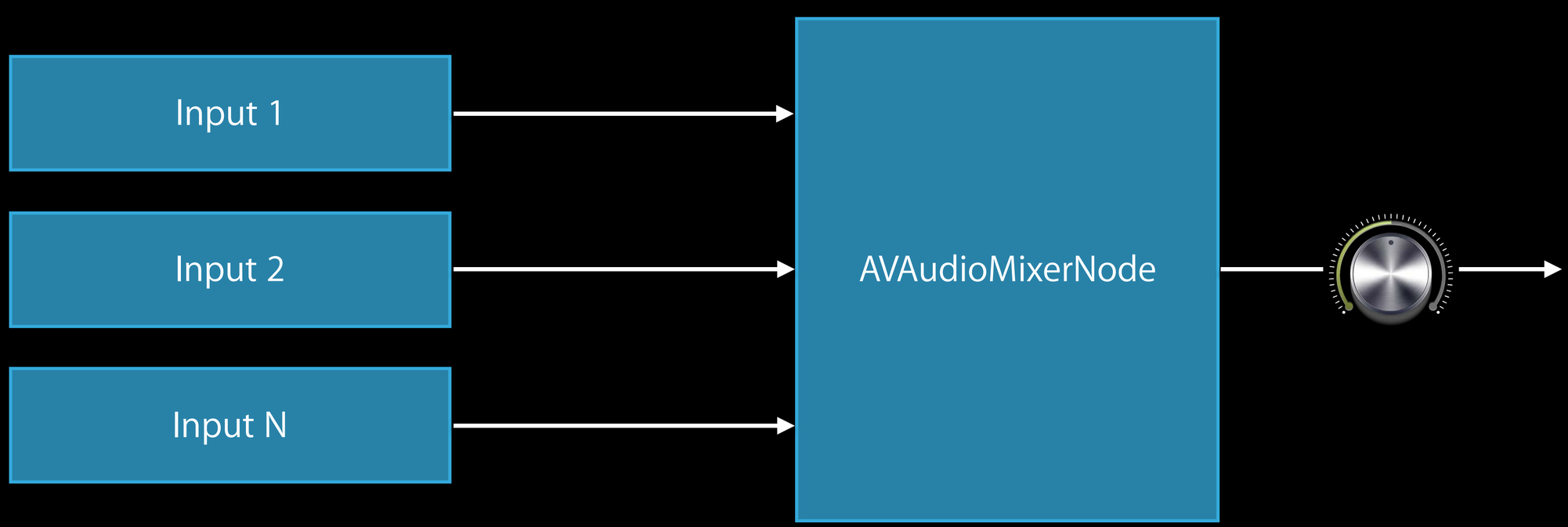
Mixer Node

AVAudioMixerNode class

Processing node that mixes N inputs to a single output

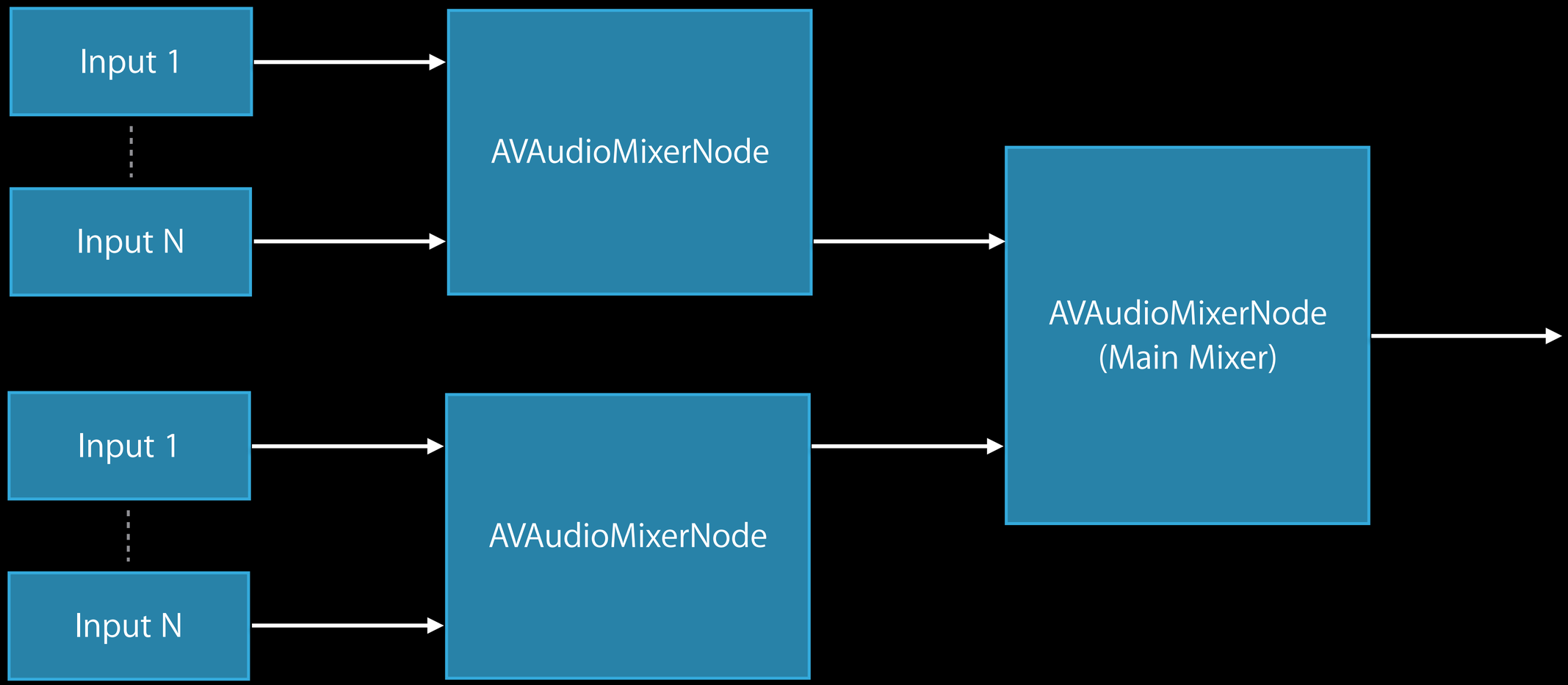
Volume control over each input bus

Volume control of output bus



Sub-Mixing

AVAudioMixerNode class



Mixer Node

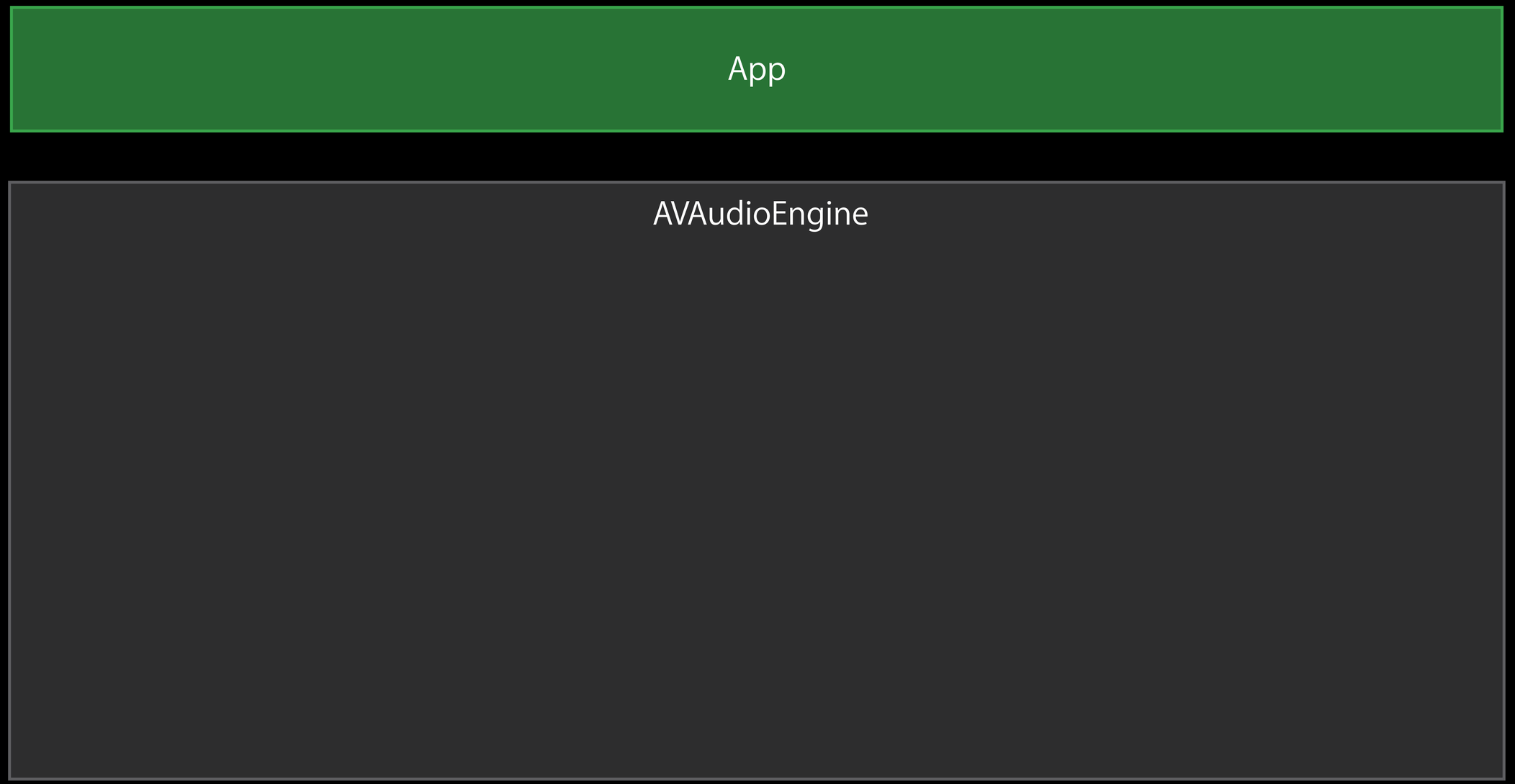
AVAudioMixerNode class

Engine has an implicit mixer node

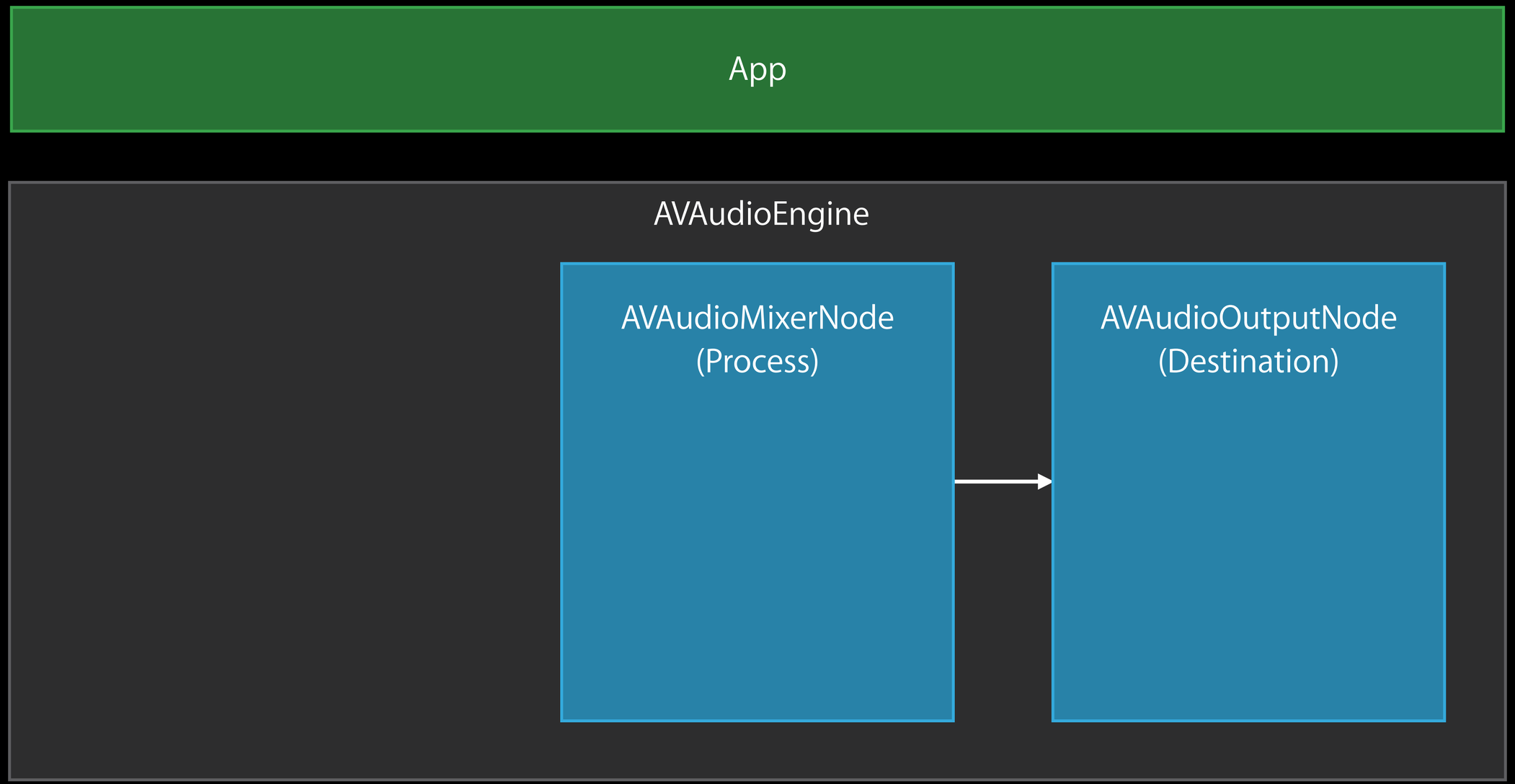
Additional mixer nodes can be created and attached to the engine

Mixer inputs can have different audio formats

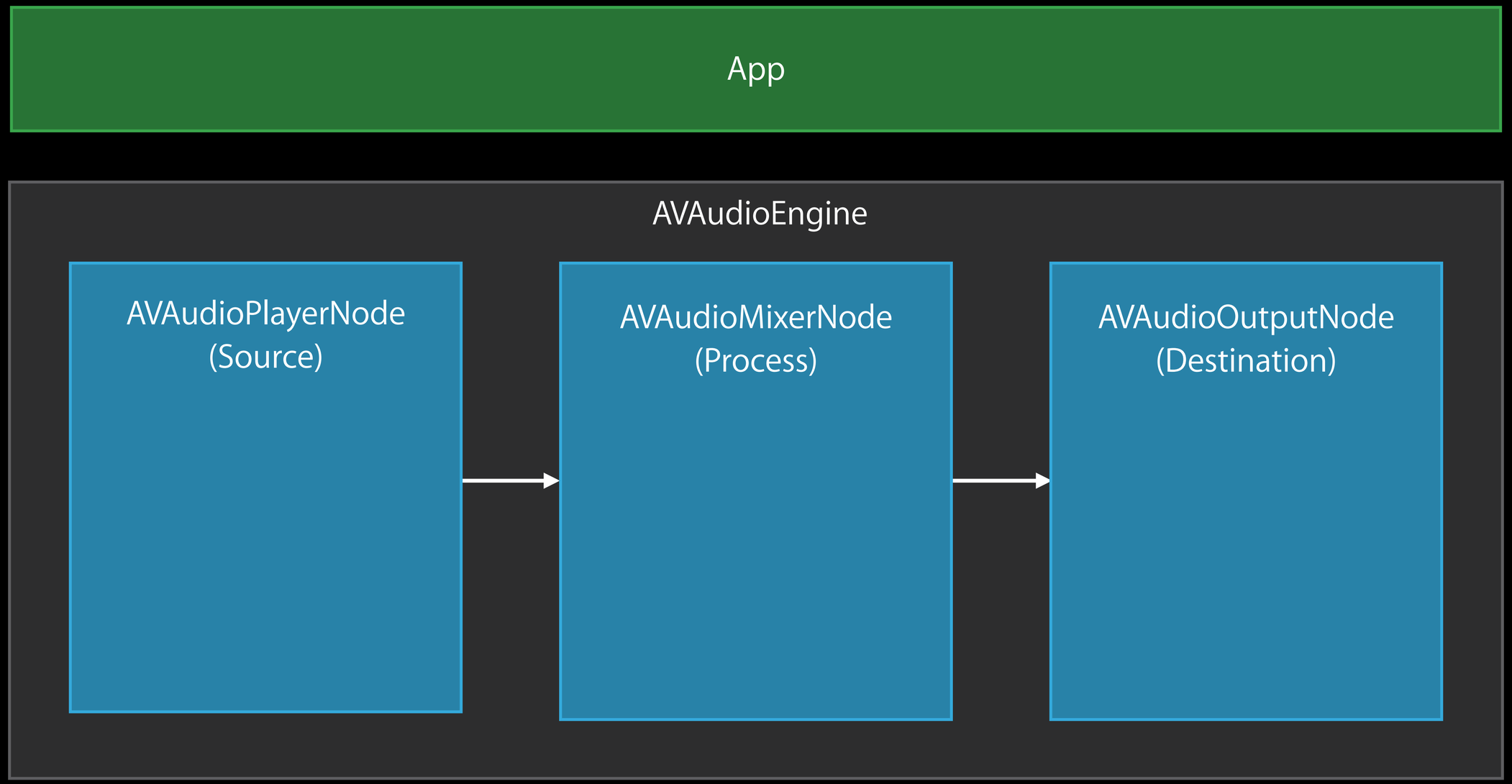
AVAudioEngine Architecture



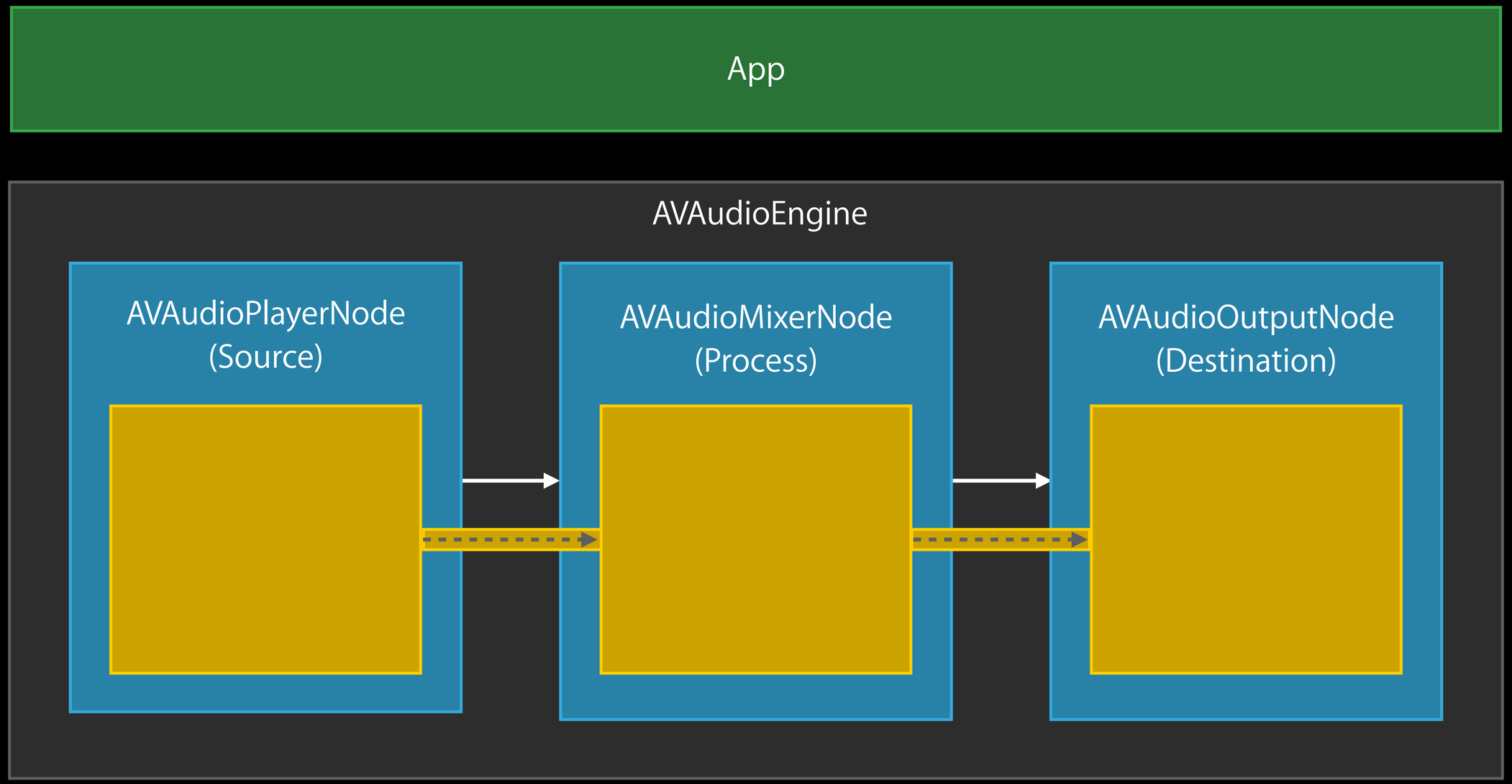
AVAudioEngine Architecture



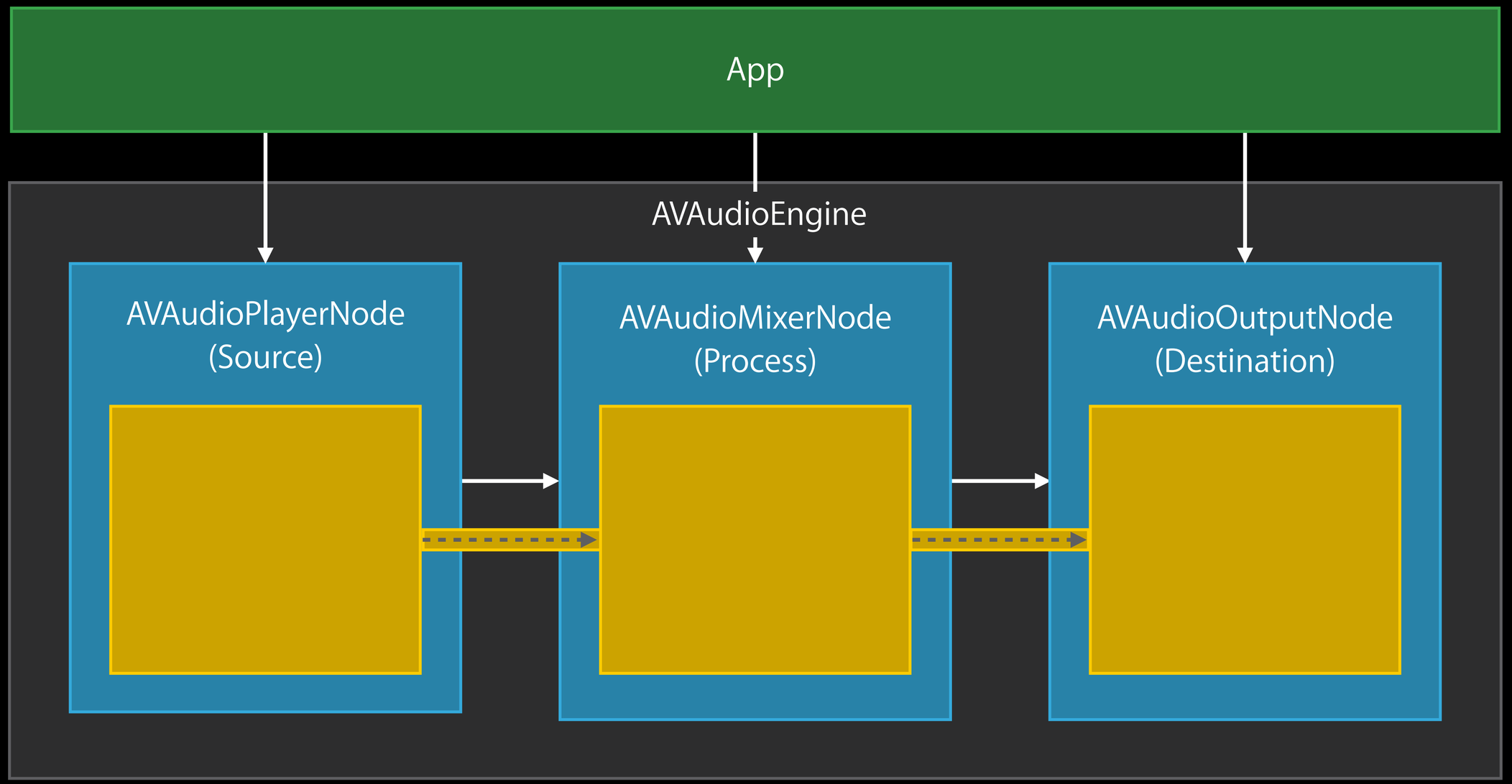
AVAudioEngine Architecture



AVAudioEngine Architecture



AVAudioEngine Architecture



Pushing Data on the Render Thread

Running engine = active render thread

Use player nodes to push data

Player Node

AVAudioPlayerNode class

Player nodes play data from files and buffers

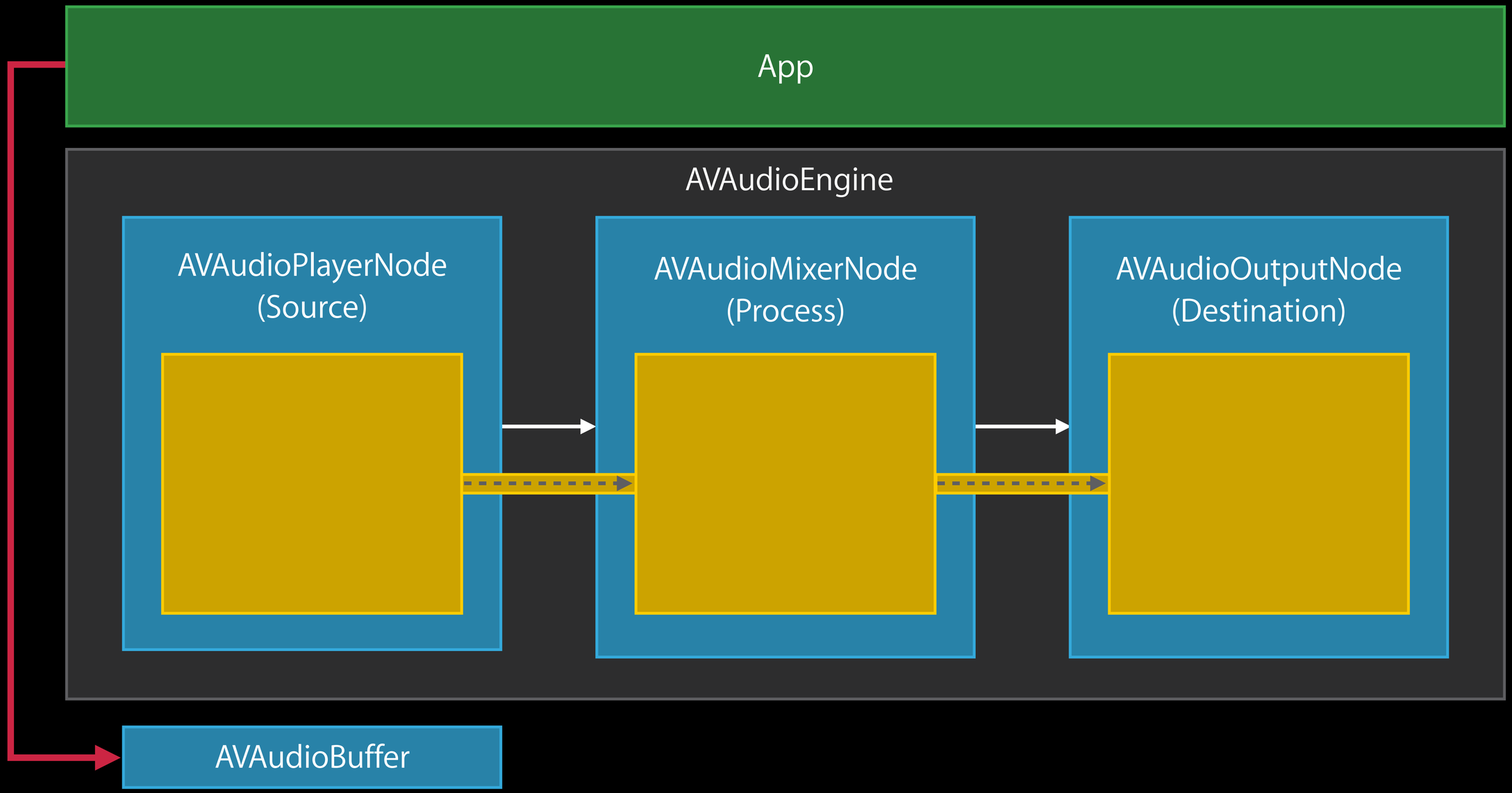
Schedule events—Play data at a specified time

Schedule buffers

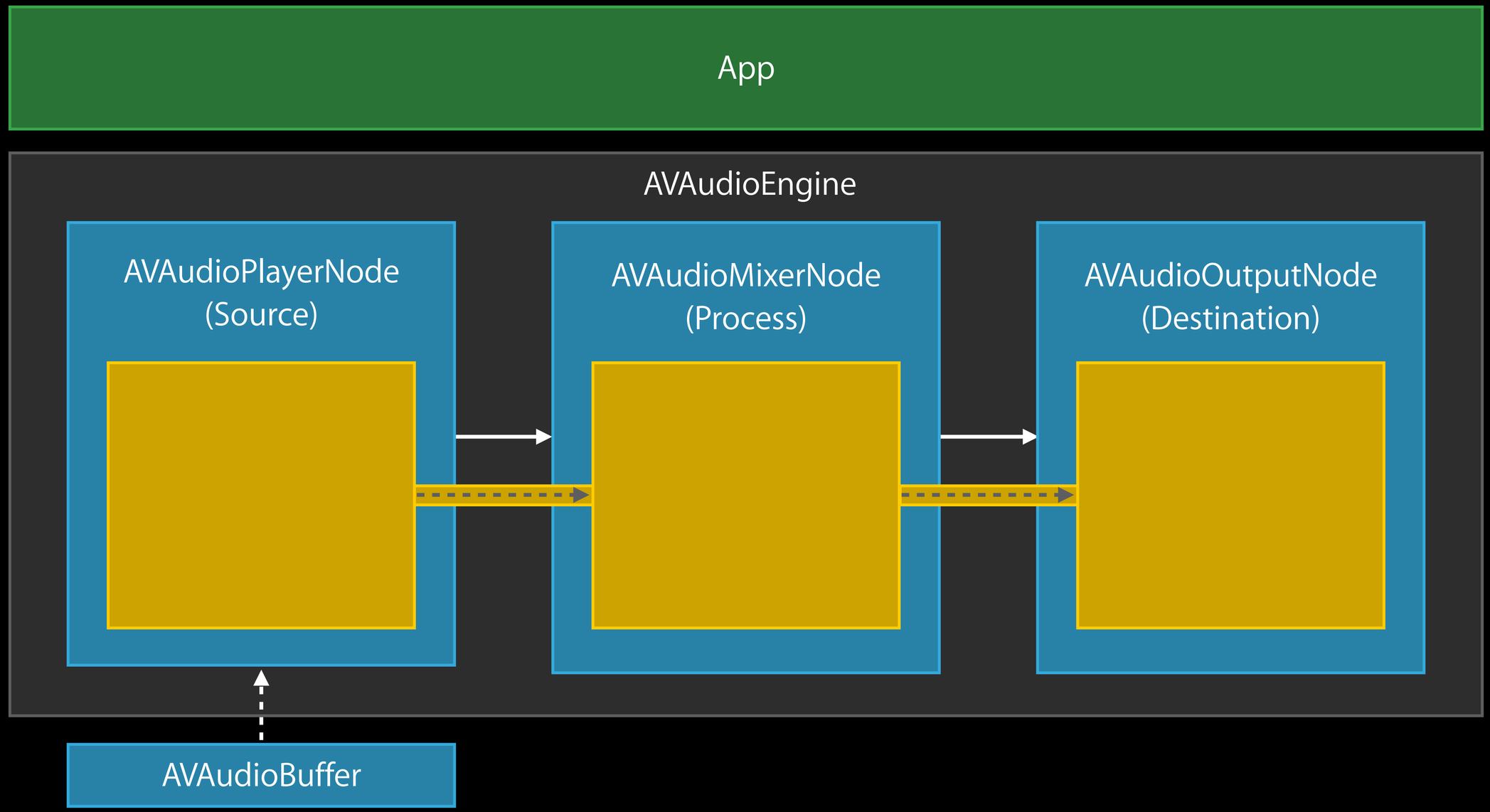
- Multiple buffers with individual callbacks
- Single buffer that loops

Schedule files and file segments

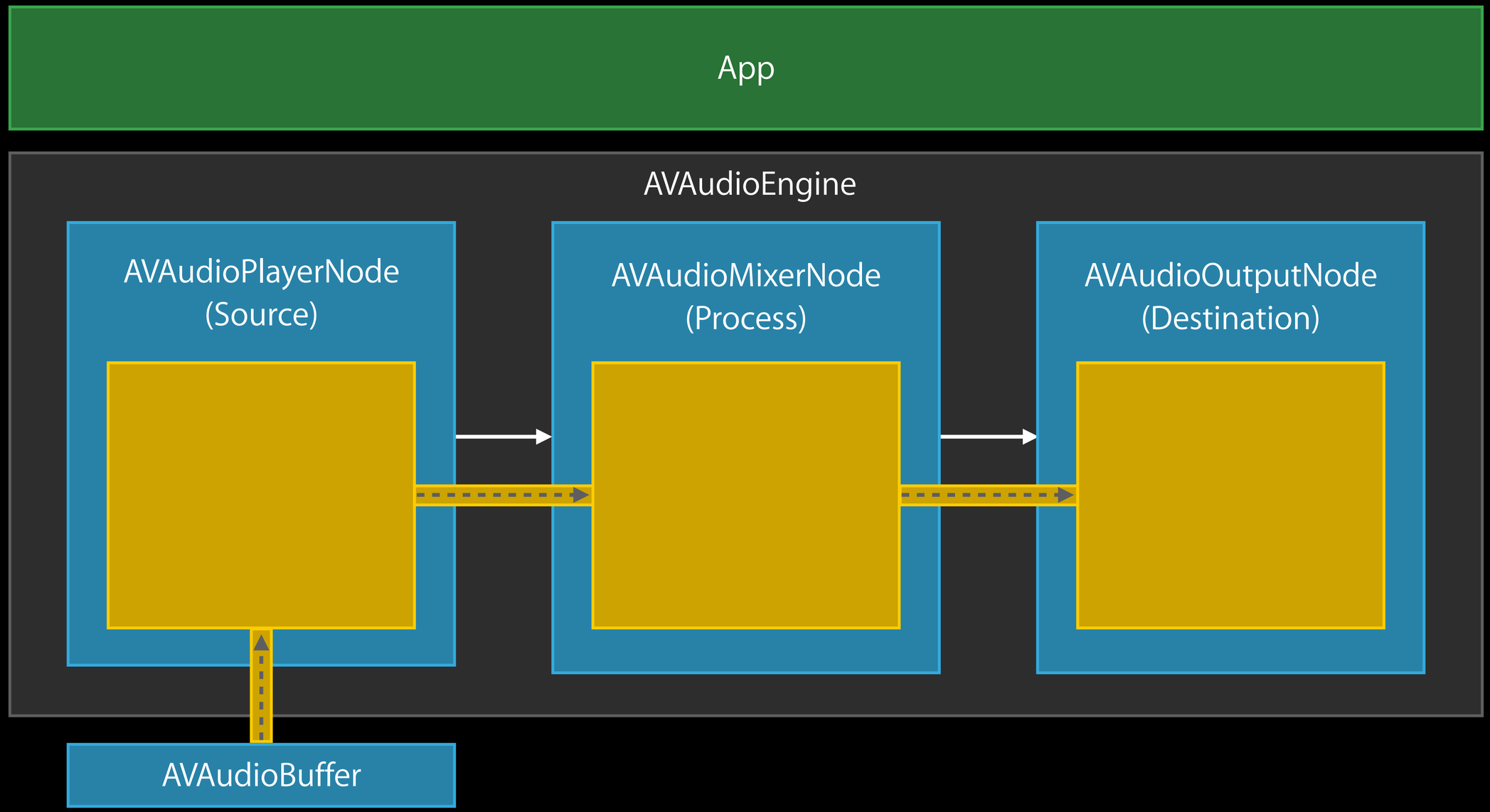
Player Node—Single Buffer



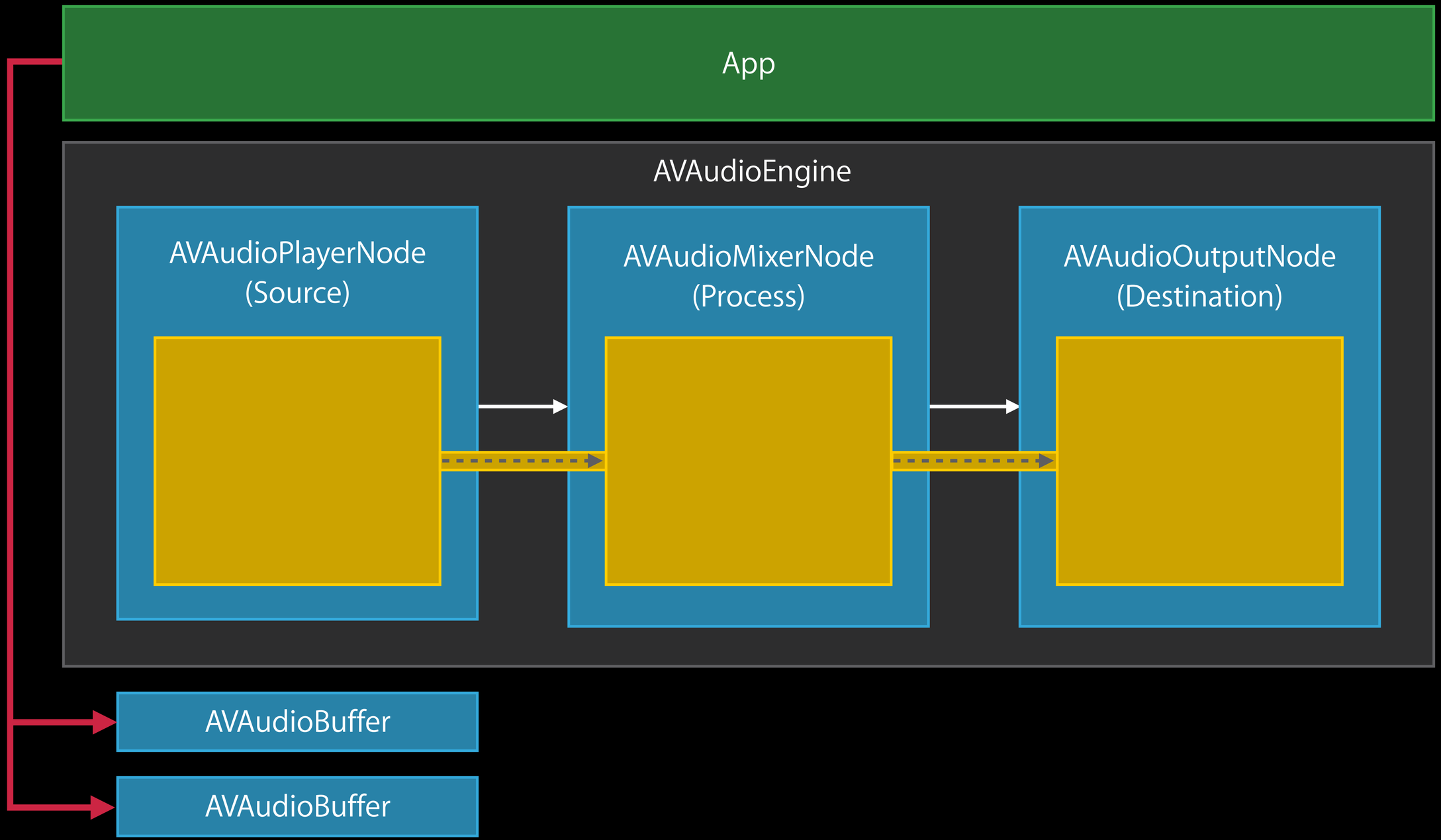
Player Node—Single Buffer



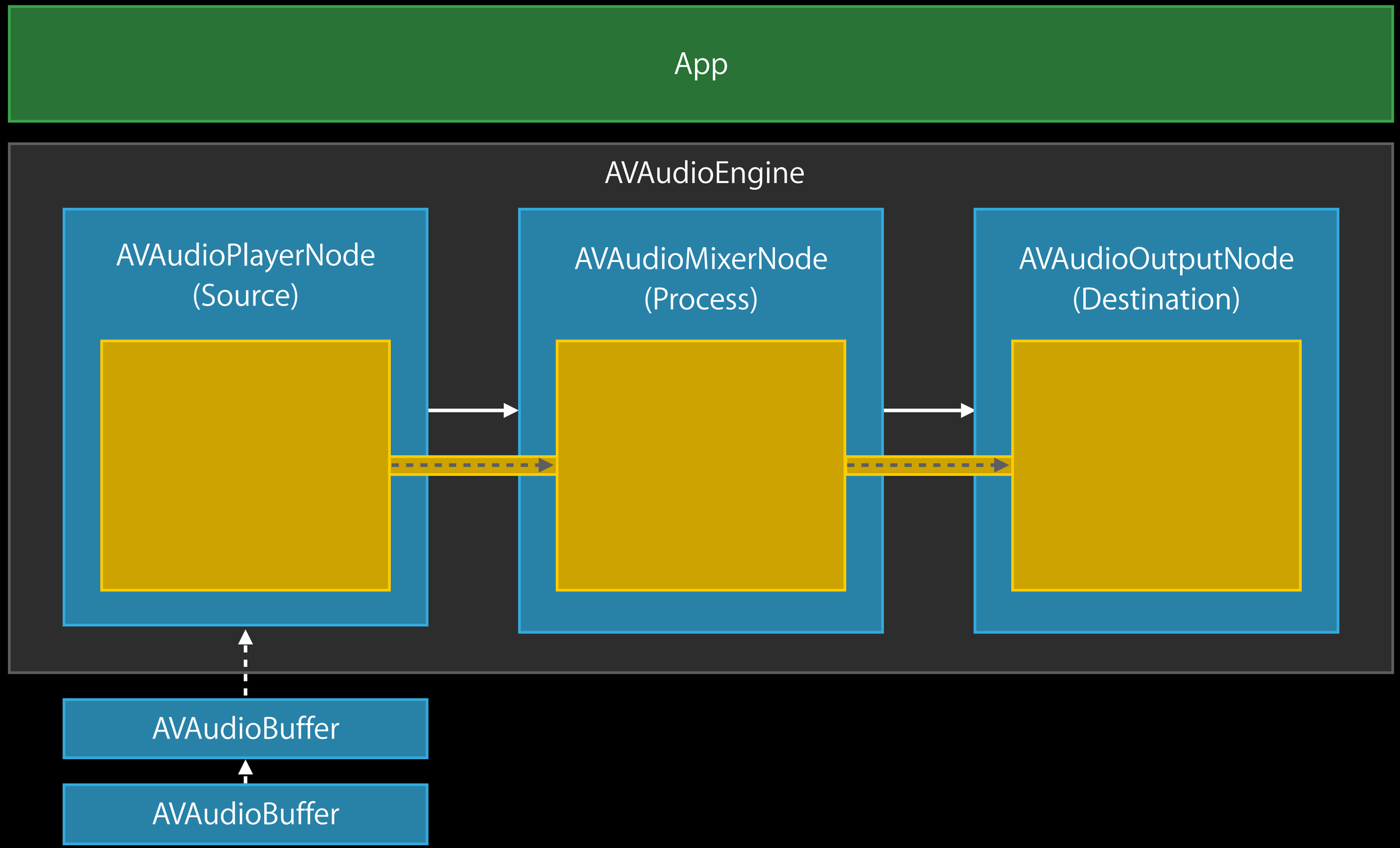
Player Node—Single Buffer



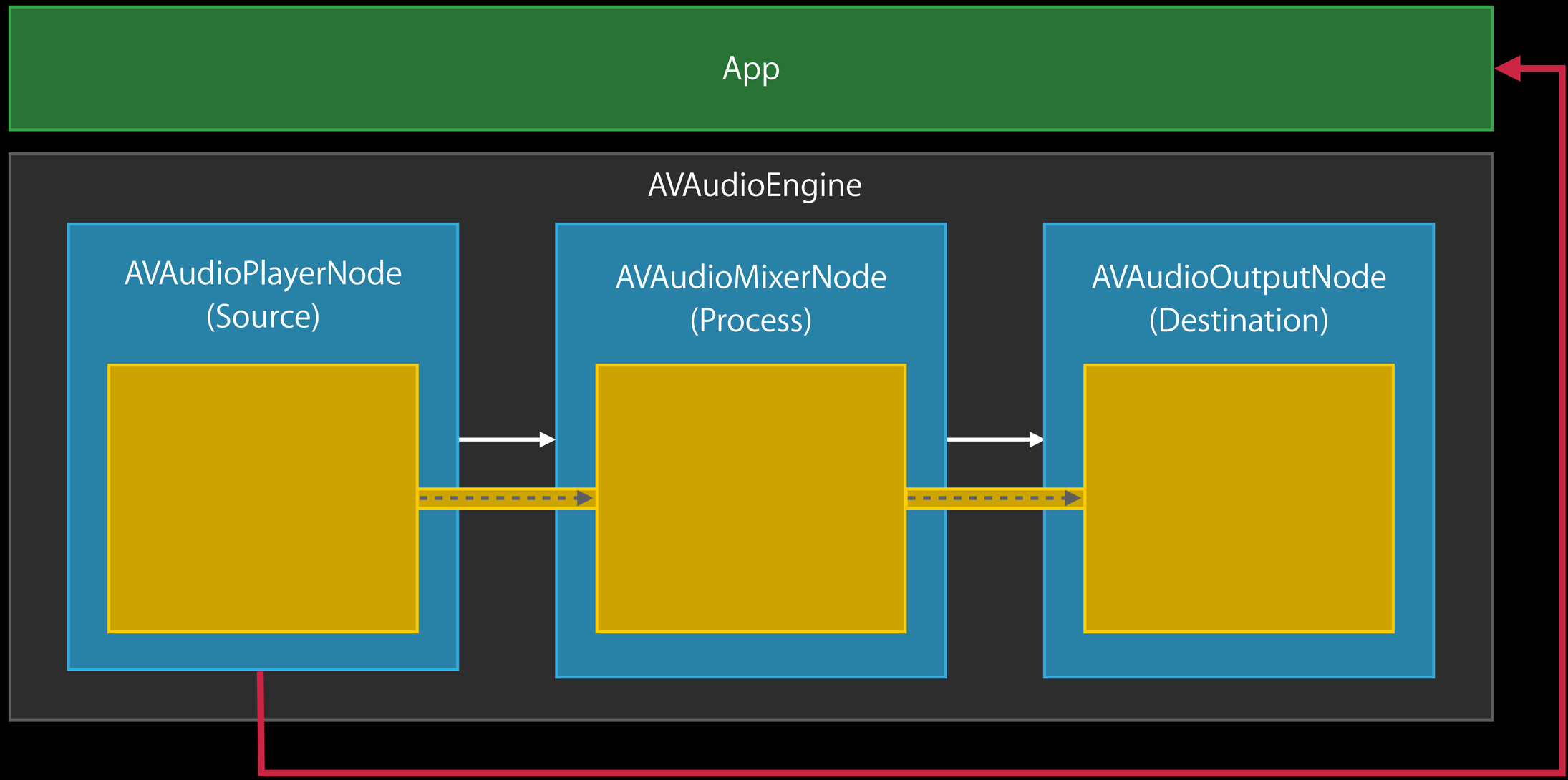
Player Node—Single Buffer



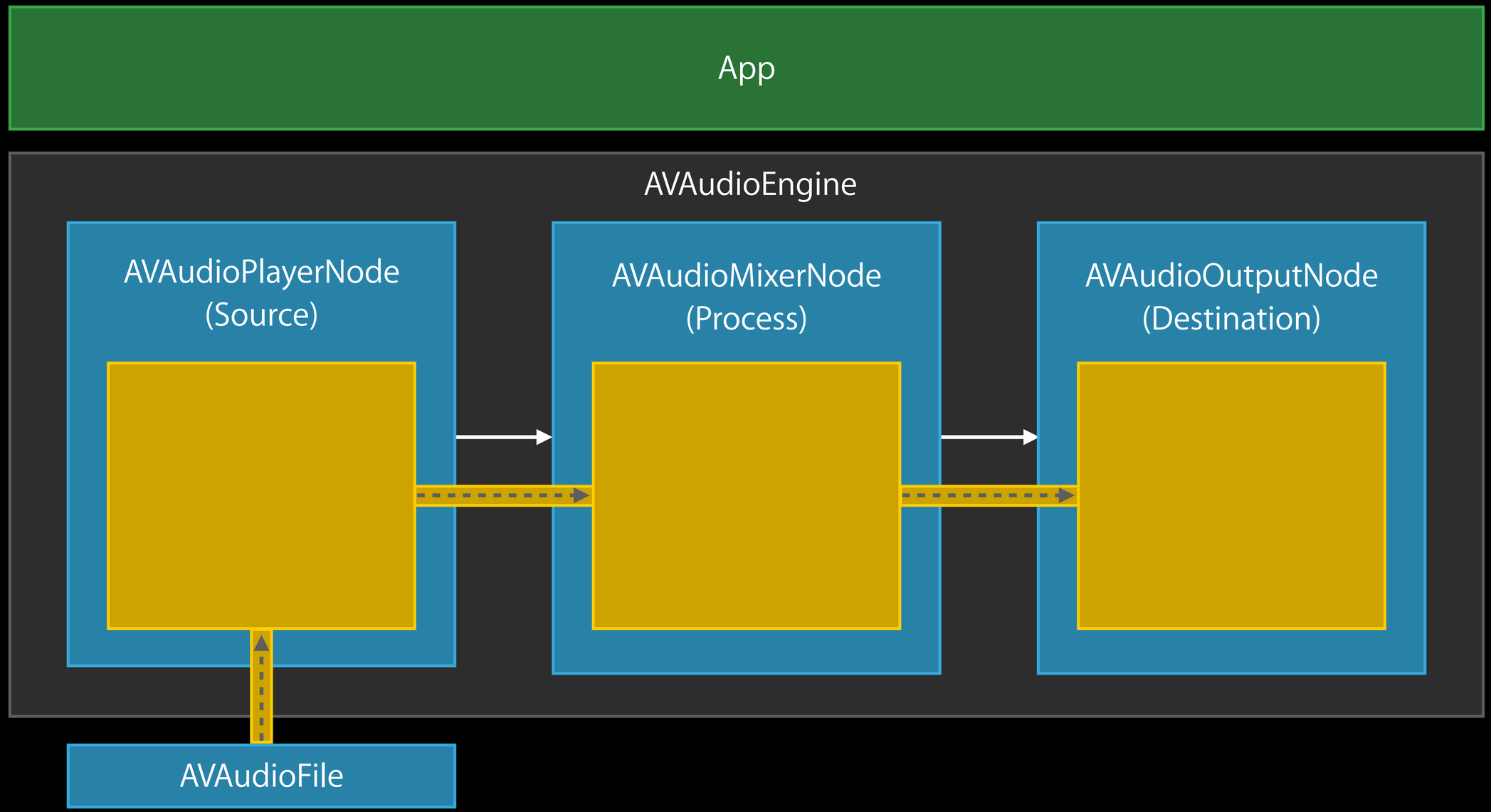
Player Node—Single Buffer



Player Node—Single Buffer



Player Node—File



AVAudioEngine

Code example

Create Engine and Node

Code example

```
AVAudioEngine *engine = [[AVAudioEngine alloc] init];

AVAudioPlayerNode *player = [[AVAudioPlayerNode alloc] init];

[engine attachNode:player];
```

Set up Player (File)

Code example

```
AVAudioFile *file = [[AVAudioFile alloc] initForReading:fileURL
error:&error];

AVAudioMixerNode *mainMixer = [engine mainMixerNode];
[engine connect:player to:mainMixer format:file.processingFormat];
[player scheduleFile:file atTime:nil completionHandler:nil];
```

Set up Player (File)

Code example

```
AVAudioFile *file = [[AVAudioFile alloc] initForReading:fileURL
error:&error];

AVAudioMixerNode *mainMixer = [engine mainMixerNode];
[engine connect:player to:mainMixer format:file.processingFormat];

[player scheduleFile:file atTime:nil completionHandler:nil];
```

Set up Player (File)

Code example

```
AVAudioFile *file = [[AVAudioFile alloc] initForReading:fileURL
error:&error];

AVAudioMixerNode *mainMixer = [engine mainMixerNode];
[engine connect:player to:mainMixer format:file.processingFormat];

[player scheduleFile:file atTime:nil completionHandler:nil];
```

Set up Player (Buffer)

Code example

```
AVAudioPCMBuffer *buffer = …

AVAudioMixerNode *mainMixer = [engine mainMixerNode];
[engine connect:player to:mainMixer format:buffer.format];

[player scheduleBuffer:buffer atTime:nil options:nil completionHandler:nil];
```

Set up Player (Buffer)

Code example

```
AVAudioPCMBuffer *buffer = …

AVAudioMixerNode *mainMixer = [engine mainMixerNode];
[engine connect:player to:mainMixer format:buffer.format];

[player scheduleBuffer:buffer atTime:nil options:nil completionHandler:nil];
```

Start Engine and Play

Code example

```
NSError *error;
[engine startAndReturnError:&error]

[player play];
```

Start Engine and Play

Code example

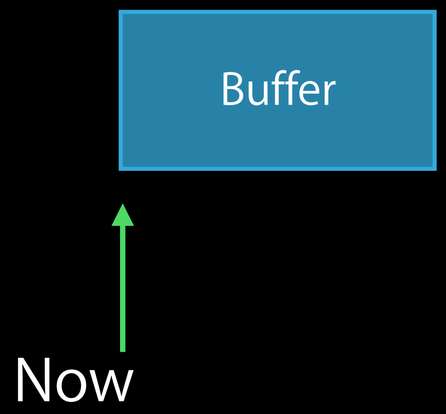
```
NSError *error;
[engine startAndReturnError:&error]

[player play];
```

Buffer Schedule Options

AVAudioPlayerNode class

1. Play buffer now

```
[player scheduleBuffer:buffer atTime:nil options:nil completionHandler:nil];
[player play];
```

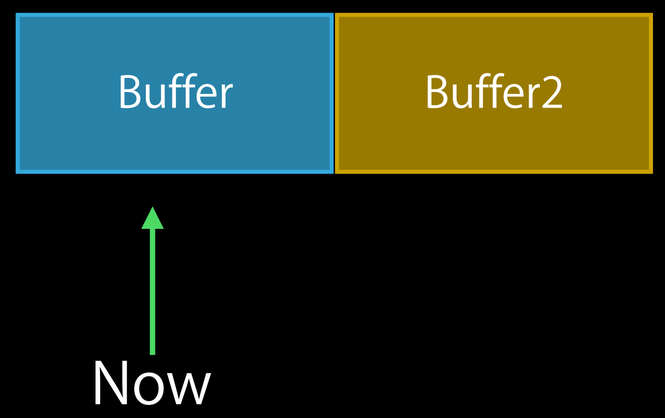


Buffer Schedule Options

AVAudioPlayerNode class

2. Append new buffer

```
[player scheduleBuffer:buffer atTime:nil options:nil completionHandler:nil];
[player play]
[player scheduleBuffer:buffer2 atTime:nil options:nil completionHandler:nil];
```

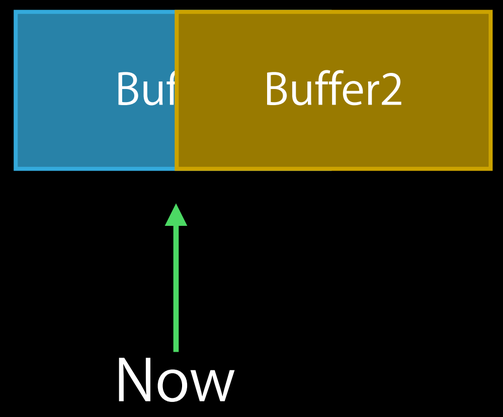


Buffer Schedule Options

AVAudioPlayerNode class

3. Interrupt with new buffer

```
[player scheduleBuffer:buffer atTime:nil options:nil completionHandler:nil];
[player play]
[player scheduleBuffer:buffer2 atTime:nil
options:AVAudioPlayerNodeBufferInterrupts completionHandler:nil];
```

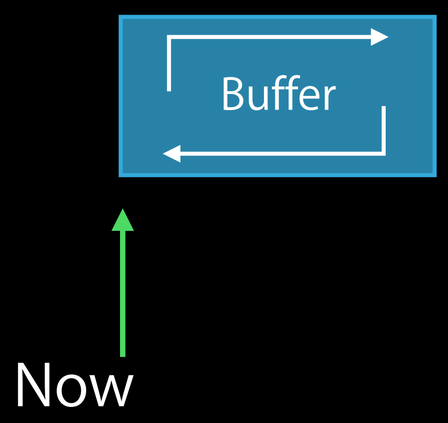


Buffer Schedule Options

AVAudioPlayerNode class

4. Loop single buffer

```
[player scheduleBuffer:buffer atTime:nil options:AVAudioPlayerNodeBufferLoops
completionHandler:nil];
[player play];
```

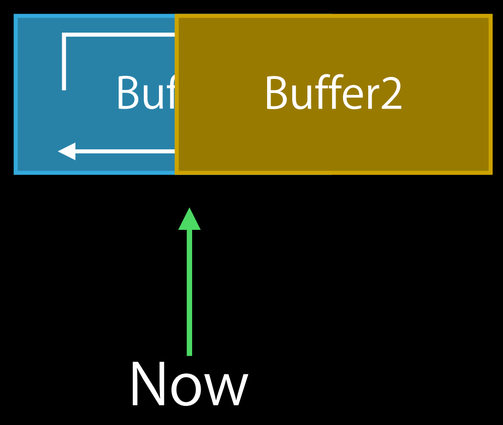


Buffer Schedule Options

AVAudioPlayerNode class

5. Interrupt looping buffer

```
[player scheduleBuffer:buffer atTime:nil options:AVAudioPlayerNodeBufferLoops
completionHandler:nil];
[player play];
[player scheduleBuffer:buffer atTime:nil
options:AVAudioPlayerNodeBufferInterrupts completionHandler:nil];
```

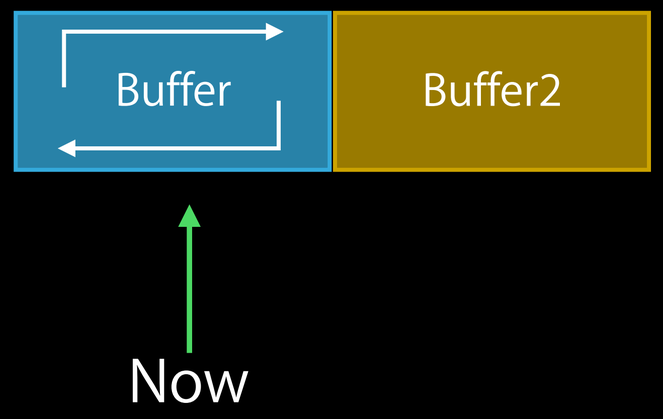


Buffer Schedule Options

AVAudioPlayerNode class

6. Interrupt looping buffer after current loop finishes

```
[player scheduleBuffer:buffer atTime:nil options:AVAudioPlayerNodeBufferLoops
completionHandler:nil];
[player play];
[player scheduleBuffer:buffer atTime:nil
options:AVAudioPlayerNodeBufferInterruptsAtLoop completionHandler:nil];
```

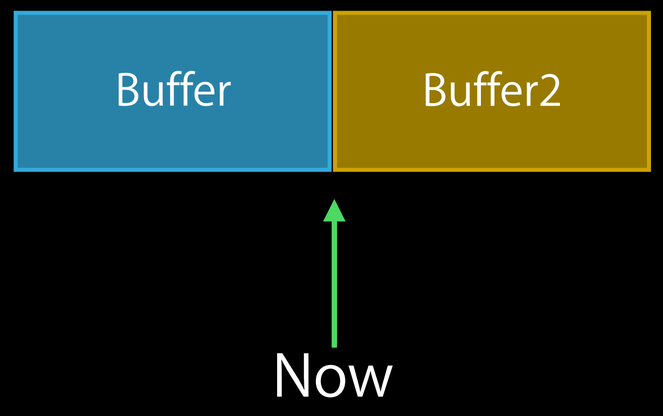


Buffer Schedule Options

AVAudioPlayerNode class

6. Interrupt looping buffer after current loop finishes

```
[player scheduleBuffer:buffer atTime:nil options:AVAudioPlayerNodeBufferLoops
completionHandler:nil];
[player play];
[player scheduleBuffer:buffer atTime:nil
options:AVAudioPlayerNodeBufferInterruptsAtLoop completionHandler:nil];
```



Buffer Looping Example

AVAudioPlayerNode class

Attack, Sustain, Release

Buffer Looping Example

AVAudioPlayerNode class

Attack, Sustain, Release


```
[player scheduleBuffer:attackBuffer atTime:nil options:nil
completionHandler:nil];

[player scheduleBuffer:sustainBuffer atTime:nil
options:AVAudioPlayerNodeBufferLoops completionHandler:nil];

[player play];

// after some time
[player scheduleBuffer:releaseBuffer atTime:nil
options:AVAudioPlayerNodeBufferInterruptsAtLoop completionHandler:nil];
```

Buffer Looping Example

AVAudioPlayerNode class

Attack, Sustain, Release


```
[player scheduleBuffer:attackBuffer atTime:nil options:nil
completionHandler:nil];

[player scheduleBuffer:sustainBuffer atTime:nil
options:AVAudioPlayerNodeBufferLoops completionHandler:nil];

[player play];

// after some time
[player scheduleBuffer:releaseBuffer atTime:nil
options:AVAudioPlayerNodeBufferInterruptsAtLoop completionHandler:nil];
```

Buffer Looping Example

AVAudioPlayerNode class

Attack, Sustain, Release


```
[player scheduleBuffer:attackBuffer atTime:nil options:nil
completionHandler:nil];

[player scheduleBuffer:sustainBuffer atTime:nil
options:AVAudioPlayerNodeBufferLoops completionHandler:nil];

[player play];

// after some time
[player scheduleBuffer:releaseBuffer atTime:nil
options:AVAudioPlayerNodeBufferInterruptsAtLoop completionHandler:nil];
```

Buffer Looping Example

AVAudioPlayerNode class

Attack, Sustain, Release


```
[player scheduleBuffer:attackBuffer atTime:nil options:nil
completionHandler:nil];

[player scheduleBuffer:sustainBuffer atTime:nil
options:AVAudioPlayerNodeBufferLoops completionHandler:nil];

[player play];

// after some time
[player scheduleBuffer:releaseBuffer atTime:nil
options:AVAudioPlayerNodeBufferInterruptsAtLoop completionHandler:nil];
```

Schedule to Play in the Future

AVAudioPlayerNode class

Buffers and files can be scheduled to play in the future

```
AVAudioTime *tenSecsInTheFuture = [AVAudioTime timeWithSampleTime:(10 *
buffer.format.sampleRate) atRate:buffer.format.sampleRate];

[player scheduleBuffer:buffer atTime: tenSecsInTheFuture options:nil
completionHandler:nil];

[player play];
```

Schedule to Play in the Future

AVAudioPlayerNode class

Buffers and files can be scheduled to play in the future

```
AVAudioTime *tenSecsInTheFuture = [AVAudioTime timeWithSampleTime:(10 *
buffer.format.sampleRate) atRate:buffer.format.sampleRate];

[player scheduleBuffer:buffer atTime: tenSecsInTheFuture options:nil
completionHandler:nil];

[player play];
```

Node Tap

AVAudioNode class

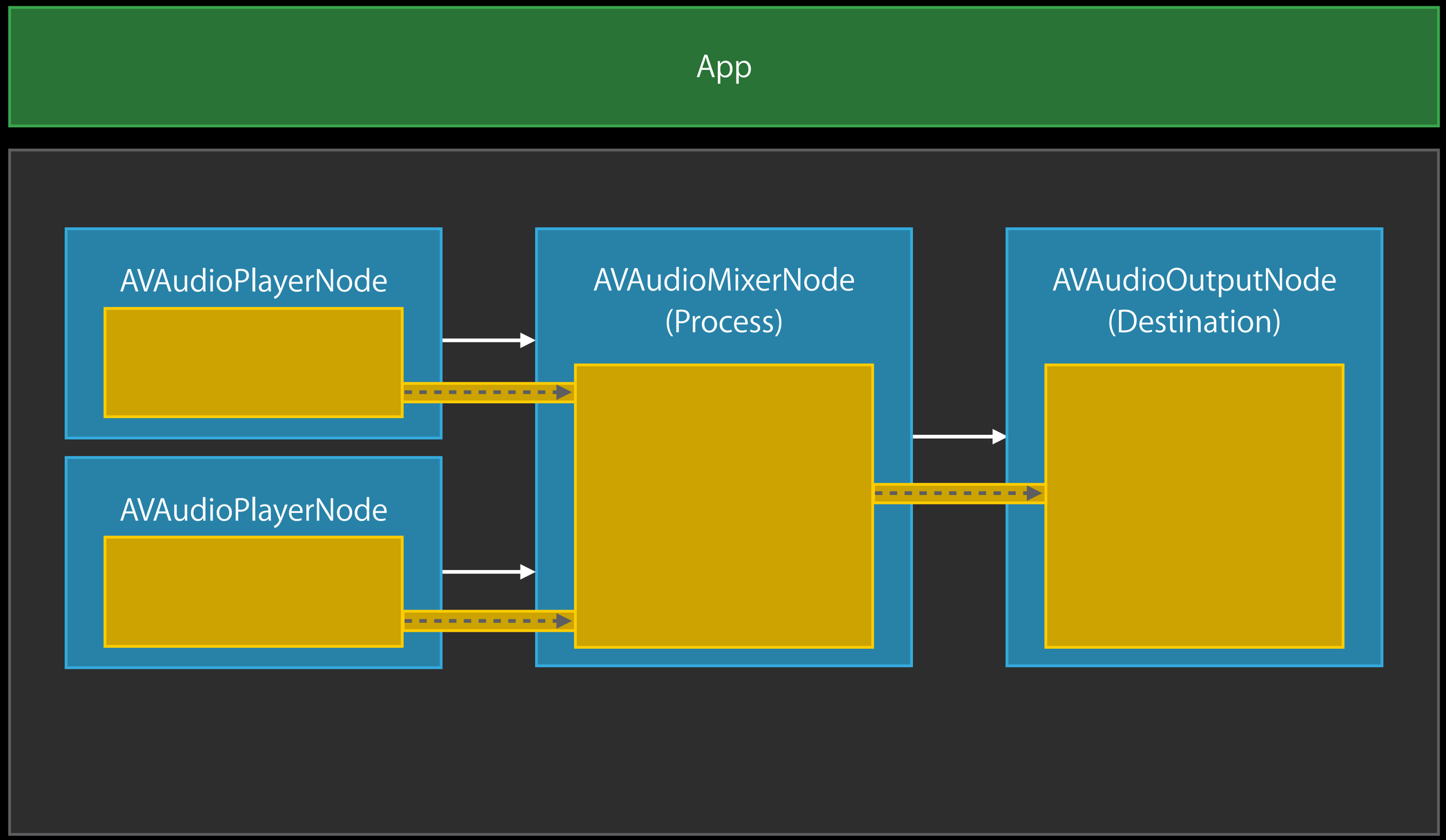
Node tap captures the output of a node

- Record microphone data
- Record a live performance in a music application
- Capture the output mix of a game

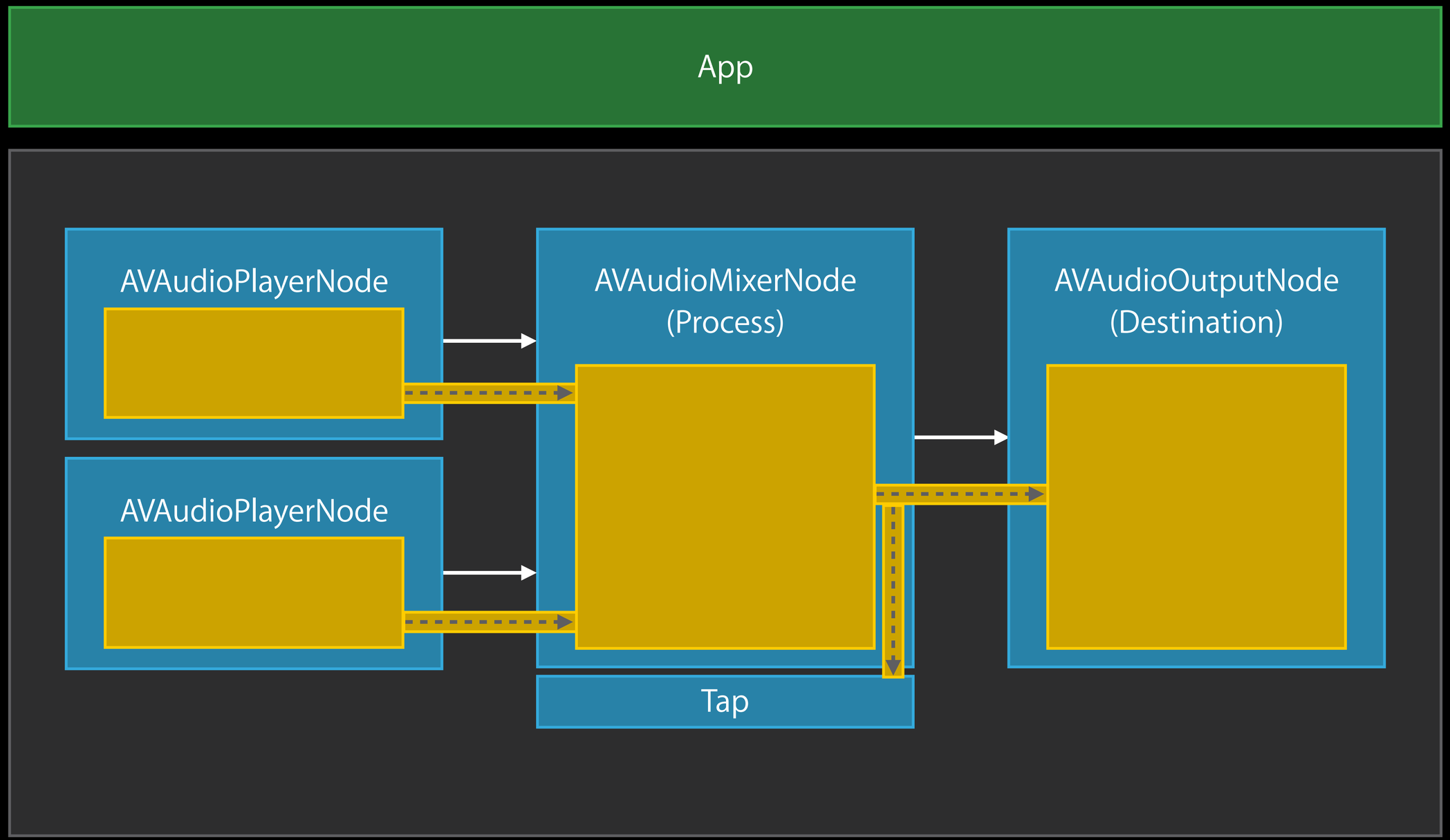
One tap per node’s output bus

Captured data is returned in a callback block

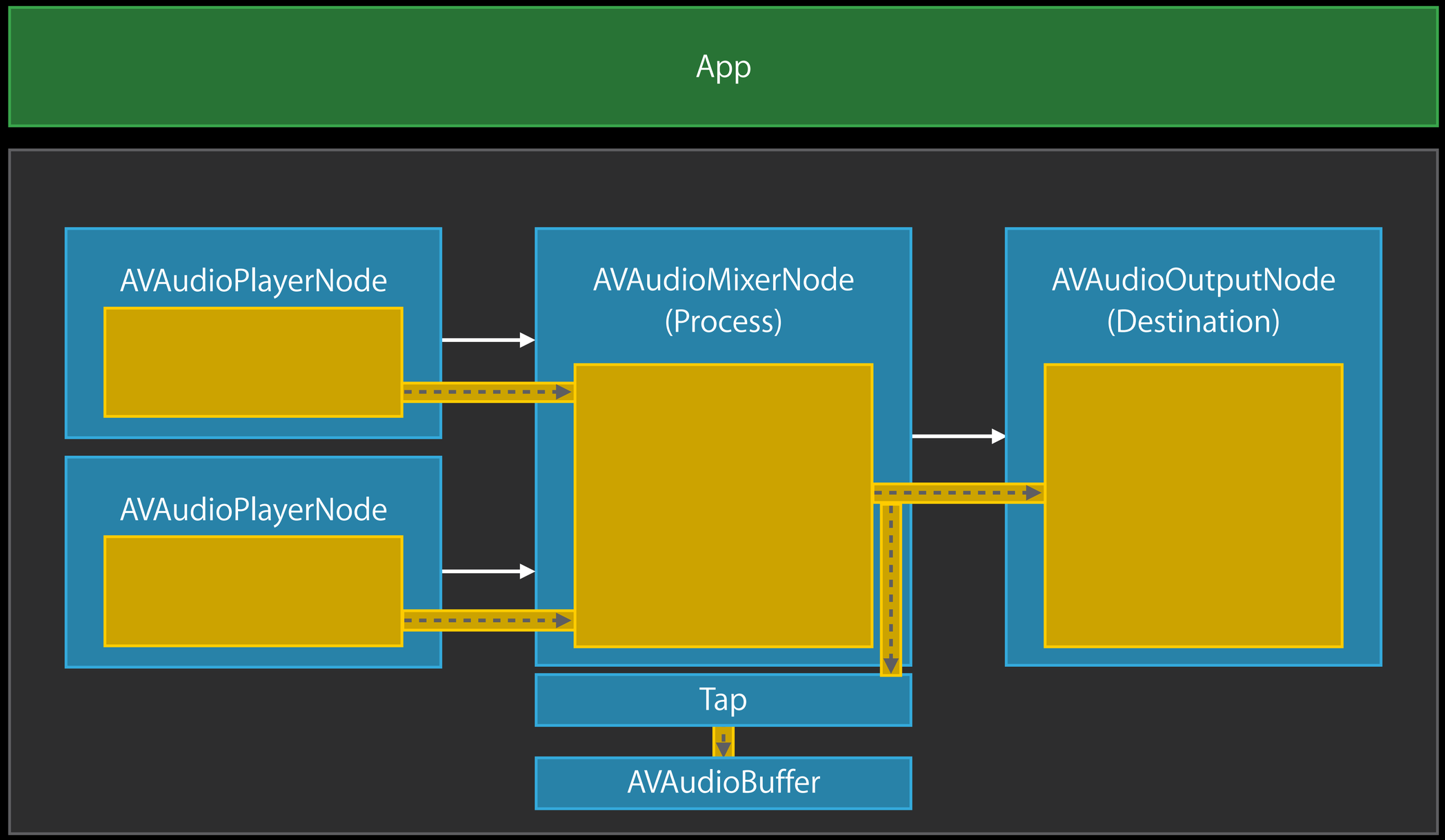
Node Tap


App
AVAudioPlayerNode
AVAudioPlayerNode
AVAudioMixerNode
(Process)
AVAudioOutputNode
(Destination)

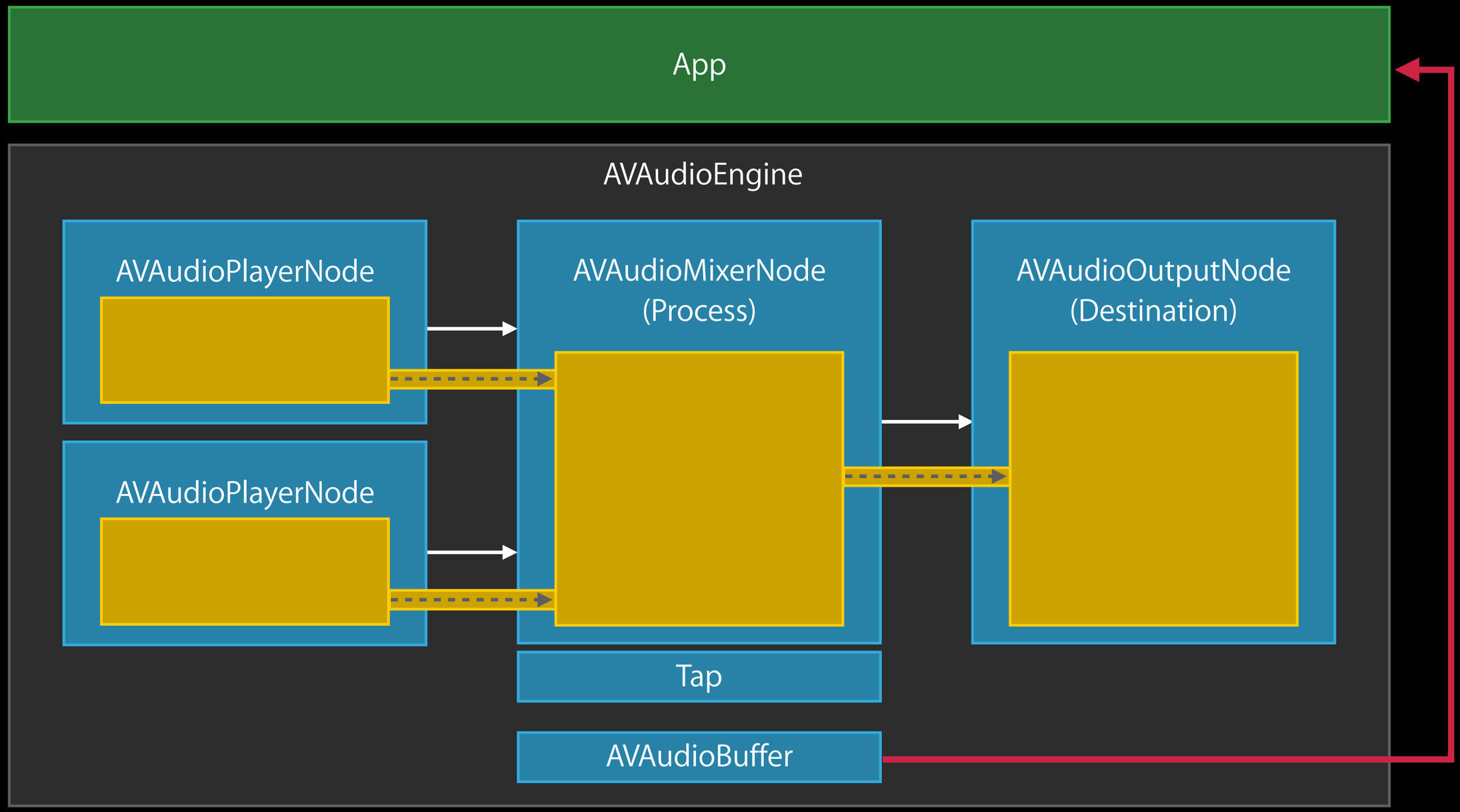
Node Tap


App
AVAudioPlayerNode
AVAudioPlayerNode
AVAudioMixerNode
(Process)
AVAudioOutputNode
(Destination)
Tap

Node Tap


App
AVAudioPlayerNode
AVAudioPlayerNode
AVAudioMixerNode
(Process)
AVAudioOutputNode
(Destination)
Tap
AVAudioBuffer

Node Tap


App
AVAudioEngine
AVAudioPlayerNode
AVAudioPlayerNode
AVAudioMixerNode
(Process)
AVAudioOutputNode
(Destination)
Tap
AVAudioBuffer

Install Tap

Code example

```
[mixer installTapOnBus:0 bufferSize:4096 format:[mixer outputFormatForBus:0]
block:^(AVAudioPCMBuffer *buffer, AVAudioTime *when) {
            // perform operation using data
       }];
```

Audio Data and the Render Thread

Players push data onto the render thread

Node taps pull data from the render thread

Getting the Mic in the Mix

AVAudioInputNode class

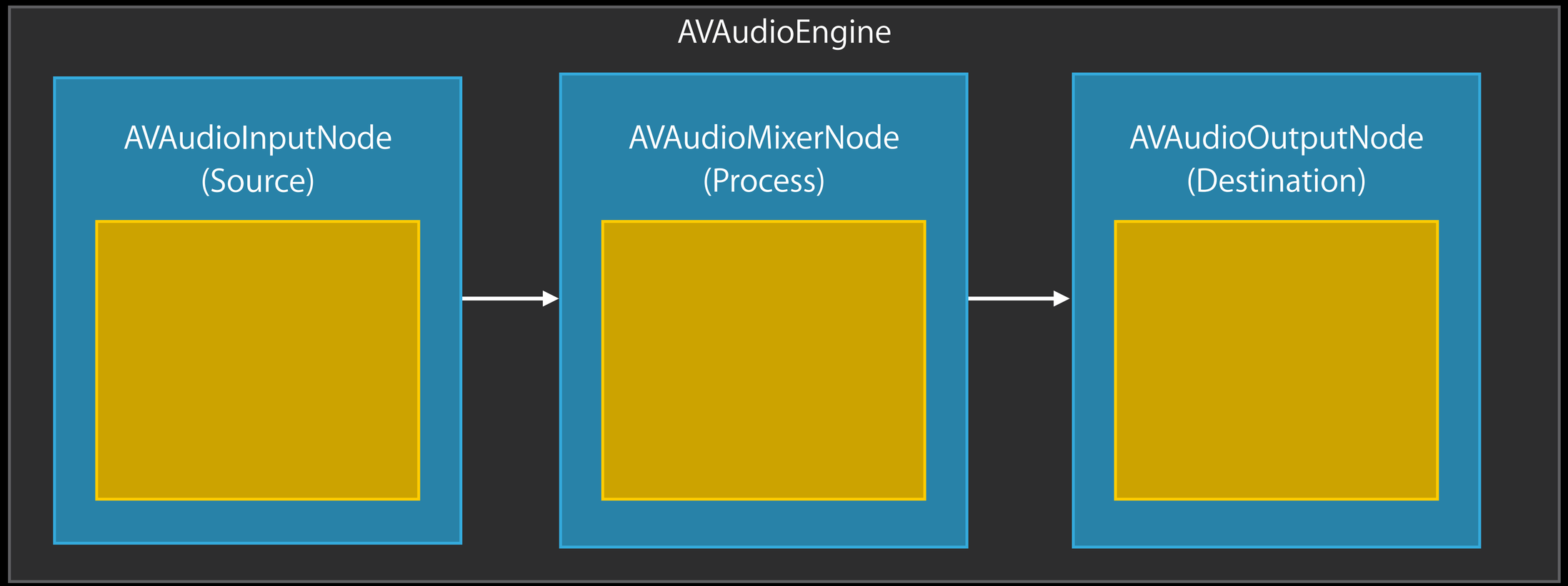
Engine has an implicit input node

Input node receives audio data from the input hardware

Data is pulled in an active connection chain

Standalone instance cannot be created

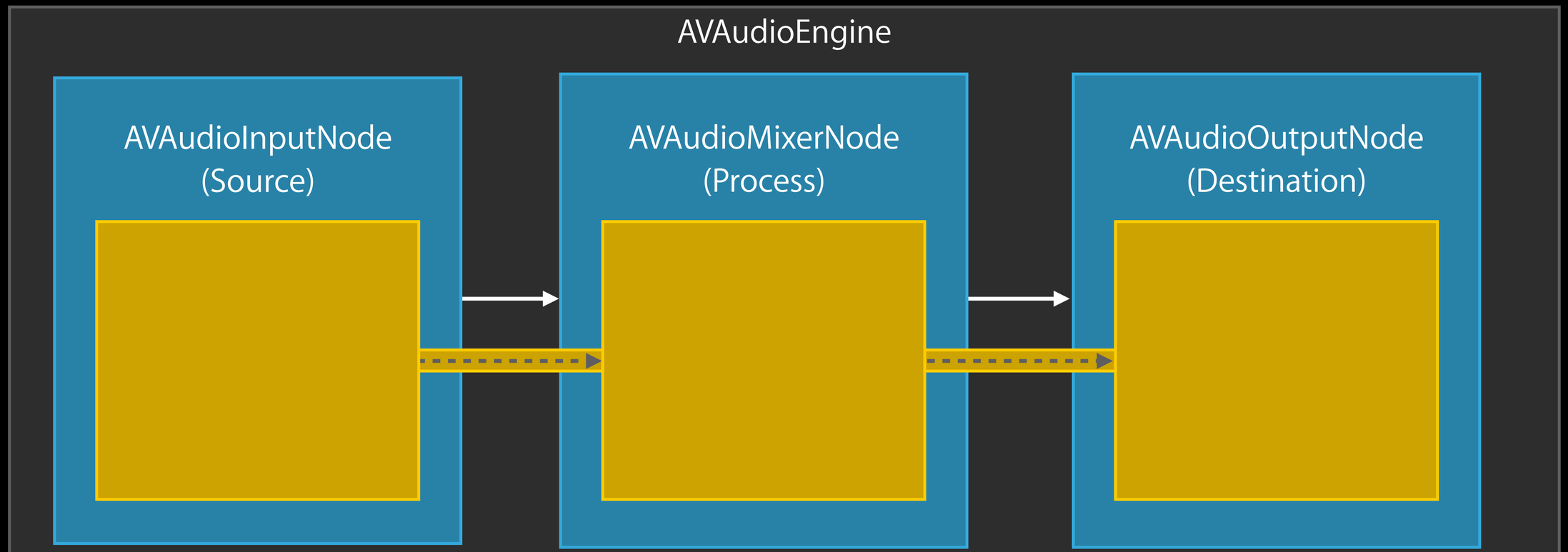
Connect Input Node



Connect Input Node

Engine is running, input node is active

Data is pulled from the input node



Connect Input Node

Code example

```
AVAudioInputNode *input = [engine inputNode];

[engine connect:input to:mixer format:[input inputFormatForBus:0]];

[engine startAndReturnError:&error];
```

Connect Input Node

Code example

```
AVAudioInputNode *input = [engine inputNode];

[engine connect:input to:mixer format:[input inputFormatForBus:0]];

[engine startAndReturnError:&error];
```

Connect Input Node

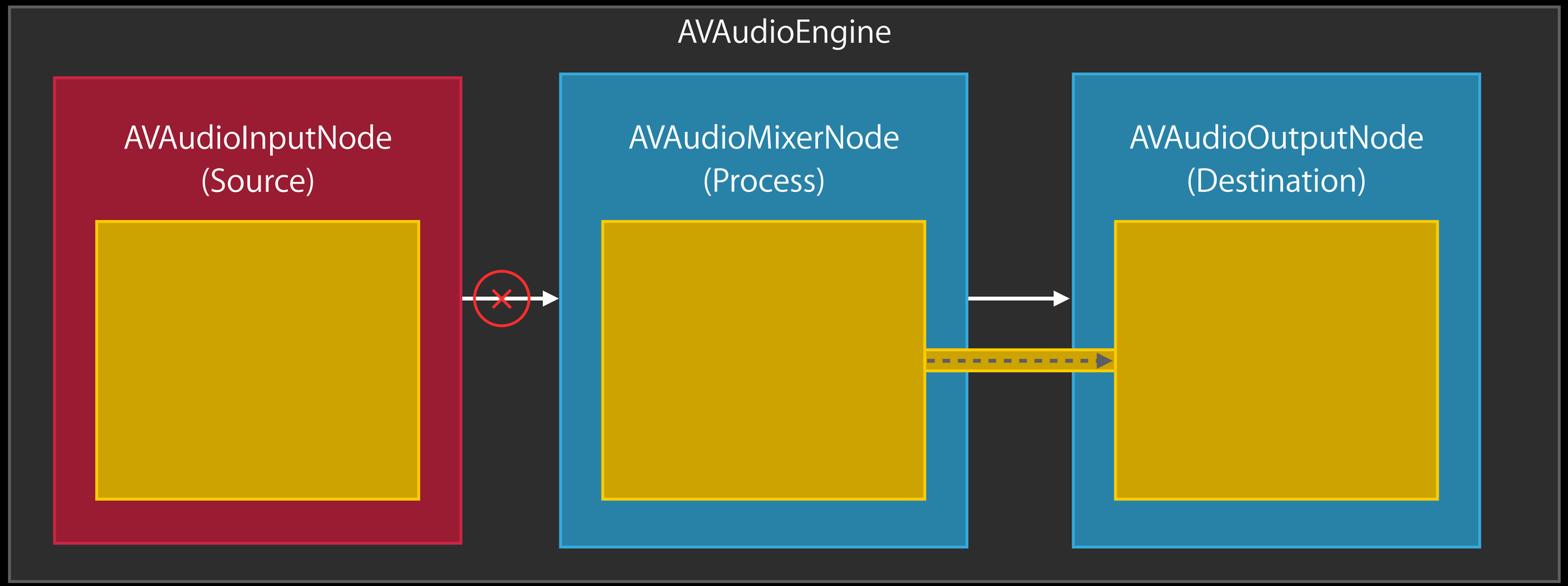
Code example

```
AVAudioInputNode *input = [engine inputNode];

[engine connect:input to:mixer format:[input inputFormatForBus:0]];

[engine startAndReturnError:&error];
```

Disconnect Input Node

Engine is running but input node is inactive

Data will not be pulled from the input node



Disconnect Input Node

Code example

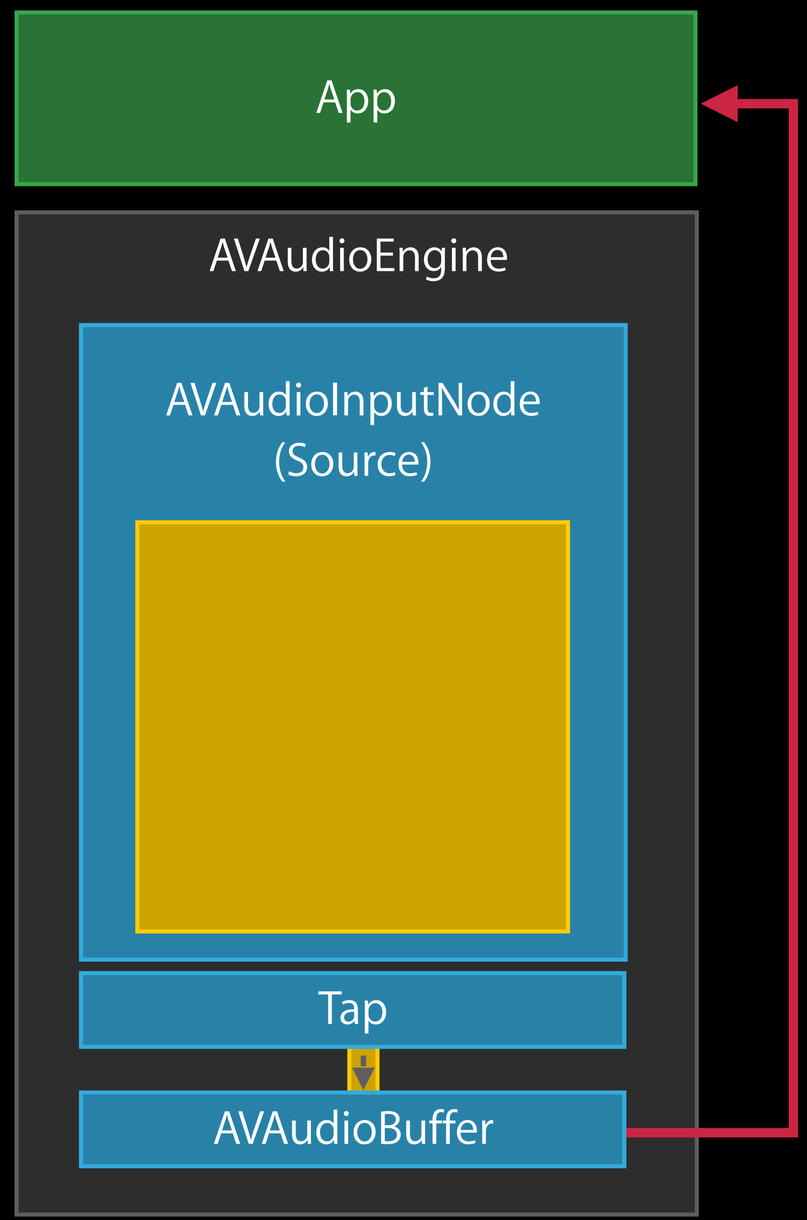
```
[engine disconnectNodeOutput:input]
```

Capturing Input

AVAudioInputNode class

Use a node tap directly with the input node

Data is pulled when engine is running



Effect Nodes

AVAudioUnitEffect, AVAudioUnitTimeEffect

Effects are nodes that process data

Two main categories

- AVAudioUnitEffect
- AVAudioUnitTimeEffect

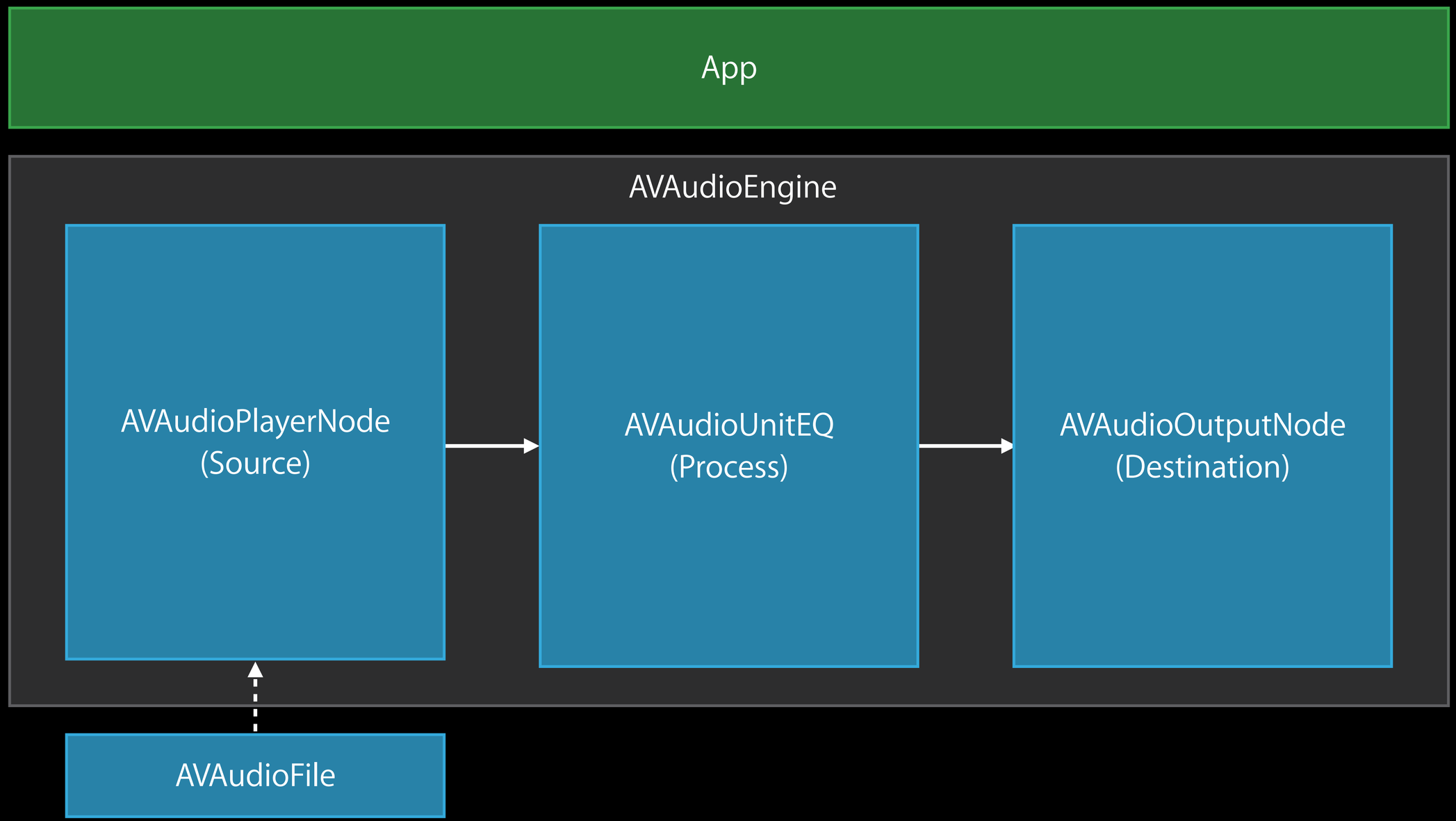
Effect Nodes

AVAudioUnitEffect	AVAudioUnitTimeEffect
N frames in, N frames out	X frames in, Y frames out
Can be connected to input node	Cannot be connected to input node

Currently Available Effects

AVAudioUnitEffect	AVAudioUnitTimeEffect
AVAudioUnitDelay	AVAudioUnitVarispeed
AVAudioUnitDistortion	AVAudioUnitTimePitch
AVAudioUnitEQ	
AVAudioUnitReverb	

Effect Node Example



EQ Node Setup

Effect node code example

```
AVAudioUnitEQ *eq = [[AVAudioUnitEQ alloc] initWithNumberOfBands:2];

AVAudioUnitEQFilterParameters *filterParameters = eq.bands[0];
filterParameters.filterType = AVAudioUnitEQFilterTypeHighPass;
filterParameters.frequency = 80;
filterParameters = eq.bands[1];
filterParameters.filterType = AVAudioUnitEQFilterTypeParametric;
filterParameters.frequency = 500;
filterParameters.bandwidth = 2.0;
filterParameters.gain = 4.0;
```

EQ Node Setup

Effect node code example

```
AVAudioUnitEQ *eq = [[AVAudioUnitEQ alloc] initWithNumberOfBands:2];

AVAudioUnitEQFilterParameters *filterParameters = eq.bands[0];
filterParameters.filterType = AVAudioUnitEQFilterTypeHighPass;
filterParameters.frequency = 80;

filterParameters = eq.bands[1];
filterParameters.filterType = AVAudioUnitEQFilterTypeParametric;
filterParameters.frequency = 500;
filterParameters.bandwidth = 2.0;
filterParameters.gain = 4.0;
```

Connect and Play

Effect node code example

```
AVAudioFile *file = …
AVAudioPlayerNode *player = …

[engine connect:player to:eq format:file.processingFormat];
[engine connect:eq to:[engine outputNode] format:file.processingFormat];
```

Demo

Channel strip

Kapil Krishnamurthy
Core Audio Rock Star

Mixer Input Bus Settings

AVAudioMixing protocol

AVAudioMixing protocol defines mixer input bus settings

Source nodes conform to this protocol

- Player node
- Input node

Protocol properties take effect when connected to a mixer node

When not connected to a mixer

- Changes to protocol property values are cached

Mixer Input Bus Settings

AVAudioMixing protocol

Common mixing protocol properties

- Volume

```
player.volume = 0.5
```

Stereo mixing protocol properties

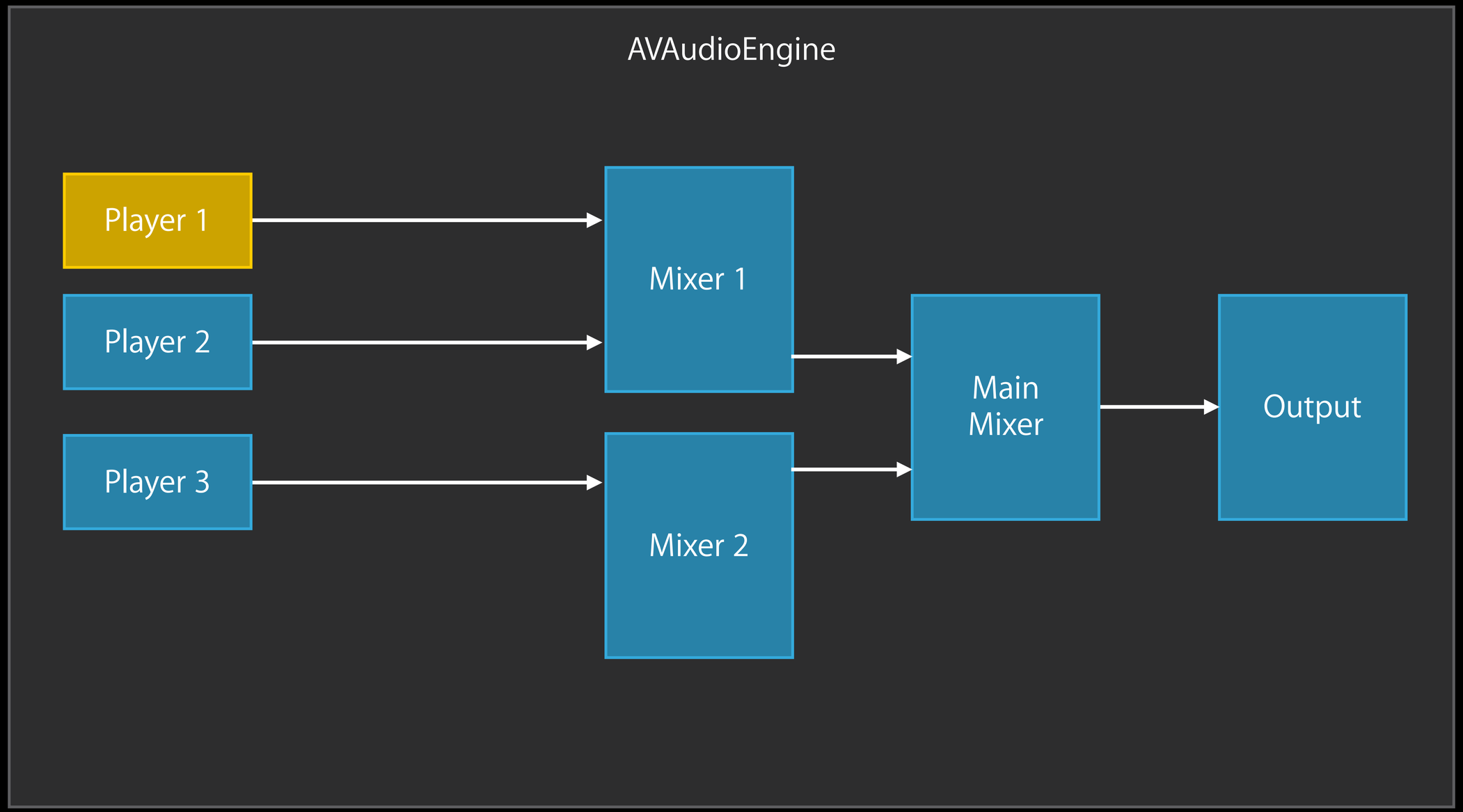
- Pan

```
player.pan = -1.0;
```

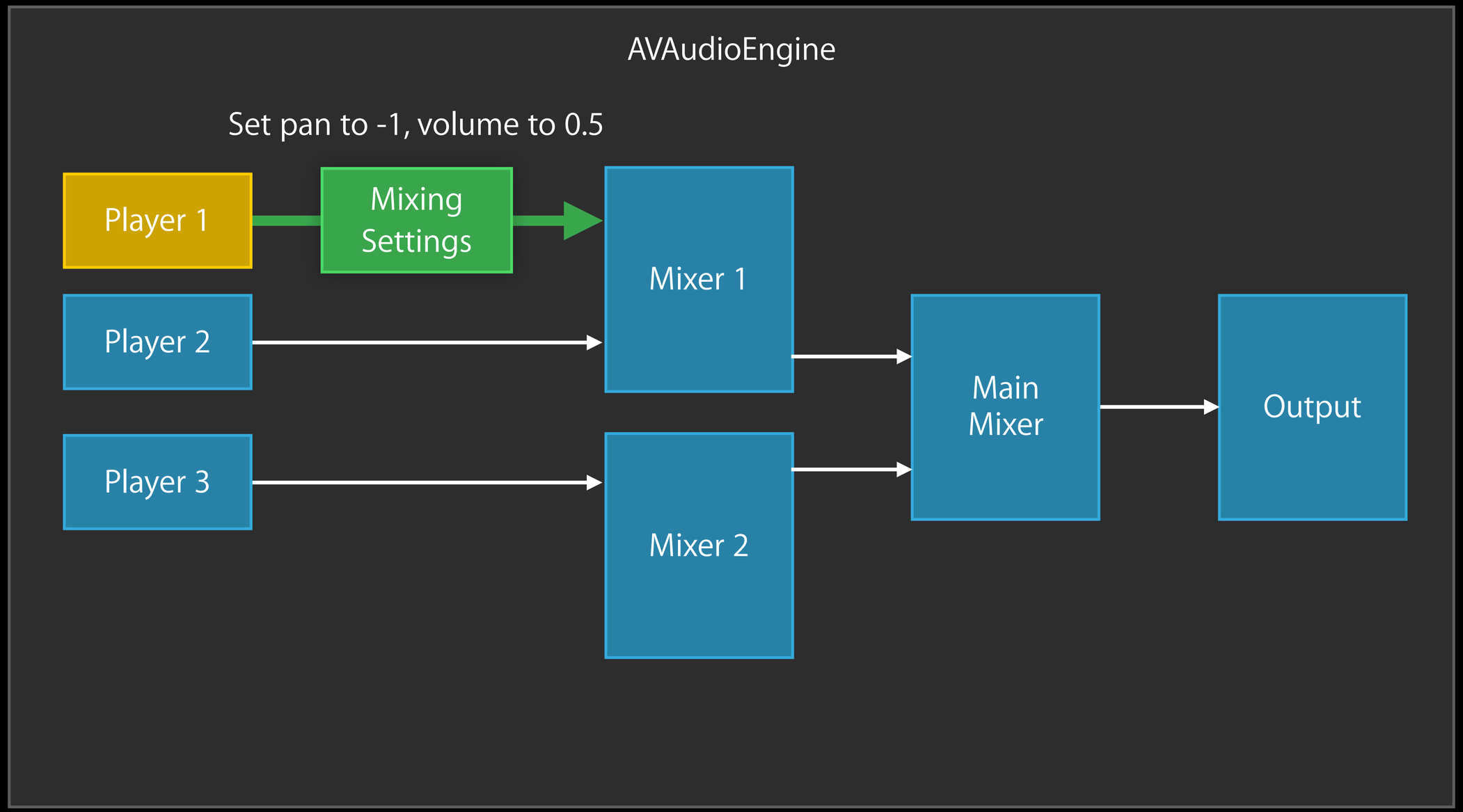
3D mixing protocol properties

- ?

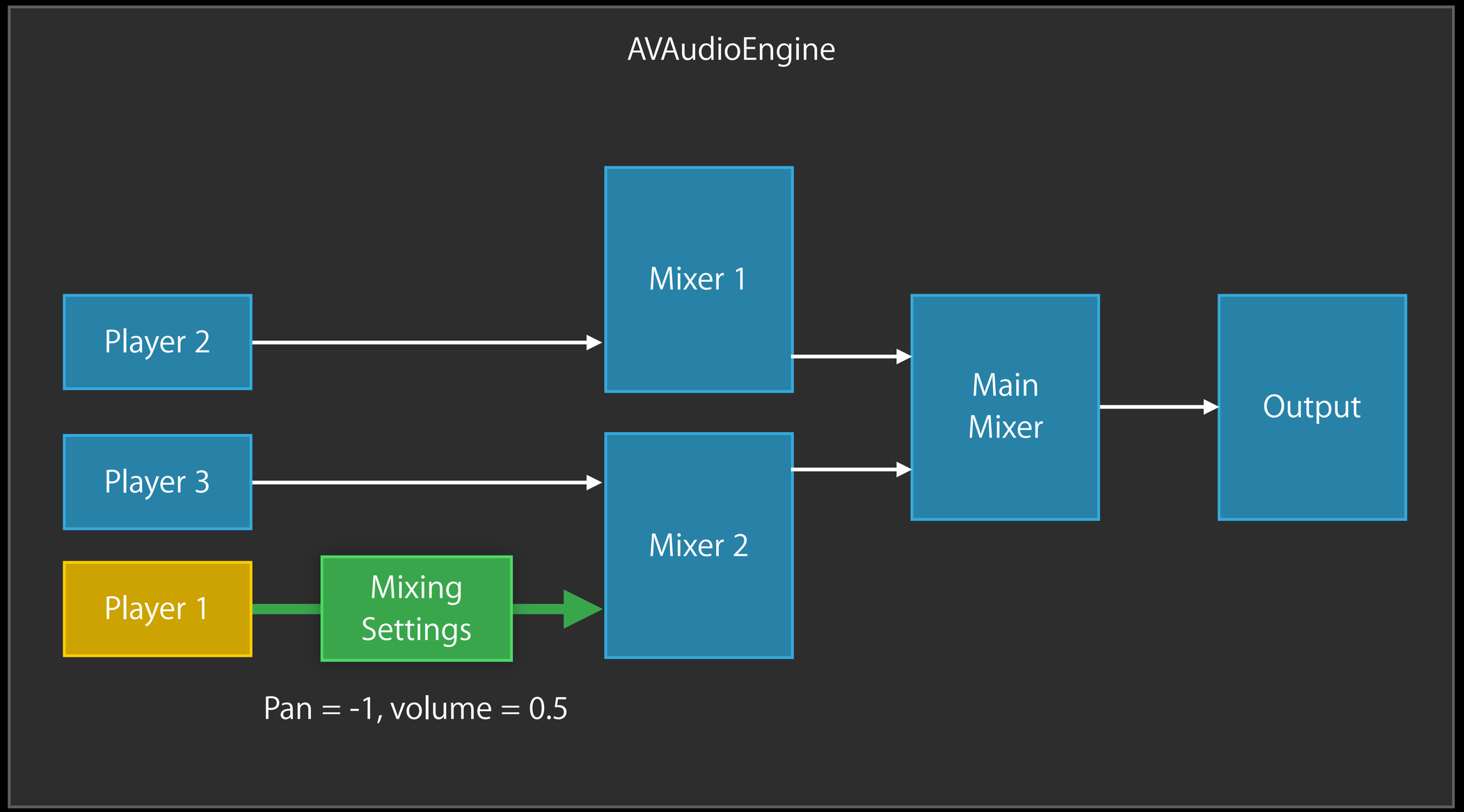
Mixer Input Bus Settings



Mixer Input Bus Settings



Mixer Input Bus Settings



AVAudioEngine

Gaming and 3D audio

Using Existing API

AudioServices	Play short sounds
AVAudioPlayer	Play music, sounds from files
OpenAL	Play sounds that get spatialized (3D)

Trade-Offs

Every API has different nomenclature

AudioServices

- No real-time guarantee
- Sounds < 30 secs

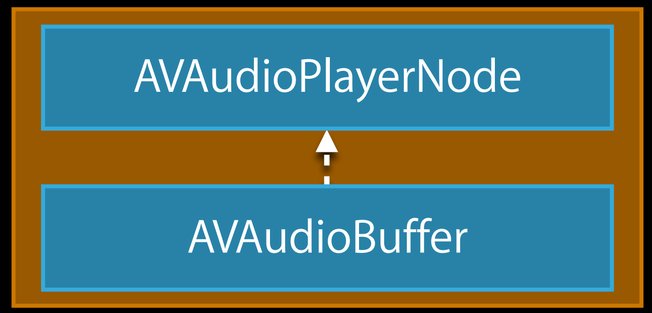
AVAudioPlayer

- Cannot play buffers

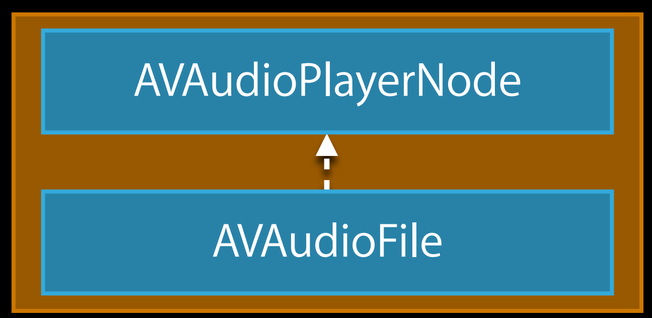
OpenAL

- Cannot play from file
- Cannot play compressed data

Using AVAudioEngine



Play short sounds



Play music, sounds from files

Play sounds that get spatialized (3D)

Environment Node

AVAudioEnvironmentNode class

Mixer node that simulates a 3D space

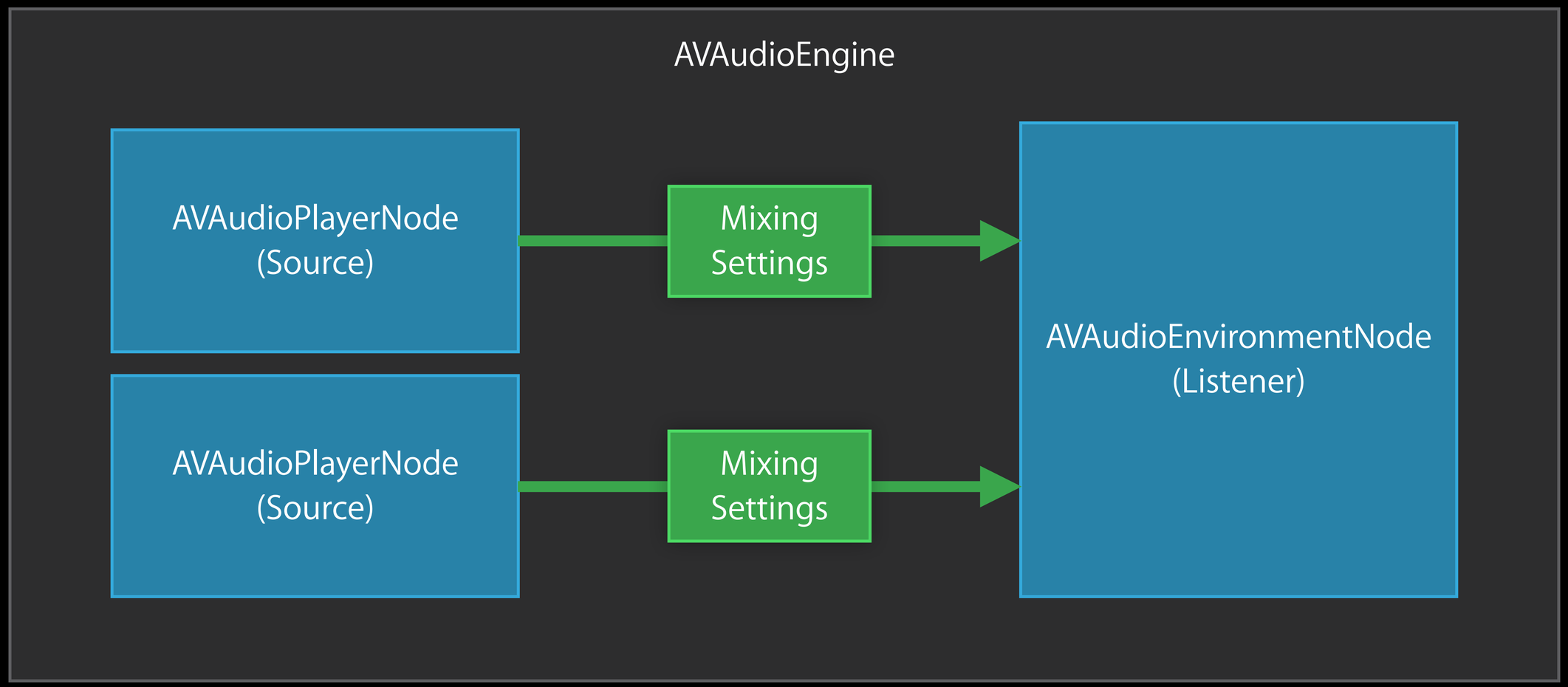
Implicit listener

Source nodes act as sources in this space

Source node properties are set via AVAudioMixing protocol

Only mono inputs are spatialized

Environment Node



What Makes It Sound 3D?

Source

- Position
- Rendering algorithm
- Obstruction, occlusion

Environment

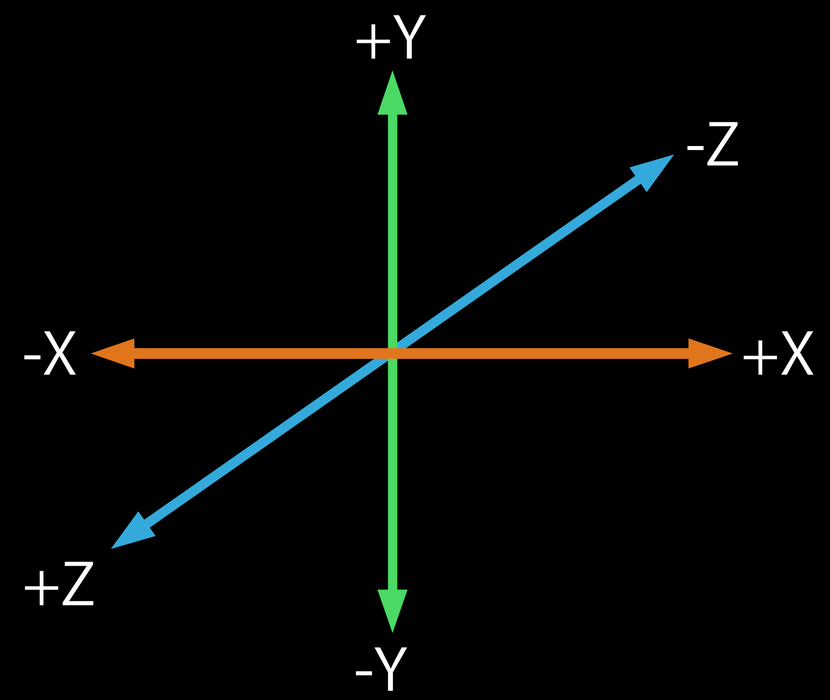
- Listener position, orientation
- Distance attenuation
- Reverberation

Source Position

AVAudioMixing protocol

Right-handed cartesian coordinate system

```
player.position =
AVAudioMake3DPoint(-2.0, 0.0, 5.0);
```



Source Rendering Algorithm

AVAudioMixing protocol

Listener's directional cues

- Inter-aural time difference
- Inter-aural level difference
- Effect of head and ear filtering

Available rendering algorithms

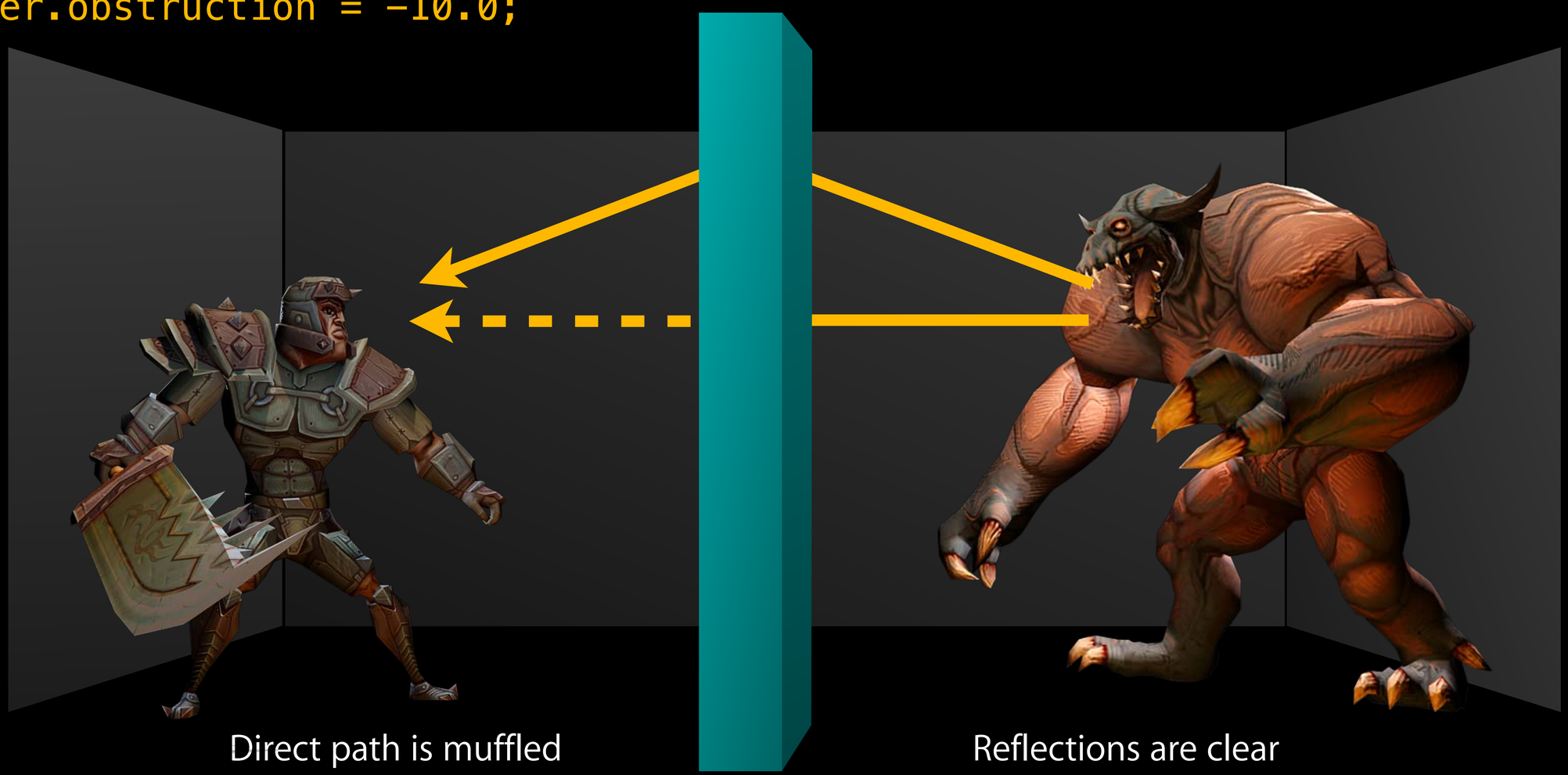
- Equal Power Panning
- Spherical Head
- HRTF
- Sound Field

```
player.renderingAlgorithm = AVAudio3DMixingRenderingAlgorithmEqualPowerPanning;
```

Source Obstruction

AVAudioMixing protocol

```
player.obstruction = -10.0;
```



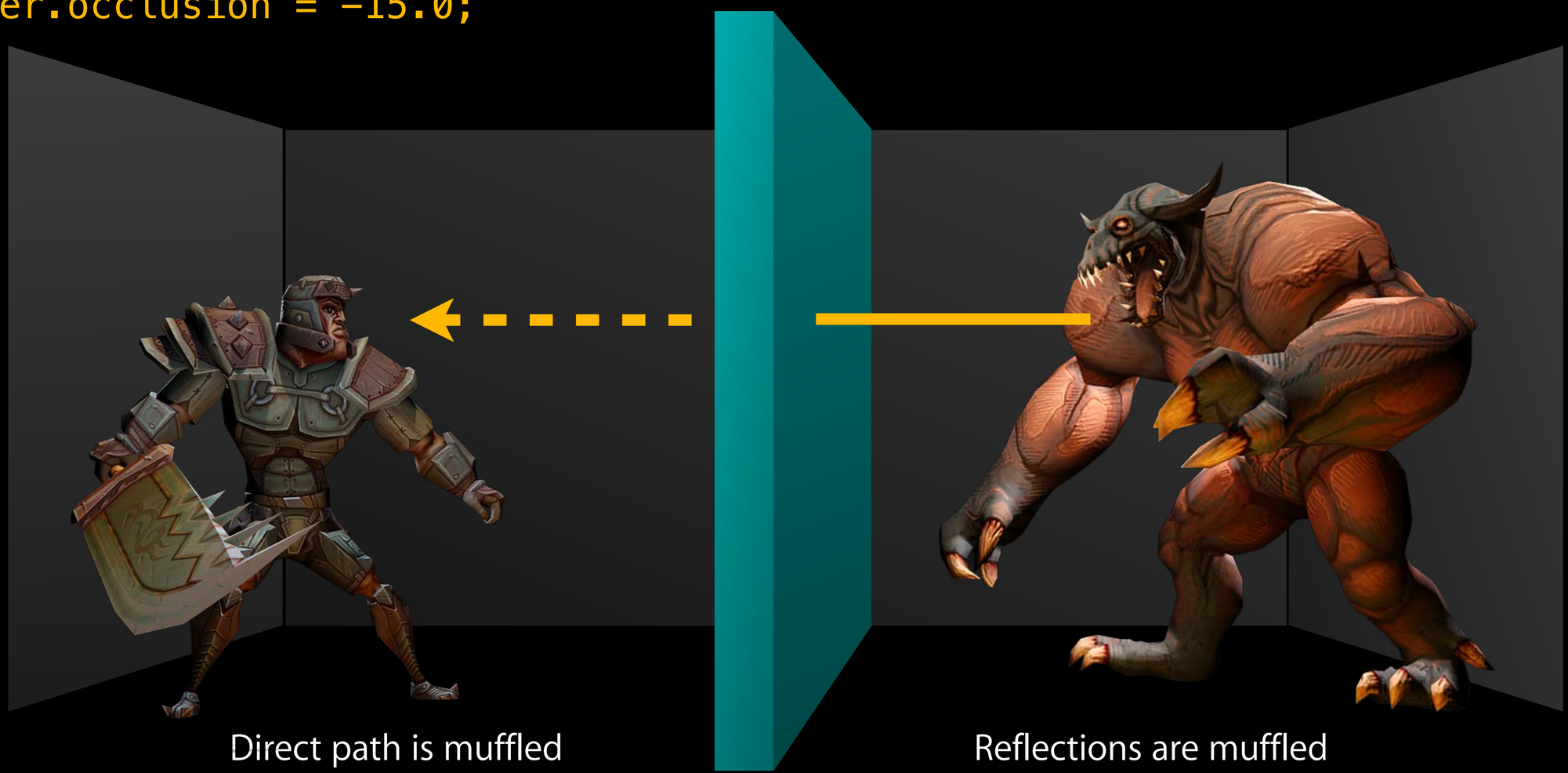
Direct path is muffled

Reflections are clear

Source Occlusion

AVAudioMixing protocol

```
player.occlusion = -15.0;
```



Direct path is muffled

Reflections are muffled

Listener Position and Orientation

AVAudioEnvironmentNode class

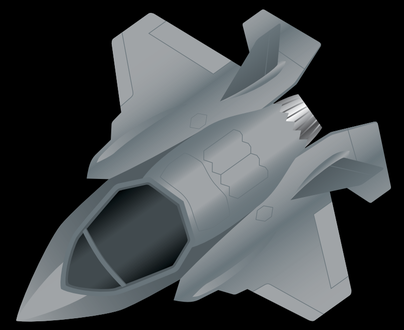
Implicit listener

Listener coordinates

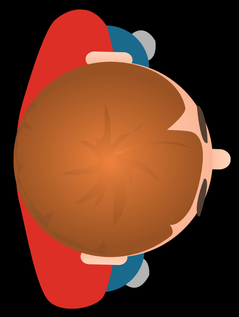
- Right handed cartesian coordinate system

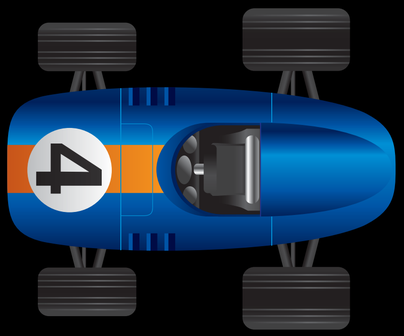
Listener orientation

- Vector or angular based orientation



```
environment.listenerPosition =
AVAudioMake3DPoint(-5.0, 0.0, 0.0);

environment.listenerAngularOrientation
= AVAudioMake3DAngularOrientation(90.0,
0.0, 0.0);
```



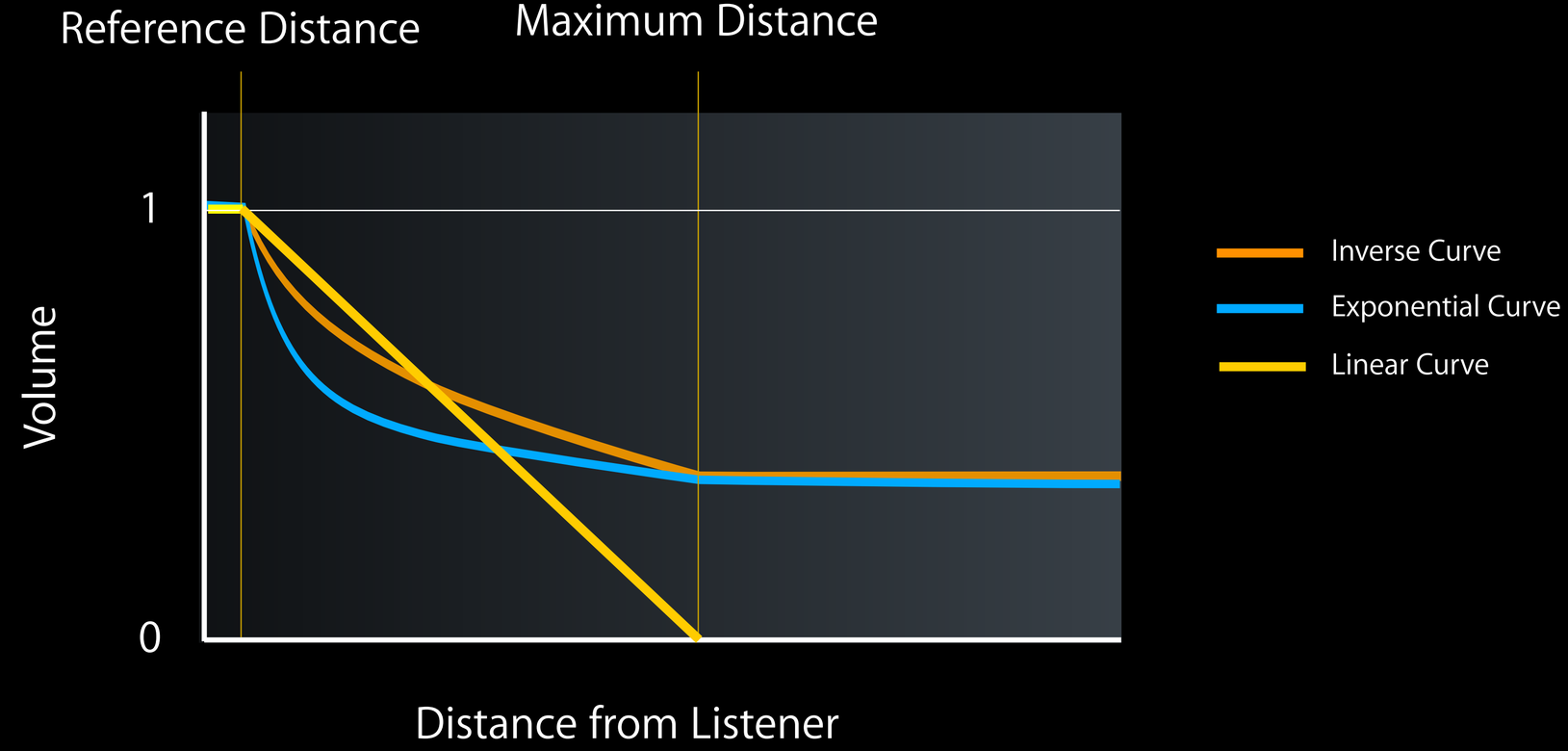


Distance Attenuation

AVAudioEnvironmentNode class

Attenuation of sound as source moves away from listener

Multiple distance attenuation models available



Distance Attenuation

AVAudioEnvironmentNode class

Attenuation of sound as source moves away from listener

Multiple distance attenuation models available

```
AVAudioEnvironmentDistanceAttenuationParameters *dap =
environment.distanceAttenuationParameters;

dap.distanceAttenuationModel =
AVAudioEnvironmentDistanceAttenuationModelInverse;

dap.referenceDistance = 5.0;
dap.maximumDistance = 100.0;
dap.rolloffFactor = 1.0;
```

Reverberation

AVAudioEnvironmentNode class

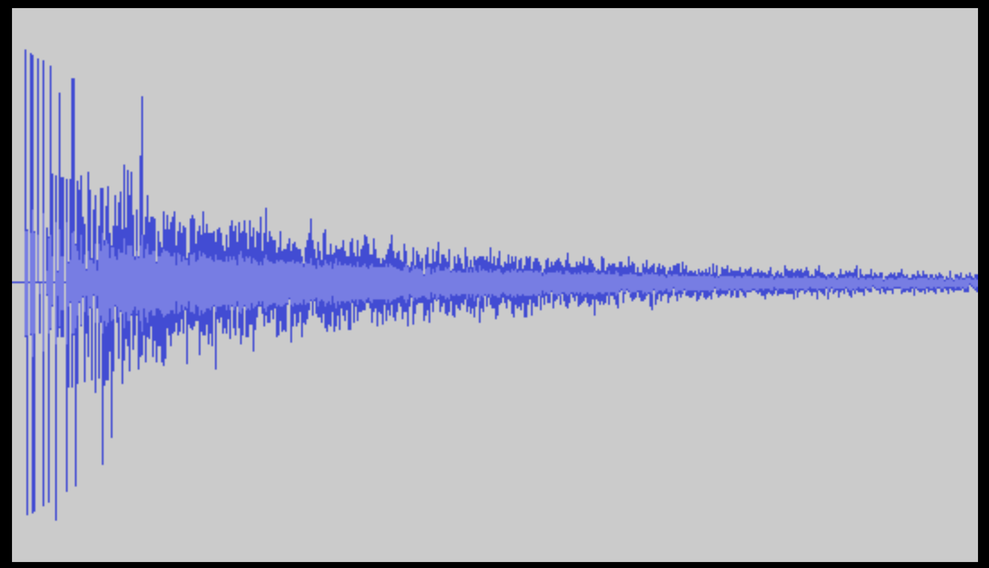
Simulates sound reflections within a space

- Room size
- Decay time
- High frequency absorption

Built in reverb with factory presets

Blend individual amount of reverb for each source

Single post-reverb filter



Reverberation

AVAudioEnvironmentNode class

```
AVAudioEnvironmentReverbParameters *reverbParameters =
environment.reverbParameters;

reverbParameters.enable = YES;
[reverbParameters loadFactoryReverbPreset:AVAudioUnitReverbPresetLargeHall];

player.reverbBlend = 0.2;
```

Moving Between Mixer Nodes

AVAudioMixing protocol

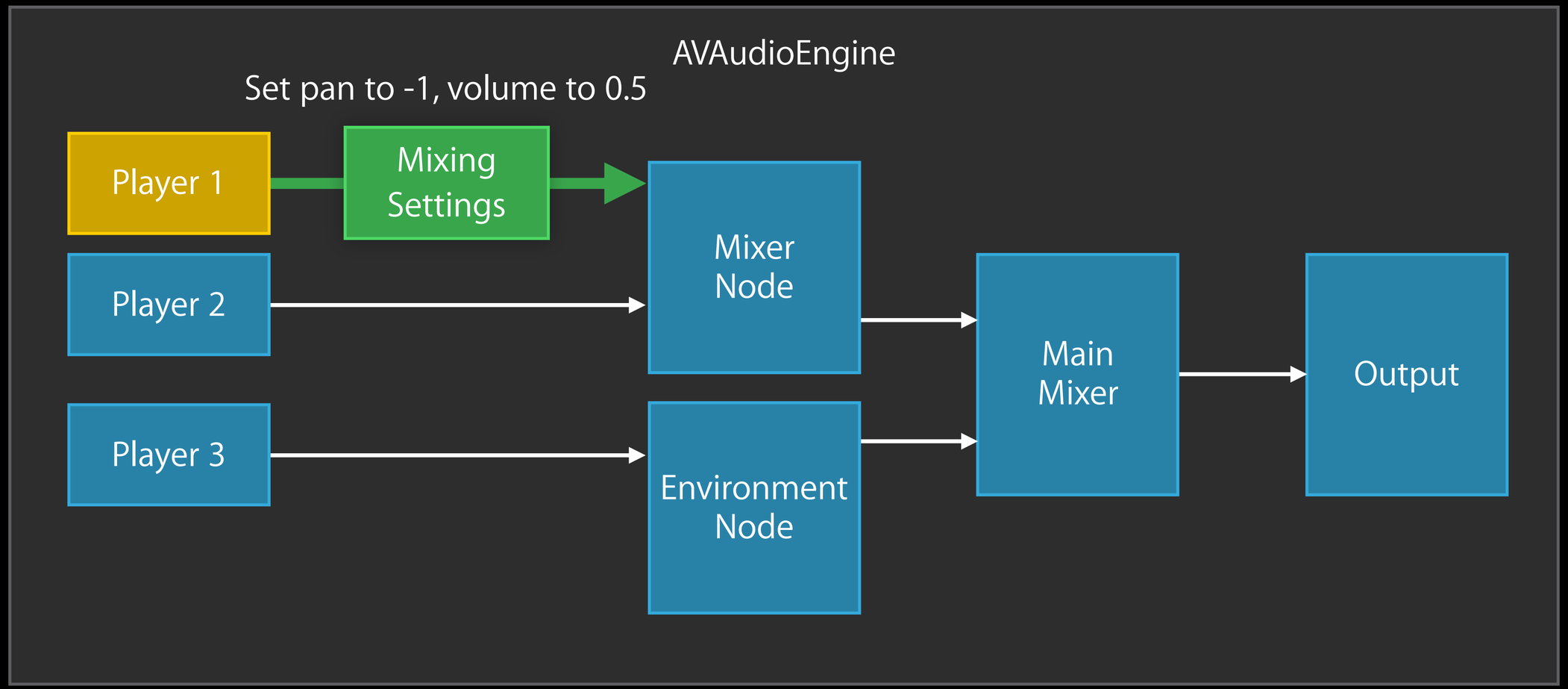
Protocol defines common, stereo and 3D properties

- AVAudioMixerNode responds to stereo properties
- AVAudioEnvironmentNode responds to 3D properties

Property changes are cached when not applicable

Moving Between Mixer Nodes

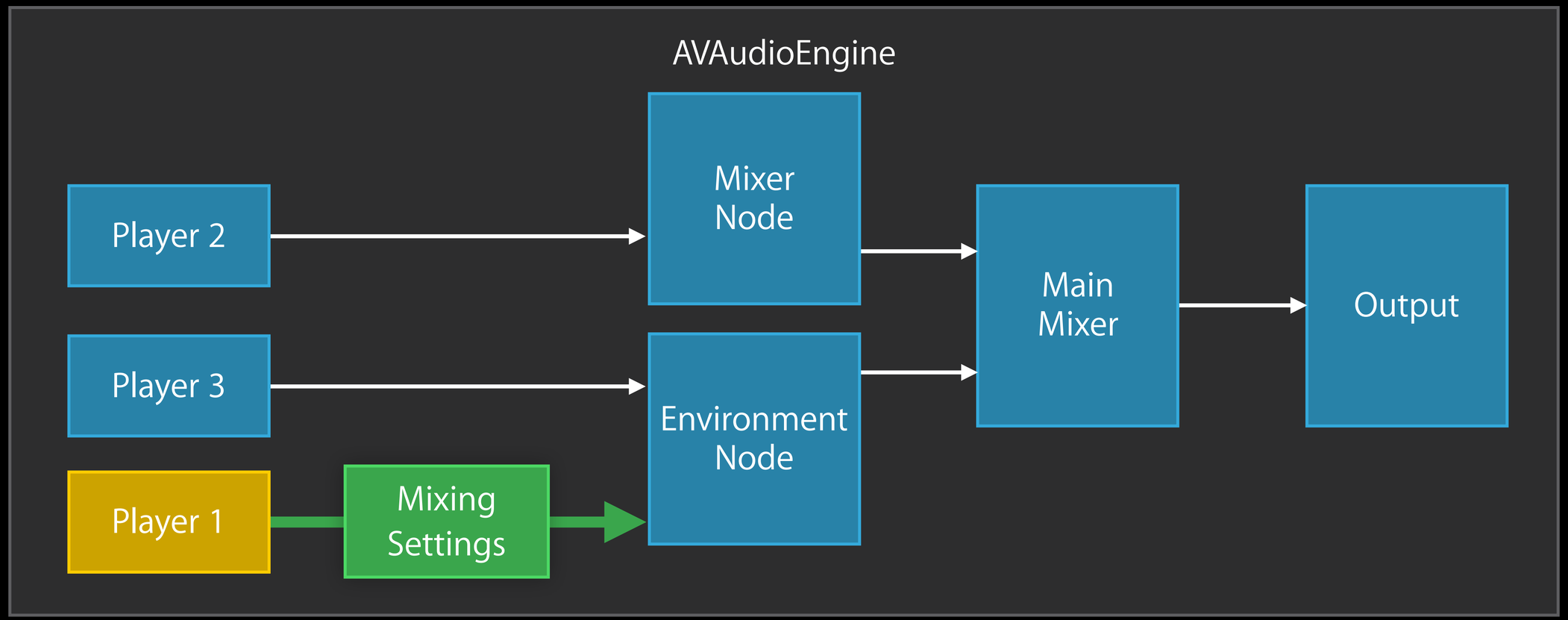
Pan and volume properties takes effect



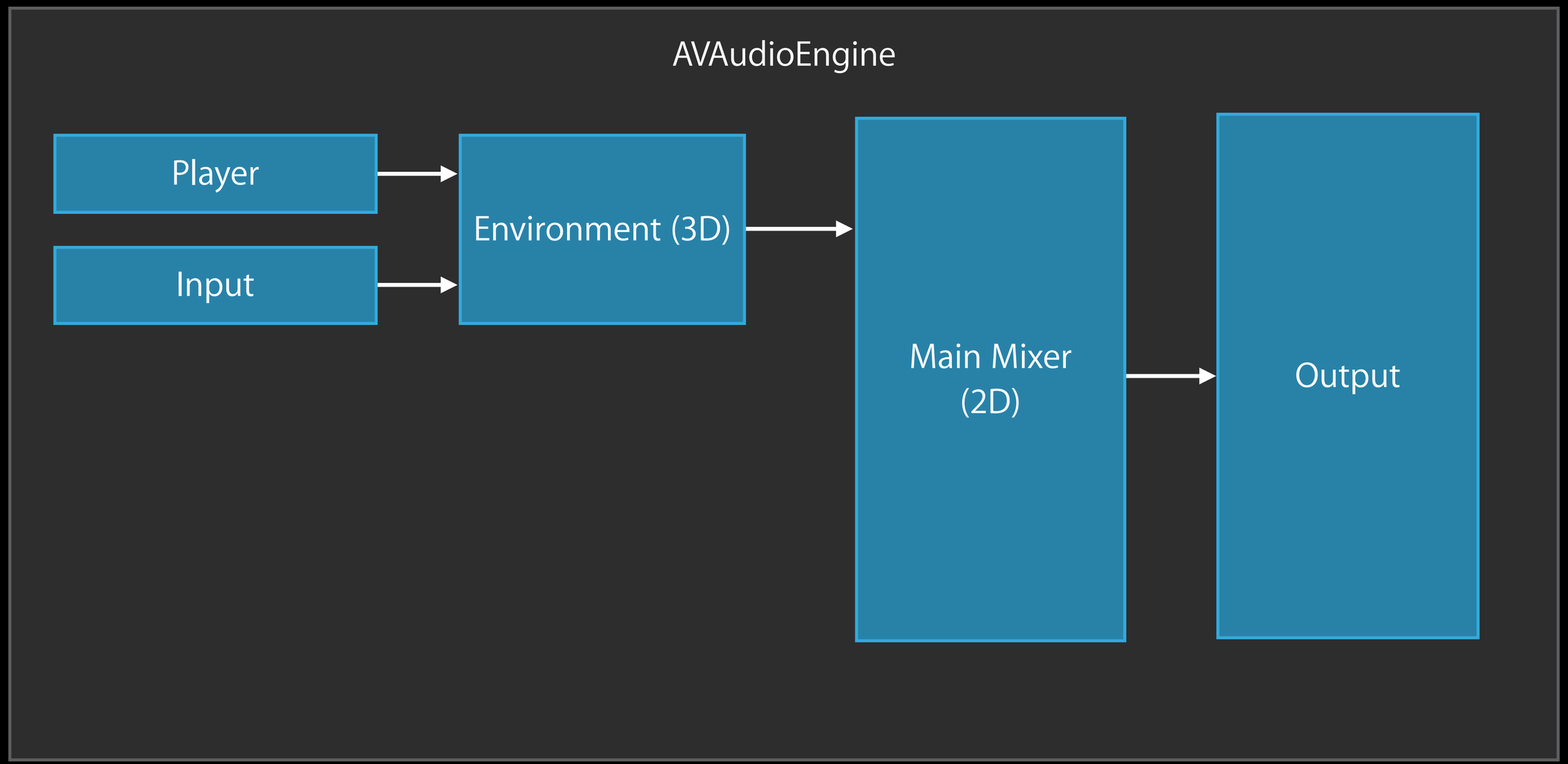
Moving Between Mixer Nodes

Pan property is cached but has no effect on environment node

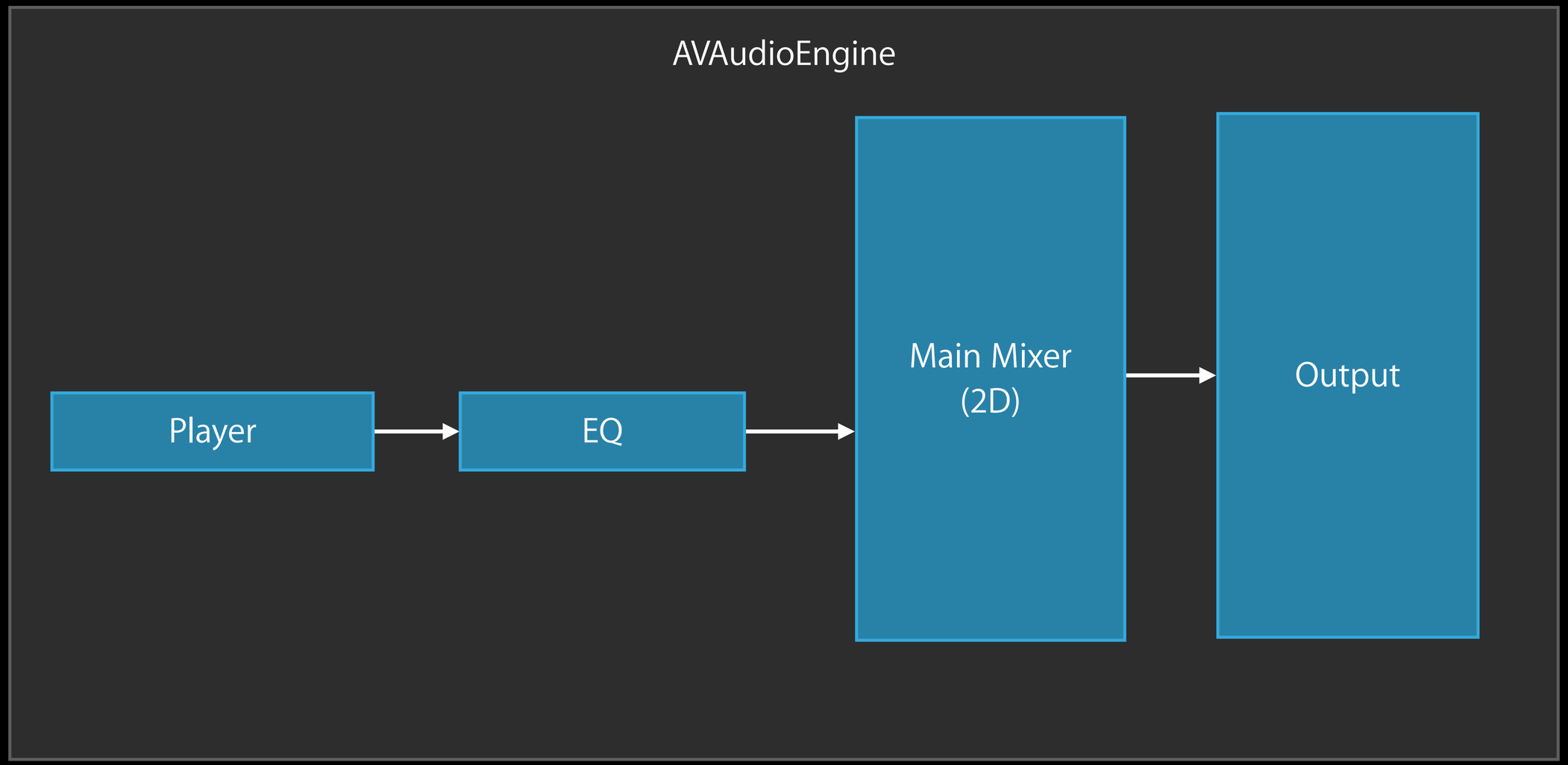
Volume property takes effect



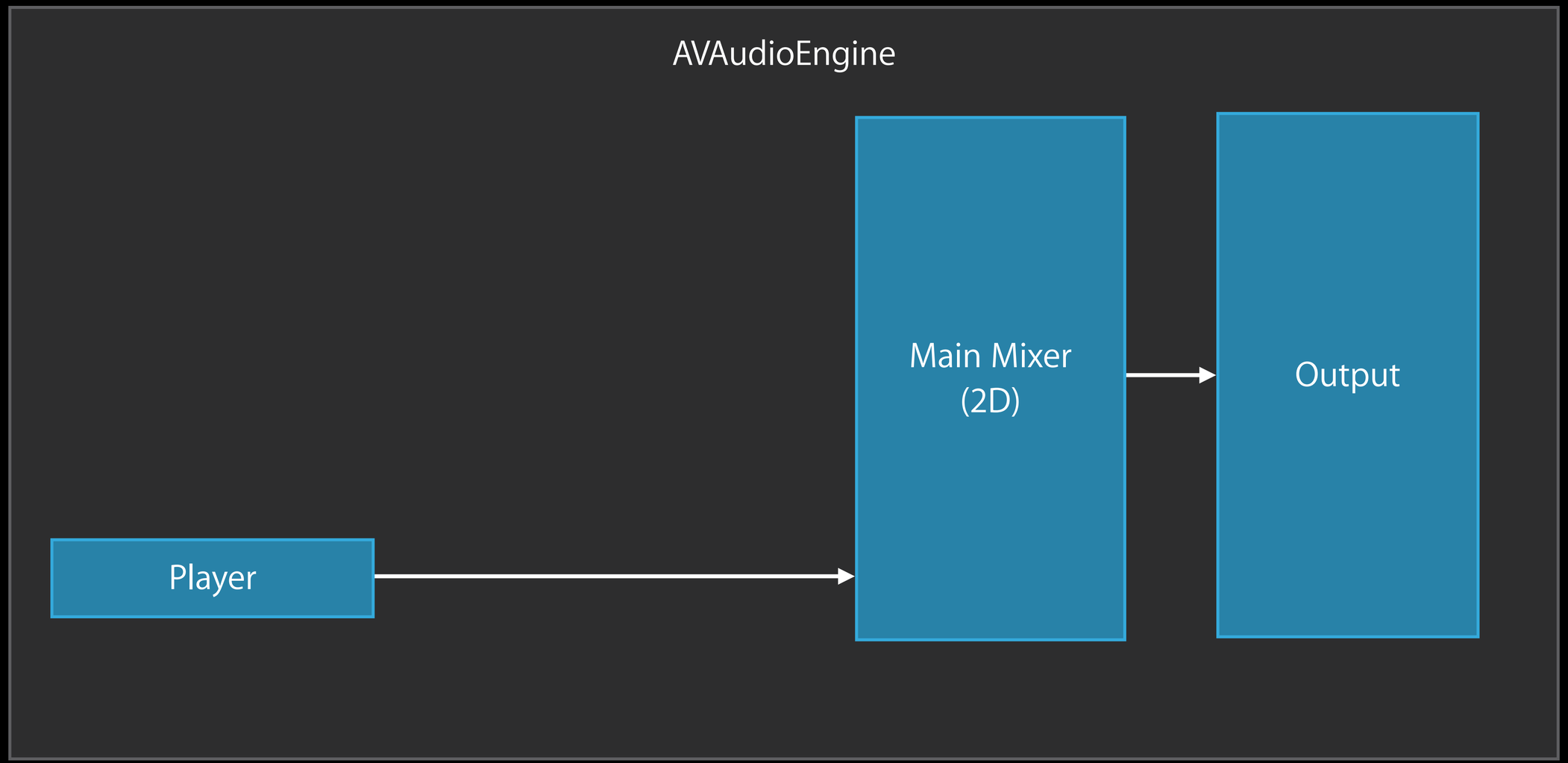
Sample Gaming Setup



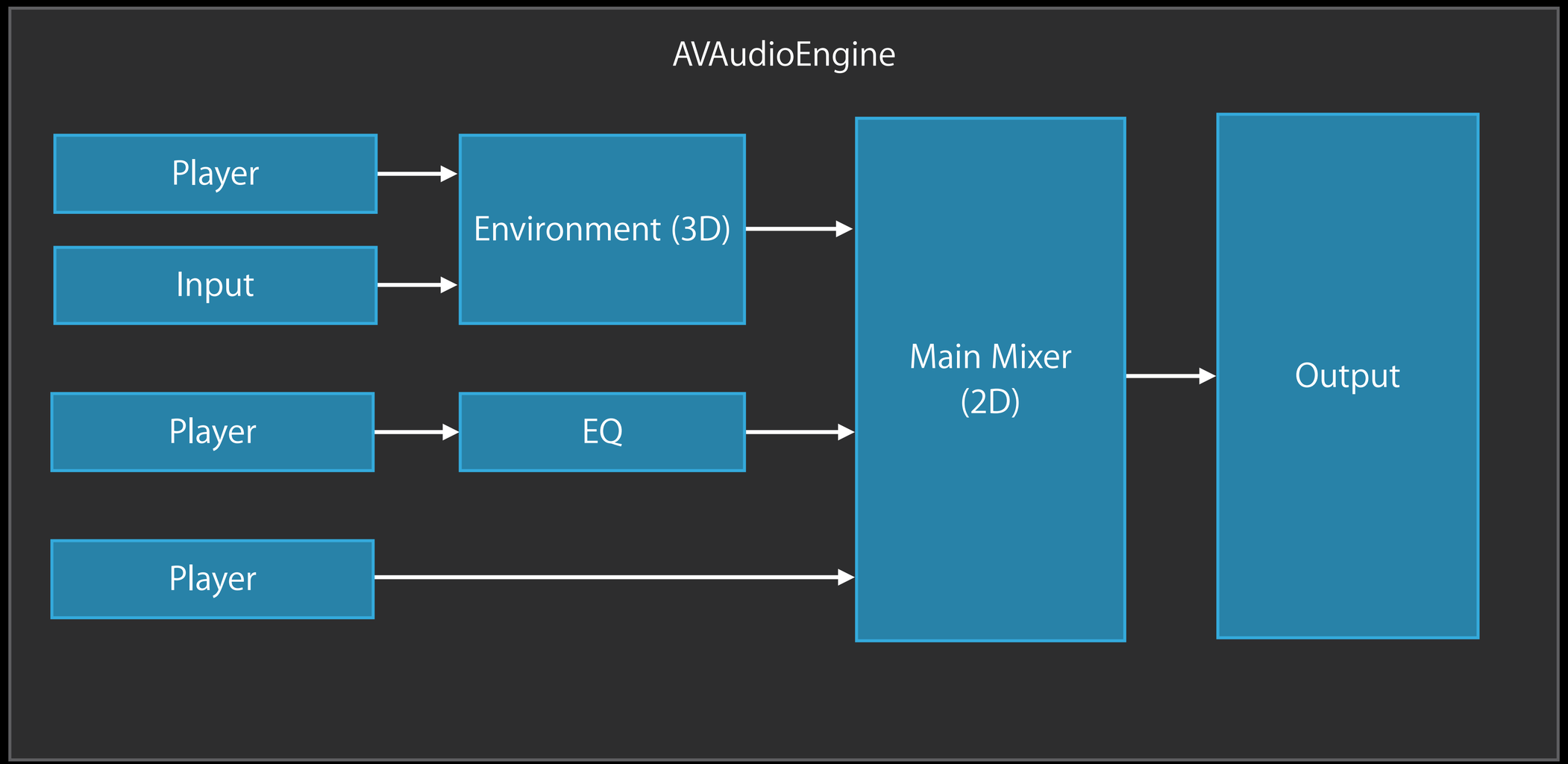
Sample Gaming Setup



Sample Gaming Setup



Sample Gaming Setup



Demo

Gaming

Kapil Krishnamurthy
3D Audio Ninja

Summary

Engine and connections

Output node

Source nodes—Player, input

Mixer nodes, AVAudioMixing protocol

Effect nodes

Node taps

AVAudioEngine v.1

More Information

Filip Iliescu
Graphics and Games Technologies Evangelist
filiescu@apple.com

Developer Technical Support
http://developer.apple.com/contact

Apple Developer Forums
http://devforums.apple.com

Labs

• Audio Lab	Media Lab A	Tuesday 11:30AM
• Audio Lab	Media Lab B	Wednesday 12:45PM

WWDC14