Delivering an Exceptional Audio Experience

A guide to audio best practices and APIs

Session 507

Saleem Mohammed Audio Craftsman
Doug Wyatt Audio Plumber

Introduction

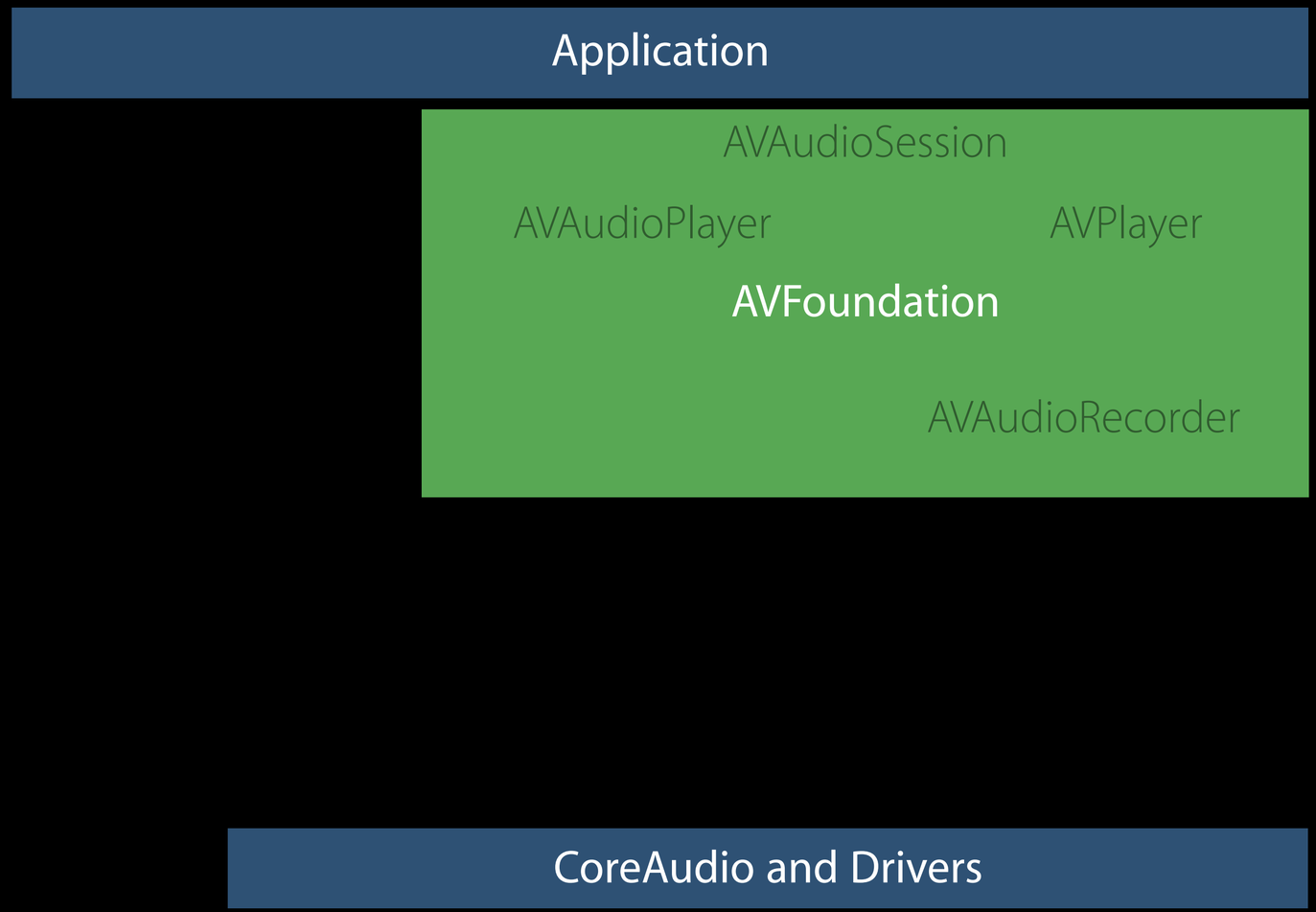
Overview

Application

CoreAudio and Drivers

Introduction

Overview



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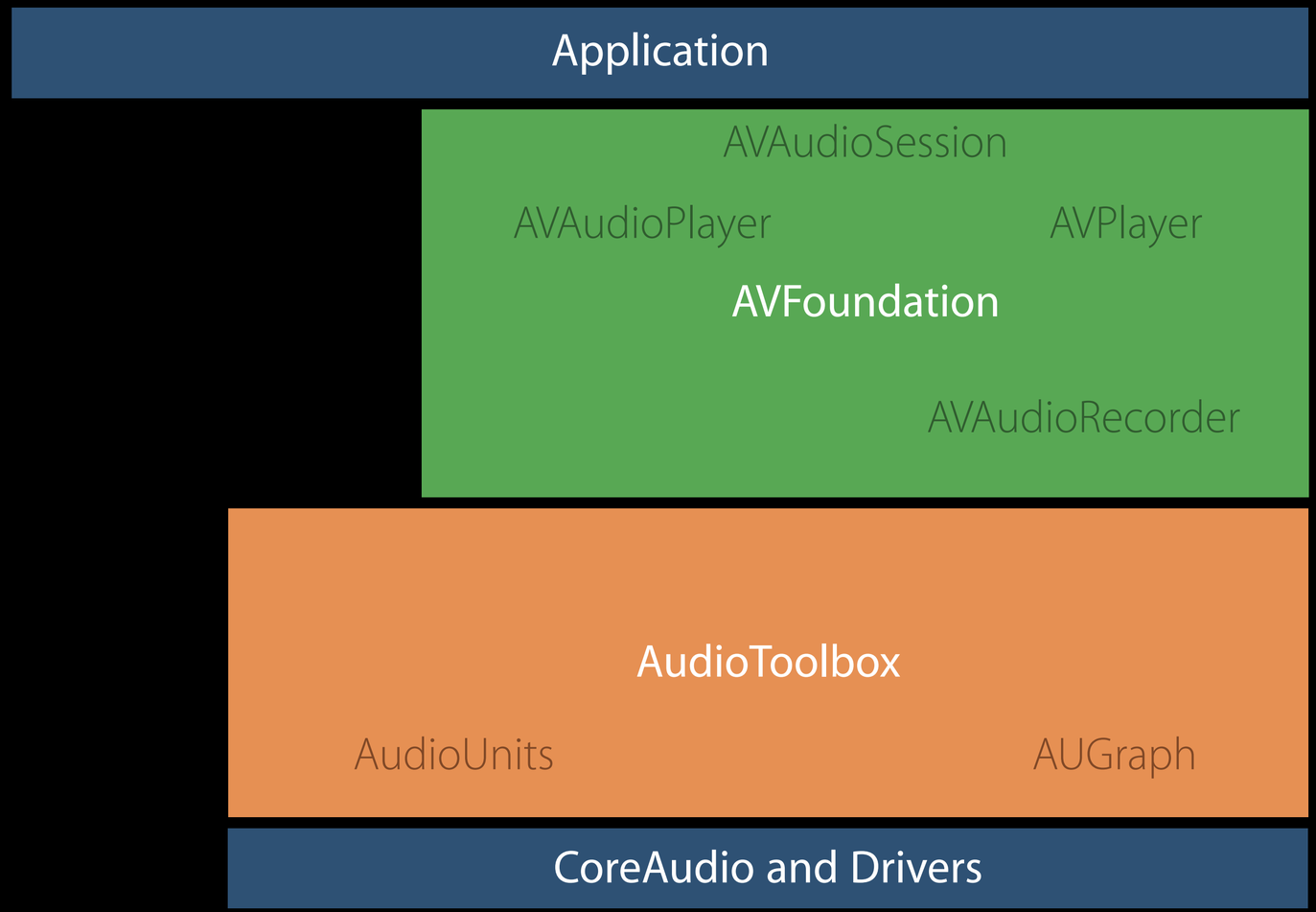

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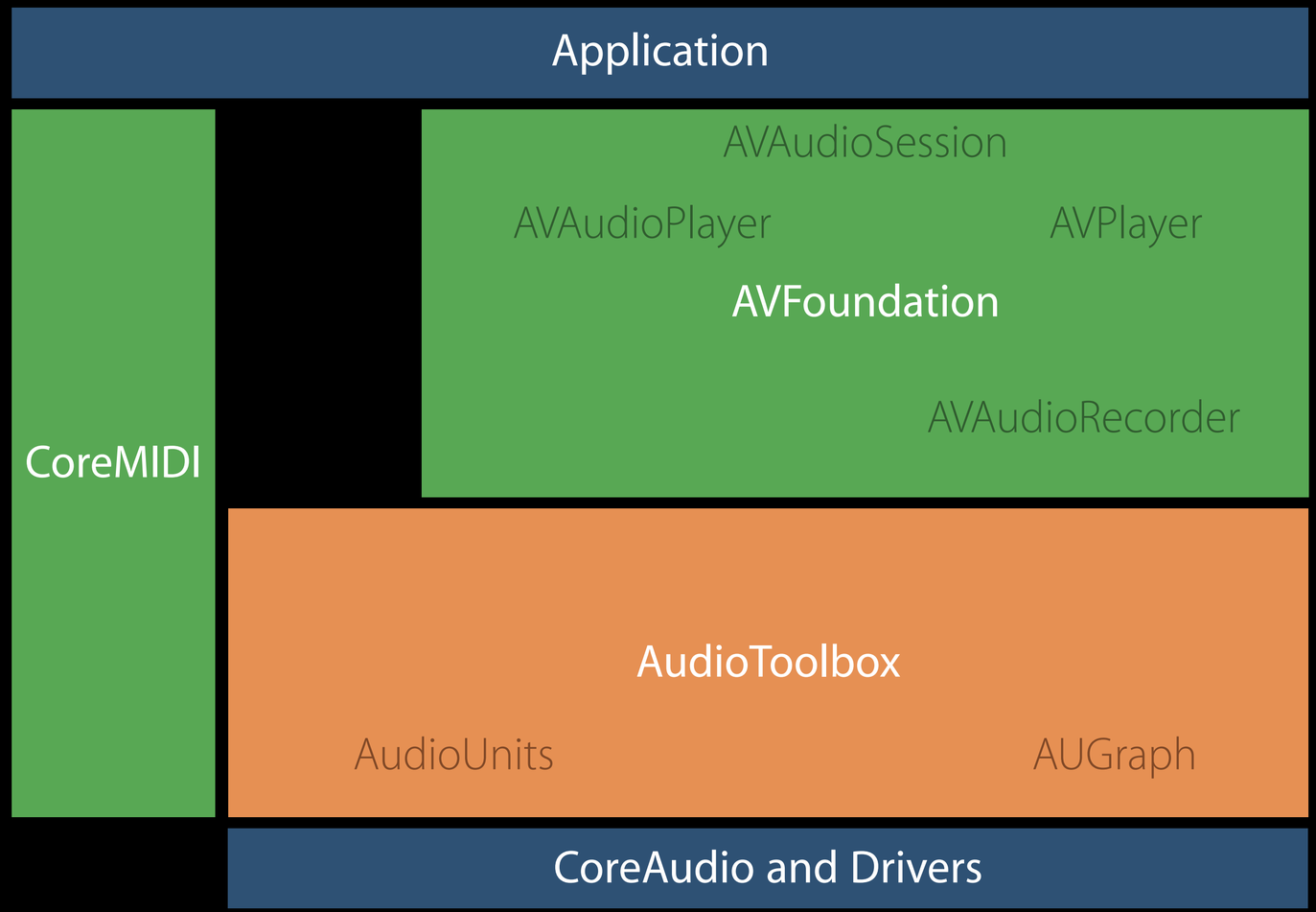

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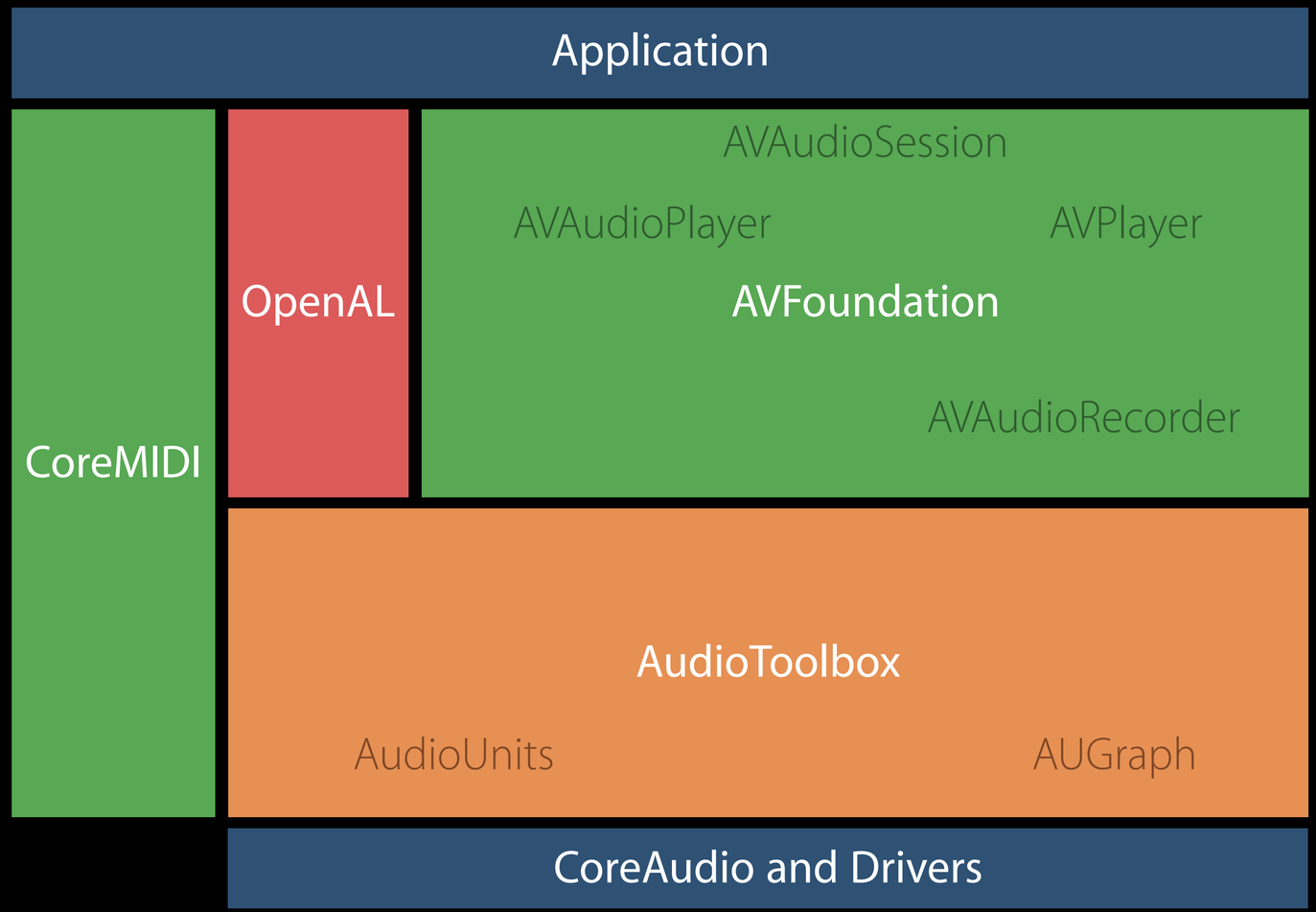

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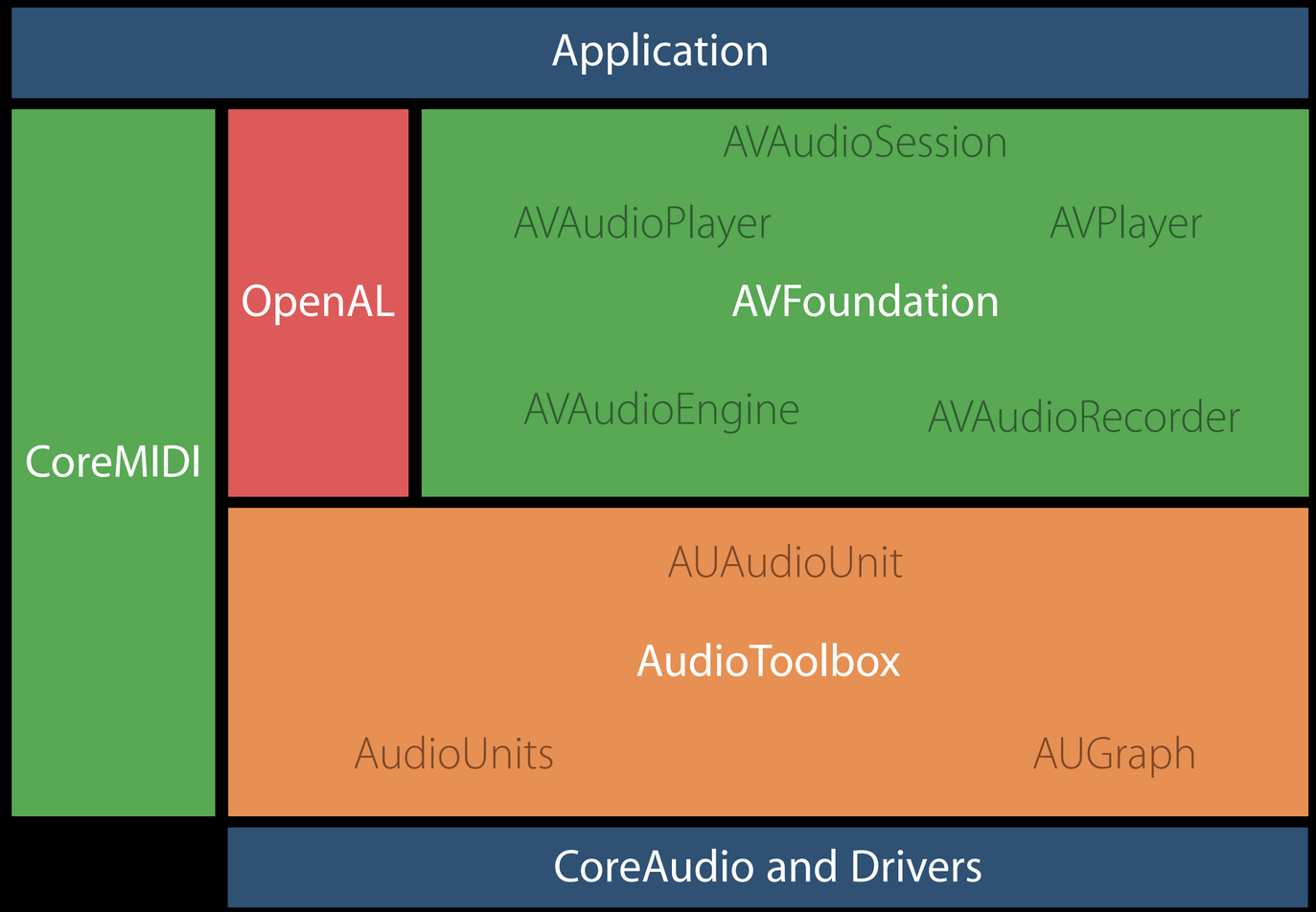

Introduction

Agenda

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Essential Setup

Simple Playback and Recording Scenarios

Advanced Playback and Recording Scenarios

Multichannel Audio

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Essential Setup

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Advanced Playback and Recording Scenarios

Multichannel Audio

Real-time Audio

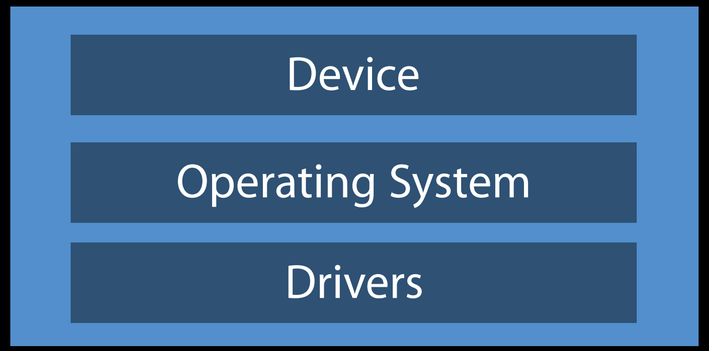
Instruments, Effects, and Generators

MIDI

Essential Setup

Configuration for iOS, tvOS, and watchOS

Audio Is a Managed Service



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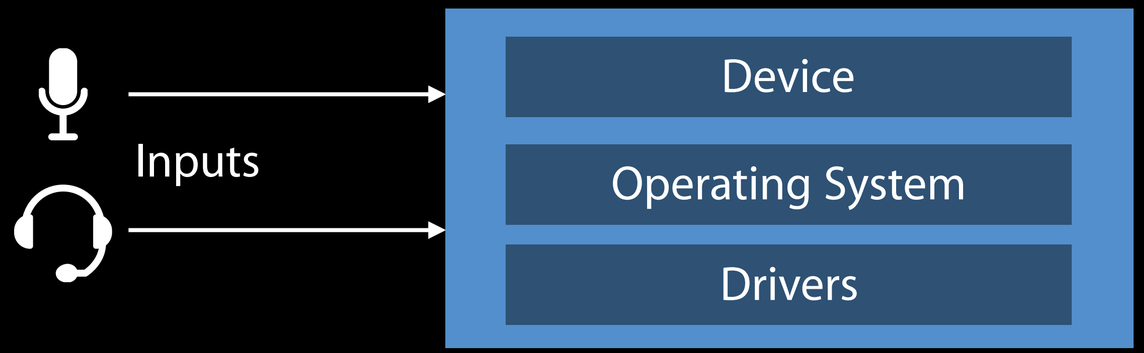

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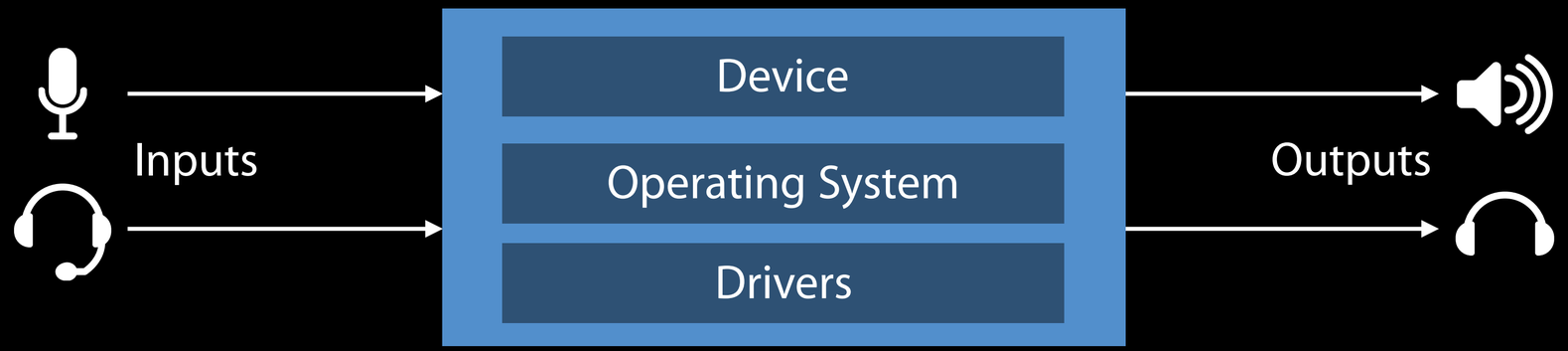

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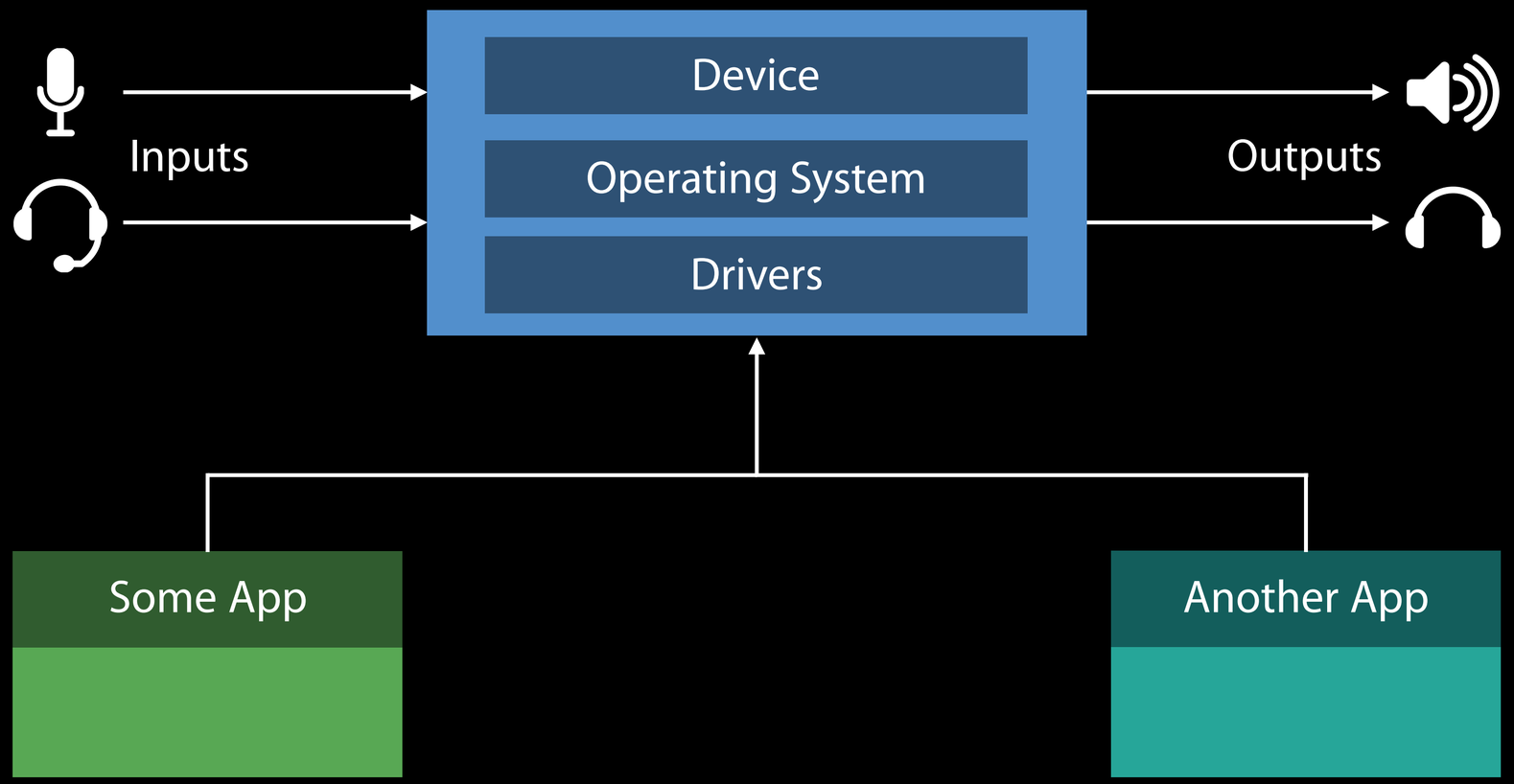

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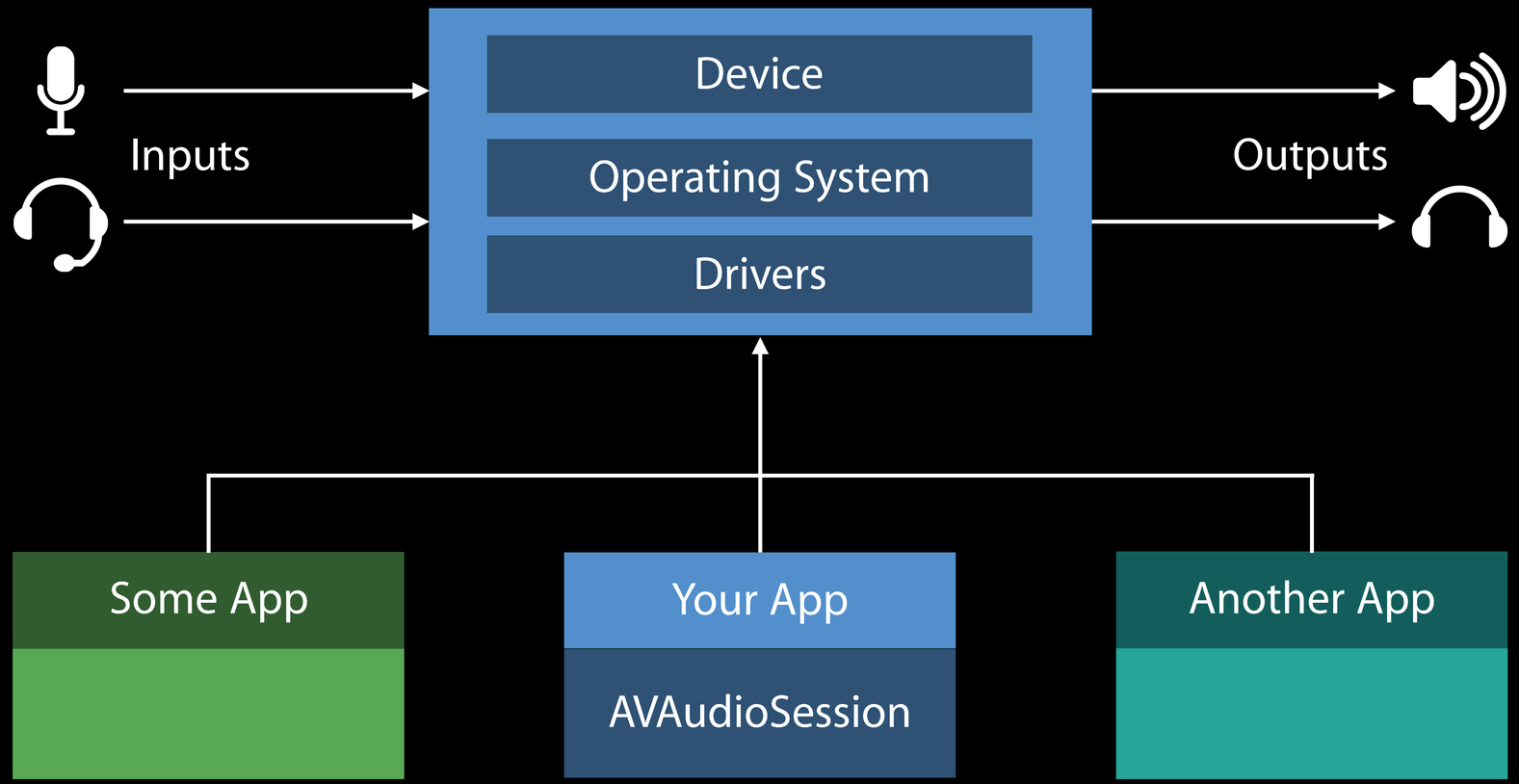
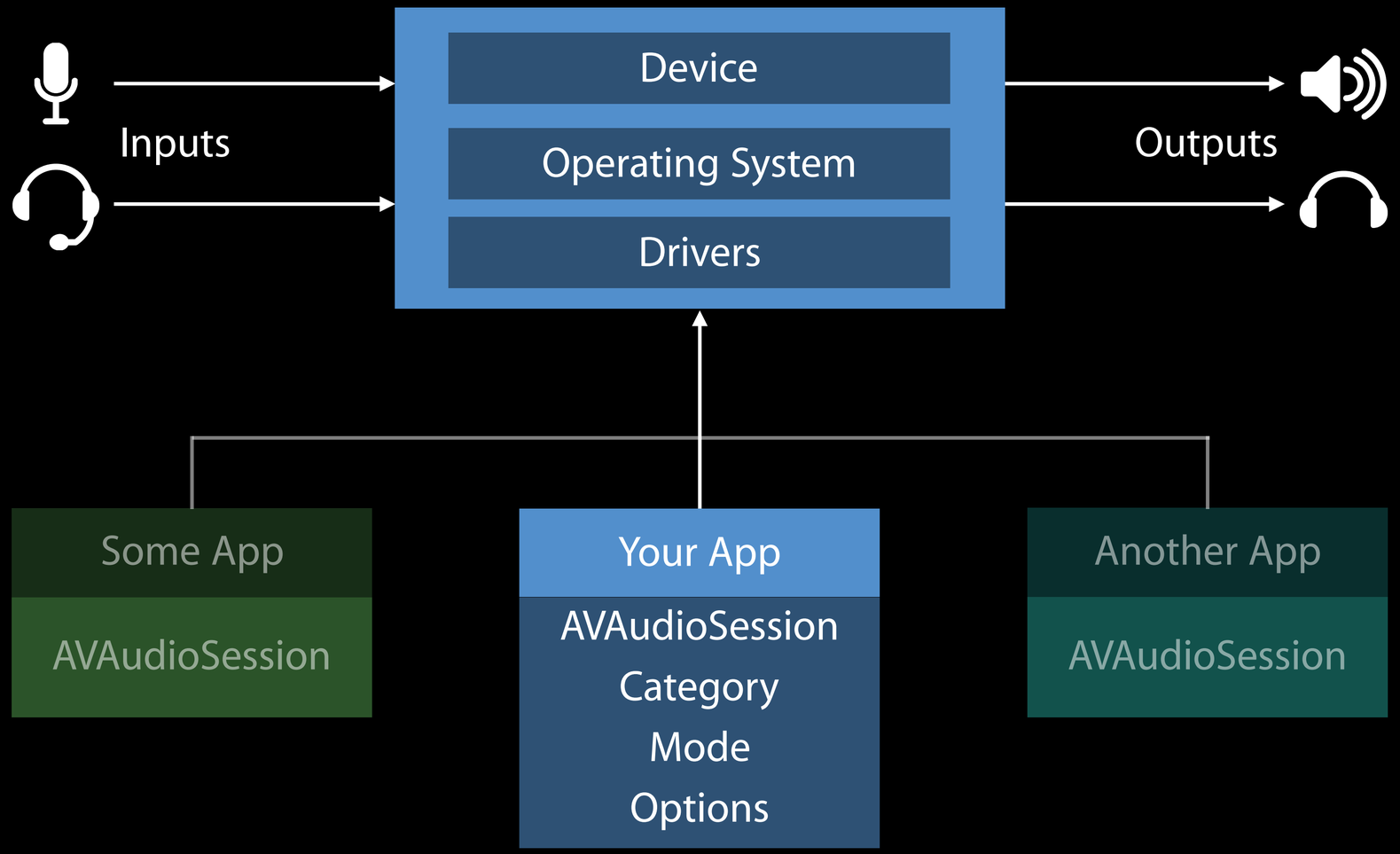


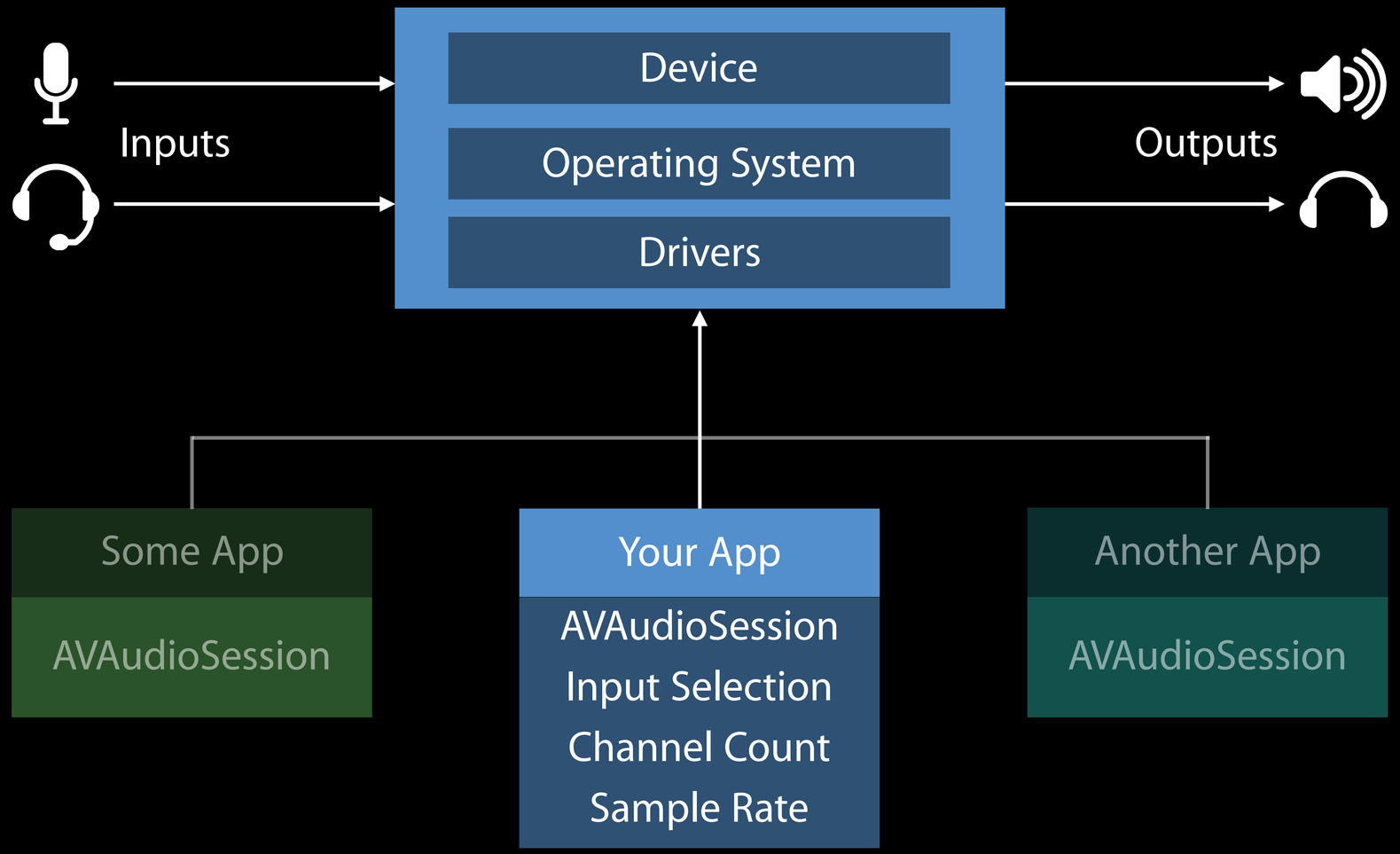
AVAudioSession

Express app's high-level audio needs



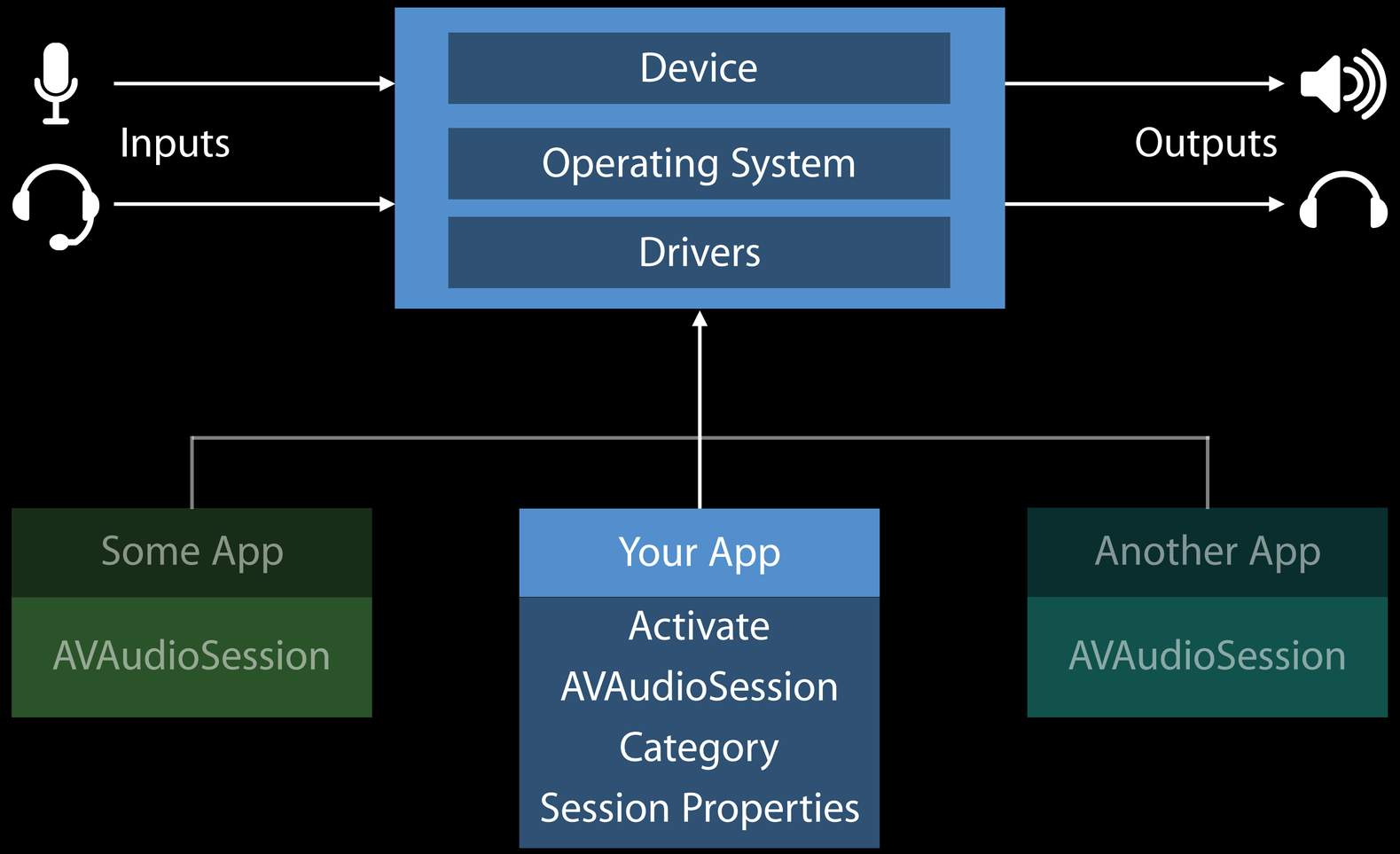
AVAudioSession

Advanced configuration



AVAudioSession

Interact with other audio apps



AVAudioSession

Essential steps

Sign up for notifications

Set category, mode, and options

Manage activation

Handle notifications

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Sign up for Notifications

AVAudioSessionInterruptionNotification

AVAudioSessionRouteChangeNotification

AVAudioSessionMediaServicesWereResetNotification

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do {
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Will obey ringer switch

Will not play audio in the background

Will always mix with others

Set Category, Mode, and Options

Podcast app

```
do {
    try AVAudioSession.sharedInstance().setCategory(AVAudioSessionCategoryPlayback)
    try AVAudioSession.sharedInstance().setMode(AVAudioSessionModeSpokenAudio)
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Will interrupt other applications

*Background audio key

Set Category, Mode, and Options

Navigation app

```
do {
    let myAudioSession = AVAudioSession.sharedInstance()
    try myAudioSession.setCategory(AVAudioSessionCategoryPlayback,
                                   mode: AVAudioSessionModeDefault,
                                   options:[.interruptSpokenAudioAndMixWithOthers, .duckOthers])
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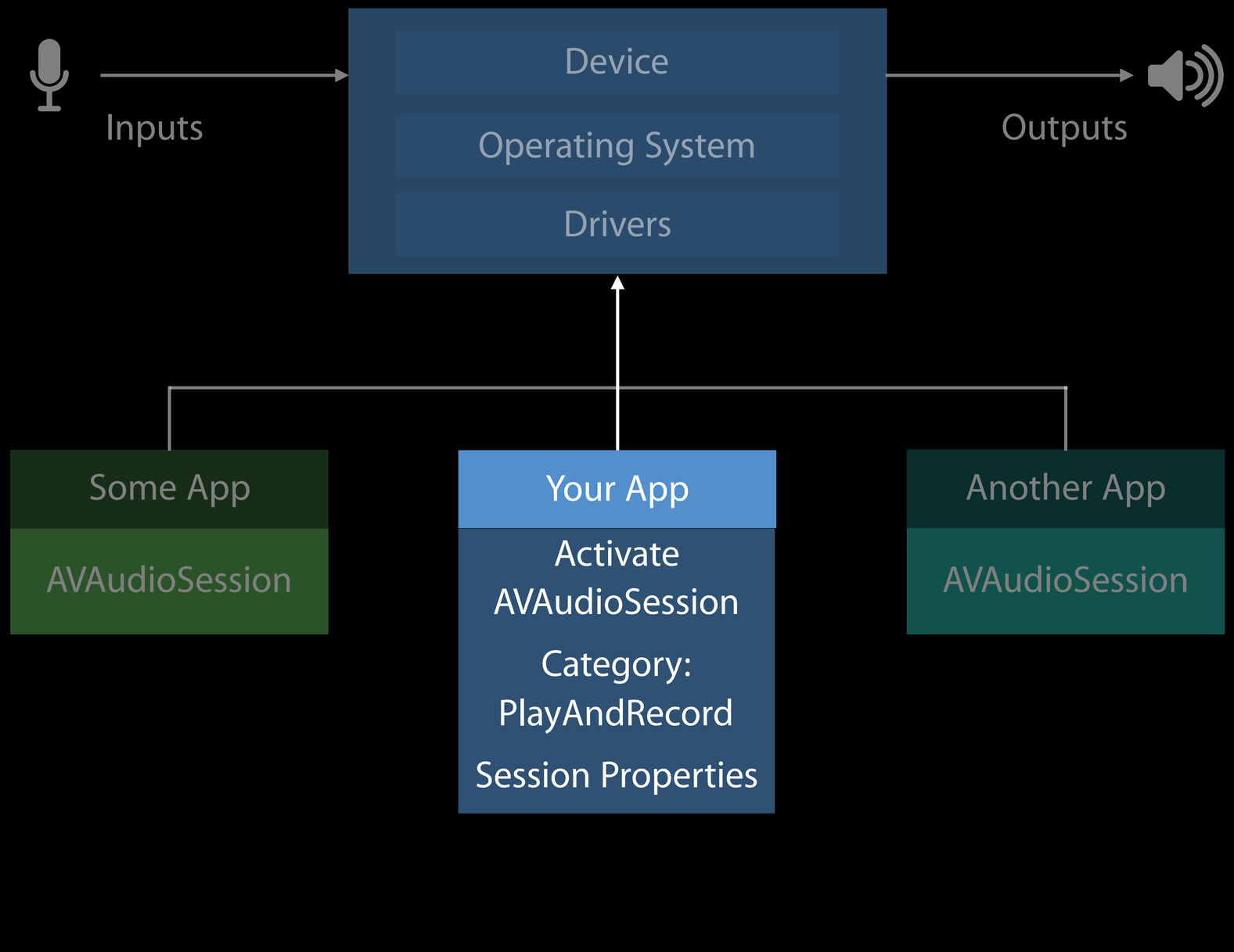
Manage Session Activation



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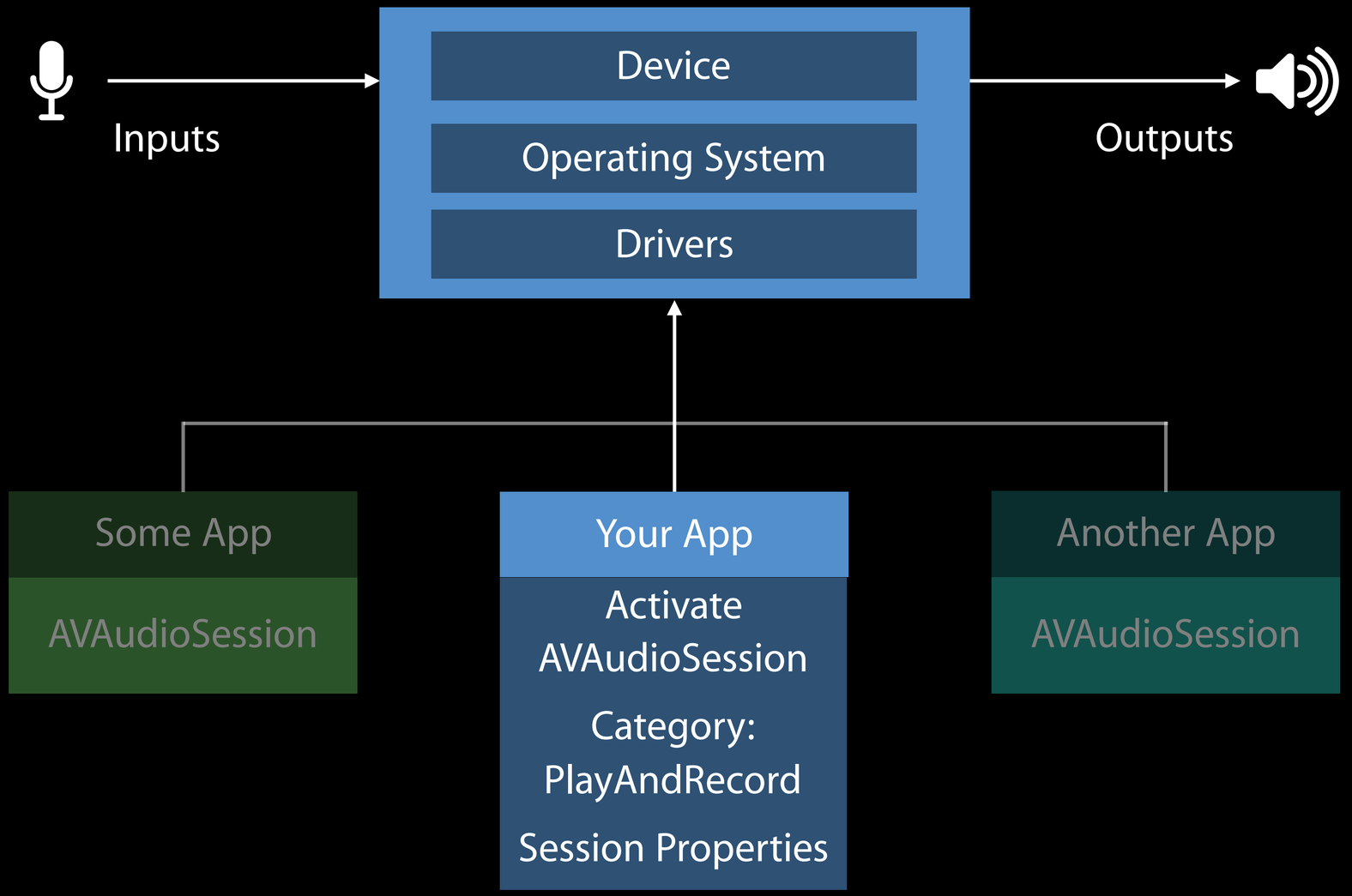

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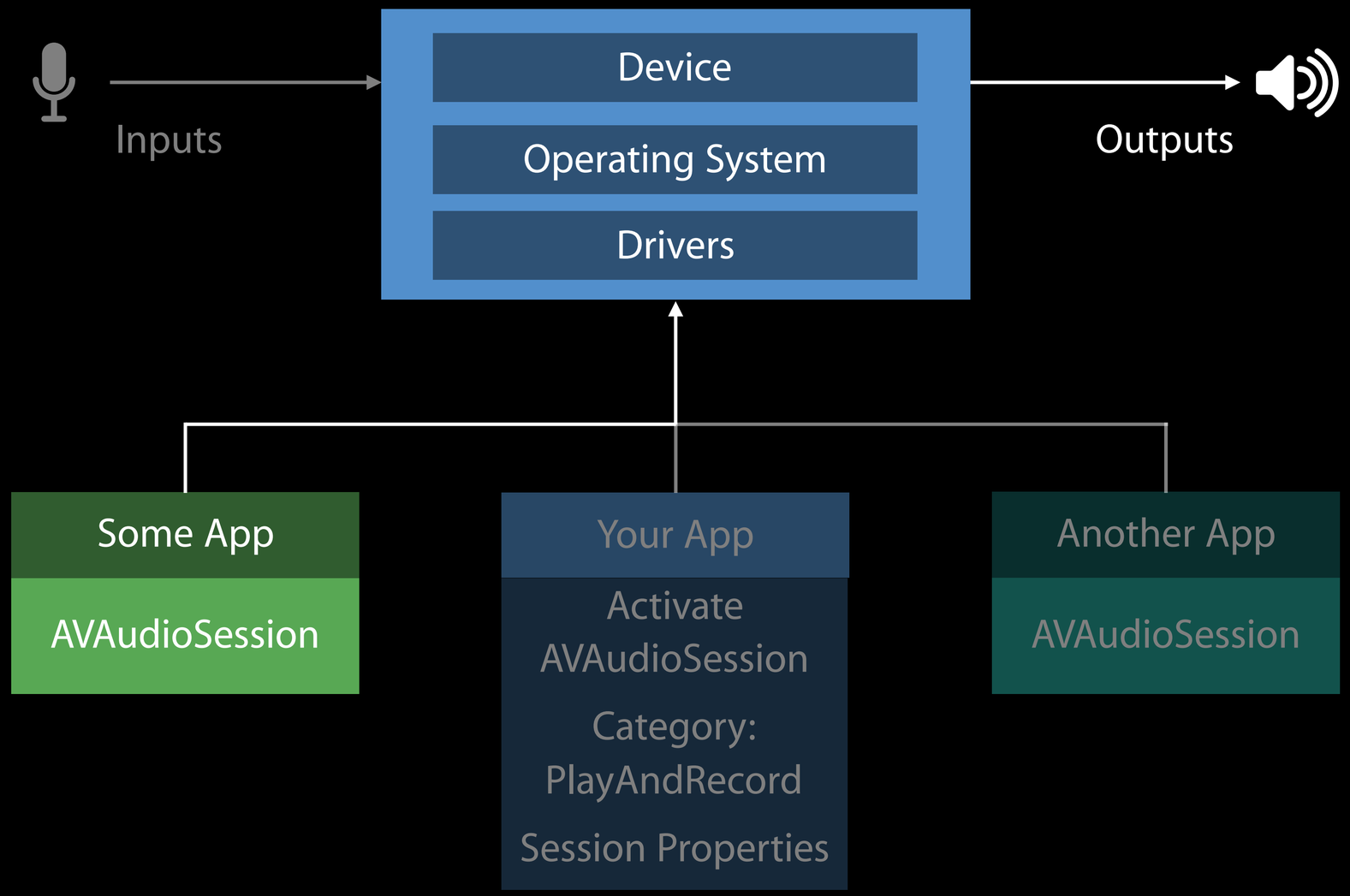

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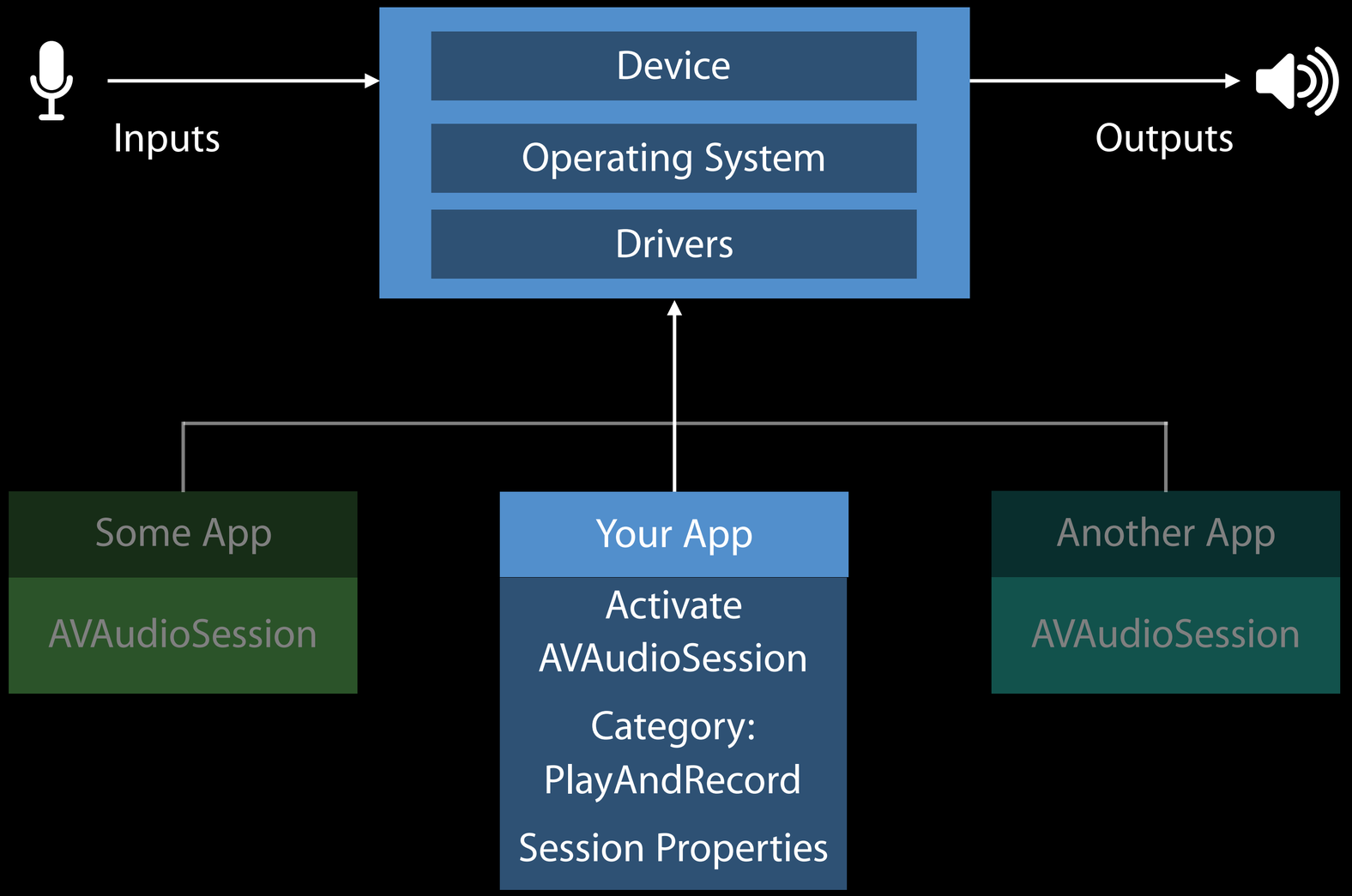

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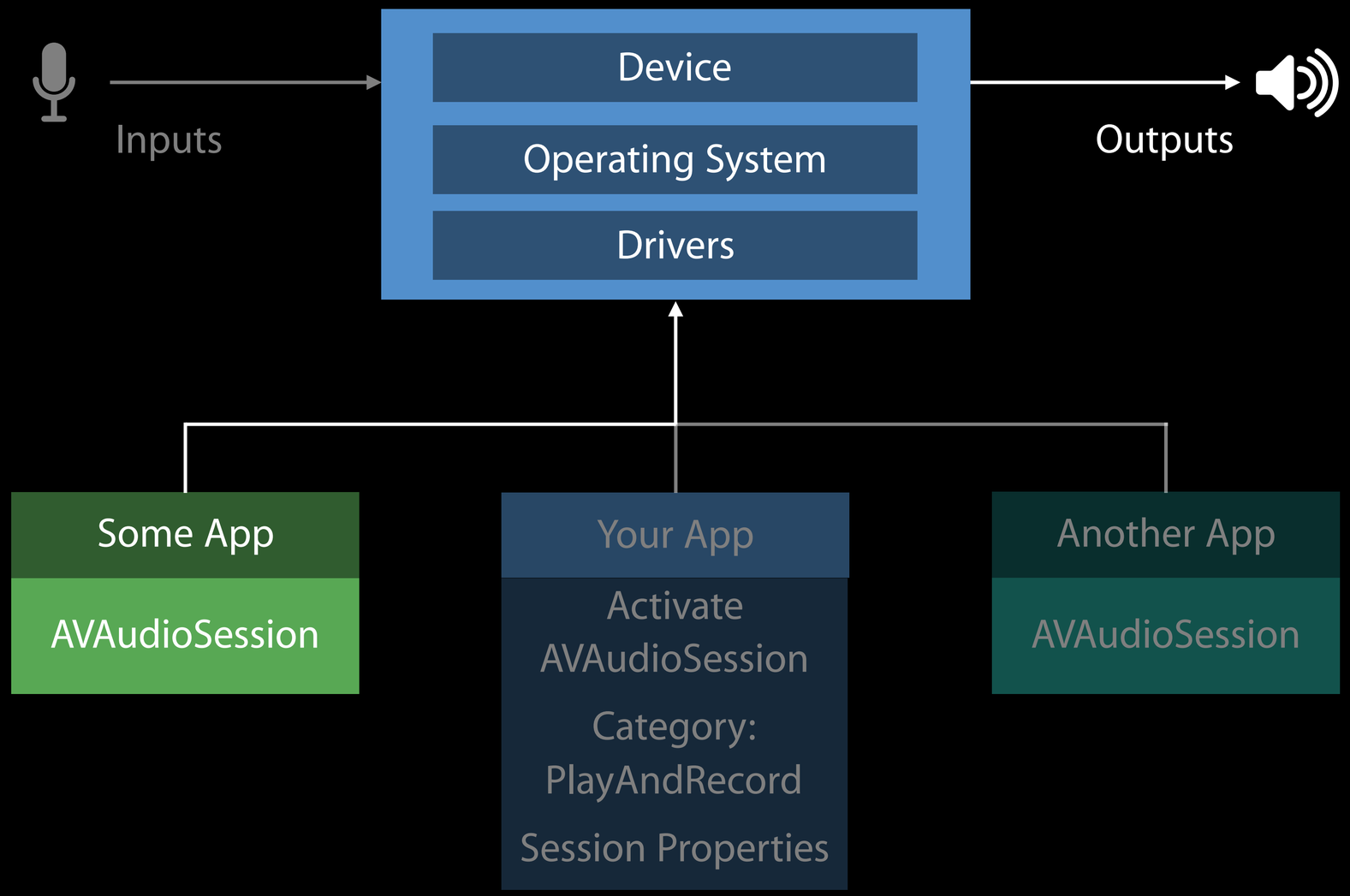

AVAudioSession

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Handle notifications

Handle Notifications

Interruptions

No Playback UI

```
func handleInterruption(notification: NSNotification) {
    let interruptionType = notification.userInfo![AVAudioSessionInterruptionTypeKey]
        as! AVAudioSessionInterruptionType

    if interruptionType == AVAudioSessionInterruptionType.began {
        //session inactive, players have been paused; update any internal state
    }
    else { //end interruption
        // activate session, start playing, update internal state
    }
}
```

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}
```

Handle Notifications

Interruptions

Playback UI

```
...
if interruptionType == AVAudioSessionInterruptionType.began {
    //session inactive, update internal state as well as UI!
}
else { //end interruption
    if let interruptionOption = notification.userInfo![AVAudioSessionInterruptionOptionKey]
        as? AVAudioSessionInterruptionOptions {
            if interruptionOption == .shouldResume {
                // activate session, start playing, update UI & internal state
             }
     }
...
```

Handle Notifications

Interruptions

Playback UI

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if interruptionType == AVAudioSessionInterruptionType.began {
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            }
    }
...
```

Handle Notifications

Interruptions

Not every Begin is followed by an End

- e.g., media players that interrupt each other

Handle Notifications

Route changes

```
let routeChangeReason = notification.userInfo![AVAudioSessionRouteChangeReasonKey]
    as! AVAudioSessionRouteChangeReason

if routeChangeReason == .oldDeviceUnavailable {
    //media players stop playback; ex. headsets unplugged while listening to music
}

if routeChangeReason == .oldDeviceUnavailable || routeChangeReason == .newDeviceAvailable {
    //advanced use cases; re-evaluate session properties; ex. Sample rate
}
```

Handle Notifications

Route changes

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AVAudioSession sharedInstance pointer still valid

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Need to destroy and recreate objects

- AVAudioEngine, queues, remote I/Os, players, etc

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Test with Settings -> Developer -> Reset Media Services

AVAudioSession

Essential steps review

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AirPlay and A2DP in PlayAndRecord

NEW

Stereo audio over Bluetooth and AirPlay

```
try AVAudioSession.sharedInstance().setCategory(AVAudioSessionCategoryPlayAndRecord,
                                                mode: AVAudioSessionModeDefault,
                                                options: [.allowAirPlay, .allowBluetoothA2DP])
```

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Now you can use microphone while playing to Bluetooth/AirPlay

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```

Now you can use microphone while playing to Bluetooth/AirPlay

Let the user pick the route from Control Center or a MPVolumeView

New Property for VoIP Apps

NEW

```
let audioSession = AVAudioSession.sharedInstance()
if let currentPort:AVAudioSessionPortDescription = audioSession.currentRoute.inputs.first {
    let disableSoftwareVoiceProcessing = currentPort.hasHardwareVoiceCallProcessing
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```

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Not needed if using Apple's Voice Processing IO

`kAudioUnitSubType_VoiceProcessingIO`

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Enhancing VoIP Apps with CallKit — Mission — Thursday 5:00PM

Further Reference

Audio Session and Multiroute Audio in iOS	WWDC 2012
What's New in Core Audio	WWDC 2014
What's New in Core Audio	WWDC 2015

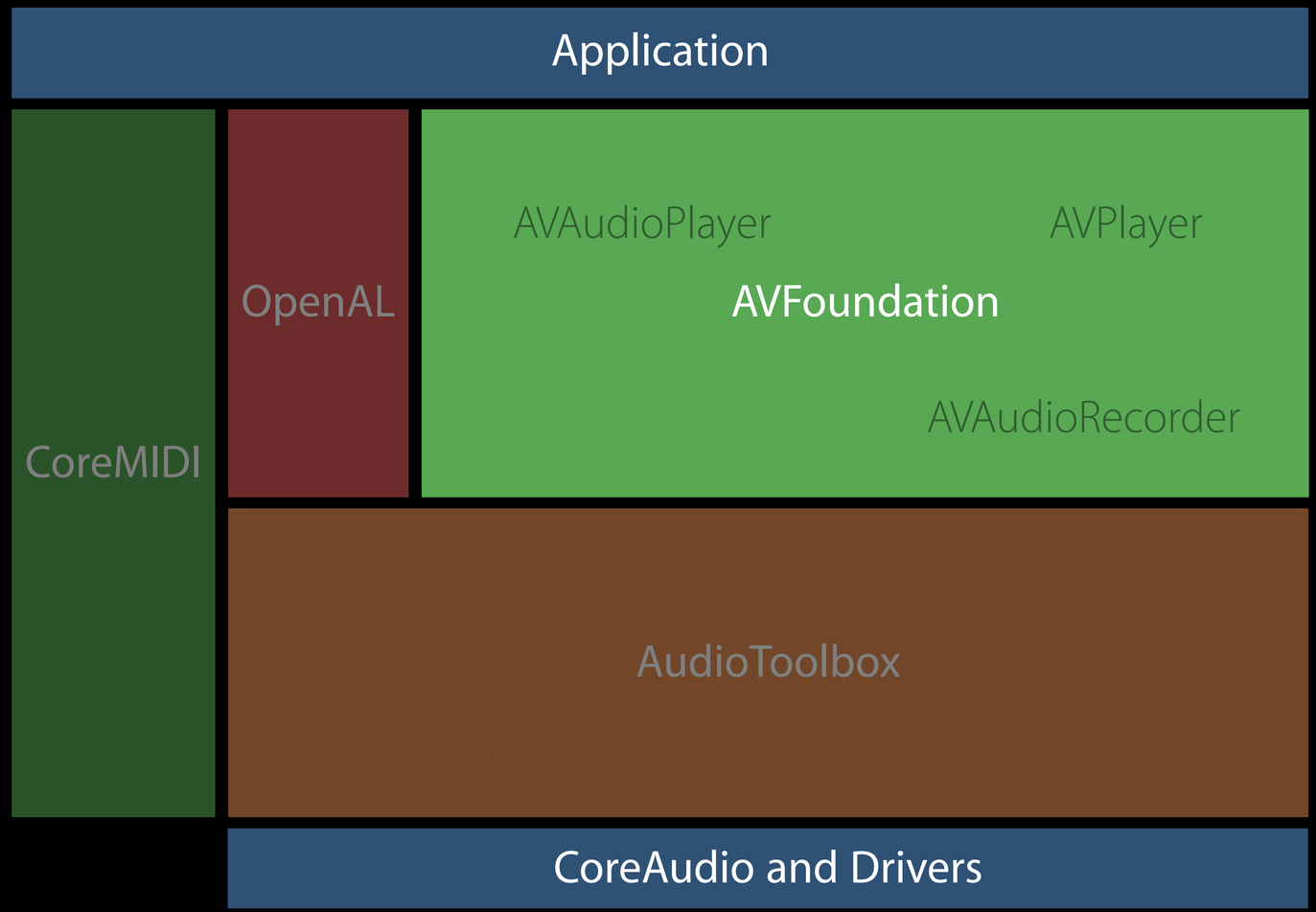
Audio session programming guide

- https://developer.apple.com/library/ios/documentation/Audio/Conceptual/AudioSessionProgrammingGuide

Simple Playback and Recording

AVFoundation Framework

Simple playback and recording



AVAudioPlayer

Simplest way to play an audio file

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Simplest way to play an audio file

Plays file types supported by AudioFile API

- e.g., wav, caf, m4a, aac, mp3, aif

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Provides basic playback operations

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Provides basic playback operations

Supports volume, metering, looping, playback rate, panning

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Channel assignment (iOS/tvOS)

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Multiple AVAudioPlayer objects for multiple sounds; synchronized playback

AVAudioPlayer

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Multiple AVAudioPlayer objects for multiple sounds; synchronized playback

```
public func setVolume(_ volume: Float, fadeDuration duration: TimeInterval)
/* fade to a new volume over a duration */
```

```swift
// AVAudioPlayer Example - Productivity App
class ViewController: UIViewController {
    var successSoundPlayer:AVAudioPlayer!
    let successSoundURL = Bundle.main().urlForResource("success", withExtension: "caf")
    override func viewDidLoad() {
        do { // setup AVAudioSession if necessary (Ambient); setup other members
            successSoundPlayer = try AVAudioPlayer.init(contentsOf: successSoundURL!)
            successSoundPlayer.prepareToPlay()
        }
        catch {
            // handle error
        }
    }
    @IBAction func saveDocument() {
        // do some other work; if successful, play success sound!
        successSoundPlayer.play() //check return value
    }
}
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AVAudioRecorder

Simplest way to record an audio file

Record for a specific duration

Records until stopped

Metering

Supports a variety of encoding formats

- AAC, HE-AAC, HE-AACv2, ALAC, LPCM

AVAudioRecorder

Settings dictionary

Format

Sample rate

Number of channels

For LPCM

- Bit depth, endian-ness

For encoded formats

- Quality, bit rate

```swift
// AVAudioRecorder Example
do { // setup AVAudioSession (Record/PlayAndRecord); user permission; input selection
    let formatSettings = [AVSampleRateKey : 44100.0,
                          AVNumberOfChannelsKey : 1,
                          AVFormatIDKey : Int(kAudioFormatMPEG4AAC),
                          AVEncoderBitRateKey : 192000,
                          AVEncoderAudioQualityKey : AVAudioQuality.high.rawValue]

     recorder = try AVAudioRecorder.init(url: recordSoundURL, settings: formatSettings)
     recorder.prepareToRecord()
}
catch { /* handle error */ }

...
@IBAction func toggleRecorder() {
    if recorder.isRecording {
        recorder.stop()
    }
    else {
        recorder.record()
        // provide feedback using meters for example
    }
 }
```

```
// AVAudioRecorder Example
do { // setup AVAudioSession (Record/PlayAndRecord); user permission; input selection
    let formatSettings = [AVSampleRateKey : 44100.0,
                          AVNumberOfChannelsKey : 1,
                          AVFormatIDKey : Int(kAudioFormatMPEG4AAC),
                          AVEncoderBitRateKey : 192000,
                          AVEncoderAudioQualityKey : AVAudioQuality.high.rawValue]

     recorder = try AVAudioRecorder.init(url: recordSoundURL, settings: formatSettings)
     recorder.prepareToRecord()
}
catch { /* handle error */ }

...
@IBAction func toggleRecorder() {
    if recorder.isRecording {
        recorder.stop()
    }
    else {
        recorder.record()
        // provide feedback using meters for example
    }
 }
```

```swift
// AVAudioRecorder Example
do { // setup AVAudioSession (Record/PlayAndRecord); user permission; input selection
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```

AVPlayer

Playback of local and stream audio

Works with file and streaming content

Standard player controls available

AVPlayerView / AVPlayerViewController

Works with both audio and video media

Advances in AVFoundation Playback	Mission	Wednesday 9:00AM

Advanced Playback and Recording

Advanced Use Cases

Advanced Use Cases

Playback and recording—files, buffers

Advanced Use Cases

Playback and recording—files, buffers

Audio processing—effects, mixing

Advanced Use Cases

Playback and recording—files, buffers

Audio processing—effects, mixing

3D audio

Advanced Use Cases

Playback and recording—files, buffers

Audio processing—effects, mixing

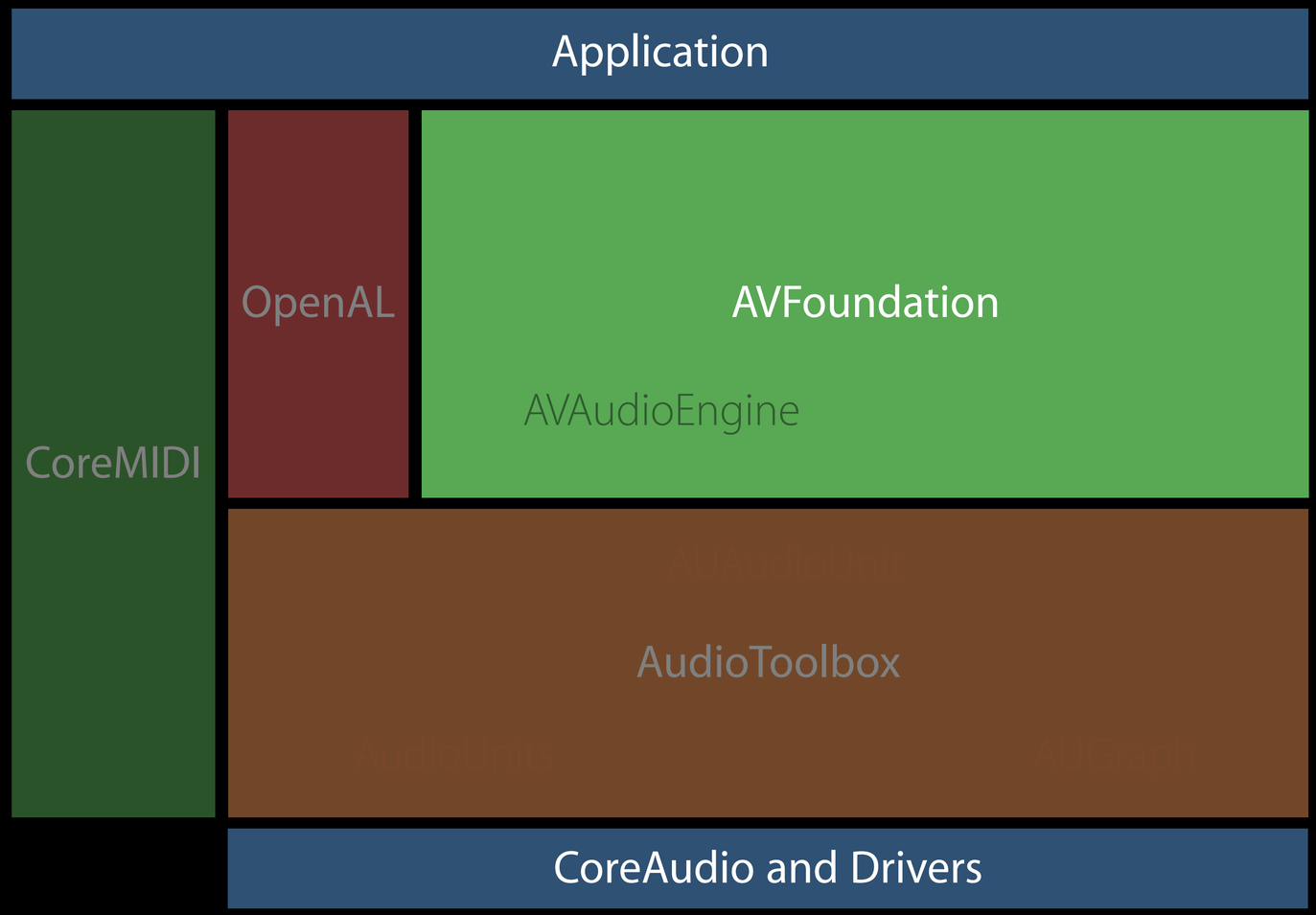
3D audio

Examples

- Karaoke app
- DJ app
- Game

AVFoundation Framework

Advanced playback and recording



AVAudioEngine

AVAudioEngine

Powerful, feature-rich Objective-C/Swift API set

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Powerful, feature-rich Objective-C/Swift API set

Simplifies real-time audio

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Powerful, feature-rich Objective-C/Swift API set

Simplifies real-time audio

Manages a graph of nodes

AVAudioEngine

Powerful, feature-rich Objective-C/Swift API set

Simplifies real-time audio

Manages a graph of nodes

Features

- Play and record audio
- Connect audio processing chains, perform mixing
- Capture audio at any point in the processing chain
- 3D Spatialization

AVAudioEngine

AVAudioNode

AVAudioEngine

AVAudioNode

Source Nodes

Provide data for rendering

AVAudioPlayerNode
AVAudioInputNode
AVAudioUnitSampler

AVAudioEngine

AVAudioNode

Source Nodes	Processing Nodes
Provide data for rendering	Process audio data
AVAudioPlayerNode	AVAudioUnitEffect
AVAudioInputNode	AVAudioMixerNode
AVAudioUnitSampler	AVAudioEnvironmentNode

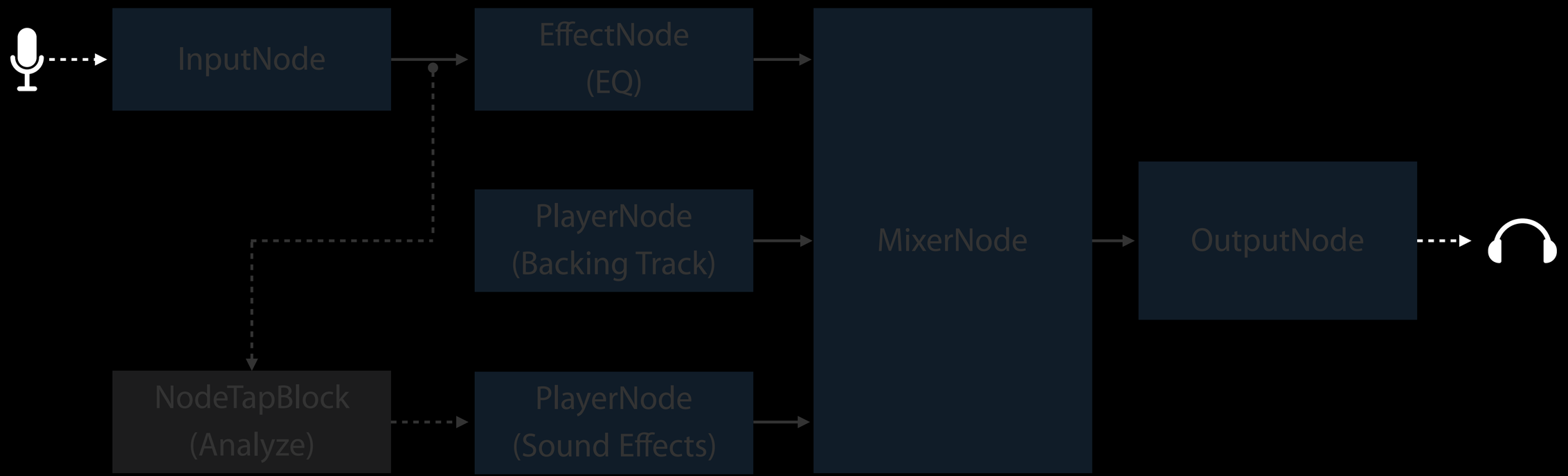
AVAudioEngine

AVAudioNode

Source Nodes	Processing Nodes	Destination Node
Provide data for rendering	Process audio data	Terminating node connected to output hardware
AVAudioPlayerNode	AVAudioUnitEffect	
AVAudioInputNode	AVAudioMixerNode	AVAudioOutputNode
AVAudioUnitSampler	AVAudioEnvironmentNode	

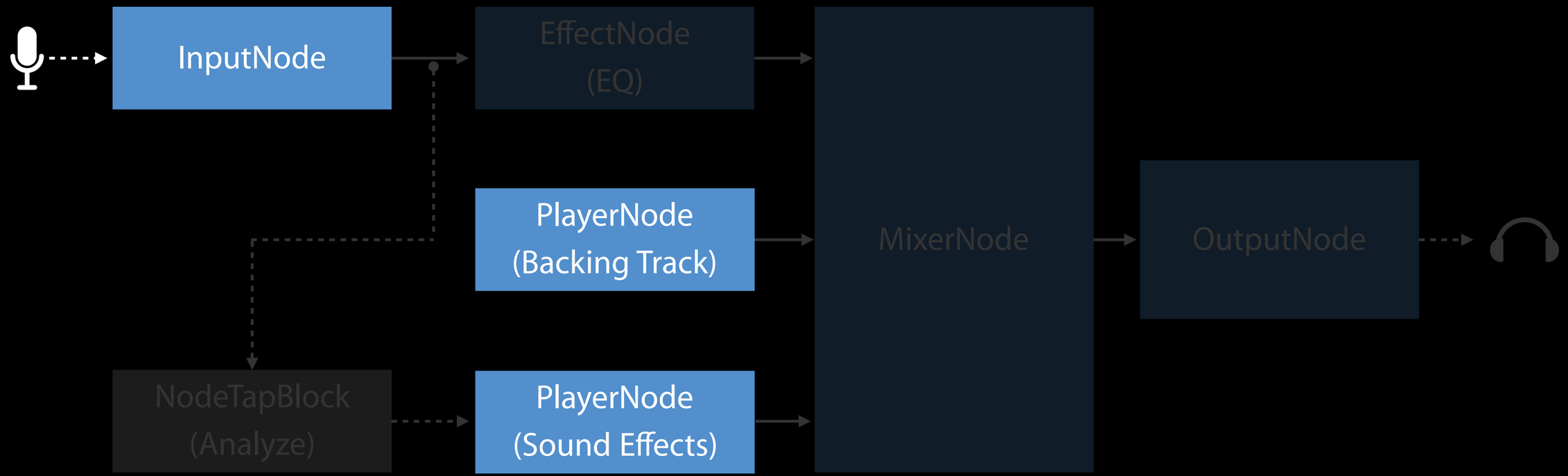
Sample Engine Setup

Karaoke



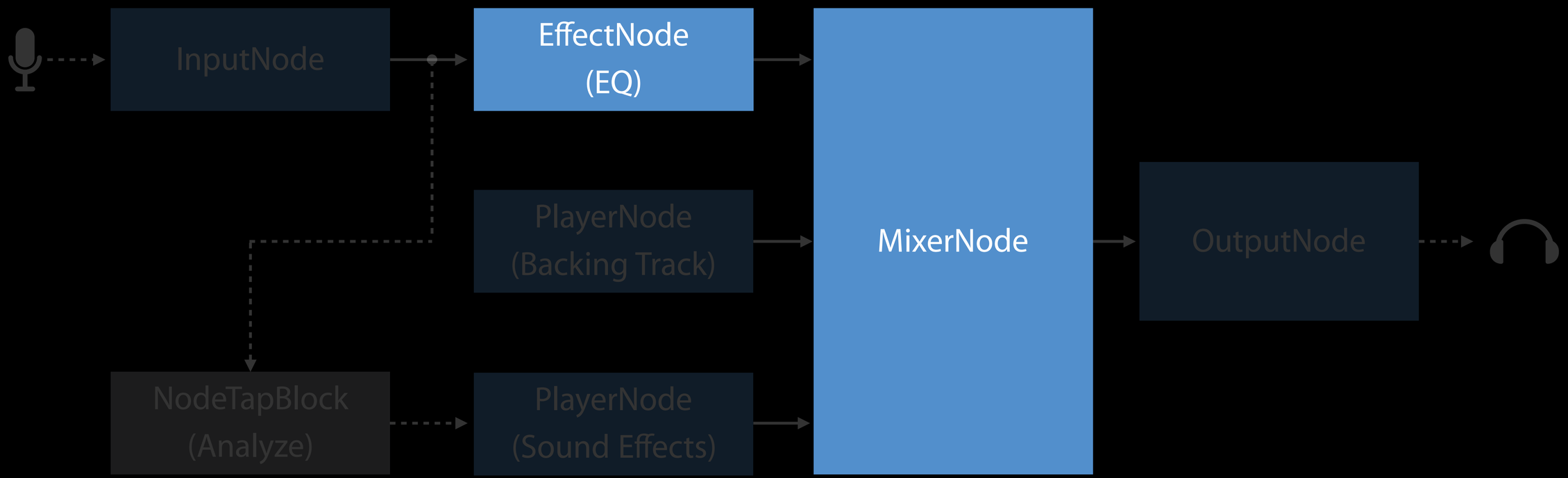
Sample Engine Setup

Karaoke



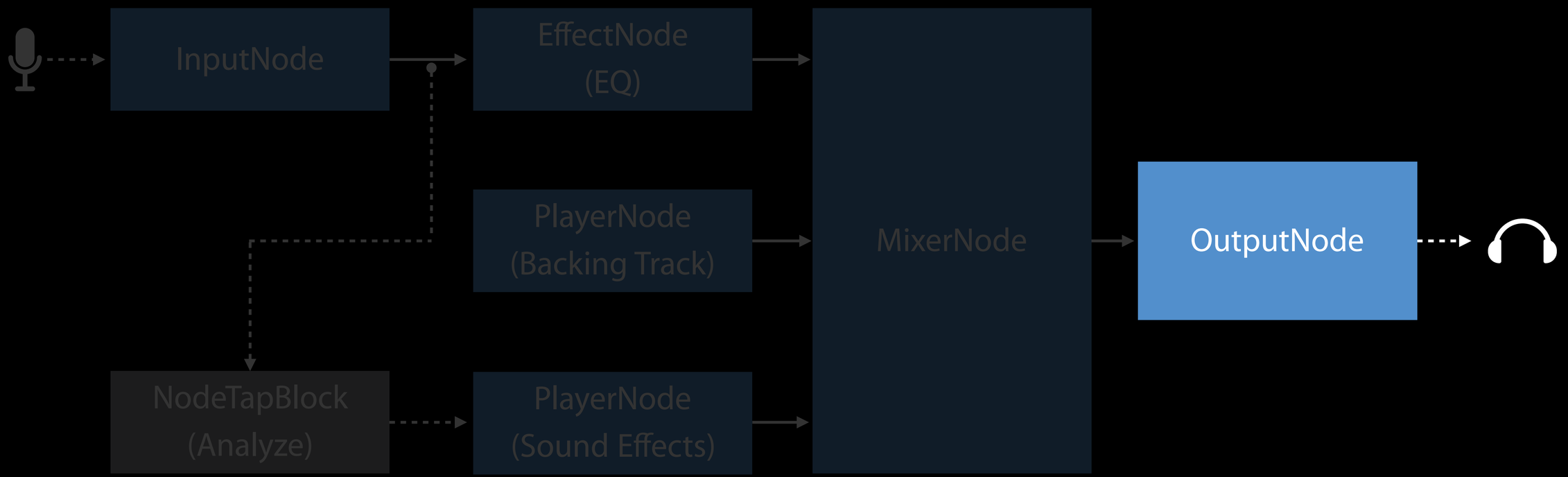
Sample Engine Setup

Karaoke



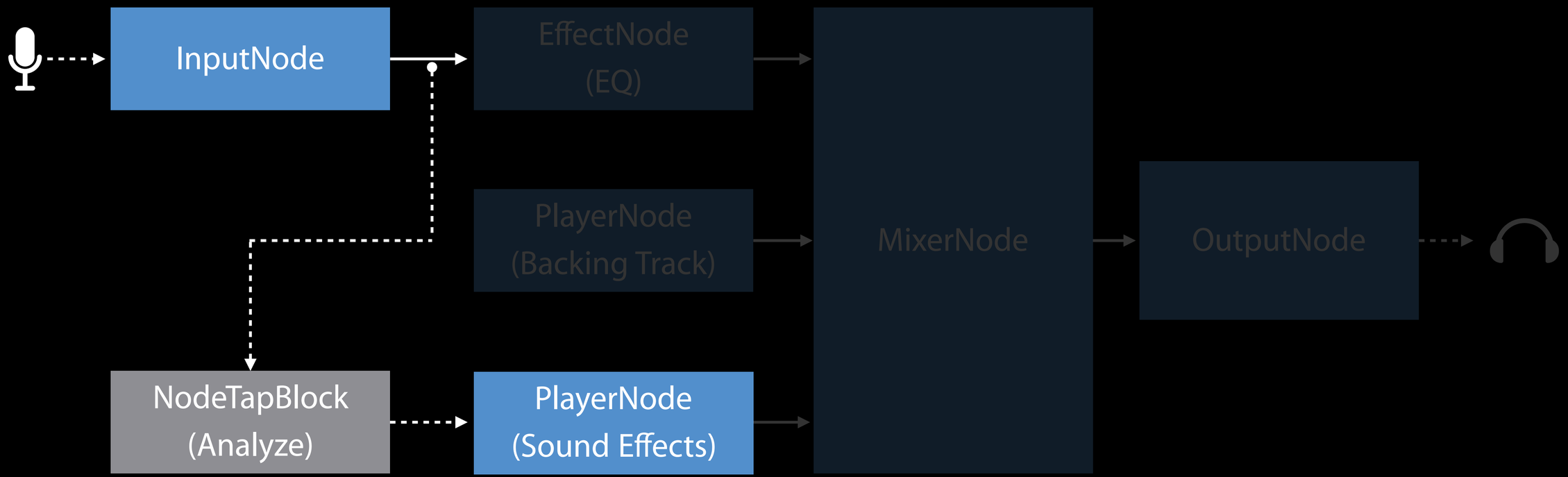
Sample Engine Setup

Karaoke



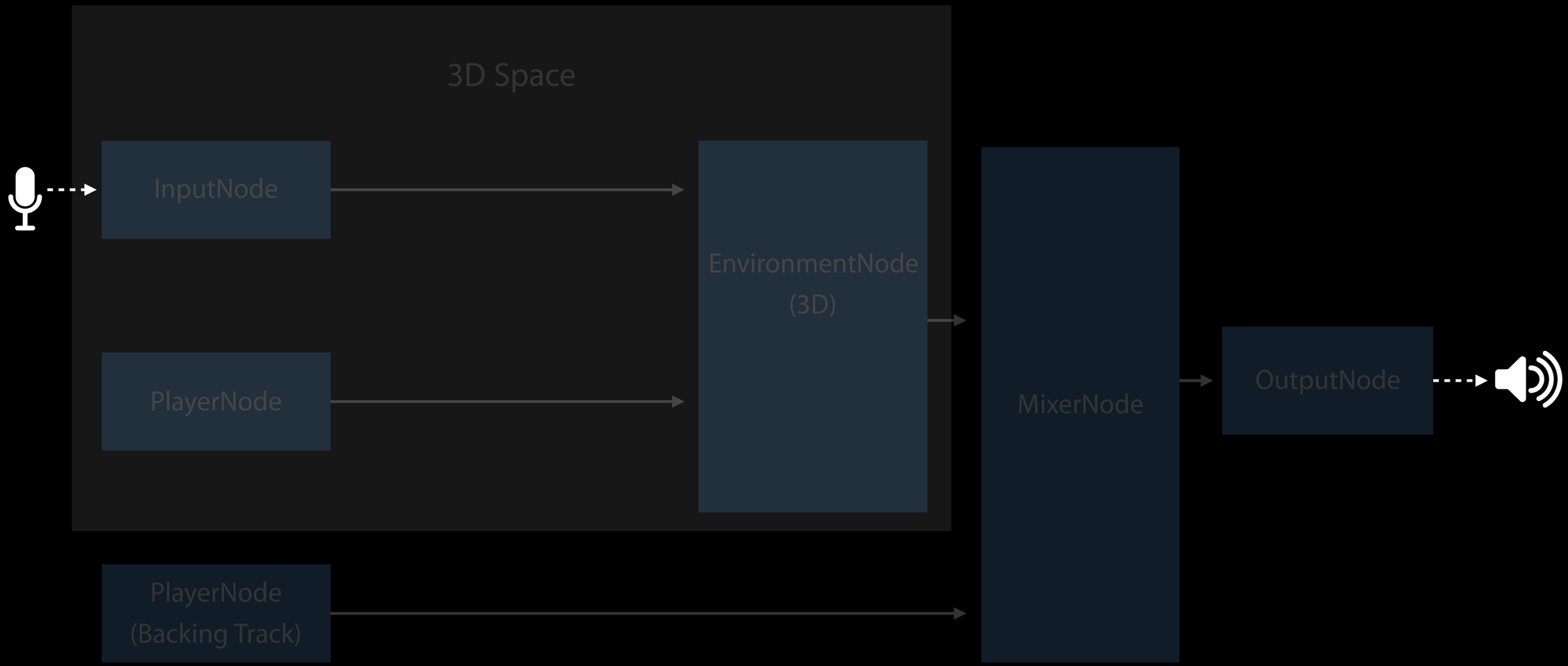
Sample Engine Setup

Karaoke



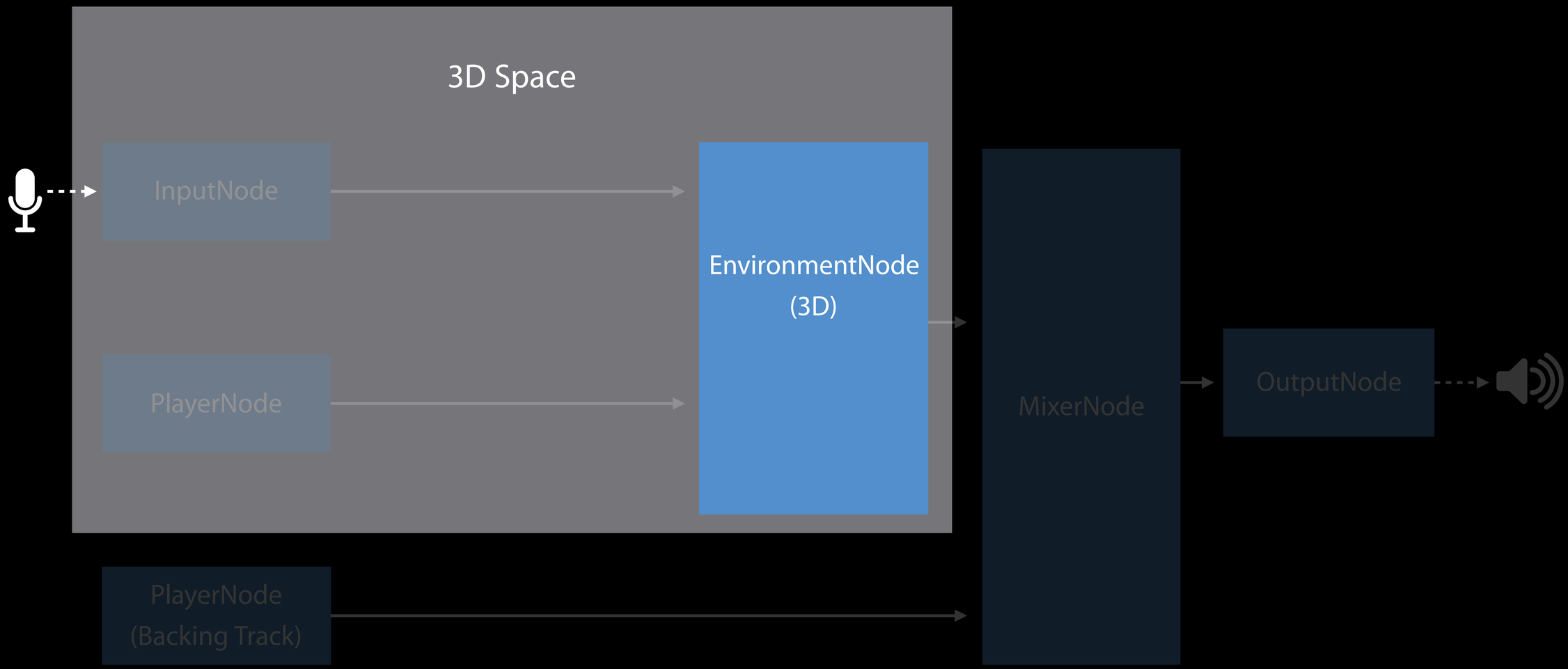
Sample Engine Setup

Game



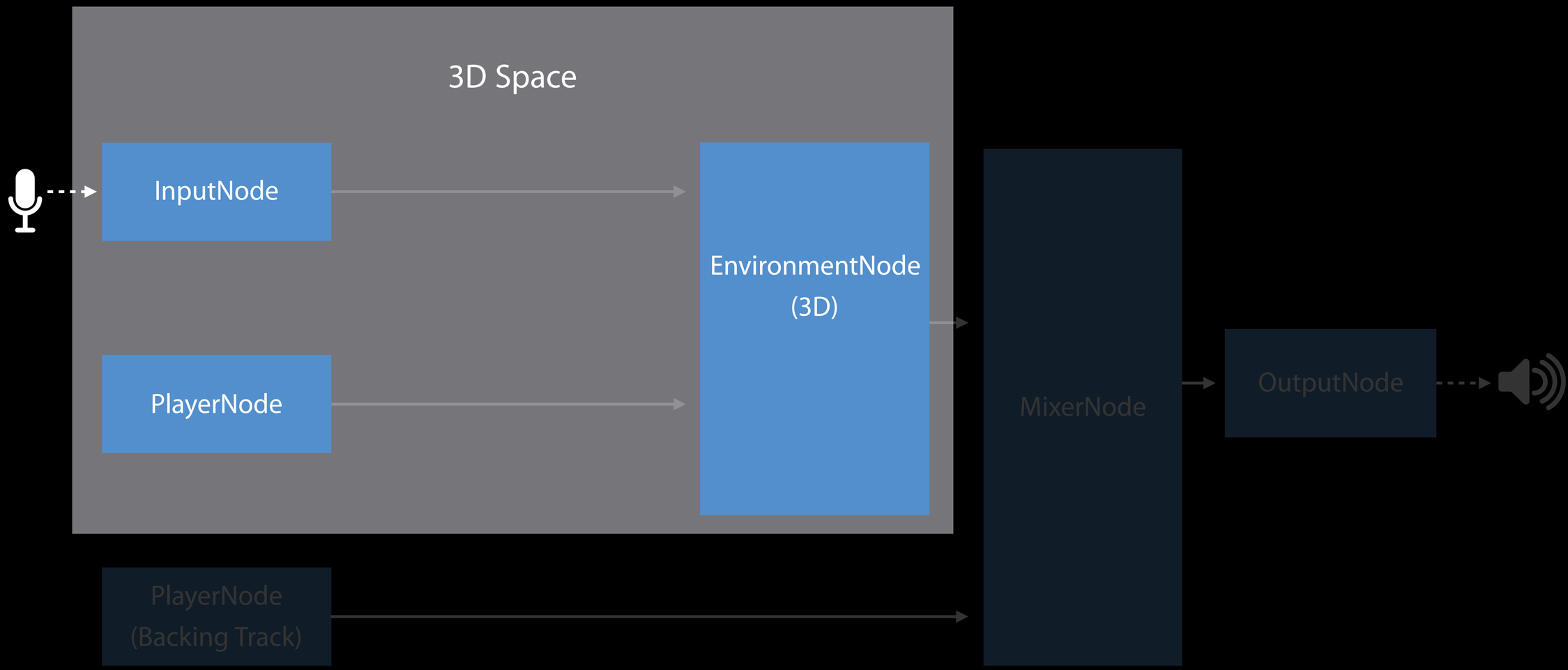
Sample Engine Setup

Game



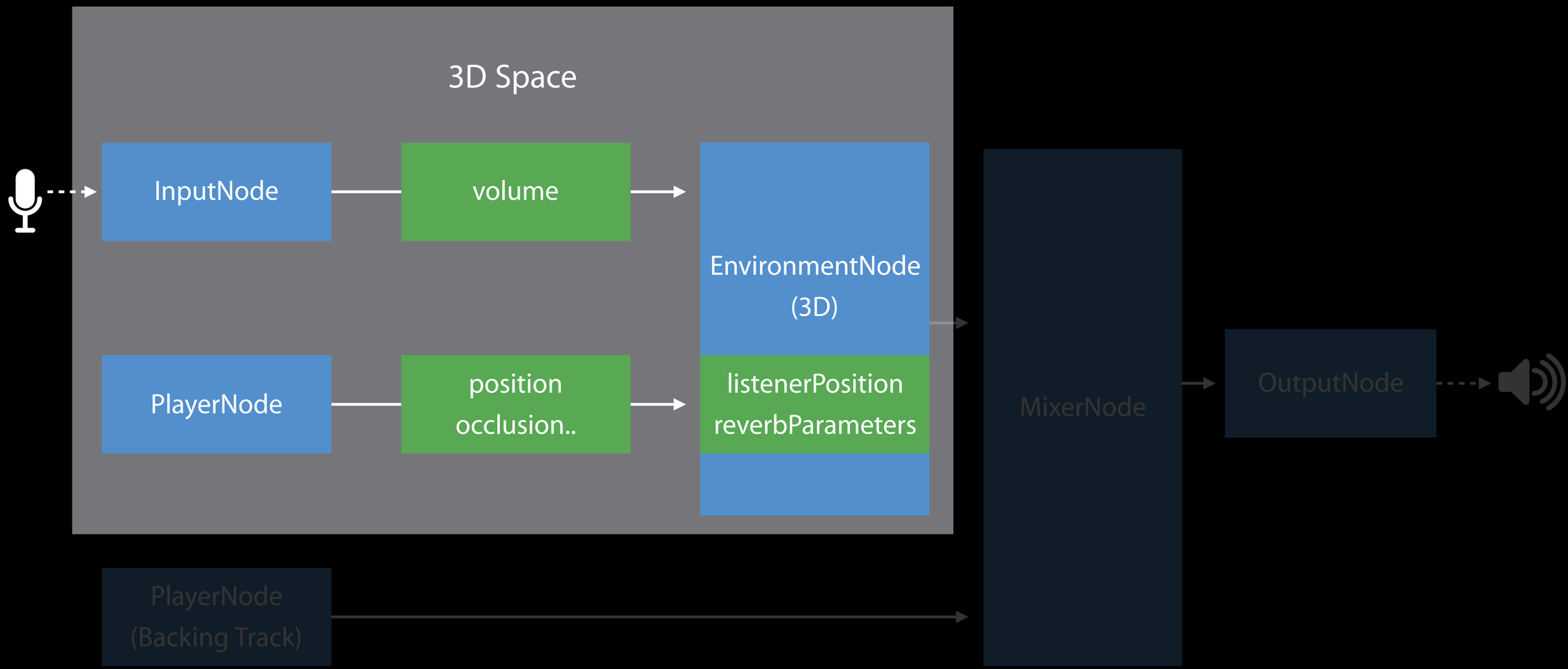
Sample Engine Setup

Game



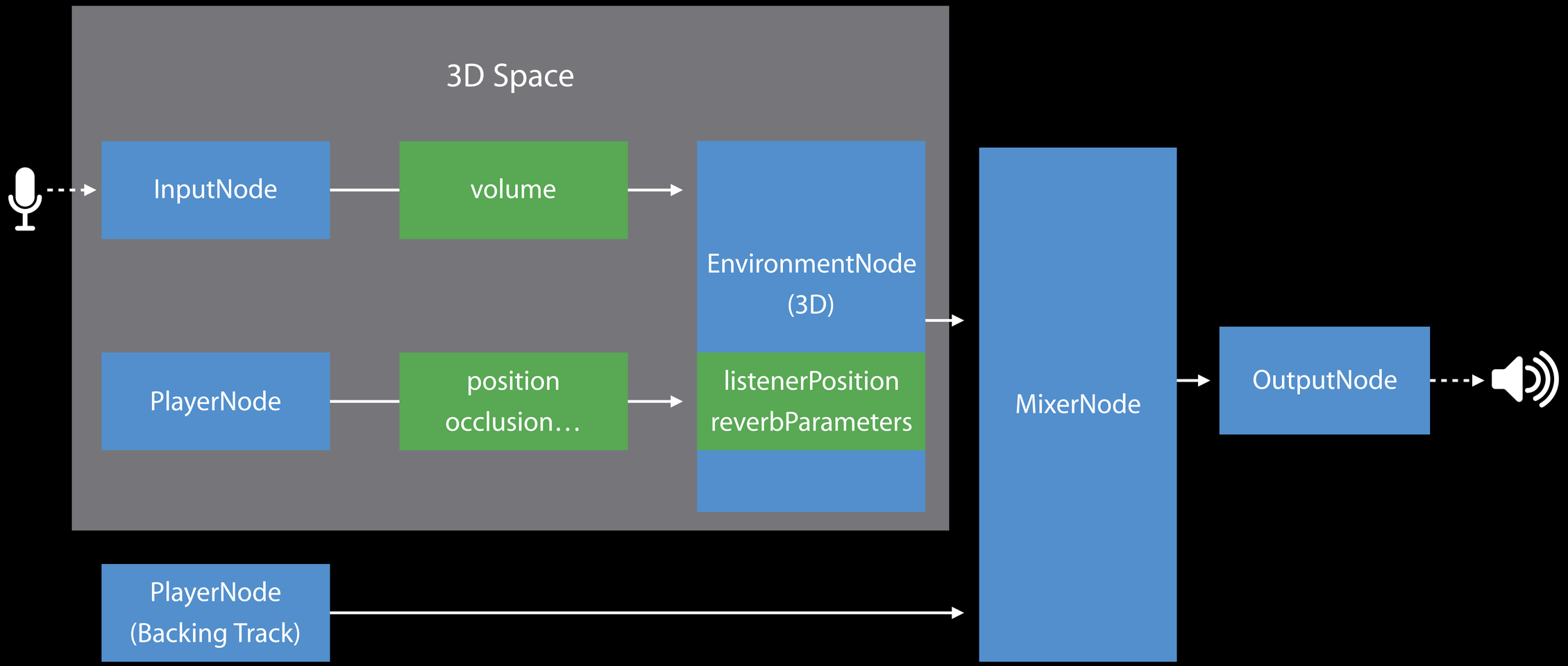
Sample Engine Setup

Game



Sample Engine Setup

Game



Core Classes

AVAudioFormat

Core classes

AVAudioFormat

Core classes

Describes data format in an audio file or stream

- Standard format—non-interleaved Float32
- Common formats—Int16/32, Float32/64
- Compressed formats—settings dictionary

AVAudioFormat

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Contains AVAudioChannelLayout

AVAudioFormat

Core classes

Describes data format in an audio file or stream

- Standard format—non-interleaved Float32
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- Compressed formats—settings dictionary

Contains AVAudioChannelLayout

Modern interface to

- AudioStreamBasicDescription
- AudioChannelLayout

AVAudioBuffer

Core classes

AVAudioBuffer

Core classes

AVAudioPCMBuffer

AVAudioCompressedBuffer

AVAudioBuffer

Core classes

AVAudioPCMBuffer

AVAudioCompressedBuffer

Modern interface to

- AudioBufferList
- AudioStreamPacketDescription

AVAudioFile

Core classes

AVAudioFile

Core classes

Read and write files of any supported format

Takes/provides data in the form of AVAudioPCMBuffer

Transparently decodes while reading, encodes while writing

AVAudioFile

Core classes

Read and write files of any supported format

Takes/provides data in the form of AVAudioPCMBuffer

Transparently decodes while reading, encodes while writing

Supersedes

- AudioFile
- ExtAudioFile

AVAudioConverter

Core classes

AVAudioConverter

Core classes

Audio format conversion

AVAudioConverter

Core classes

Audio format conversion

- PCM to PCM
  - Integer/float, bit depth, endian swap, interleave/de-interleave, sample rate conversion

AVAudioConverter

Core classes

Audio format conversion

- PCM to PCM
  - Integer/float, bit depth, endian swap, interleave/de-interleave, sample rate conversion
- PCM to/from compressed
  - Encoding, decoding

AVAudioConverter

Core classes

Audio format conversion

- PCM to PCM
  - Integer/float, bit depth, endian swap, interleave/de-interleave, sample rate conversion
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Supersedes

- AudioConverter 

AVAudioConverter

NEW

Core classes

Audio format conversion

- PCM to PCM
  - Integer/float, bit depth, endian swap, interleave/de-interleave, sample rate conversion
- PCM to/from compressed
  - Encoding, decoding

Supersedes

- AudioConverter

```
public let AVSampleRateConverterAlgorithm_MinimumPhase: String
```

Core Classes

AVAudioFormat → AVAudioChannelLayout

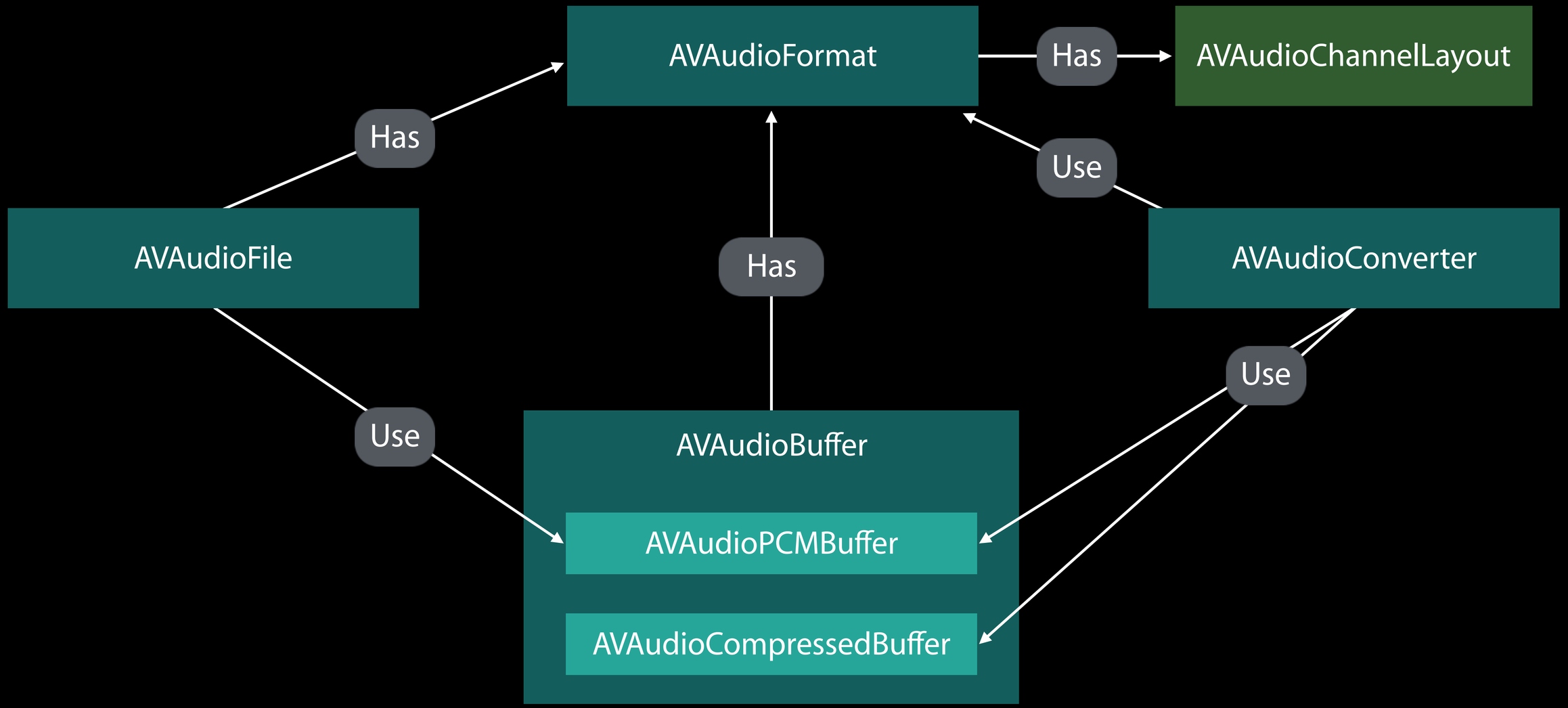
AVAudioFile

AVAudioConverter

AVAudioBuffer

- AVAudioPCMBuffer
- AVAudioCompressedBuffer

Core Classes



Core Classes with AVAudioEngine

AVAudioFormat

AVAudioNode

AVAudioFile

AVAudioNodeTapBlock

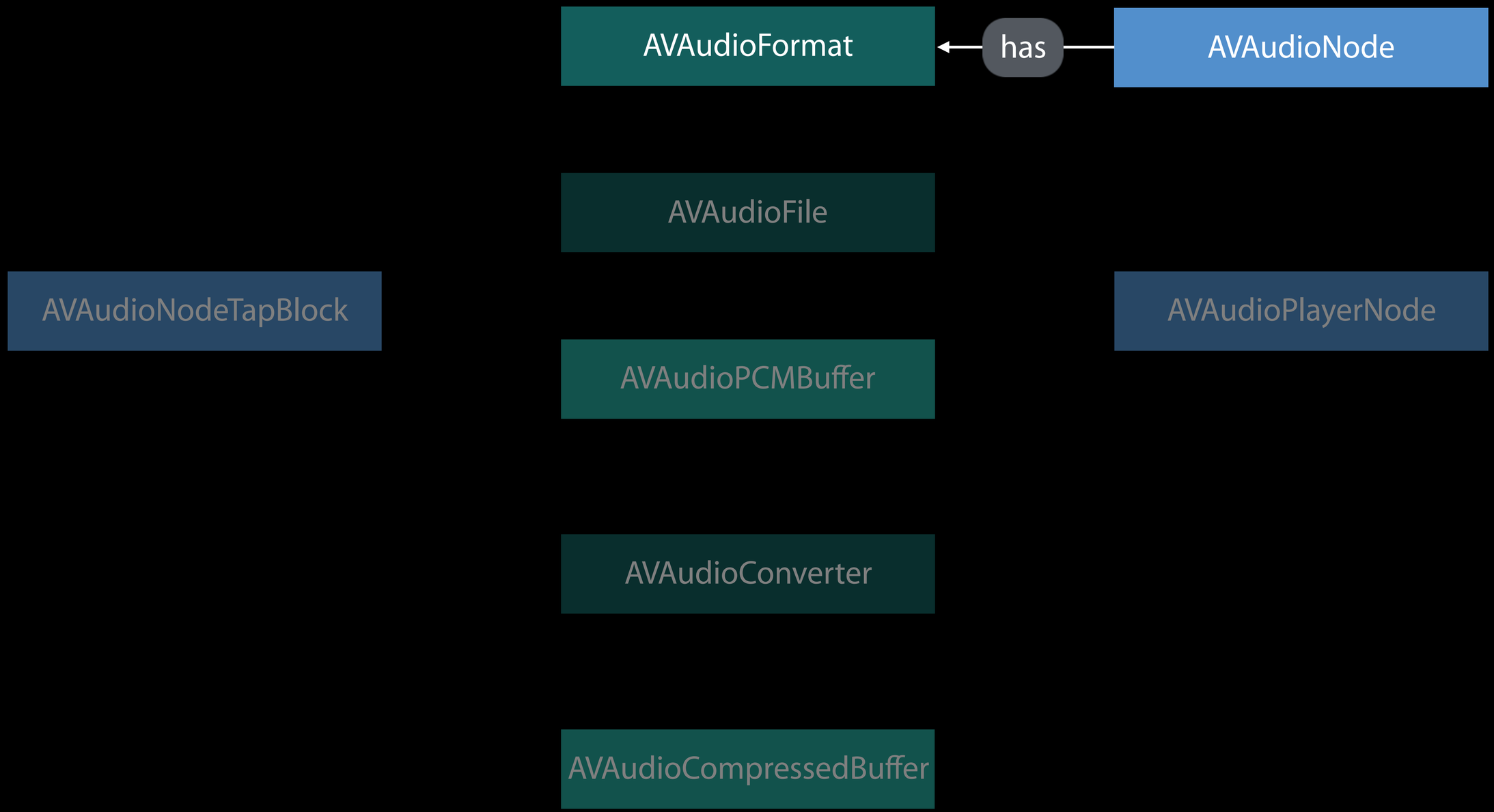
AVAudioPlayerNode

AVAudioPCMBuffer

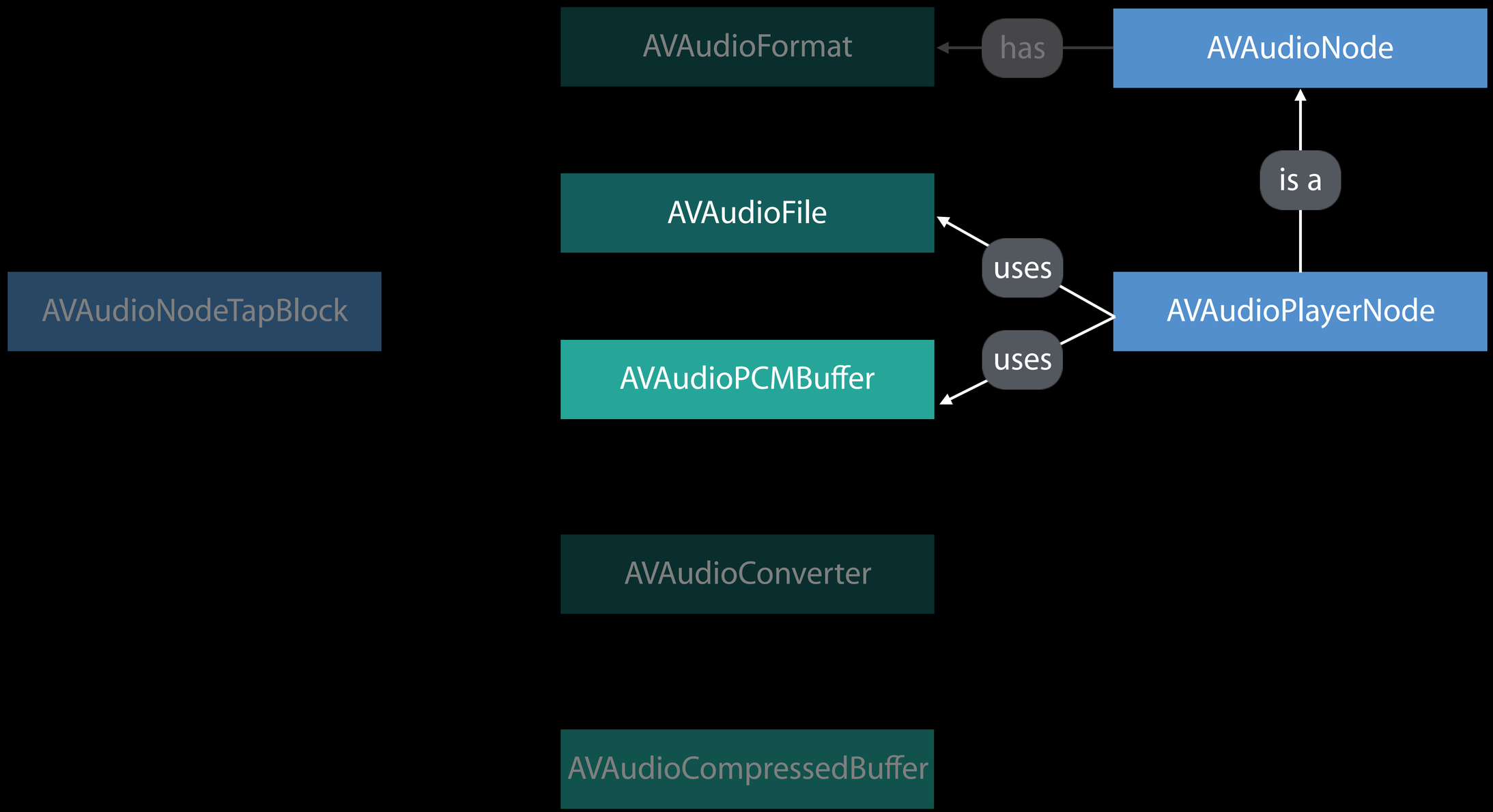
AVAudioConverter

AVAudioCompressedBuffer

Core Classes with AVAudioEngine



Core Classes with AVAudioEngine



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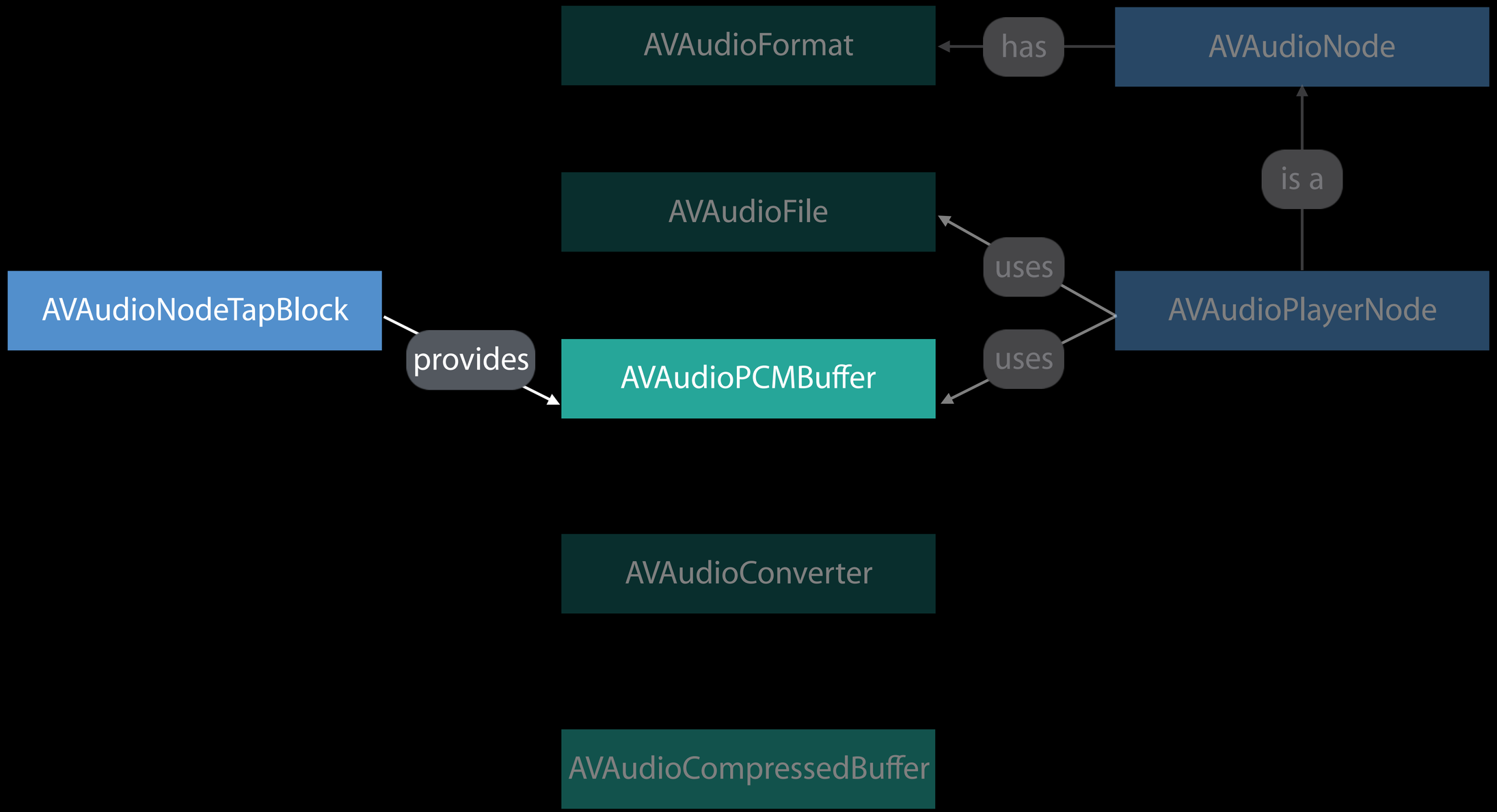
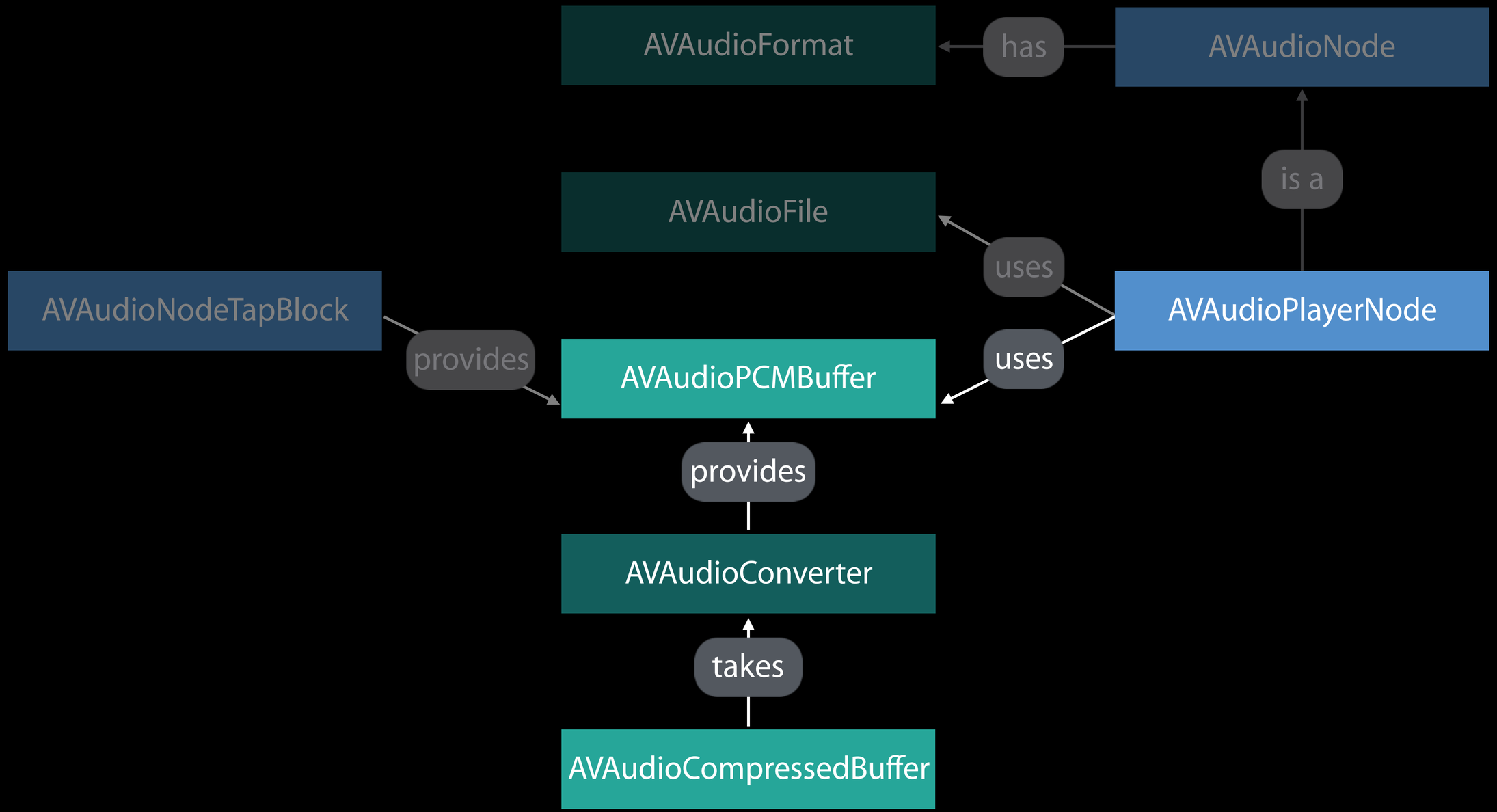
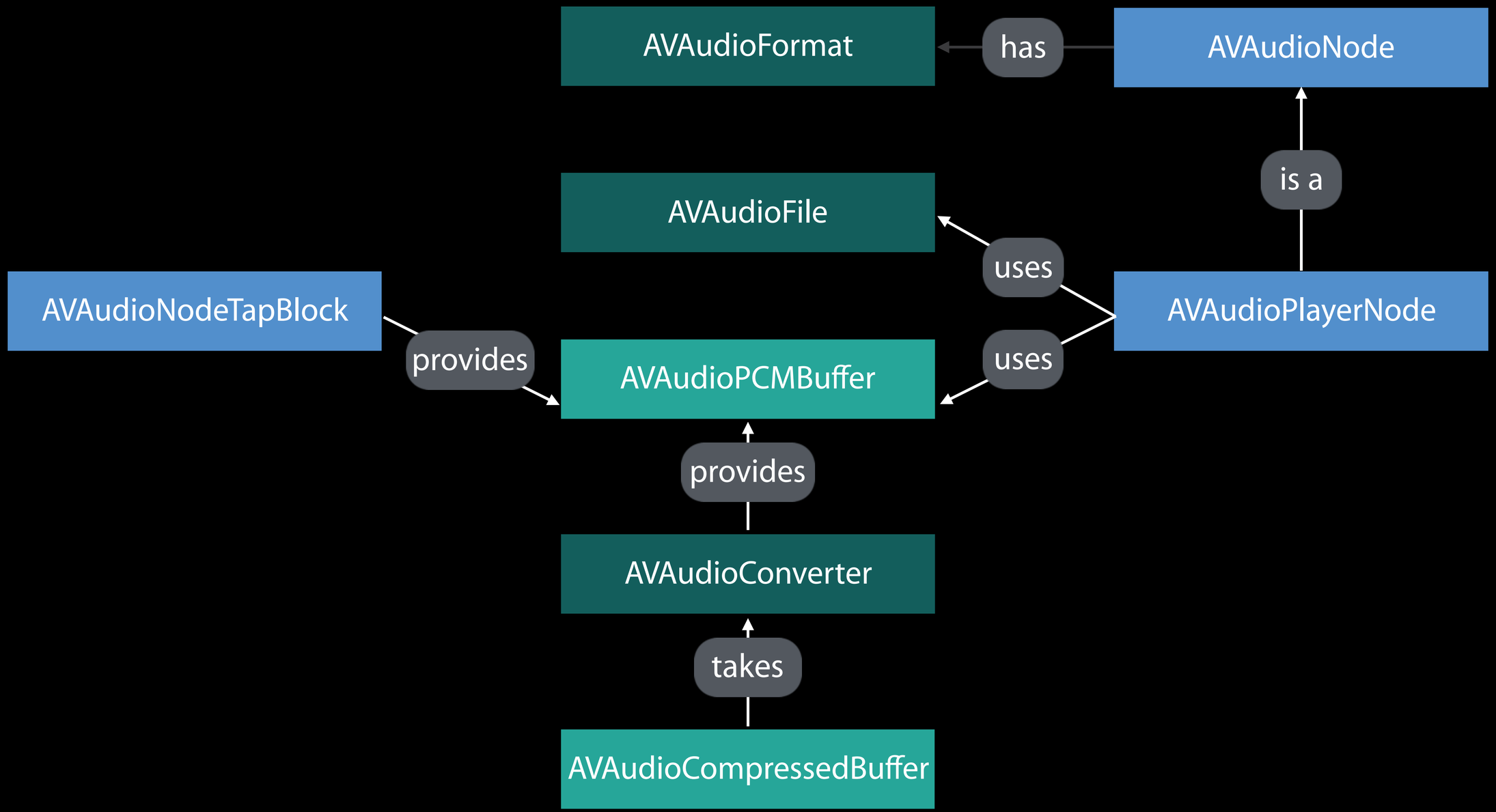


Core Classes with AVAudioEngine



Core Classes with AVAudioEngine



watchOS

Playback and mixing

NEW

AVAudioSession

Core classes

- AVAudioFormat/Buffer/File/Converter

AVAudioEngine

- AVAudioPlayerNode
- AVAudioMixerNode
- AVAudioOutputNode

Demo

AVAudioEngine on watchOS

```
// AVAudioEngine - watchOS Gaming Example
// Class setup
class GameController: WKInterfaceController {
    // other members ex. SceneKit scene
    // engine and nodes
    var audioEngine = AVAudioEngine()
    let explosionPlayer = AVAudioPlayerNode()
    let launchPlayer = AVAudioPlayerNode()

    // URLS to our audio assets
    let explosionAudioURL = URL.init(fileURLWithPath: "/path/to/explosion.caf")
    let launchAudioURL = URL.init(fileURLWithPath: "/path/to/launch.caf")

    // buffers for playback
    var explosionBuffer:AVAudioPCMBuffer?
    var launchBuffer:AVAudioPCMBuffer?
}
```

```
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```

```
audioEngine.attach(explosionPlayer)
audioEngine.attach(launchPlayer)

do {
    // for each of my url assets
    let explosionAudioFile = try AVAudioFile.init(forReading: explosionAudioURL)
    explosionBuffer = AVAudioPCMBuffer.init(pcmFormat:explosionAudioFile.processingFormat,
                                frameCapacity: AVAudioFrameCount(explosionAudioFile.length))
    try explosionAudioFile.read(into: explosionBuffer!)

    // make connections
    audioEngine.connect(explosionPlayer, to: audioEngine.mainMixerNode,
                    format: explosionAudioFile.processingFormat)
    audioEngine.connect(launchPlayer, to: audioEngine.mainMixerNode,
                    format:launchAudioFile.processingFormat)
}
catch { /* handle error */ }
```

```
    audioEngine.attach(explosionPlayer)
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}
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```

```
do {
    //start engine and players
    try audioEngine.start()
    explosionPlayer.play()
    launchPlayer.play()
}
catch { /* handle error */ }

// create an asteroid and launch
launchPlayer.scheduleBuffer(launchBuffer!, completionHandler: nil)
// wait to launch again

// asteroid is destroyed
explosionPlayer.scheduleBuffer(explosionBuffer!, completionHandler: nil)
// clean up scene and destroy the node
```

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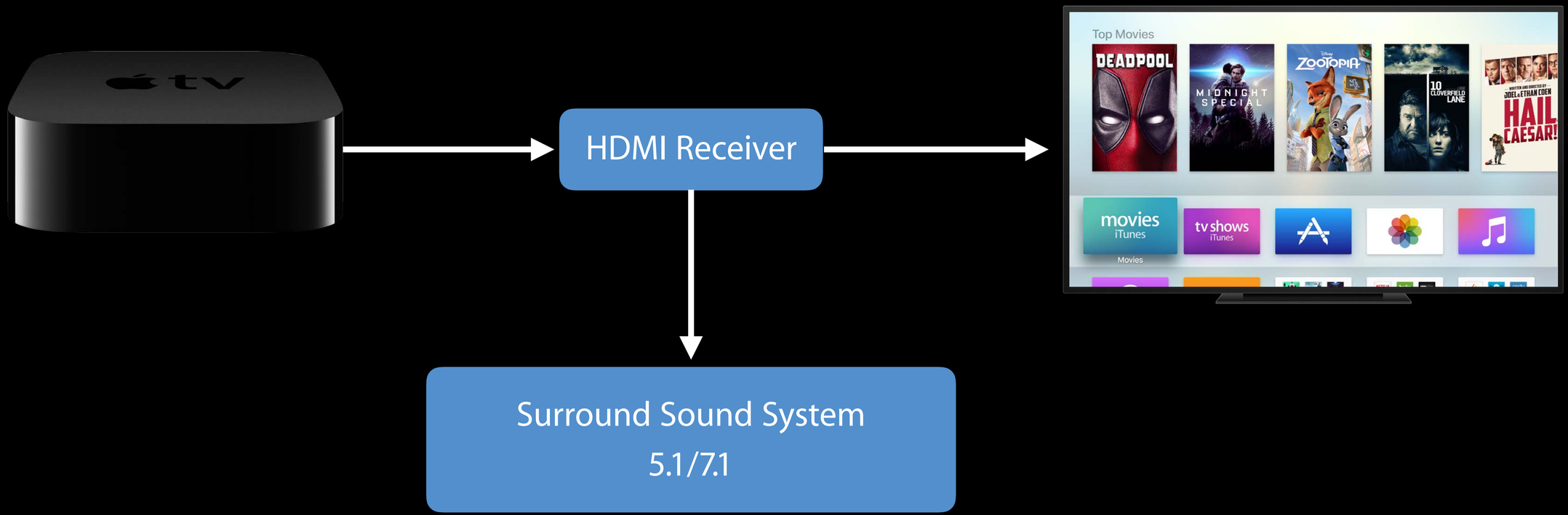
Multichannel Audio

Multichannel Audio on tvOS



AVAudioSession Channel Count

Review

```
do {
    //set category, mode & options etc...
    let audioSession = AVAudioSession.sharedInstance()
    try audioSession.setActive(true)
    let desiredNumberOfChannels = 6 // 5.1 surround rendering
    if audioSession.maximumOutputNumberOfChannels >= desiredNumberOfChannels {
        try audioSession.setPreferredOutputNumberOfChannels(desiredNumberOfChannels)
    }
    let actualNumberOfChannels = audioSession.outputNumberOfChannels
    /* ... */
}
catch { /*handle error*/ }
```

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```

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    let actualNumberOfChannels = audioSession.outputNumberOfChannels
    /* ... */
}
catch { /*handle error*/ }
```
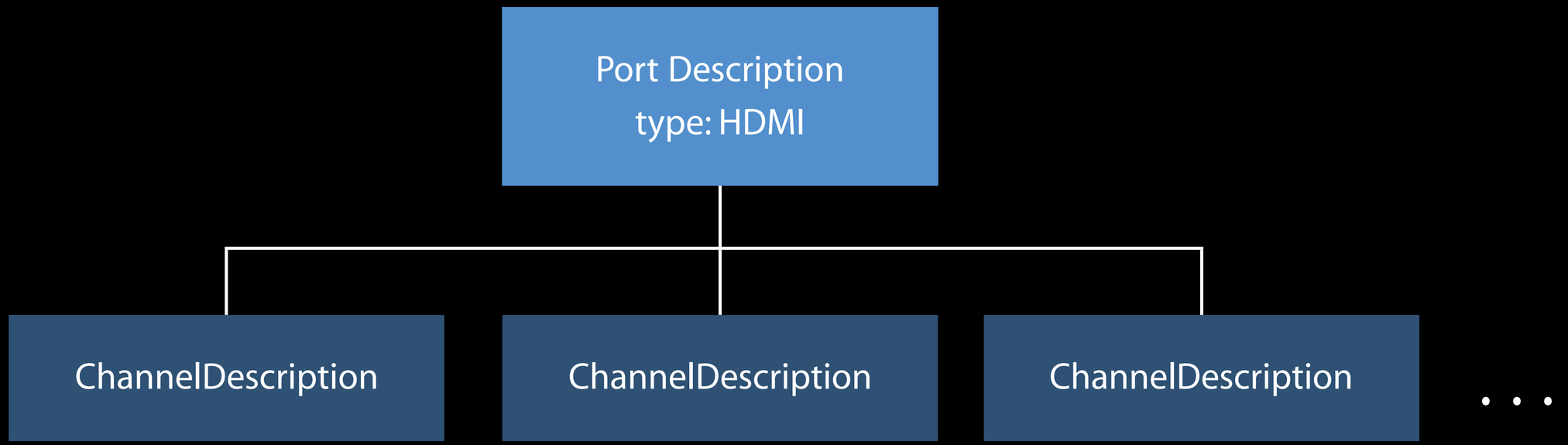
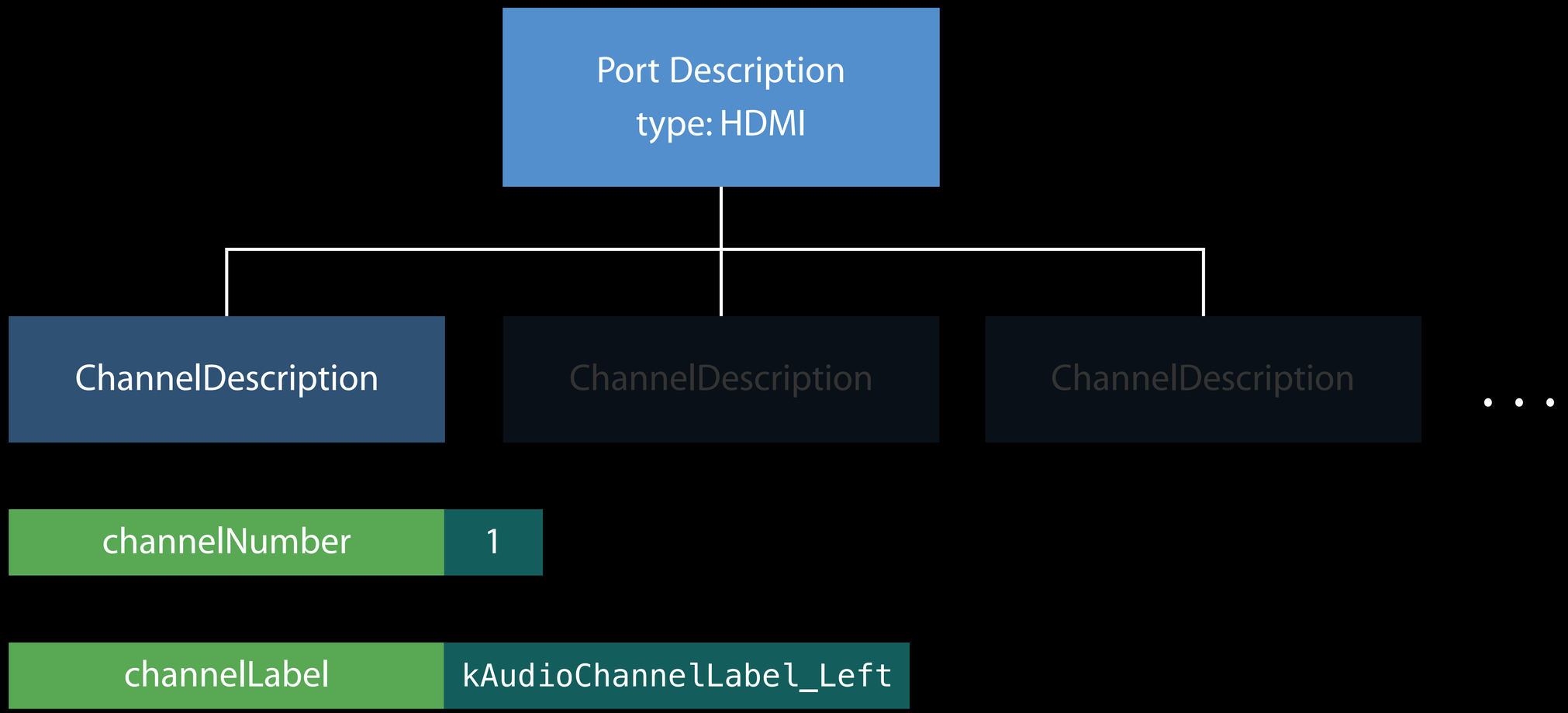

AVAudioSession Channel Labels

Port Description
type: HDMI

AVAudioSession Channel Labels



AVAudioSession Channel Labels



AVAudioEngine Setup

Multichannel content

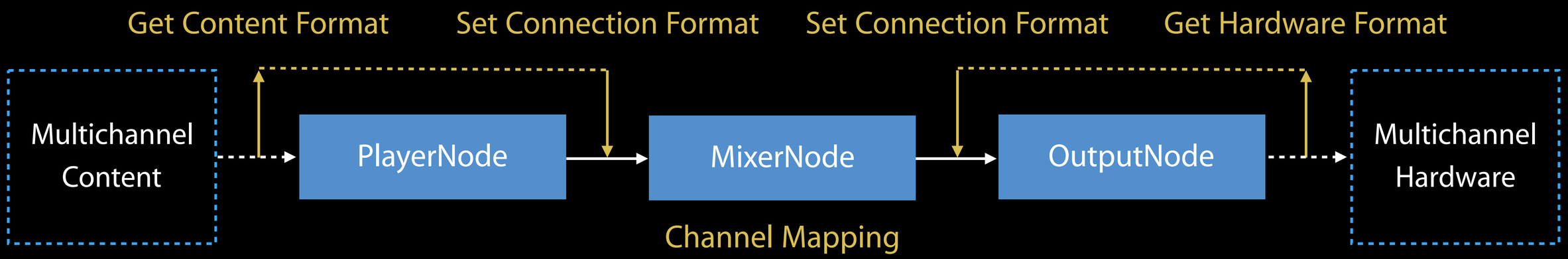
Mono content -> Spatialize (games)

AVAudioEngine Setup

Multichannel content

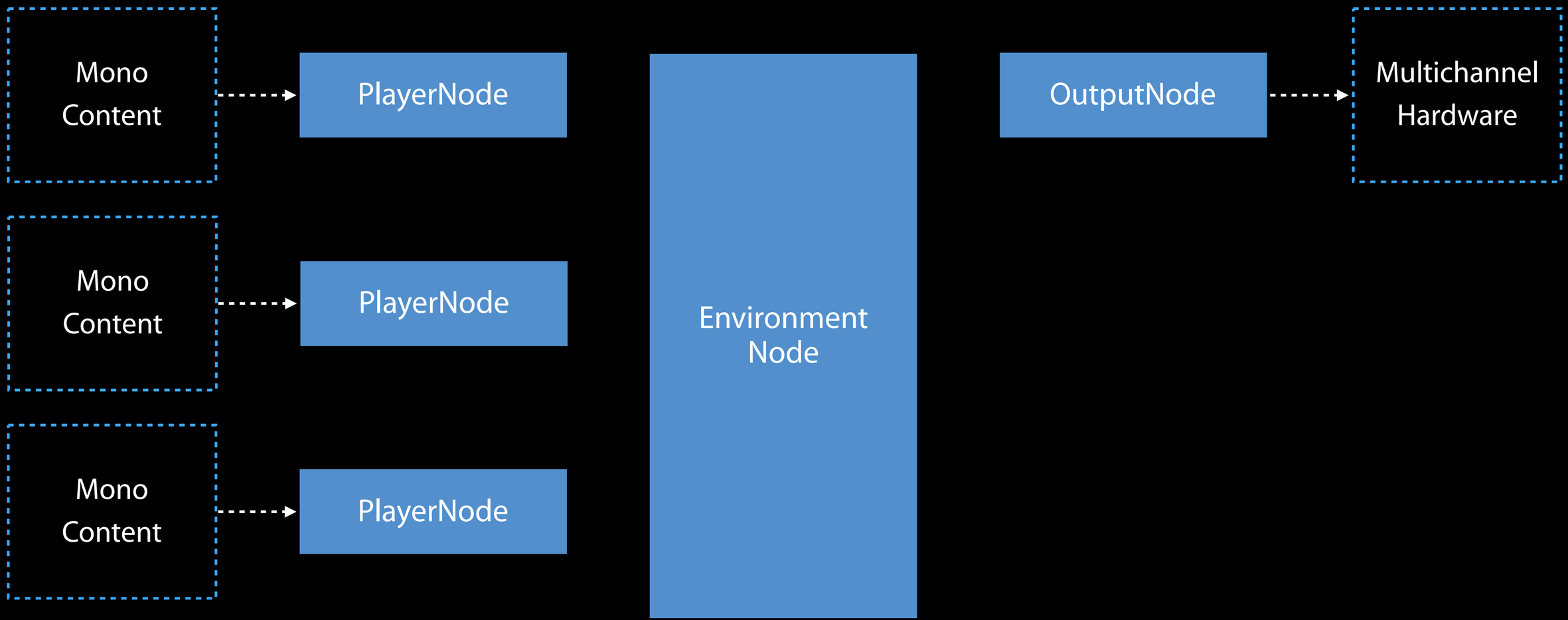
AVAudioEngine Setup

Multichannel content



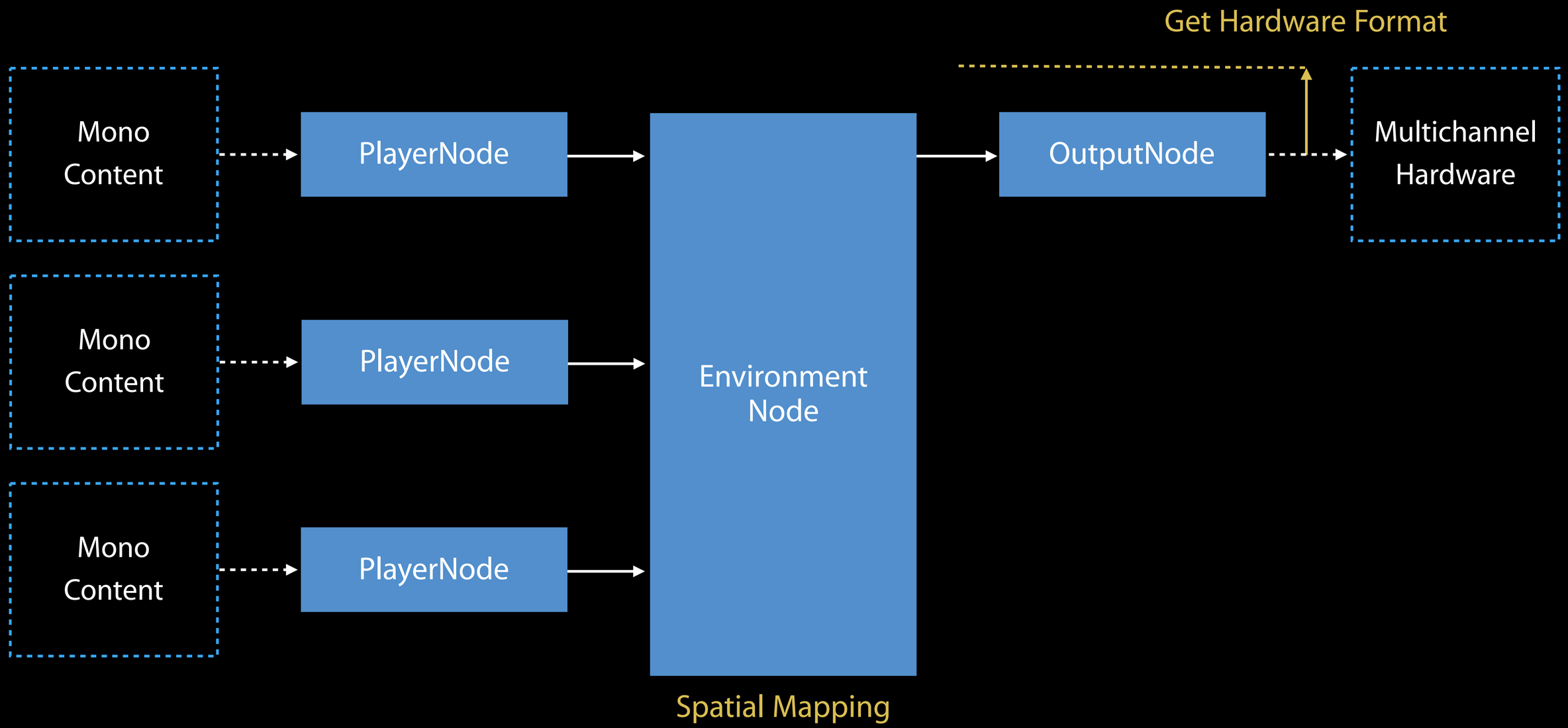
AVAudioEngine Setup

Spatialize content with multiple mono sources



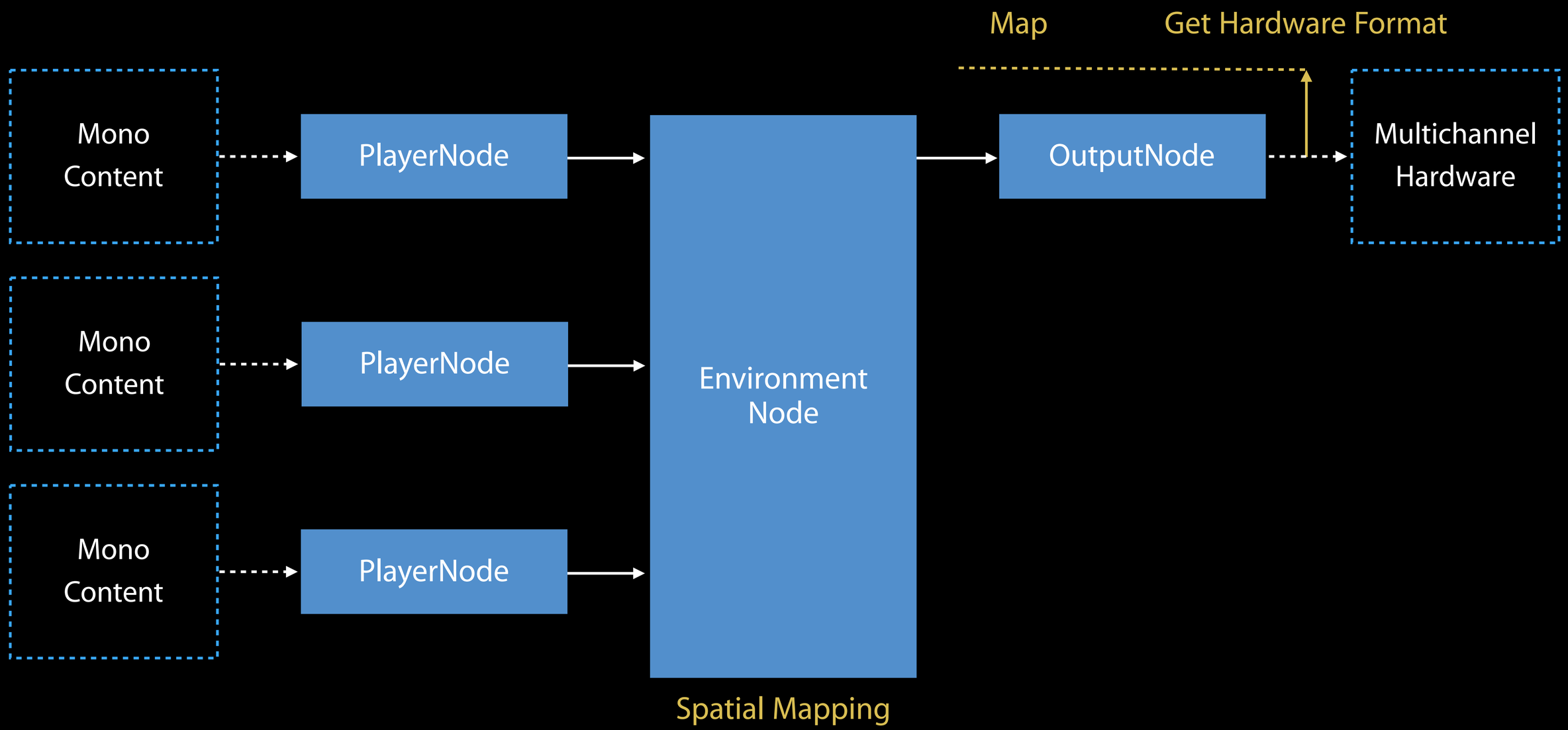
AVAudioEngine Setup

Spatialize content with multiple mono sources



AVAudioEngine Setup

Spatialize content with multiple mono sources



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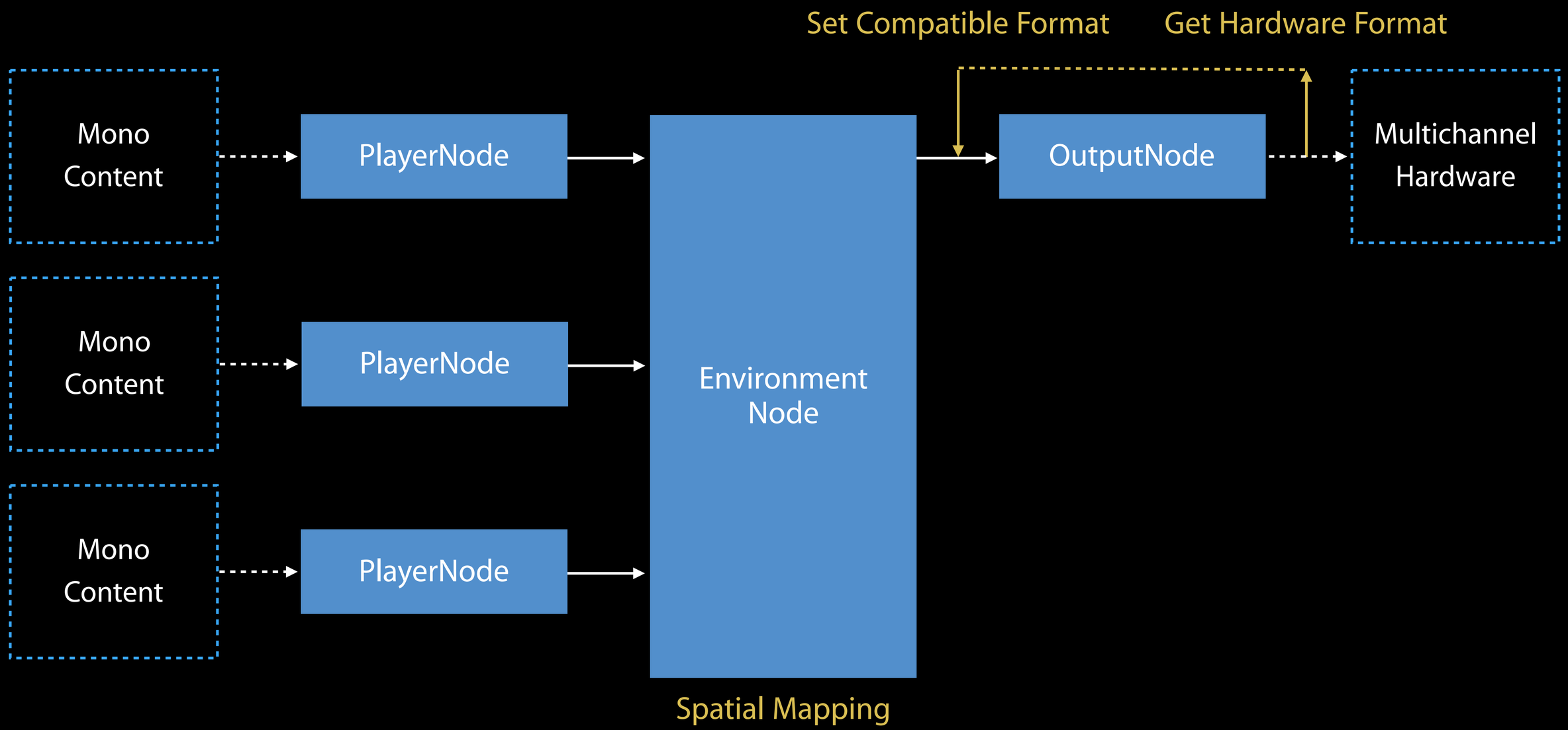

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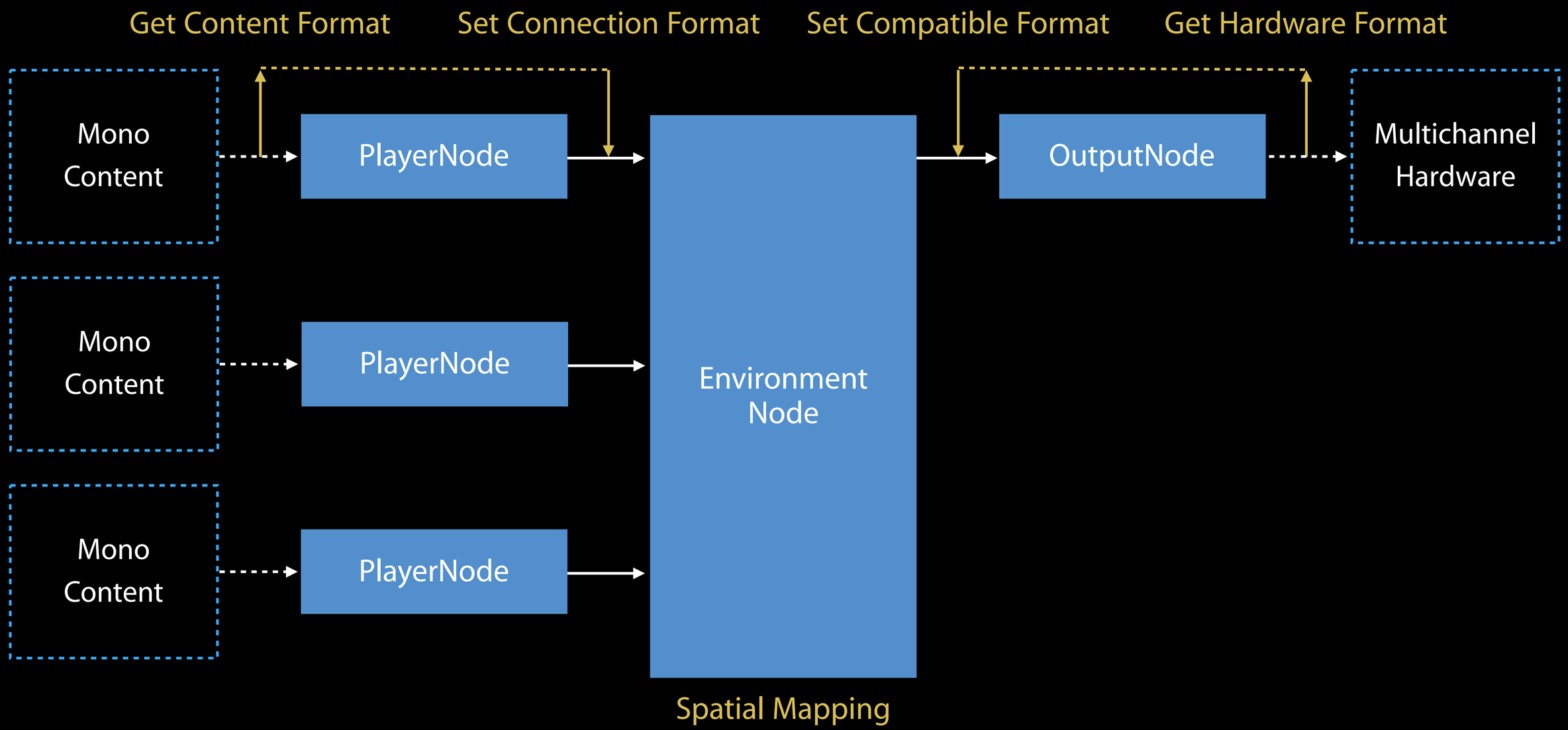

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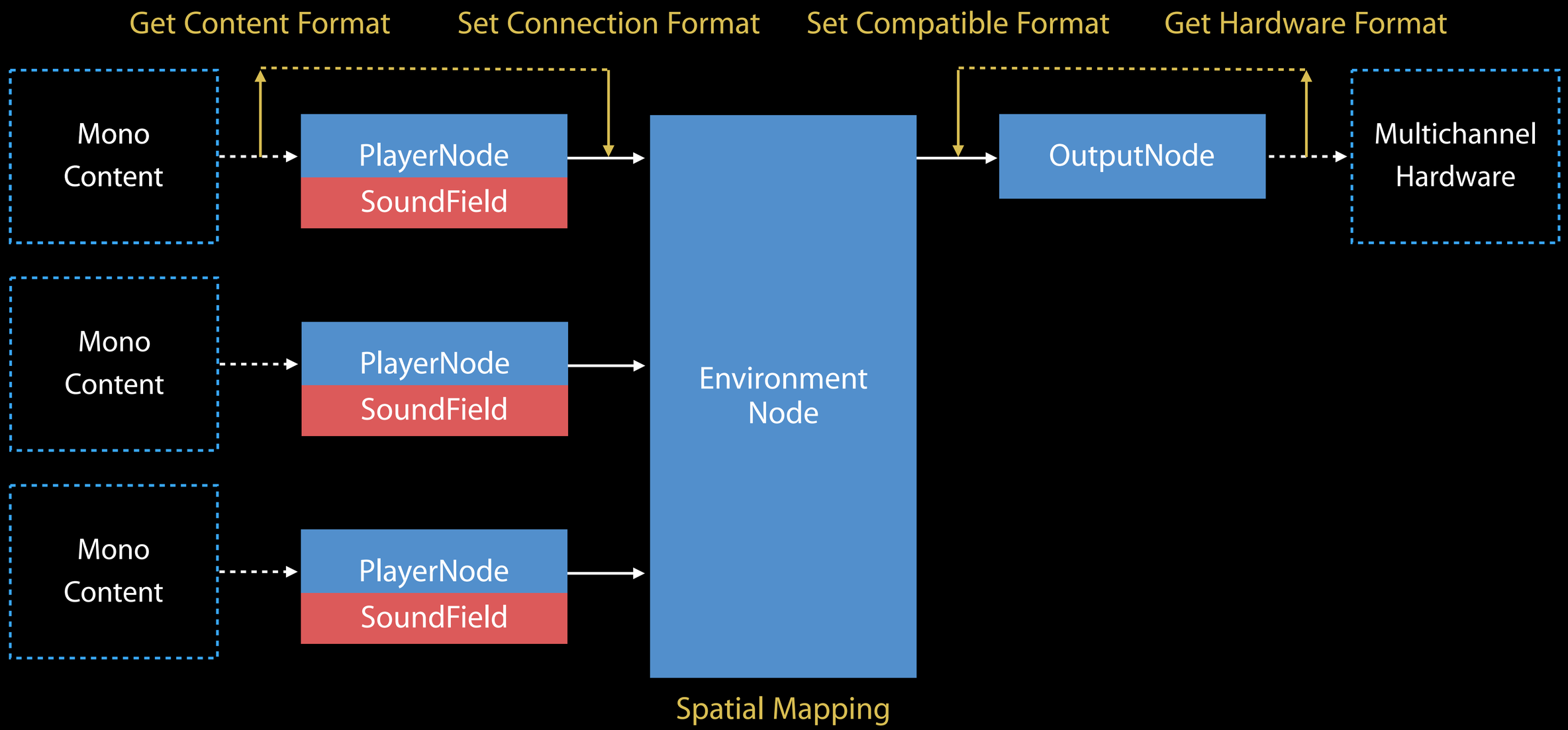

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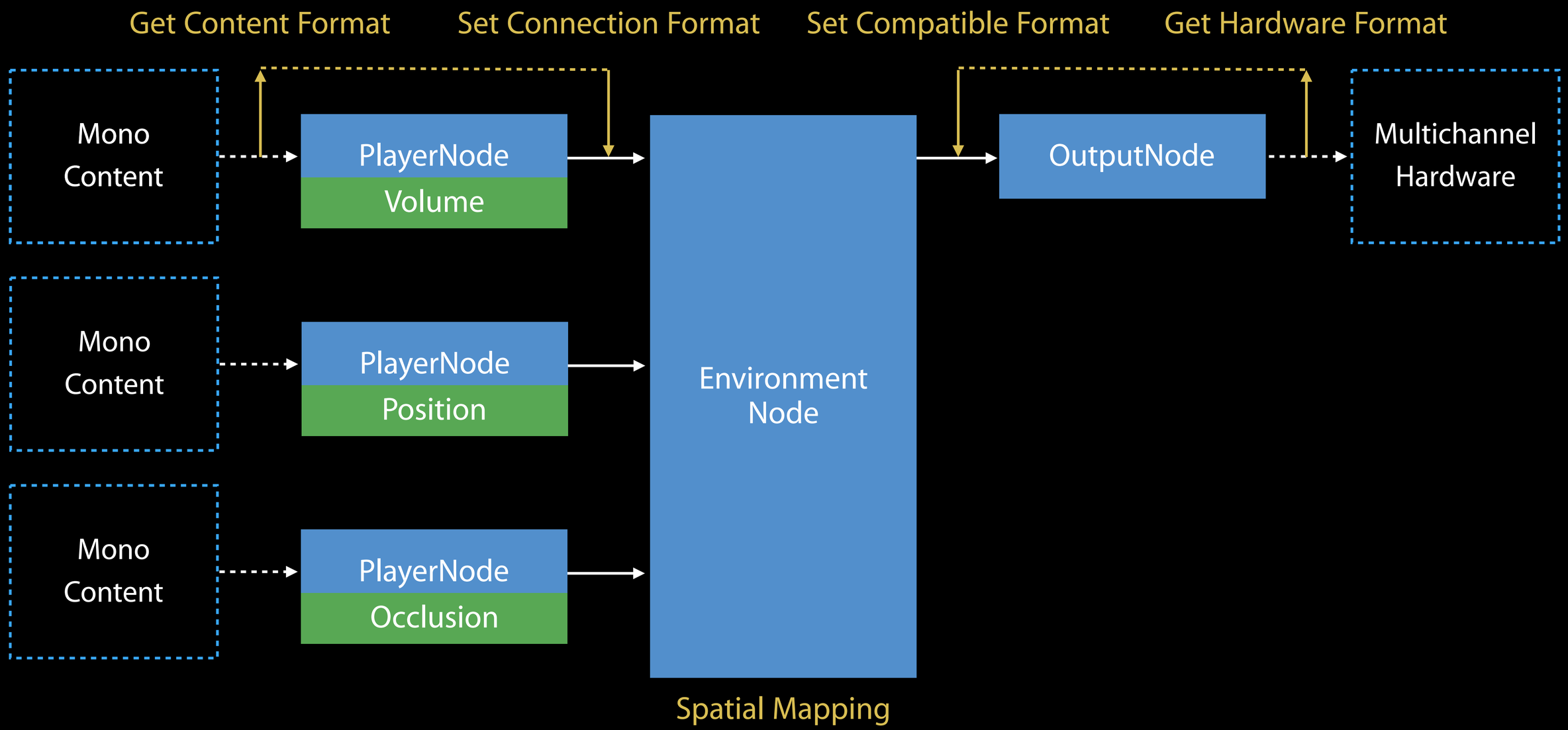

AVAudioEngine

Summary

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Powerful, feature-rich

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Simplifies real-time audio

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Multichannel, 3D audio

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Supersedes

- AUGraph
- OpenAL

References

What's New in Core Audio	WWDC 2014
AVAudioEngine in Practice	WWDC 2014
What's New in Core Audio	WWDC 2015

Real-Time Audio

Doug Wyatt Audio Plumber

What Is Real-Time Audio?

Low latency

Needed for

- Music: Software synthesizers, effects
- Telephony (VoIP)
- Other interactive engines

What Is Real-Time Audio?

Deadline: You have N milliseconds to produce N milliseconds of audio

Typically ~3–20 ms

Real-Time Constraints

Real-Time Constraints

Must not block by

- Allocating memory
- Taking a mutex or waiting on a semaphore
- Reading from a file
- Logging
- Calling libdispatch (notably async)
- Calling ObjC and Swift runtimes
- Doing anything else that involves memory allocation or a mutex

Real-Time Audio

Real-Time Audio

Audio Units

- Modular, reusable signal generation/processing blocks

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You can host them

- System built-in units
- Units chosen by user

Real-Time Audio

Audio Units

- Modular, reusable signal generation/processing blocks

You can host them

- System built-in units
- Units chosen by user

Build your own

- As plug-ins (extensions)
- Registered privately to your app

Audio Units: Components

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AudioToolbox maintains a system registry

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Component key: Type/subtype/manufacturer (4-character codes)

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AudioToolbox maintains a system registry

Component key: Type/subtype/manufacturer (4-character codes)

Audio Component types

- Audio Units: Input/output, generators, instruments, effects, converters
- Codecs: Encoders, decoders

Audio Units: Components

Implementations

Audio Units: Components

Implementations

Audio Unit application extensions (macOS, iOS)

Audio Units: Components

Implementations

Audio Unit application extensions (macOS, iOS)

Component bundles (macOS only)

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Registered at runtime

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Apple built-in

Audio Input/Output Units

Audio Input/Output Units

Most commonly used

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Most commonly used

Preferred higher-level interface to the system's basic I/O path

Audio Input/Output Units

Most commonly used

Preferred higher-level interface to the system's basic I/O path

AUAudioUnit (AudioToolbox/AUAudioUnit.h)

- Modern interface to version 2 Audio Units: AUHAL, AURemoteIO

Demo

Using AUAudioUnit

Effects, Instruments, and Generators

Effects, Instruments, and Generators

Hosting

Also AUAudioUnit

Chain render blocks

Parameters

AU-provided views

Effects, Instruments, and Generators

Writing your own

Effects, Instruments, and Generators

Writing your own

Within your own app

- Subclass AUAudioUnit
- +[AUAudioUnit registerSubclass: …]

Effects, Instruments, and Generators

Writing your own

Within your own app

- Subclass AUAudioUnit
- +[AUAudioUnit registerSubclass: . . .]

To write a plug-in for distribution

- Also AUAudioUnit subclass
- Packaged as Audio Unit Extension

Demo

Audio Unit Extensions

Torrey Holbrook Walker The Demonstrator

AUAudioUnit

For more information

Audio Unit Extensions

WWDC 2015

MIDI

MIDI

Music Instrument Digital Interface

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Music Instrument Digital Interface

Task	Preferred APIs

MIDI

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Task	Preferred APIs
Play standard MIDI file (or your own sequences)	AVAudioSequencer

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Control software synth	AVAudioUnitMIDIInstrument AUAudioUnit
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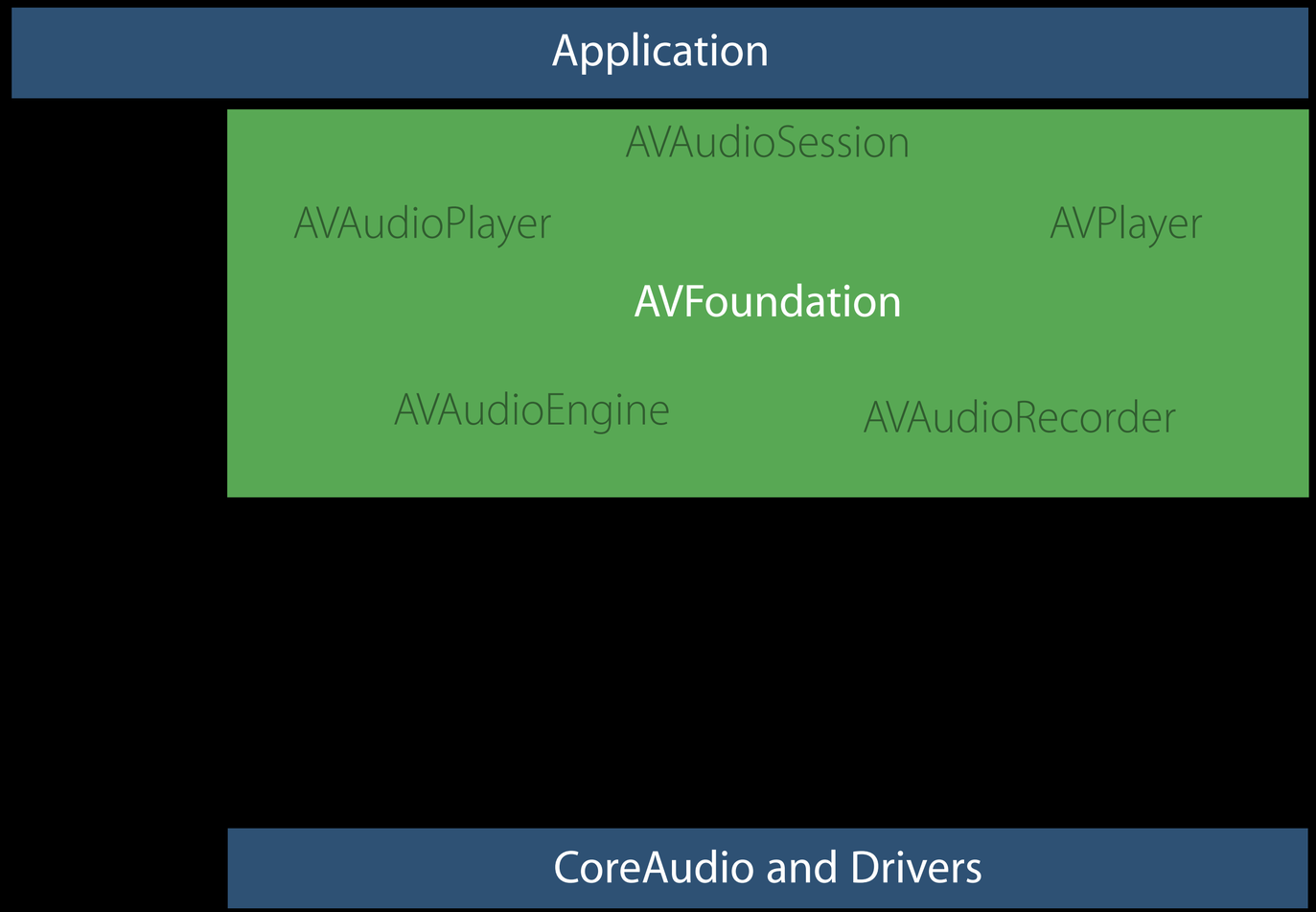
Inter-process real-time MIDI	CoreMIDI

Recap

Application

CoreAudio and Drivers

Recap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AVAudioPlayer
AVPlayer
AVFoundation
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AVAudioRecorder
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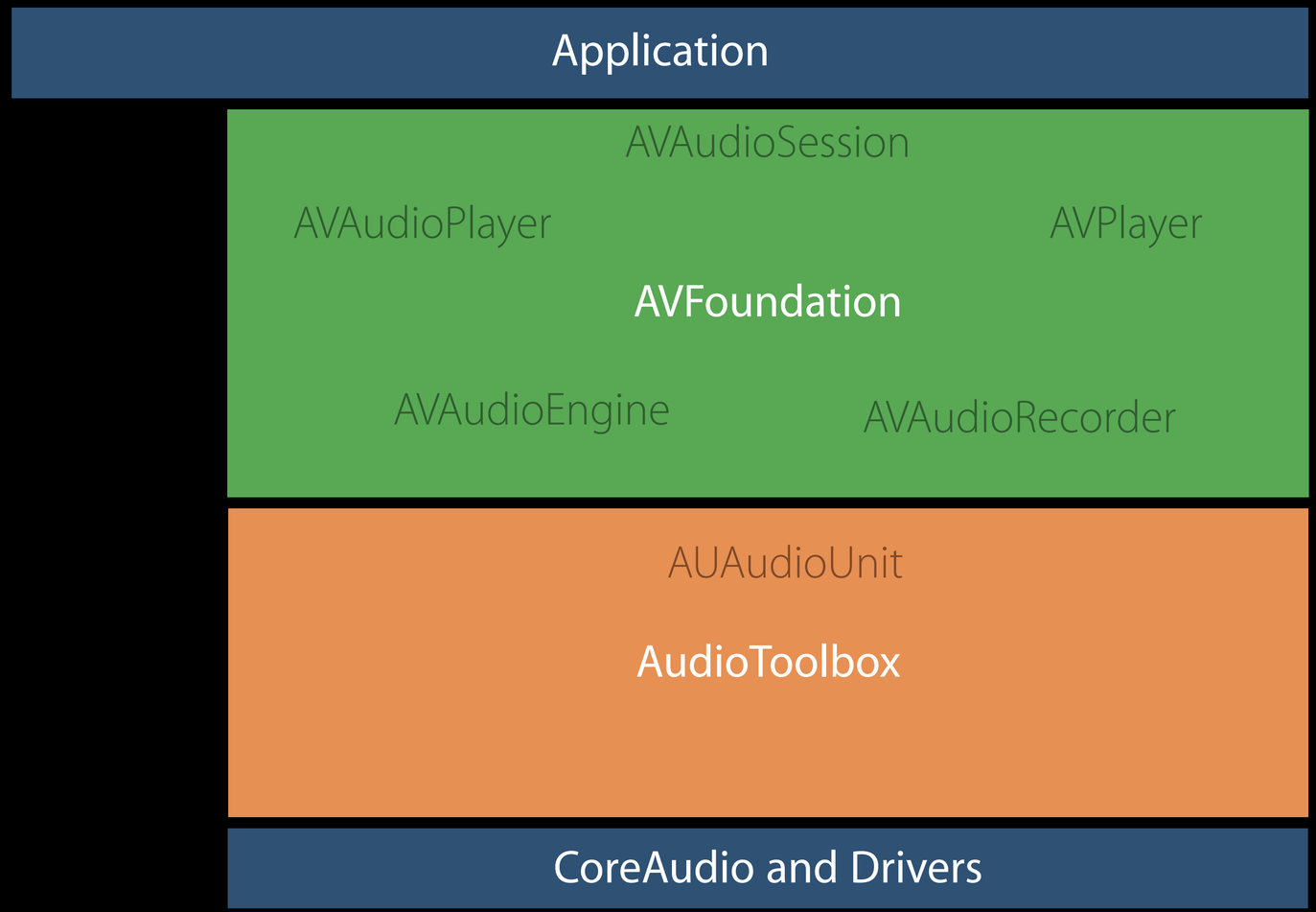
Recap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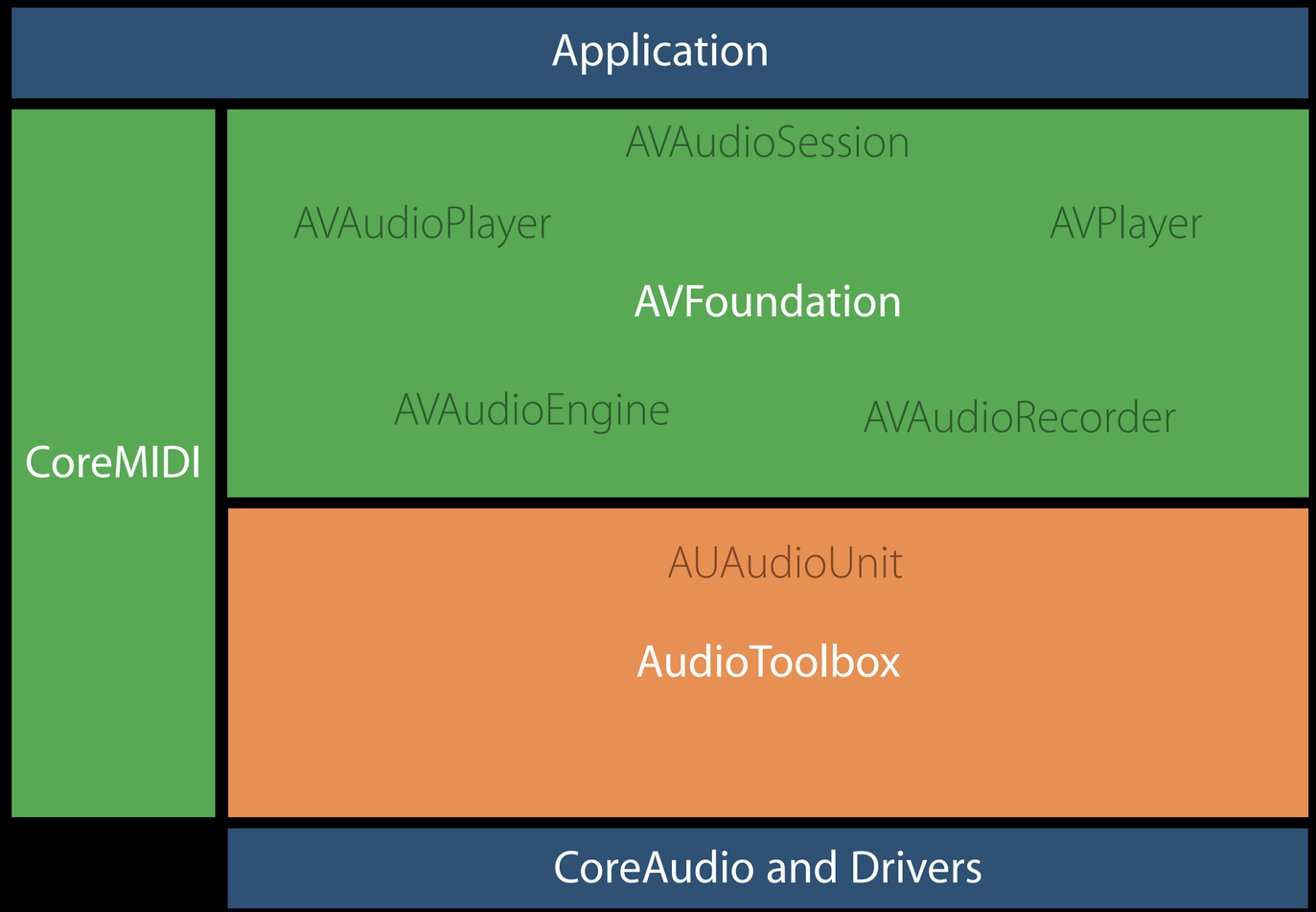
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More Information

https://developer.apple.com/wwdc16/507

Related Sessions

Enhancing VoIP Apps with CallKit	Mission	Thursday 5:00PM
Advances in AVFoundation Playback	Mission	Wednesday 9:00AM
Audio Session and Multiroute Audio in iOS		WWDC 2012
What's New in Core Audio		WWDC 2014
AVAudioEngine in Practice		WWDC 2014
What's New in Core Audio		WWDC 2015
Audio Unit Extensions		WWDC 2015

Labs

Audio Lab	Graphics, Games, and Media Lab D	Friday 3:00PM

WWDC16