#WWDC19

Advances in Camera Capture and Photo Segmentation

Brad Ford, Camera Software
Jacob Schack Vestergaard, Camera Software
David Hayward, Core Image

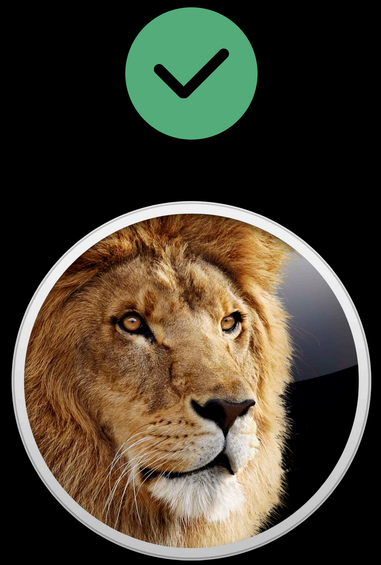
Multi-Camera Capture

Semantic Segmentation for Photos

Multi-Camera Capture

MultiCam

Multi-Camera Capture Support by Platform



OS X Lion
(2011)

Multi-Camera Capture Support by Platform

OS X Lion
(2011)

iOS 12
(2018)

Multi-Camera Capture Support

Multi-Camera Capture Support

Multi-Camera Capture Support

Multi-Camera Capture

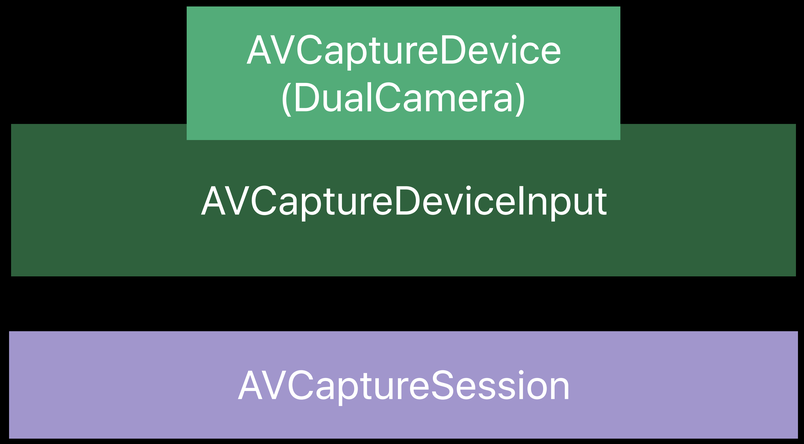
Session building

AV Foundation Capture Classes

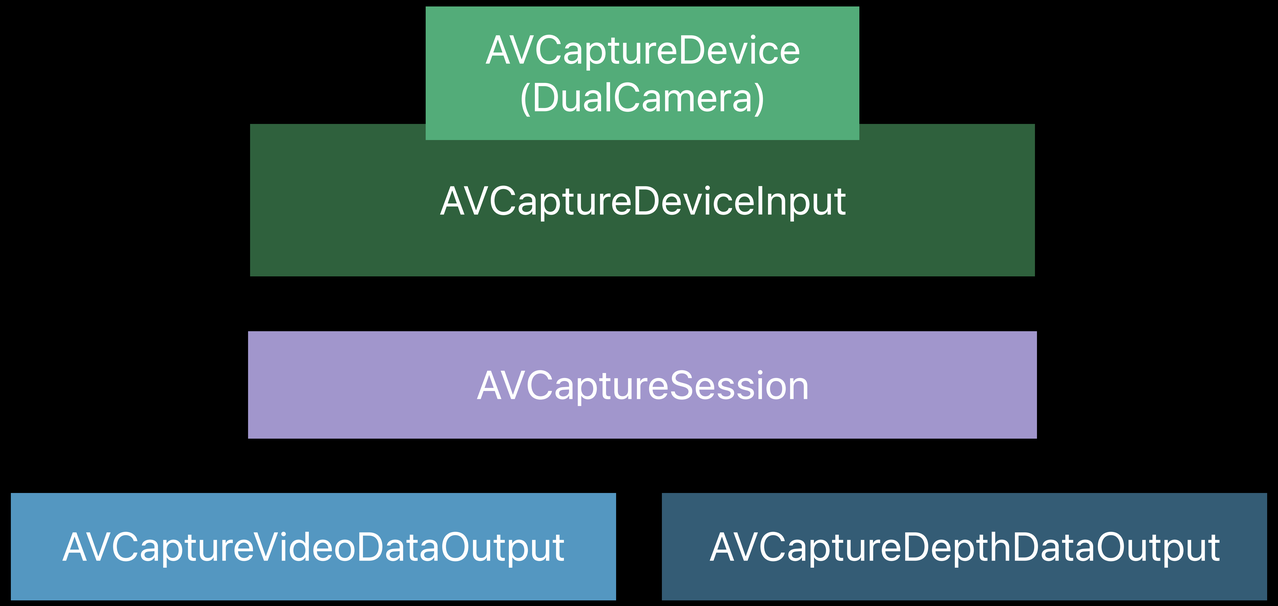
AV Foundation Capture Classes

AVCaptureSession

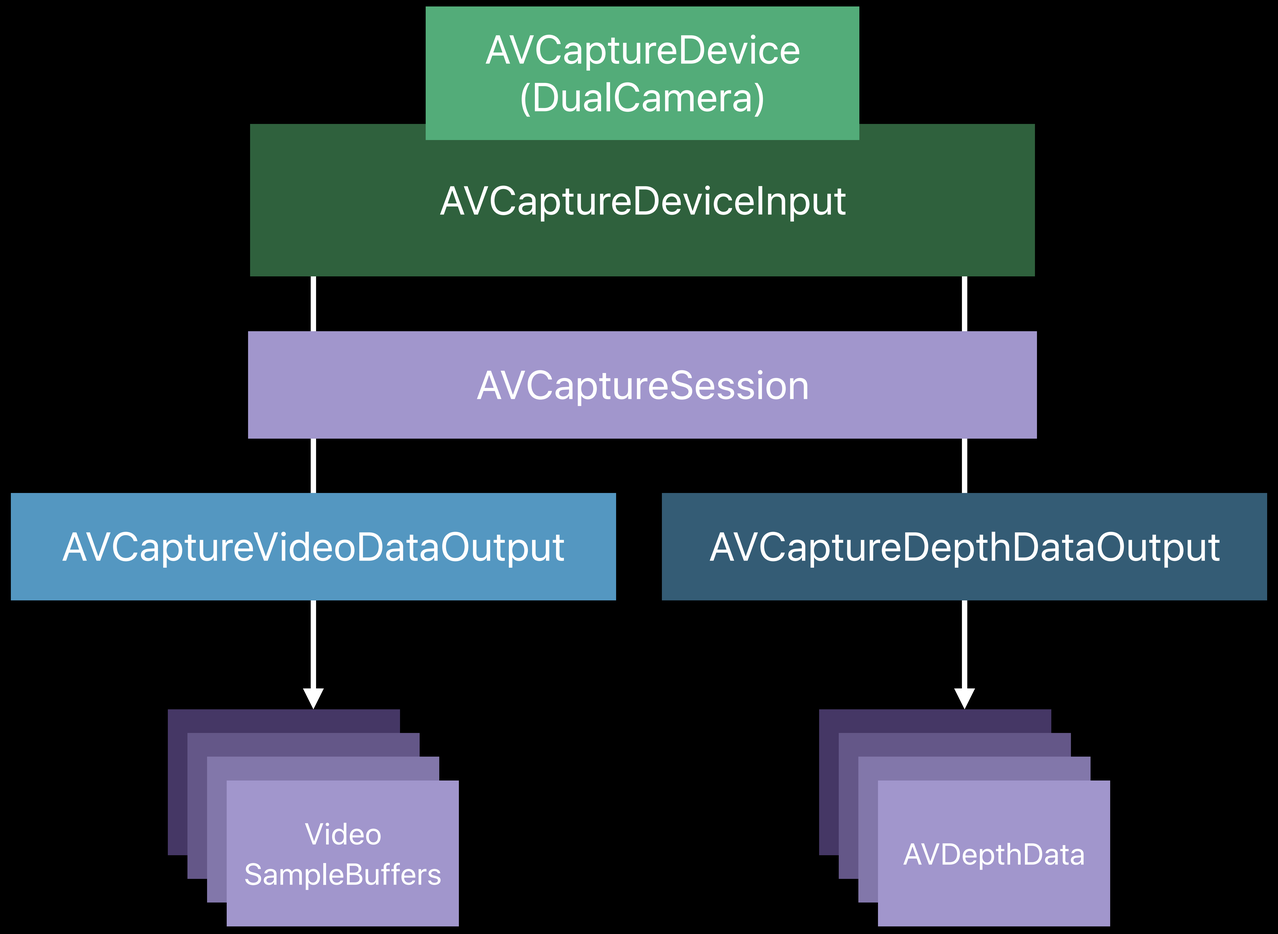
AV Foundation Capture Classes



AV Foundation Capture Classes



AV Foundation Capture Classes



Introducing AVCaptureMultiCamSession

NEW

Multiple AVCaptureDeviceInputs

Multiple AVCaptureOutputs of the same type

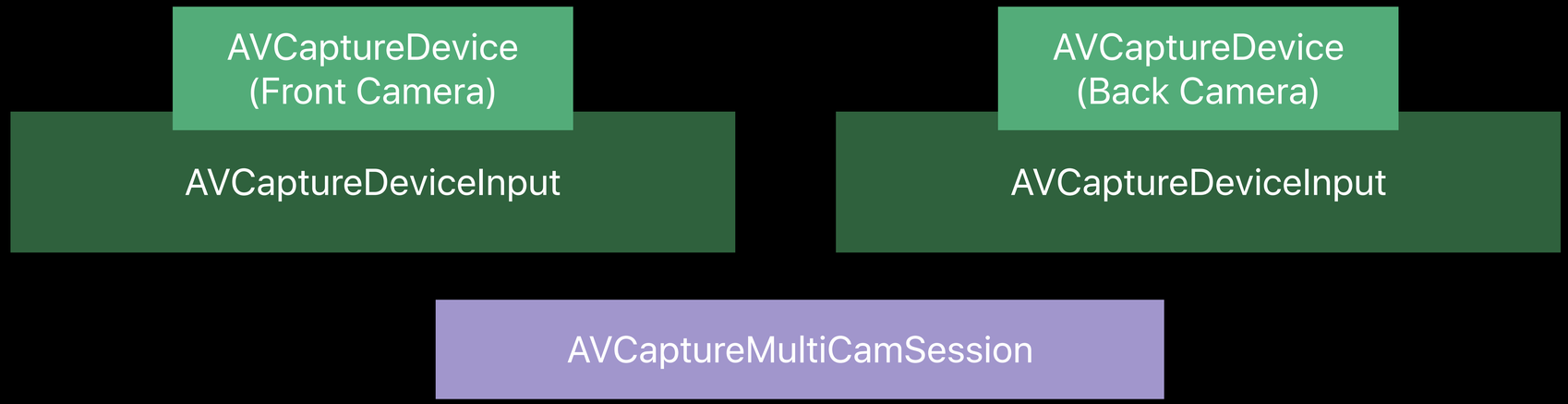
Multiple AVCaptureVideoPreviewLayers

Not a replacement for AVCaptureSession

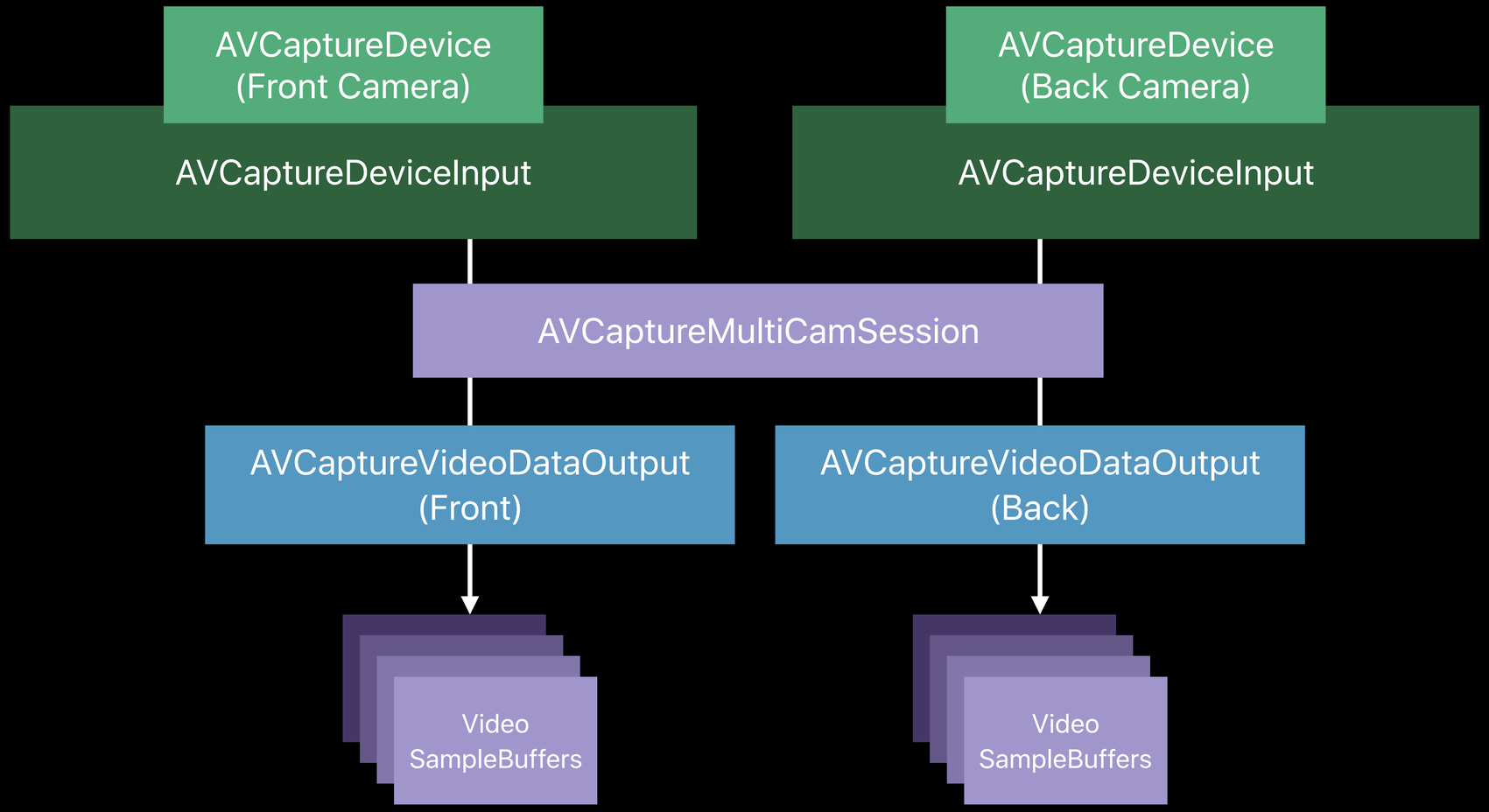
AVCaptureMultiCamSession Example

AVCaptureMultiCamSession

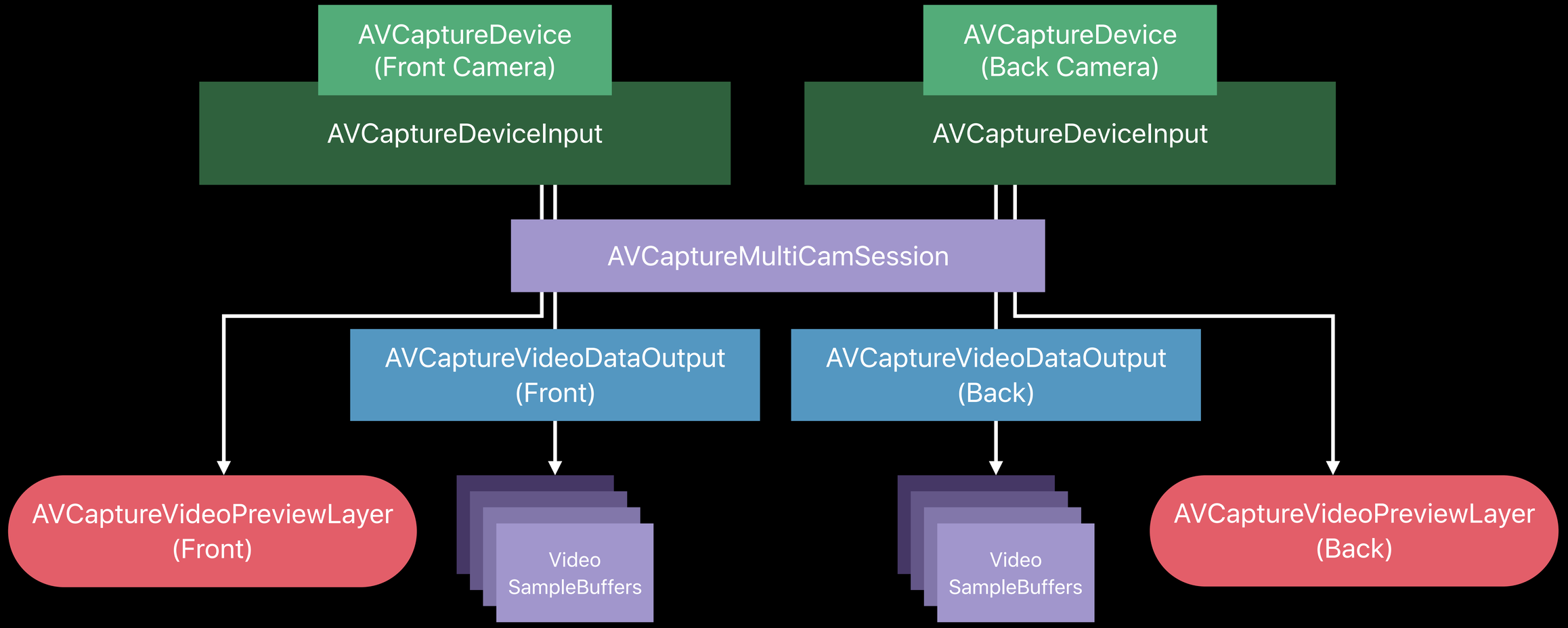
AVCaptureMultiCamSession Example



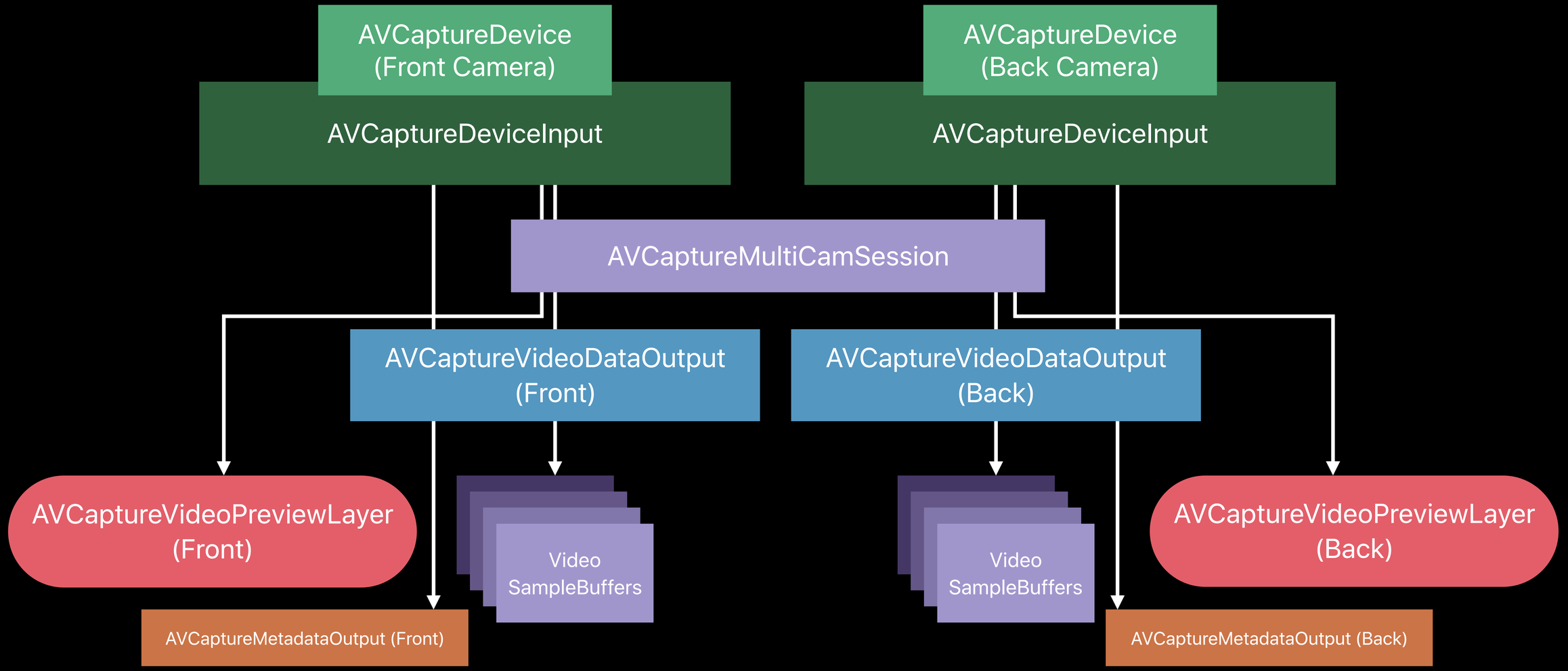
AVCaptureMultiCamSession Example



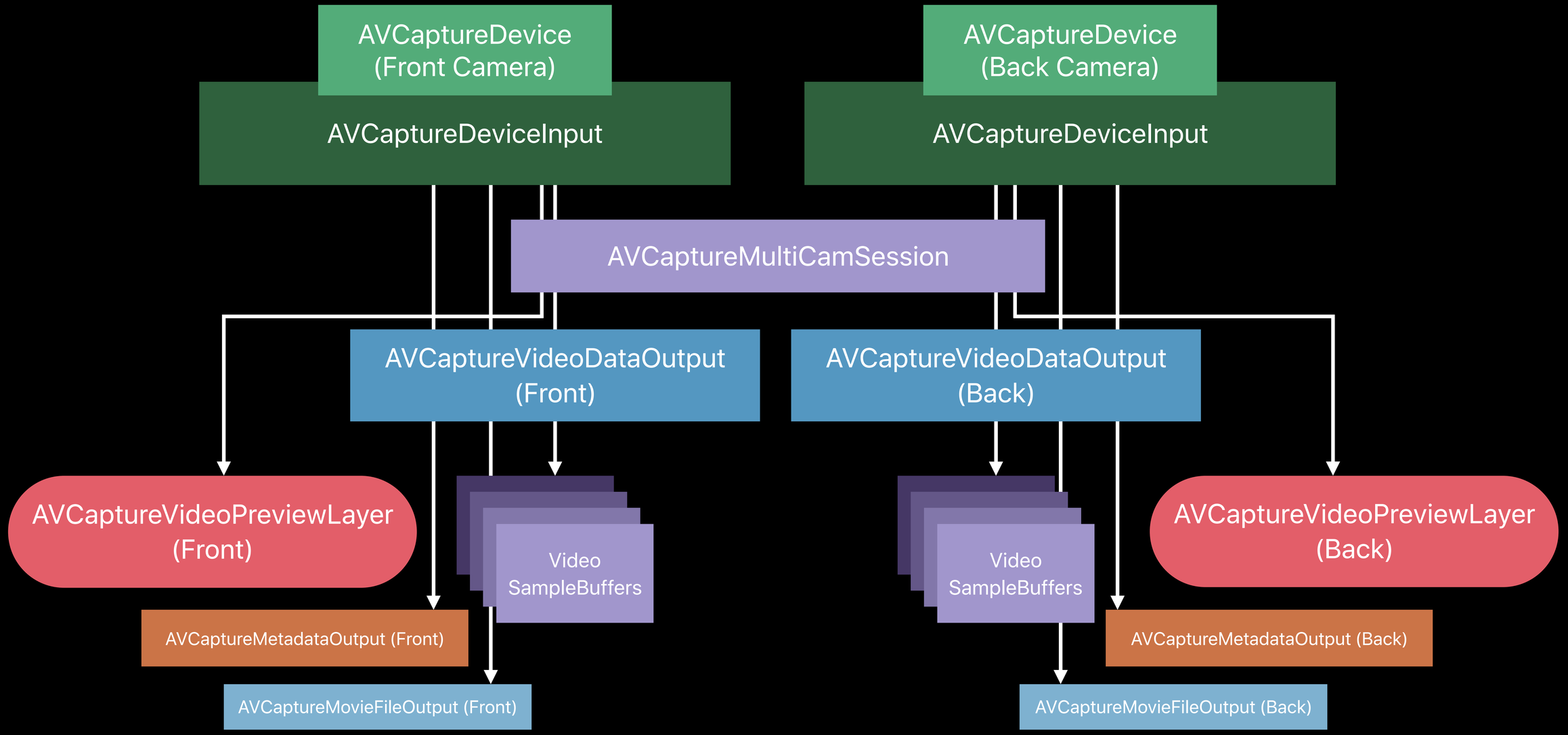
AVCaptureMultiCamSession Example



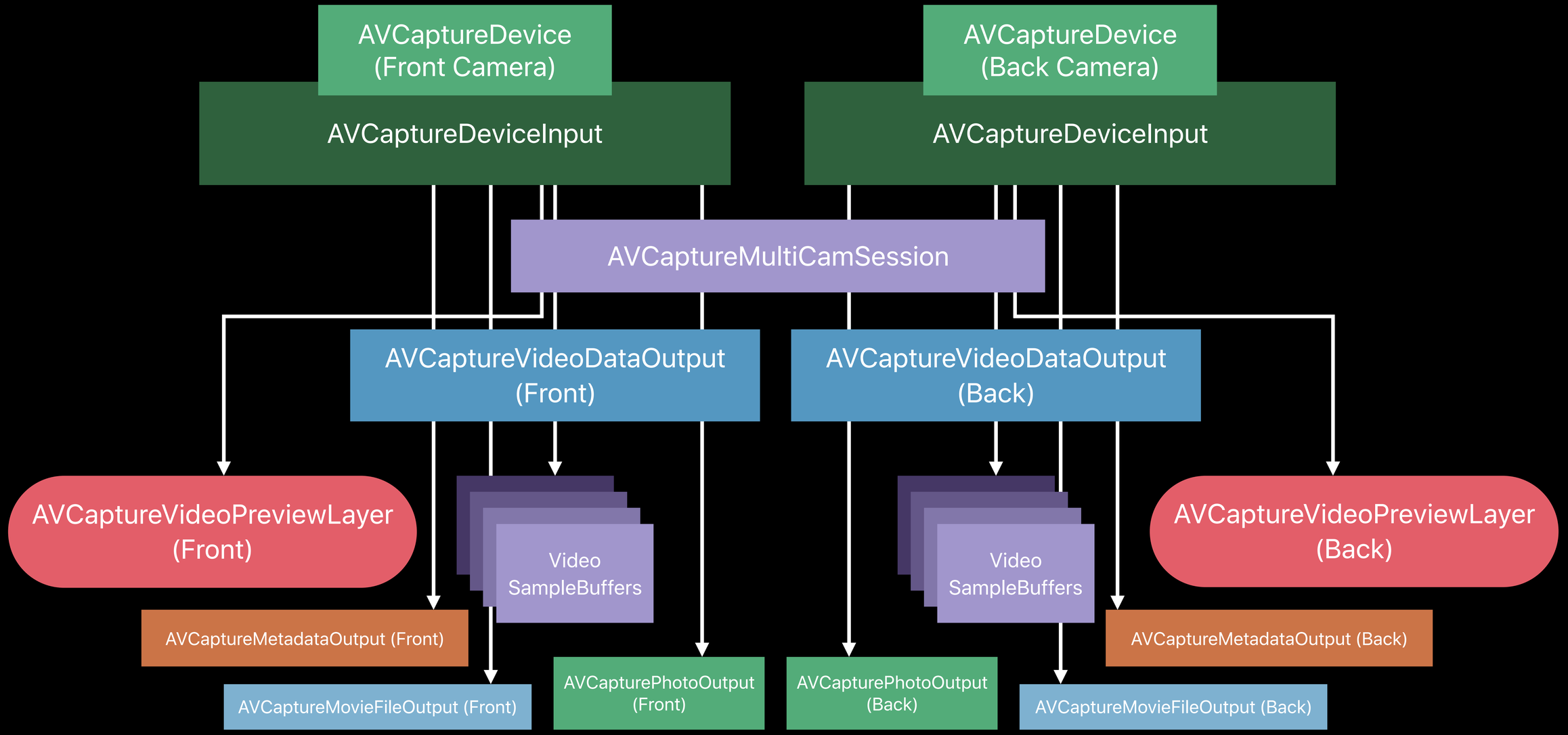
AVCaptureMultiCamSession Example



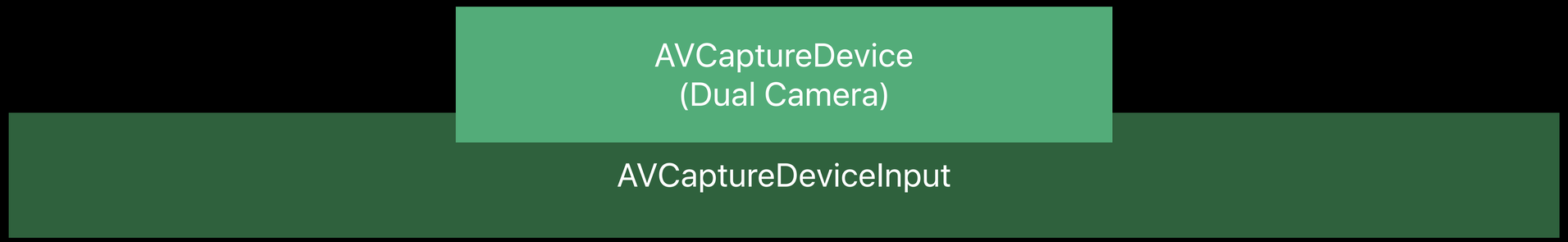
AVCaptureMultiCamSession Example



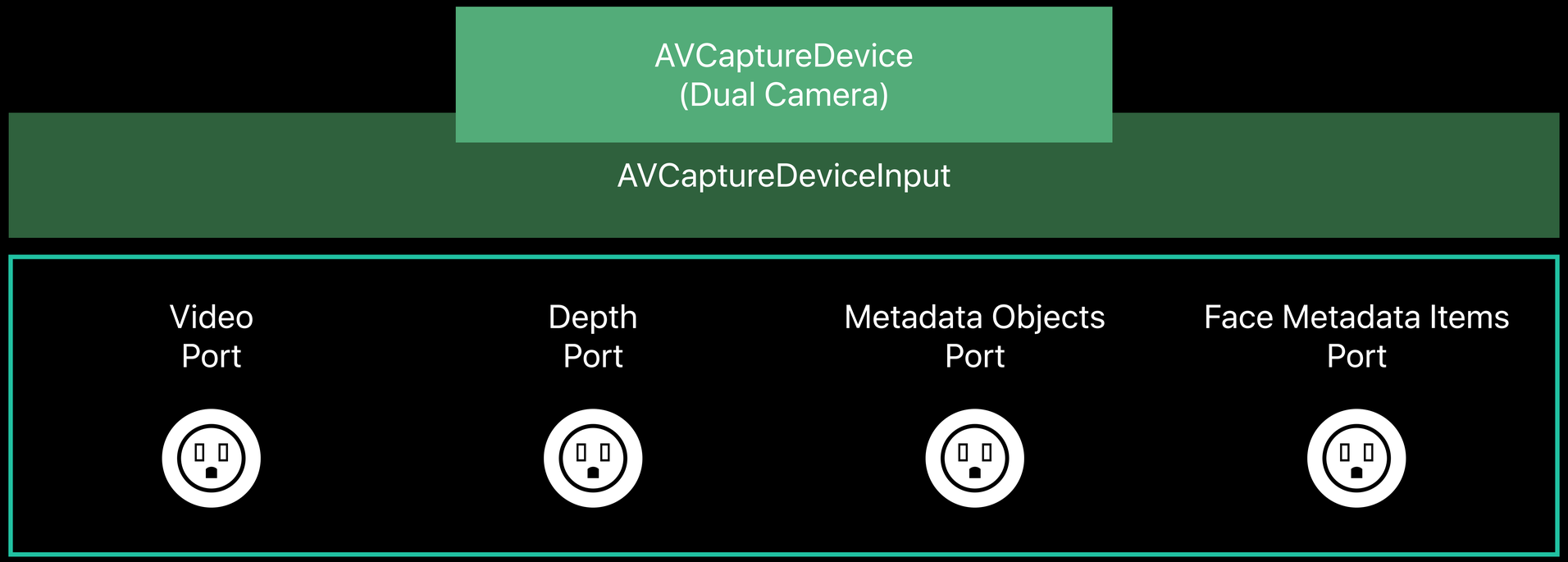
AVCaptureMultiCamSession Example



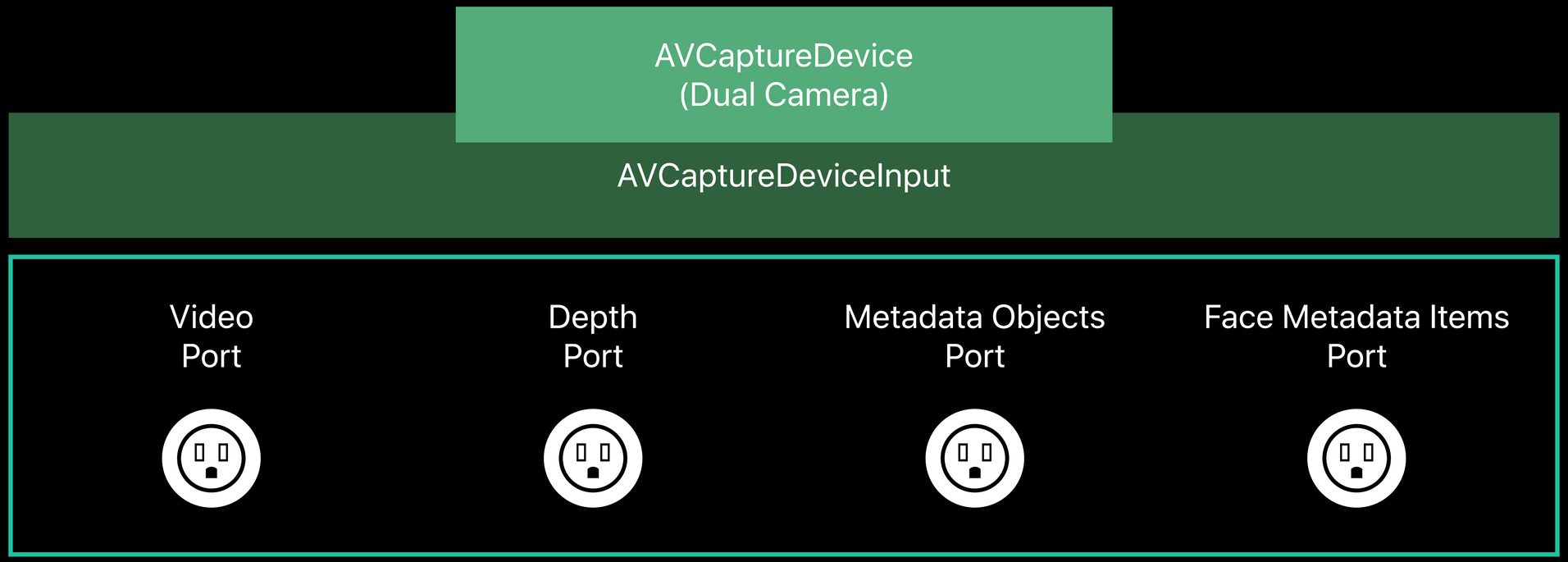
Anatomy of a Connection



Anatomy of a Connection

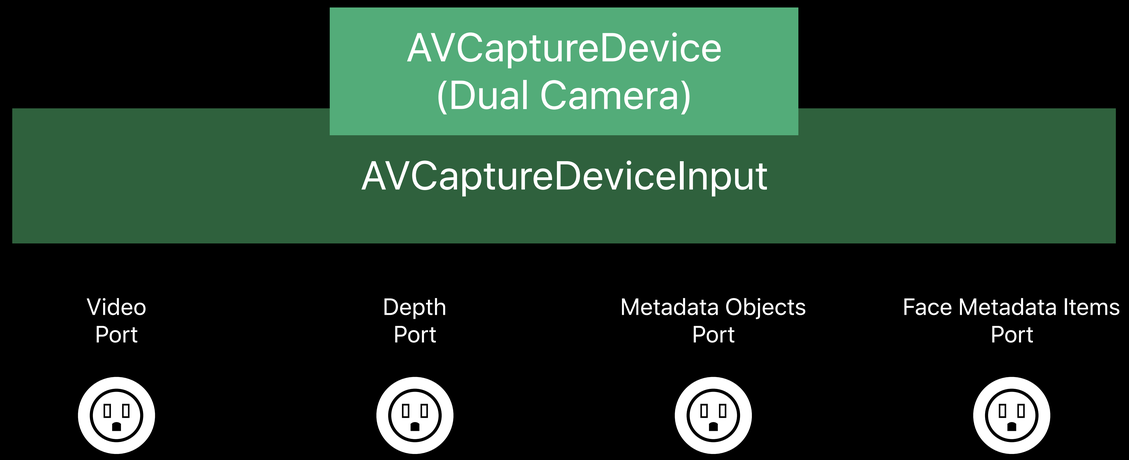


Anatomy of a Connection



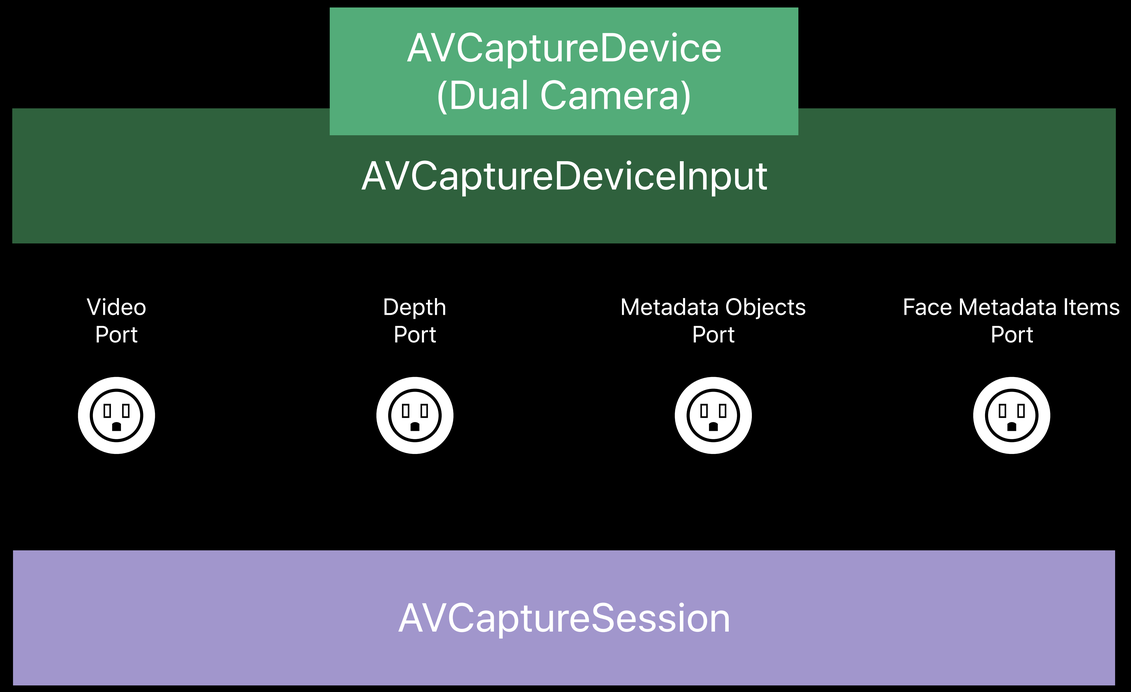

```
let ports: [AVCaptureInput.Port] = dualCameraDeviceInput.ports
```

Anatomy of a Connection

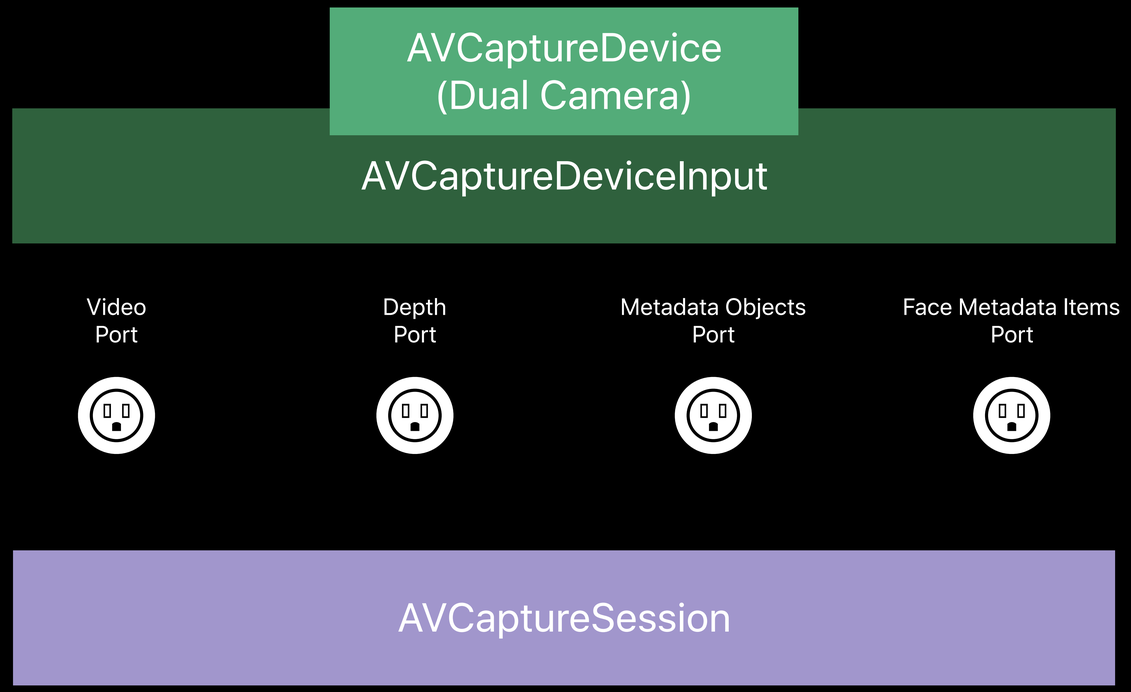


Anatomy of a Connection

```
session.addInput(dualCameraInput)
```



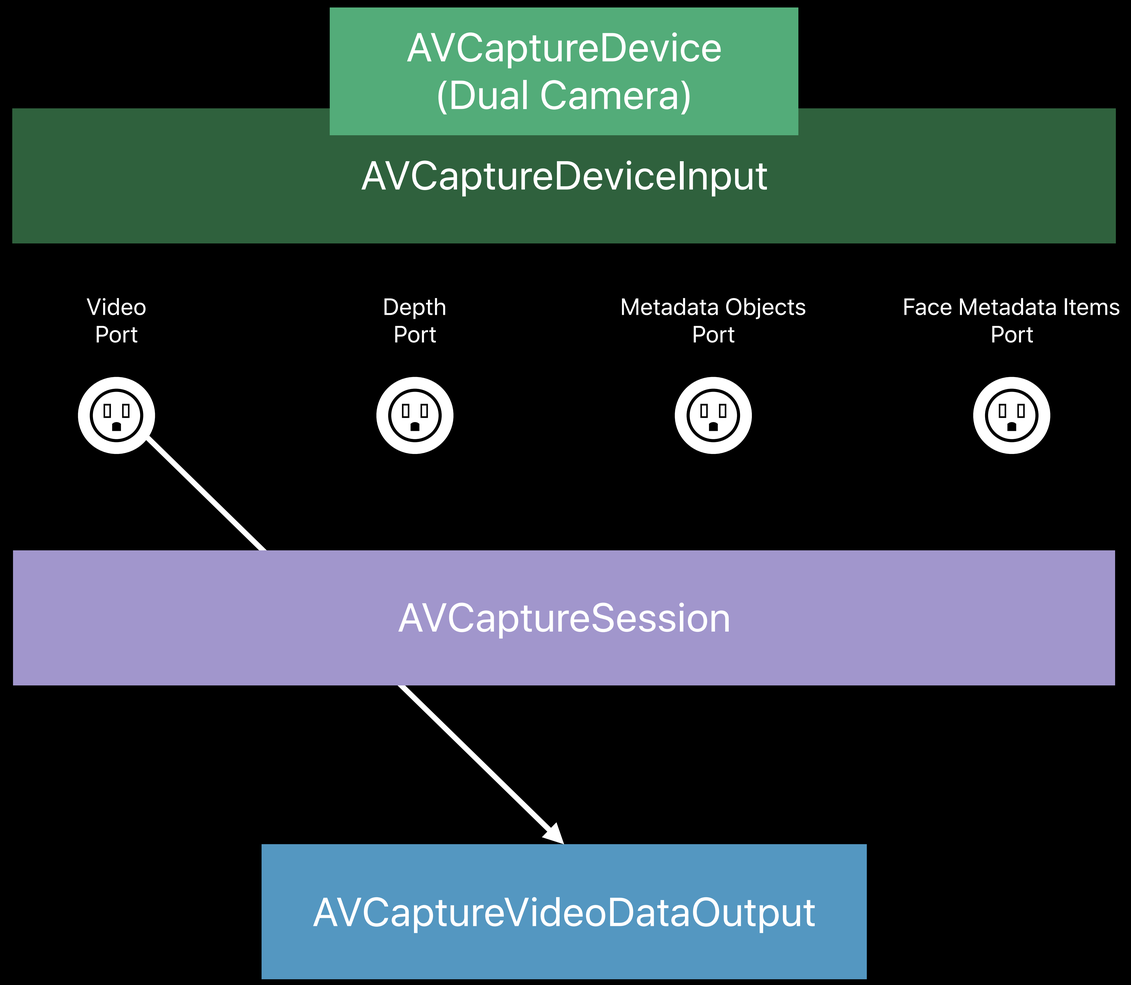
Anatomy of a Connection




```
session.addOutput(videoDataOutput)
```

AVCaptureVideoDataOutput

Anatomy of a Connection



MultiCam Session Building Best Practices

When adding inputs and outputs

MultiCam Session Building Best Practices

When adding inputs and outputs

- Use `addInputWithNoConnections` or `addOutputWithNoConnections`

MultiCam Session Building Best Practices

When adding inputs and outputs

- Use `addInputWithNoConnections` or `addOutputWithNoConnections`

When adding video preview layers

MultiCam Session Building Best Practices

When adding inputs and outputs

- Use `addInputWithNoConnections` or `addOutputWithNoConnections`

When adding video preview layers

- Use `AVCaptureVideoPreviewLayer.setSessionWithNoConnections()`

MultiCam Session Building Best Practices

Then create and add explicit connections

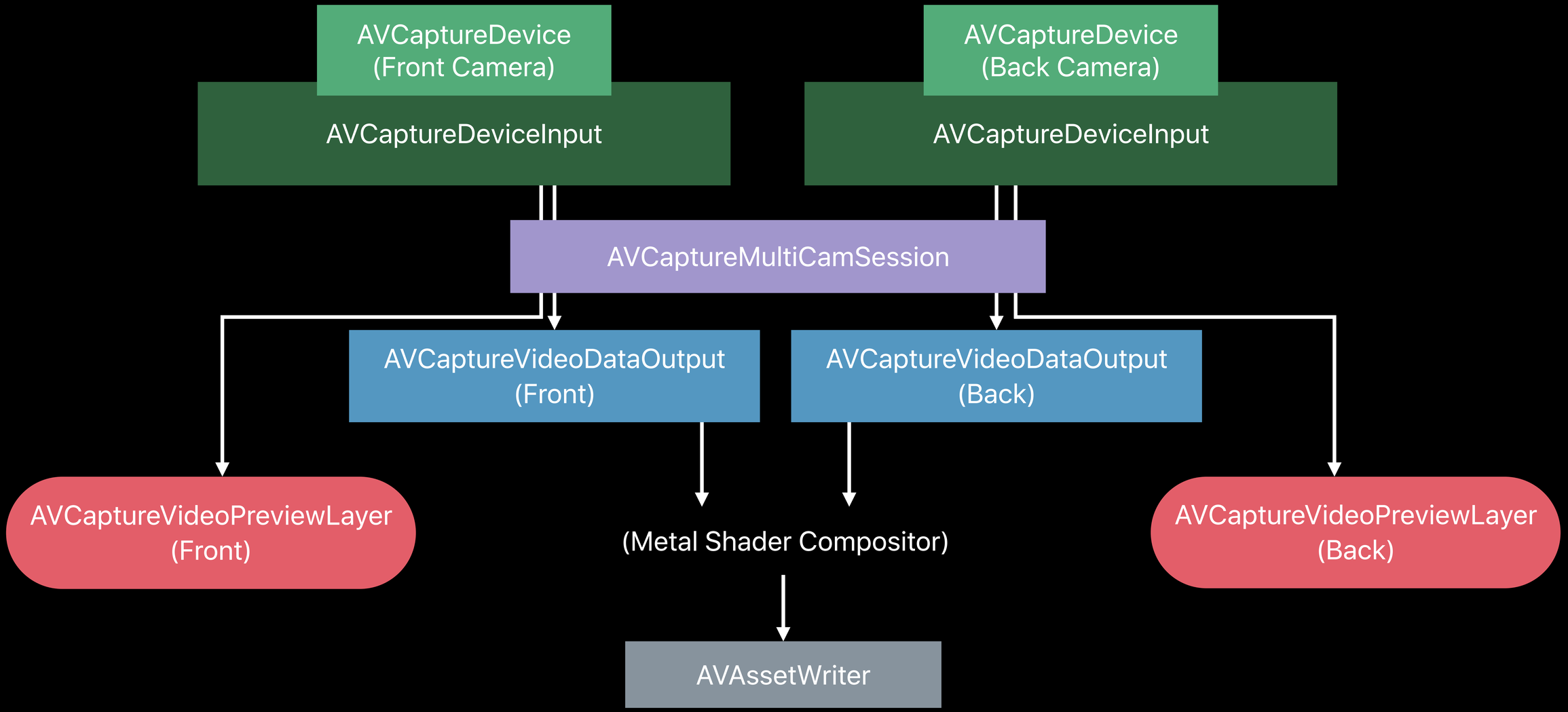
```
let backCameraVideoConnection =
     AVCaptureConnection(inputPorts: [backCameraVideoPort],
                                output: backVideoDataOutput)

session.addConnection(backCameraVideoConnection)
```

Demo

AVMultiCamPiP app

Nikolas Gelo, Camera Software

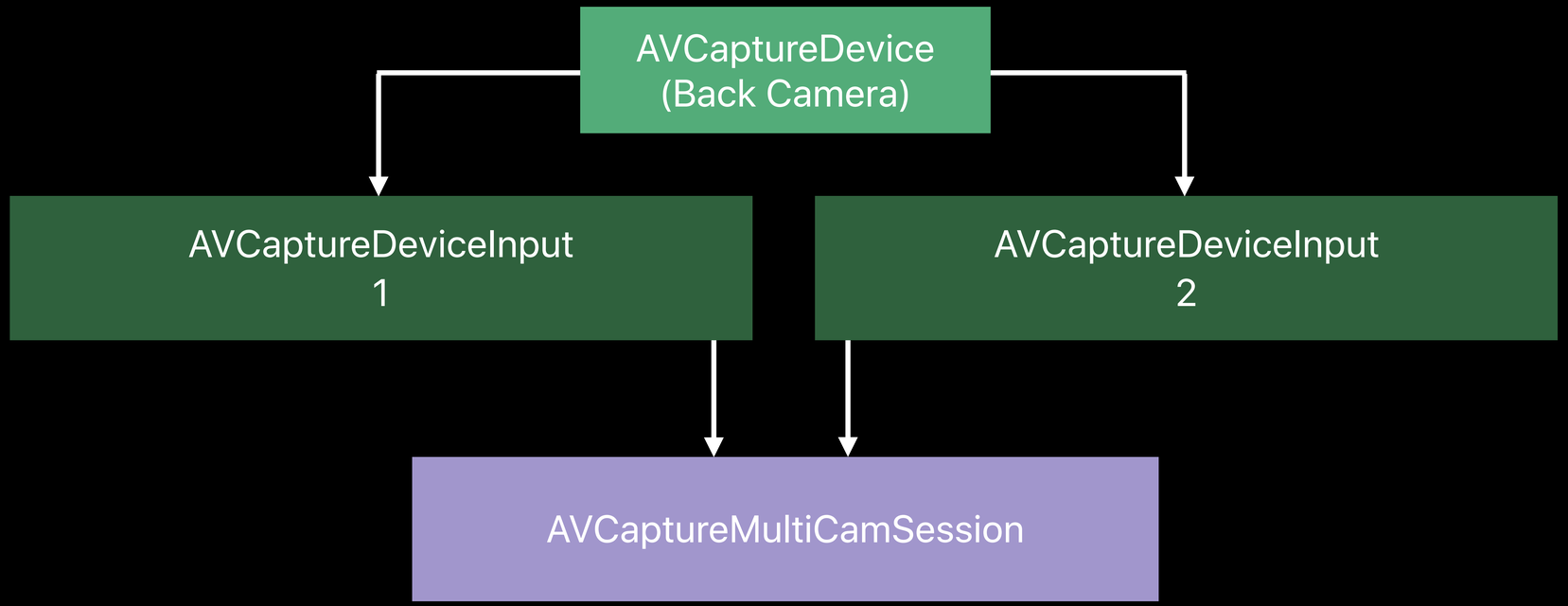
AVMultiCamPiP Graph Topology



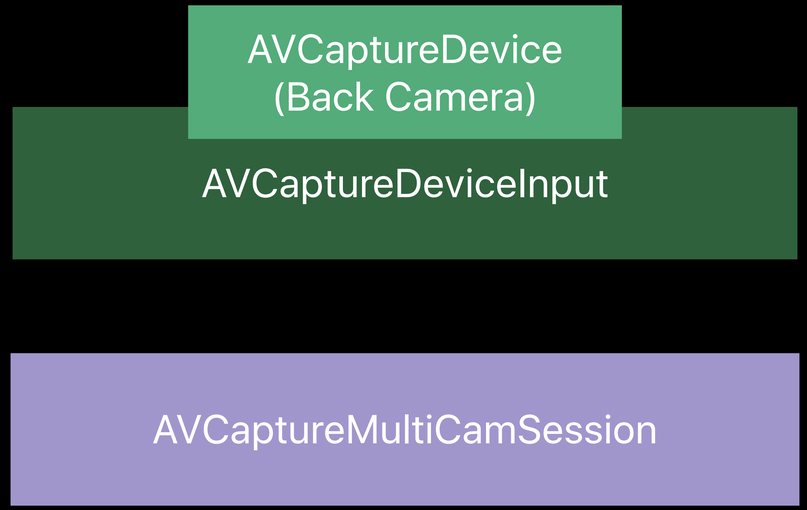
Multi-Camera Capture

Limitations

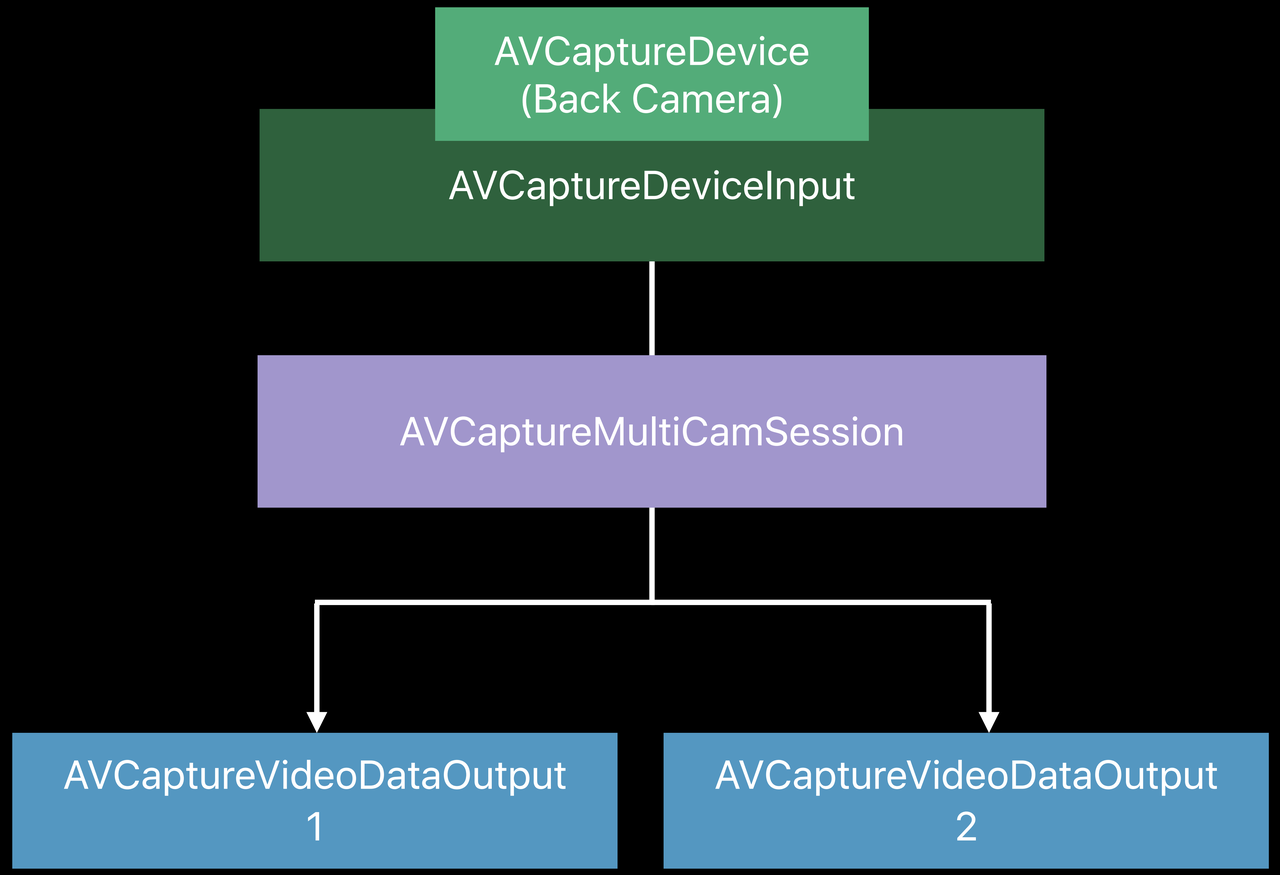
No Camera Cloning at the Input



No Split Personality Camera Output



No Split Personality Camera Output



No Multi-Camera Output Stuffing

AVCaptureDevice
(Back Camera)

AVCaptureDeviceInput

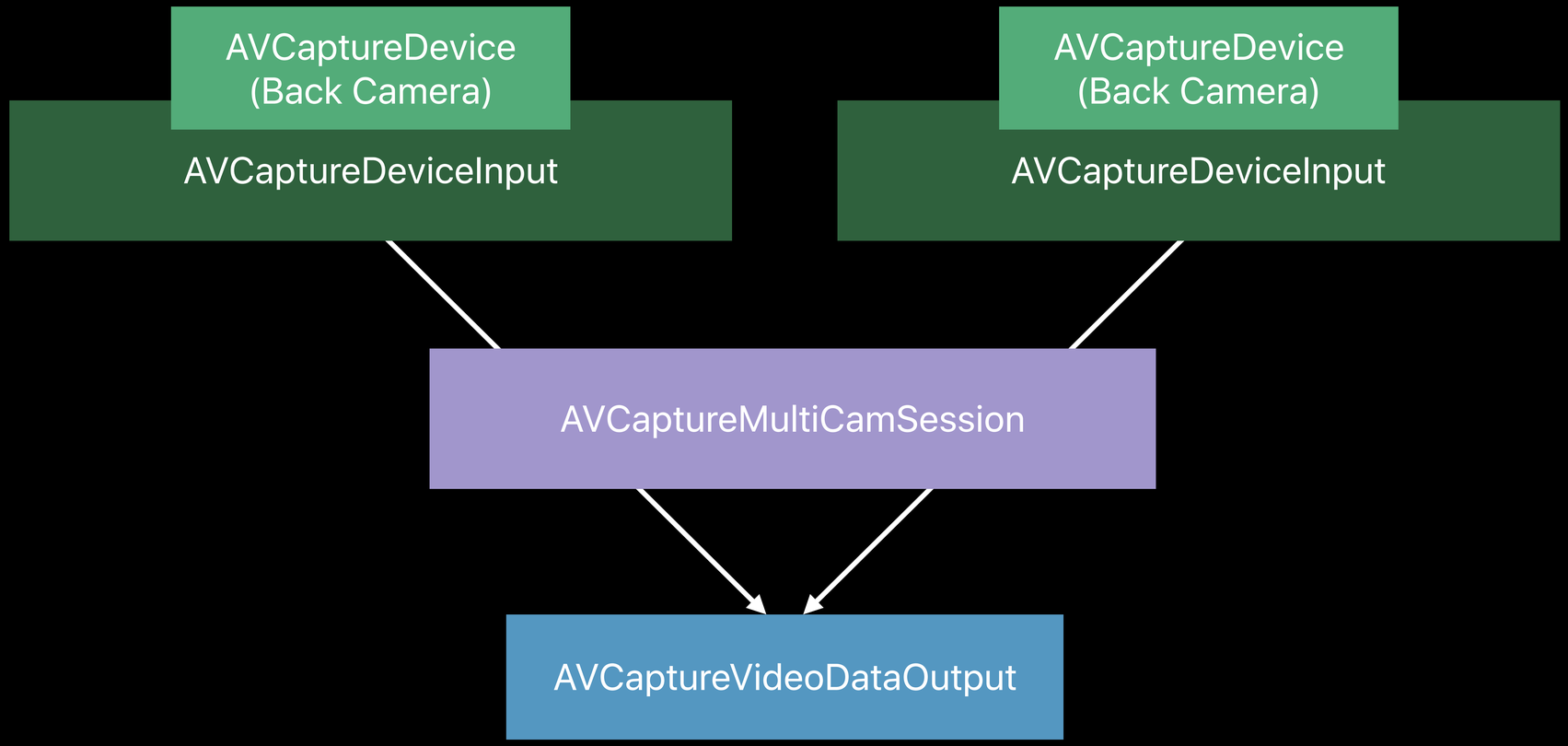
AVCaptureDevice
(Back Camera)

AVCaptureDeviceInput

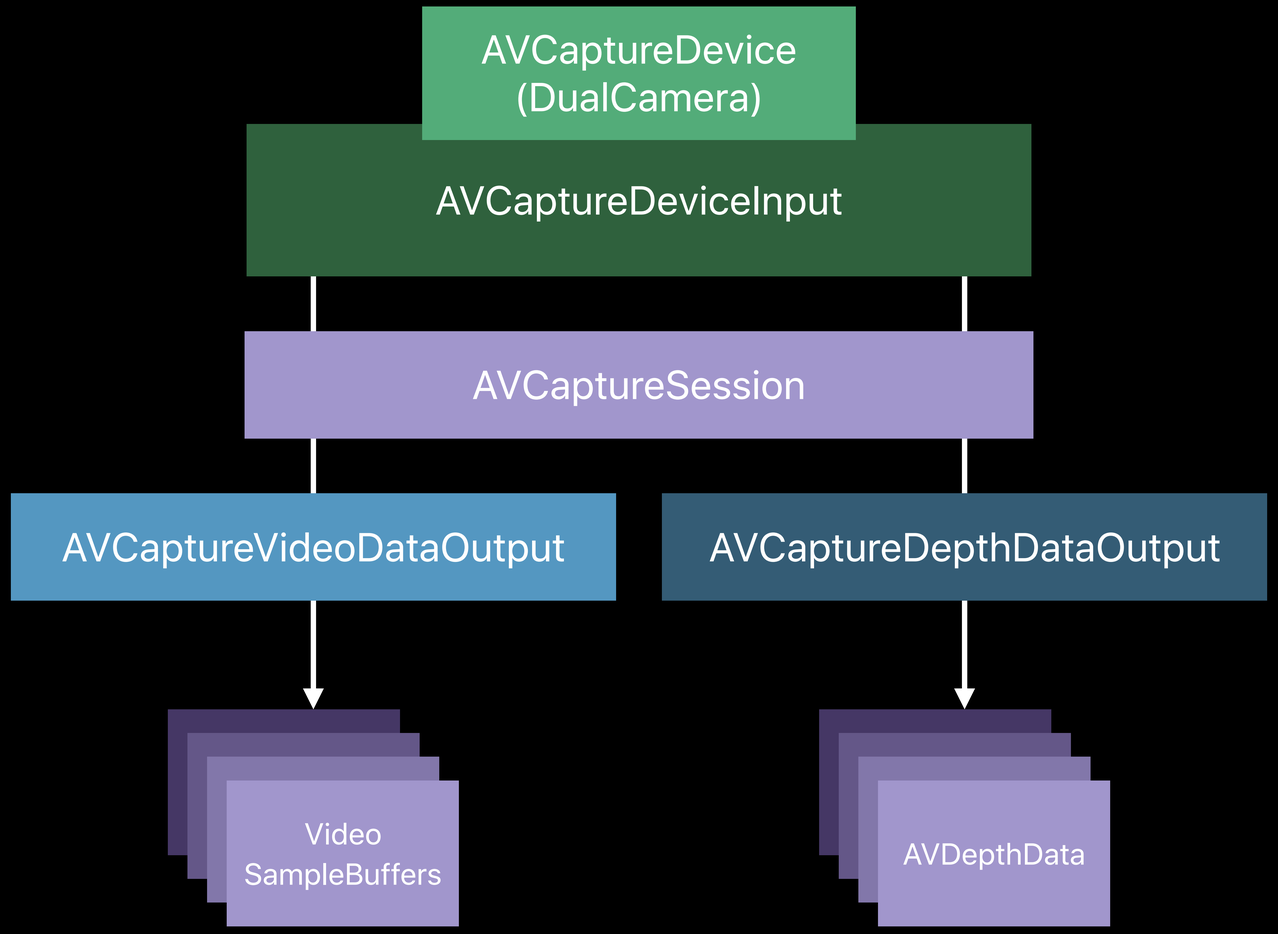
AVCaptureMultiCamSession

AVCaptureVideoDataOutput

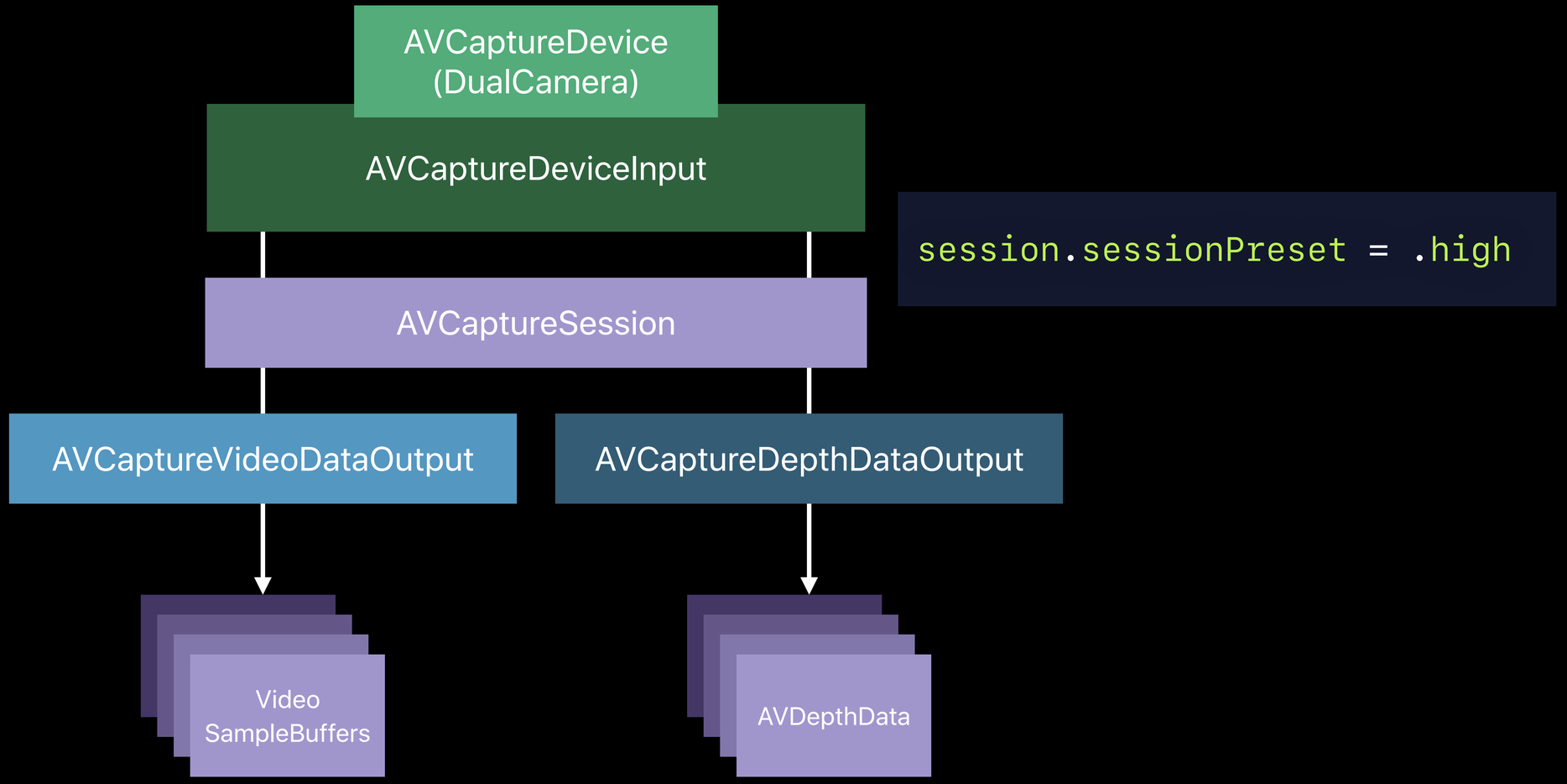
No Multi-Camera Output Stuffing



Presets


AVCaptureDevice
(DualCamera)
AVCaptureDeviceInput
AVCaptureSession
AVCaptureVideoDataOutput
AVCaptureDepthDataOutput
Video
SampleBuffers
AVDepthData

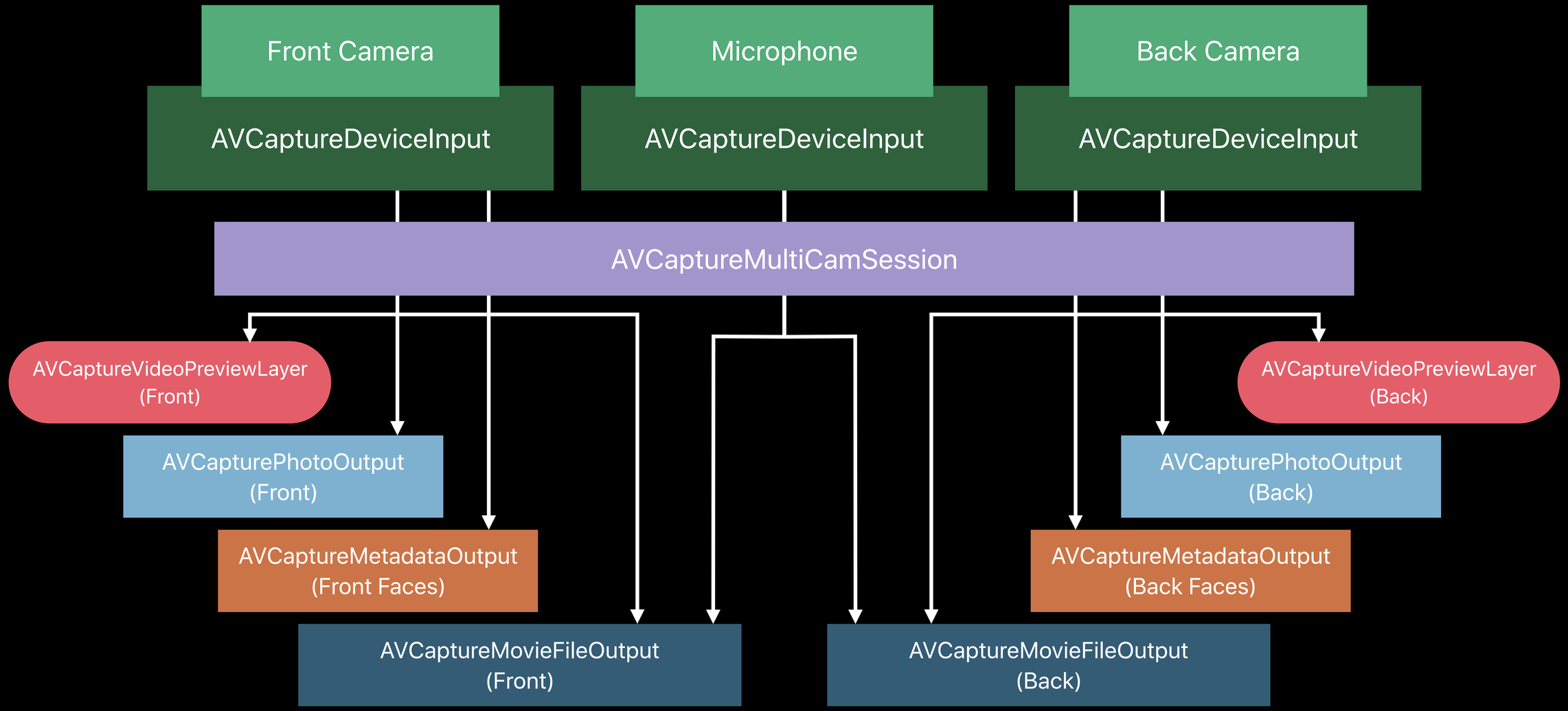
Presets



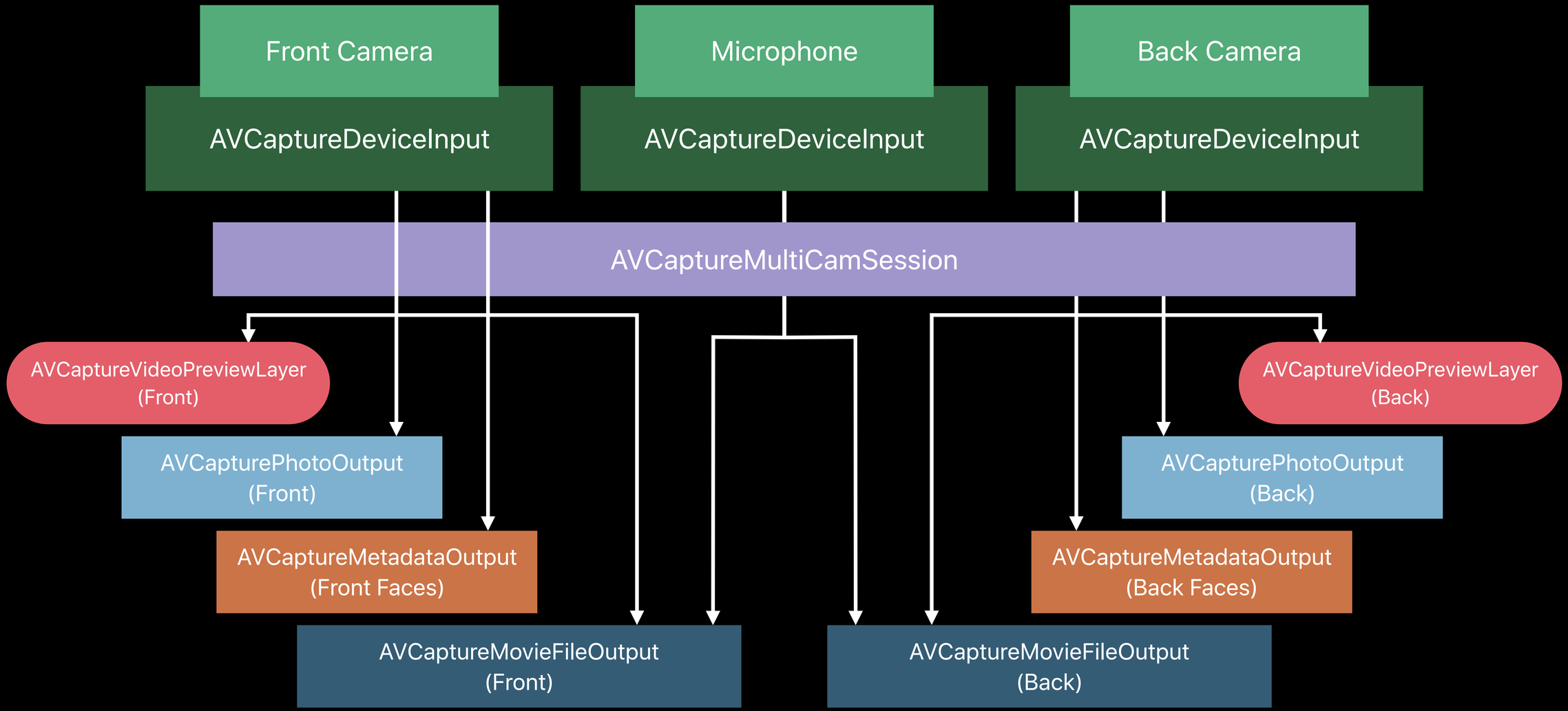

```
session.sessionPreset = .high
```

Presets? We Don’t Need No Stinkin’ Presets

Presets? We Don’t Need No Stinkin’ Presets



Presets? We Don’t Need No Stinkin’ Presets



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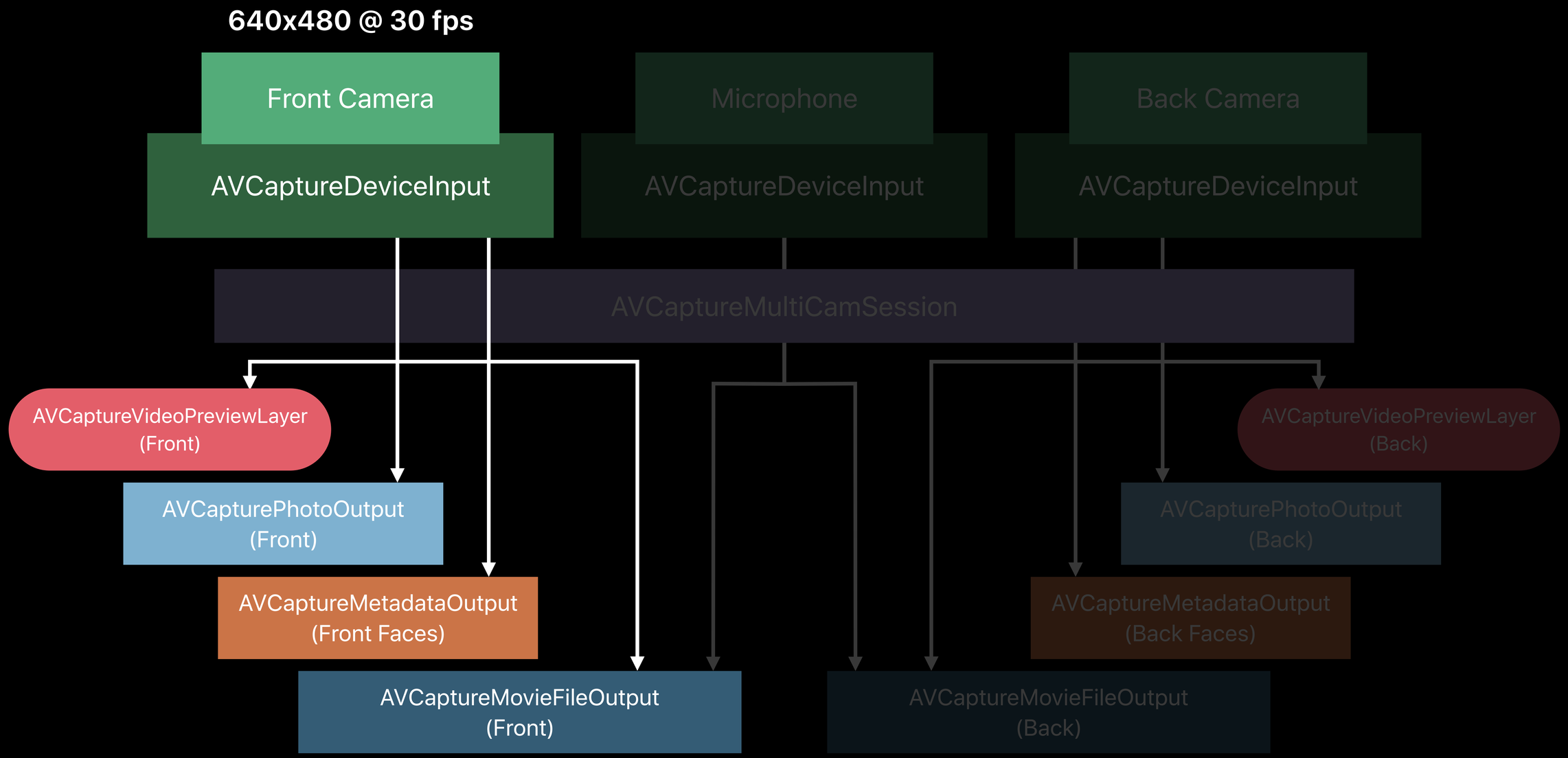

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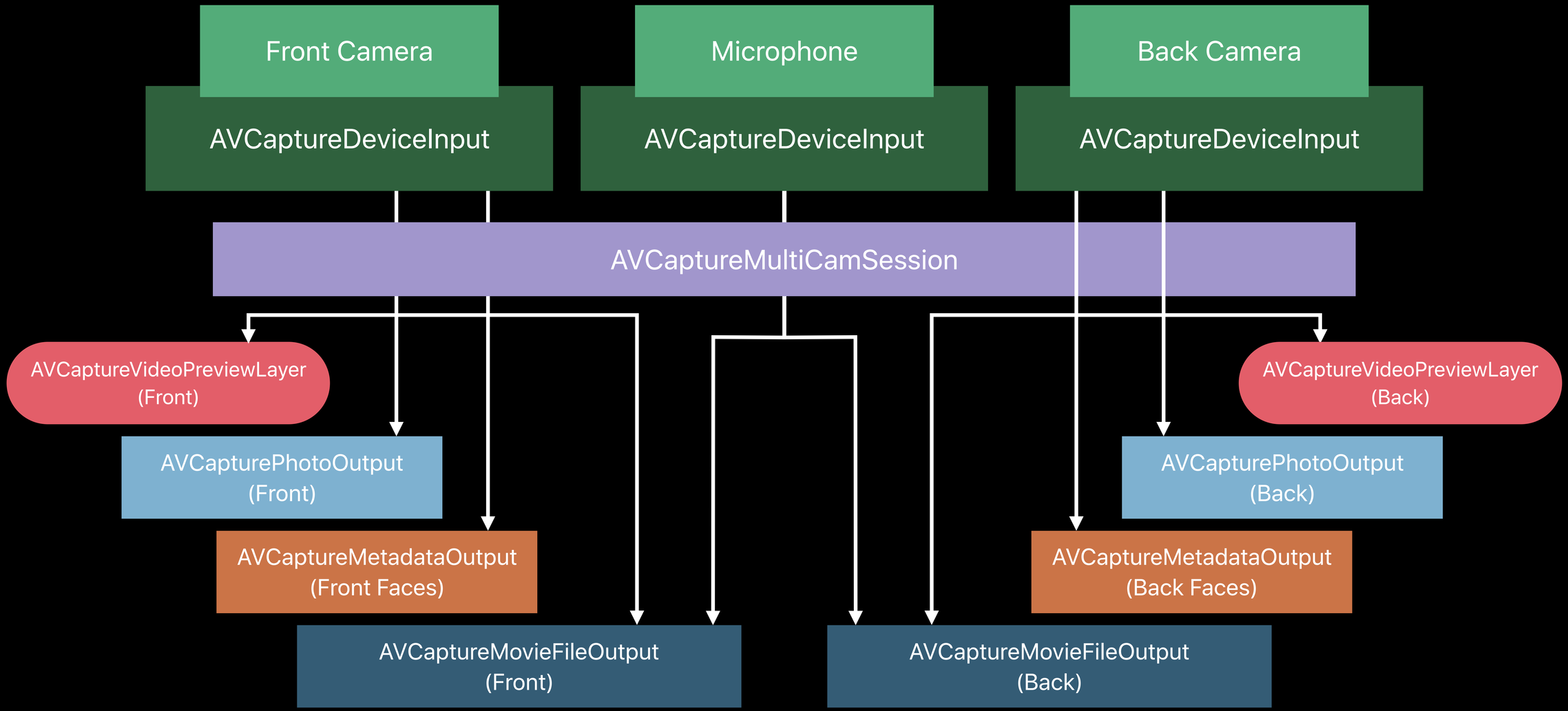

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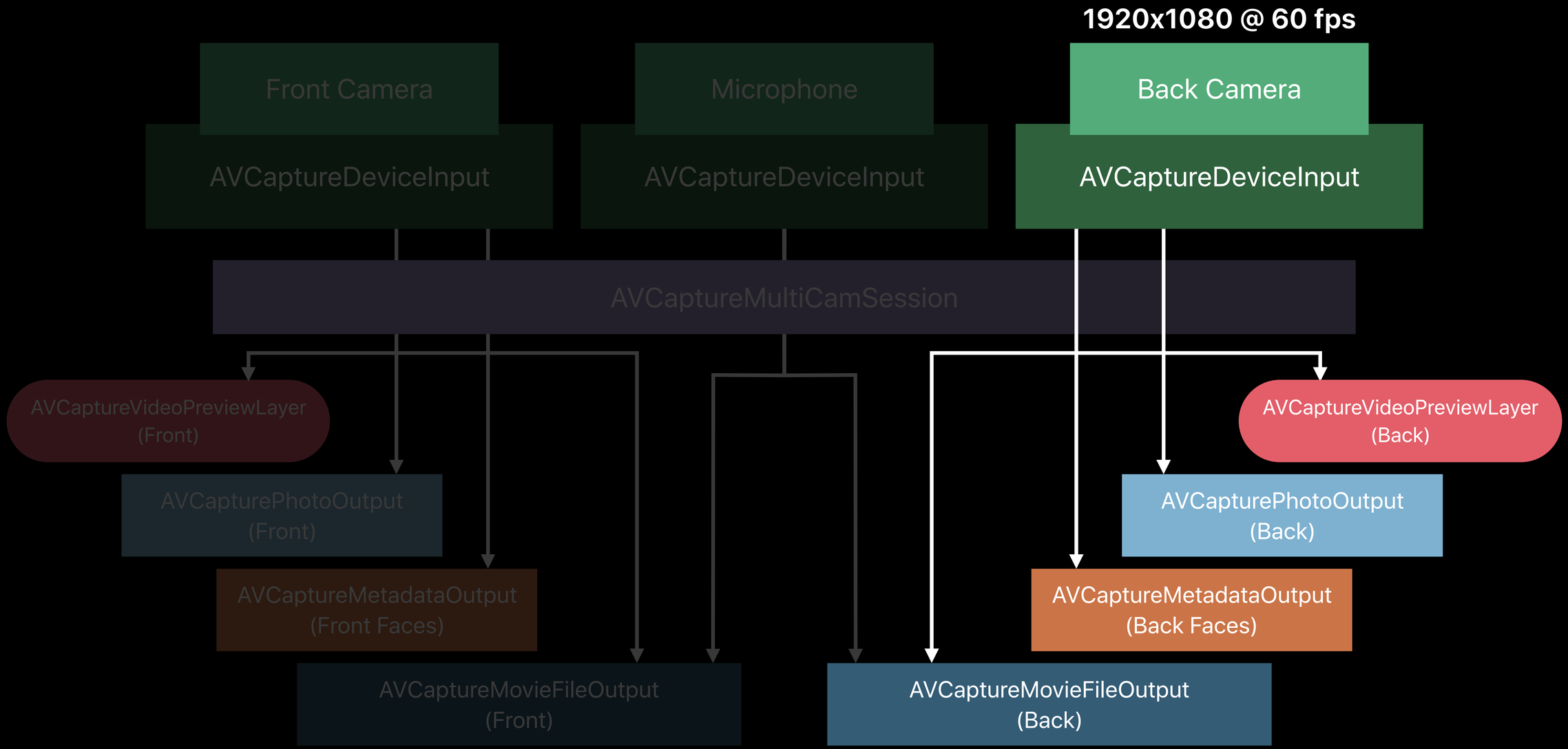


Multi-Camera Capture

Cost functions

“There’s no such thing as a free lunch.”

- Somebody who wants you to pay for lunch

Hardware Costs

Multiple cameras = multiple sensors

Hardware Costs

Multiple cameras = multiple sensors

One ISP, limited to n pixels per clock

Hardware Costs

Multiple cameras = multiple sensors

One ISP, limited to n pixels per clock

Contributors to hardware cost

Hardware Costs

Multiple cameras = multiple sensors

One ISP, limited to n pixels per clock

Contributors to hardware cost

- Video resolution

Hardware Costs

Multiple cameras = multiple sensors

One ISP, limited to n pixels per clock

Contributors to hardware cost

- Video resolution
- Max frame rate

Hardware Costs

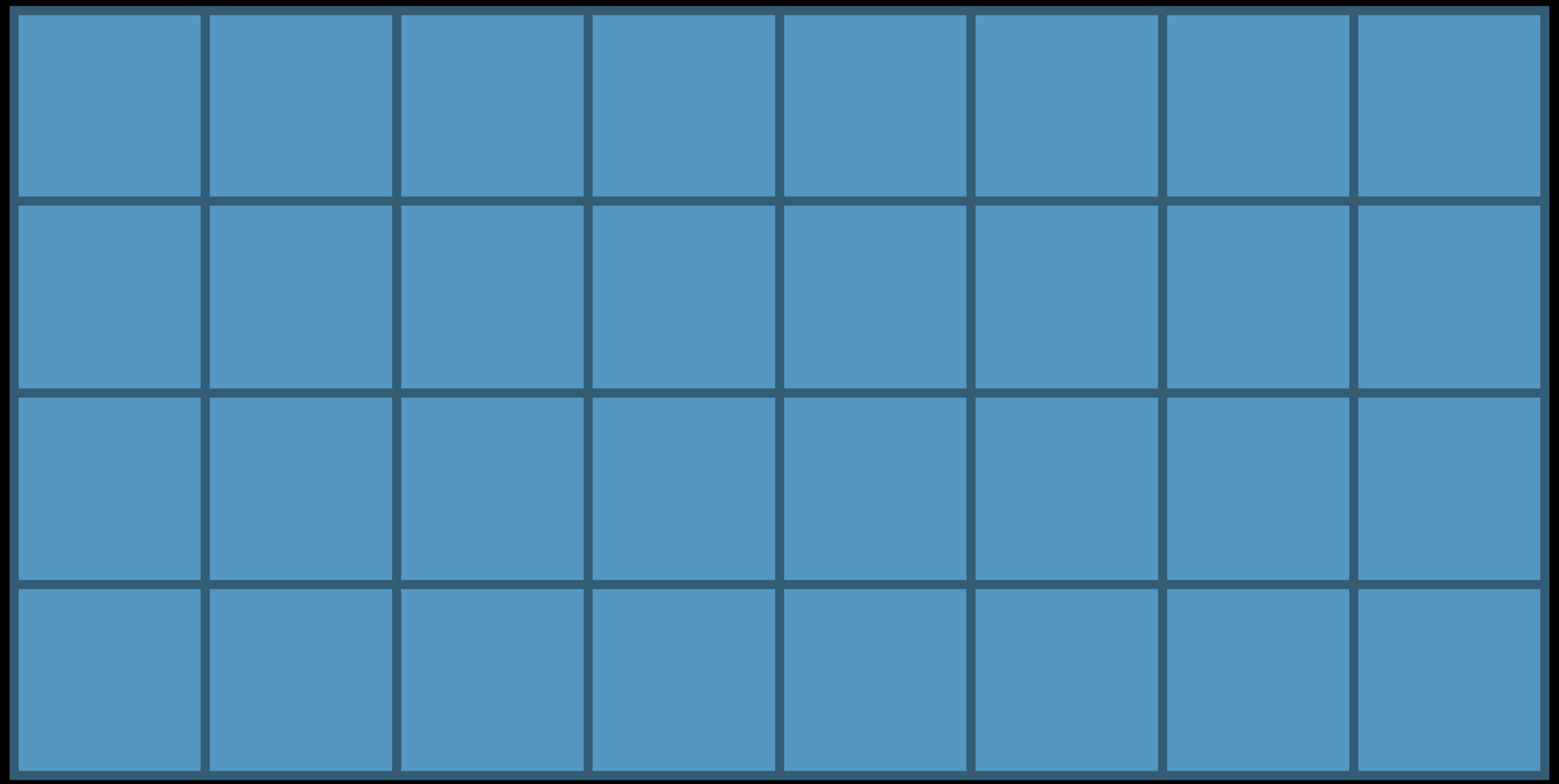
Multiple cameras = multiple sensors

One ISP, limited to n pixels per clock

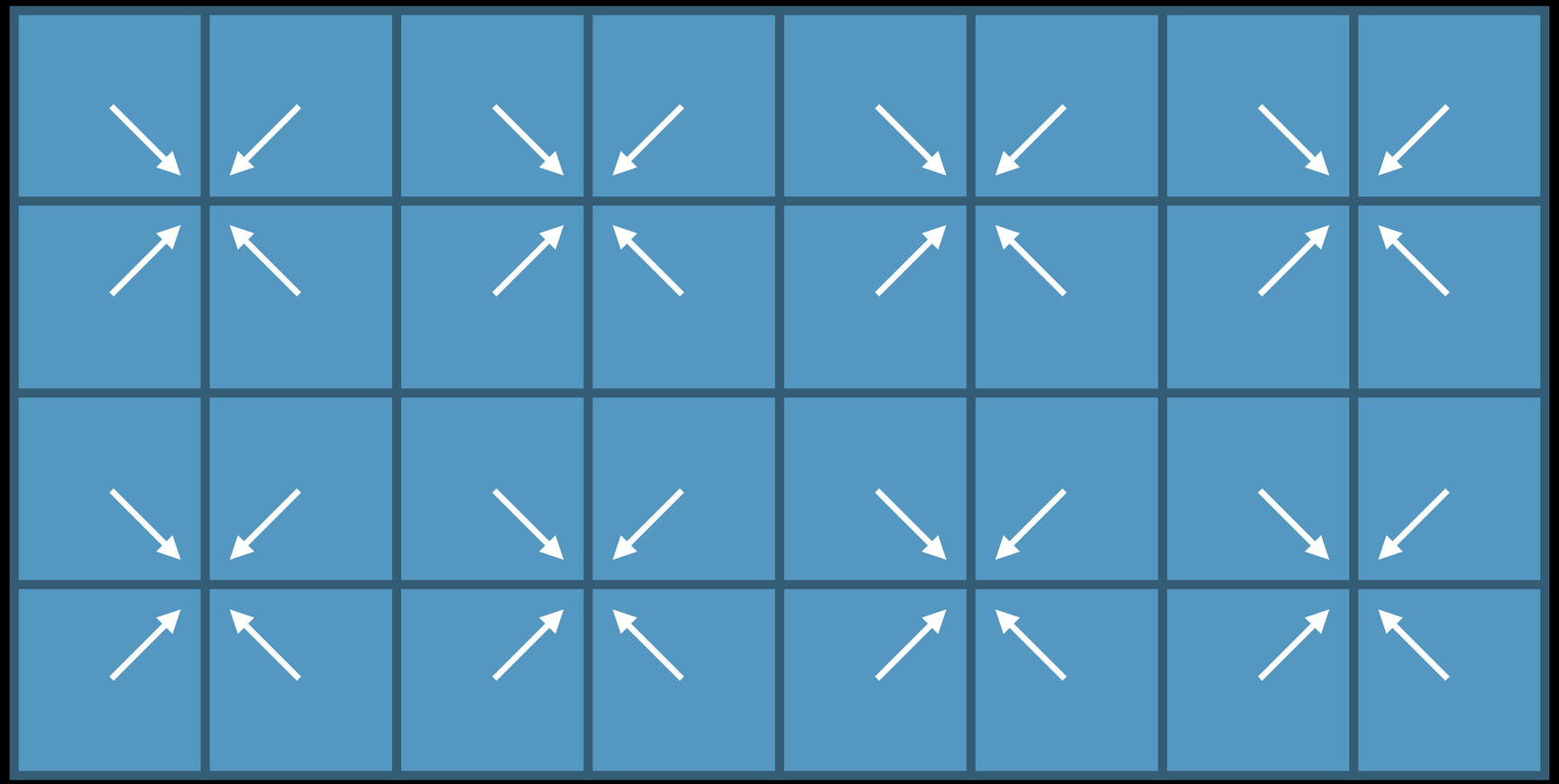
Contributors to hardware cost

- Video resolution
- Max frame rate
- Sensor “binning”

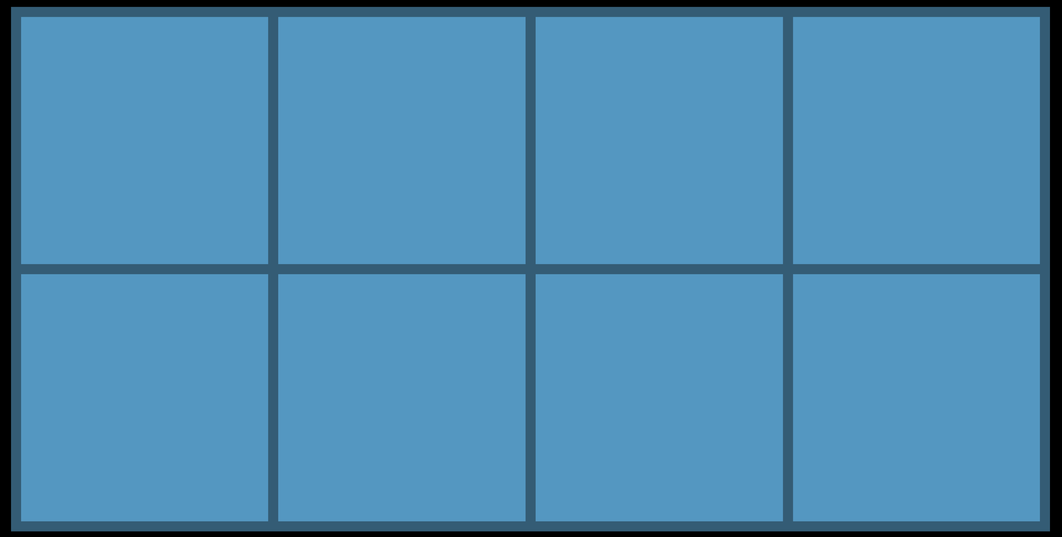
Sensor Binning



Sensor Binning



Sensor Binning



Hardware Cost Reporting

Hardware Cost Reporting

```
multicamSession.hardwareCost
```

Hardware Cost Reporting

```
multicamSession.hardwareCost
```

≥ 0.0 && ≤ 1.0 : Runnable

Hardware Cost Reporting

```
multicamSession.hardwareCost
```

≥ 0.0 && ≤ 1.0 : Runnable

≥ 1.0 : No Bueno

Hardware Cost Reporting

```
multicamSession.hardwareCost
```

≥ 0.0 && ≤ 1.0 : Runnable

≥ 1.0 : No Bueno

```
AVCaptureSessionRuntimeError = hardwareCostOverage
```

How to Reduce Your Hardware Cost

Refer to AVMultiCamPiP Sample Code

How to Reduce Your Hardware Cost

Lower the camera resolution

Choose a binned format

Refer to AVMultiCamPiP Sample Code

How to Reduce Your Hardware Cost

Lower the camera resolution

Choose a binned format

Lower the camera max frame rate

Refer to AVMultiCamPiP Sample Code

How to Reduce Your Hardware Cost

Lower the camera resolution

Choose a binned format

~~Lower the camera max frame rate~~

Refer to AVMultiCamPiP Sample Code

How to Reduce Your Hardware Cost

Lower the camera resolution

Choose a binned format

~~Lower the camera max frame rate~~

Set a max frame rate override at the device input

Refer to AVMultiCamPiP Sample Code

How to Reduce Your Hardware Cost

NEW

Lower the camera resolution

Choose a binned format

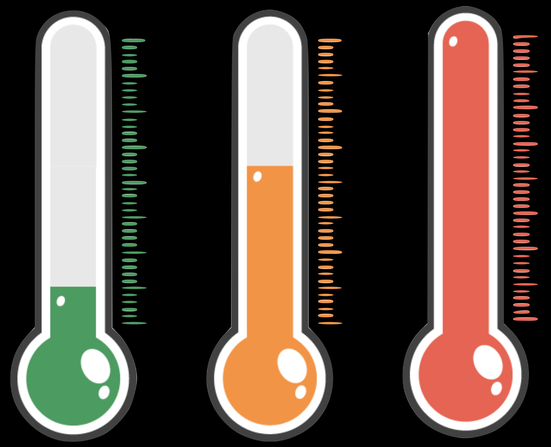
~~Lower the camera max frame rate~~

Set a max frame rate override at the device input

```
CMTime thirtyFPS = CMTimeMake( 1, 30 )
deviceInput.videoMinFrameDurationOverride = thirtyFPS
```

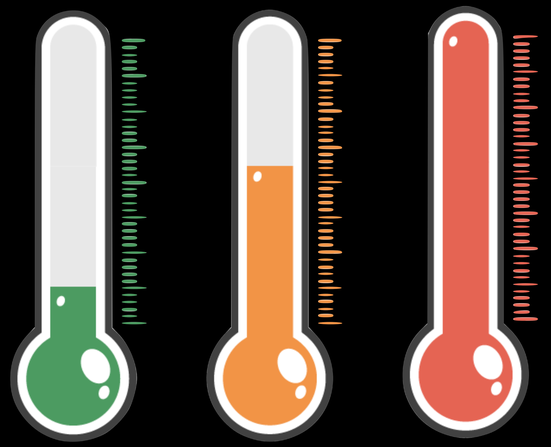
Refer to AVMultiCamPiP Sample Code

System Pressure States



System Pressure States

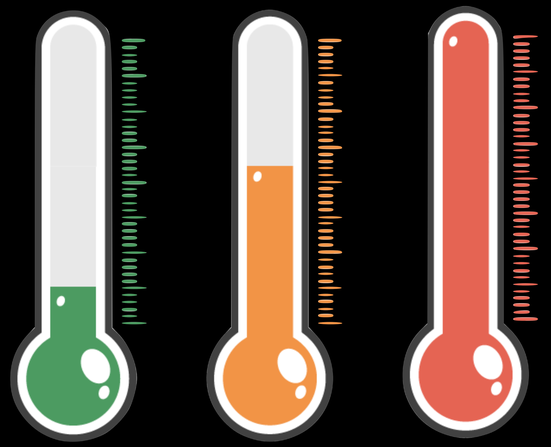
Camera System Pressure States
introduced in iOS 11



System Pressure States

Camera System Pressure States introduced in iOS 11

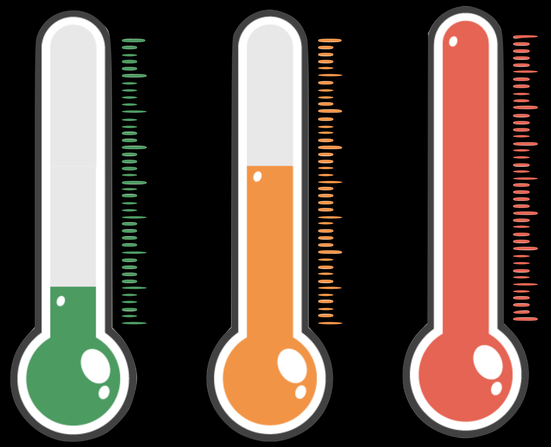
- System Temperature



System Pressure States

Camera System Pressure States introduced in iOS 11

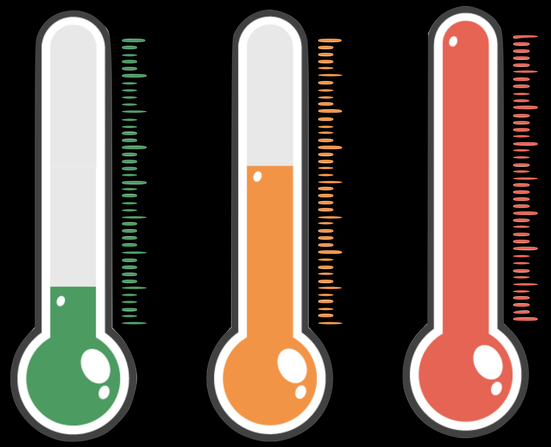
- System Temperature
- Peak Power Demands



System Pressure States

Camera System Pressure States introduced in iOS 11

- System Temperature
- Peak Power Demands
- Infrared Projector Temperature



System Pressure States

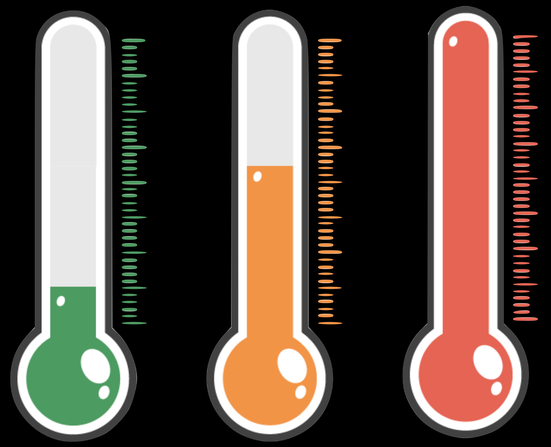
Nominal

Fair

Serious

Critical

Shutdown

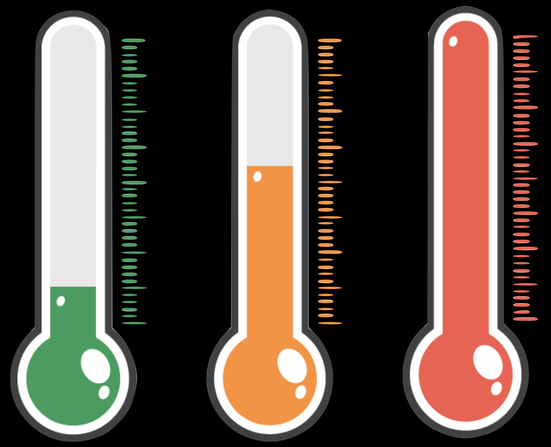


System Pressure Cost

Camera system cost excluding all other factors

Contributors

- Same as hardware cost contributors
- VIS, OIS
- Smart HDR
- Infrared sensor and projector power for TrueDepth
- Microphone power

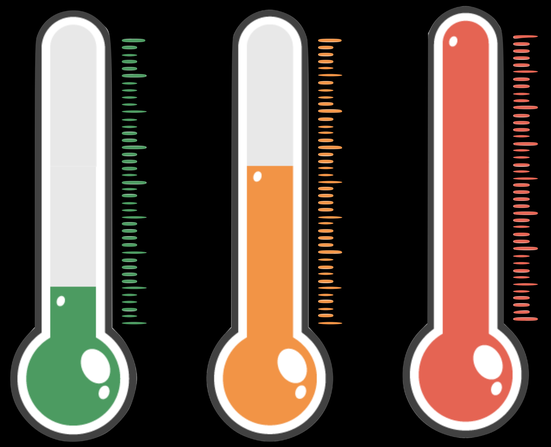


System Pressure Cost Reporting

MultiCamSession tallies a system pressure cost

Independent of current system pressure state

Accounts only for factors the session knows about



System Pressure Cost Reporting

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multicamSession.systemPressureCost
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System Pressure Cost Reporting

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- < 1.0 : Runnable indefinitely

System Pressure Cost Reporting

```
multicamSession.systemPressureCost
```

- < 1.0 : Runnable indefinitely
- ≥ 1.0 && ≤ 2.0 : Runnable for 15 minutes

System Pressure Cost Reporting

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multicamSession.systemPressureCost
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- < 1.0 : Runnable indefinitely
- ≥ 1.0 && ≤ 2.0 : Runnable for 15 minutes
- ≥ 2.0 && ≤ 3.0 : Runnable for 10 minutes

System Pressure Cost Reporting

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multicamSession.systemPressureCost
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- < 1.0 : Runnable indefinitely
- ≥ 1.0 && ≤ 2.0 : Runnable for 15 minutes
- ≥ 2.0 && ≤ 3.0 : Runnable for 10 minutes
- > 3.0 : ¿Como se dice en fuego?

System Pressure Cost Reporting

```
multicamSession.systemPressureCost
```

- < 1.0 : Runnable indefinitely
- ≥ 1.0 && ≤ 2.0 : Runnable for 15 minutes
- ≥ 2.0 && ≤ 3.0 : Runnable for 10 minutes
- > 3.0 : ¿Como se dice en fuego?

MultiCamSession will interrupt your session when system pressure = Shutdown

How to Reduce System Pressure While Running

Lower one or more capture device frame rates

Throttle any GPU or CPU processing in your app code

Disable a camera (session keeps running!)

How to Reduce System Pressure While Running

NEW

Lower one or more capture device frame rates

Throttle any GPU or CPU processing in your app code

Disable a camera (session keeps running!)

```
frontCameraInputVideoPort.enabled = false
```

Unreported Costs

Unreported costs are unreported

Artificial constraints on devices and formats

Supported Device Combinations (iPhone XS)

	Back Wide	Back Telephoto	Back Dual Camera	Front	Front TrueDepth
1			✓		
2	✓			✓	
3	✓	✓			
4	✓				✓
5		✓		✓	
6		✓			✓

```
guard AVCaptureMultiCamSession.isMultiCamSupported else {
    print("MultiCam not supported on this device")
    setupResult = .multiCamNotSupported
    return
}

// Find the supported multicam device combinations

let deviceTypes = [AVCaptureDevice.DeviceType.builtInDualCamera,
                   AVCaptureDevice.DeviceType.builtInWideAngleCamera
                   AVCaptureDevice.DeviceType.builtInTelephotoCamera]
let session = AVCaptureDevice.DiscoverySession(deviceTypes: deviceTypes,
                                               mediaType: .video,
                                                position: .unspecified)

let multicamSupportedDeviceSets = session.supportedMultiCamDeviceSets
```

```
guard AVCaptureMultiCamSession.isMultiCamSupported else {
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// Find the supported multicam device combinations

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                                               mediaType: .video,
                                                position: .unspecified)

let multicamSupportedDeviceSets = session.supportedMultiCamDeviceSets
```

Supported MultiCam Formats (iPhone XS)

Resolution	Max FPS	Binned?	Hi-Res Stills
640x480	60	Yes	2016x1512
1280x720	60	Yes	2112x1188
1440x1080	60	Yes	2016x1512
1920x1080	30	No	4224x2376
1920x1080	60	Yes	2112x1188
1920x1440	30	No	4032x3024
1920x1440	60	Yes	2016x1512

Supported MultiCam Formats (iPhone XS)

Resolution	Max FPS	Binned?	Hi-Res Stills
640x480	60	Yes	2016x1512
1280x720	60	Yes	2112x1188
1440x1080	60	Yes	2016x1512
1920x1080	30	No	4224x2376
1920x1080	60	Yes	2112x1188
1920x1440	30	No	4032x3024
1920x1440	60	Yes	2016x1512

Supported MultiCam Formats (iPhone XS)

Resolution	Max FPS	Binned?	Hi-Res Stills
640x480	60	Yes	2016x1512
1280x720	60	Yes	2112x1188
1440x1080	60	Yes	2016x1512
1920x1080	30	No	4224x2376
1920x1080	60	Yes	2112x1188
1920x1440	30	No	4032x3024
1920x1440	60	Yes	2016x1512

Supported MultiCam Formats (iPhone XS)

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640x480	60	Yes	2016x1512
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1440x1080	60	Yes	2016x1512
1920x1080	30	No	4224x2376
1920x1080	60	Yes	2112x1188
1920x1440	30	No	4032x3024
1920x1440	60	Yes	2016x1512

```
// Find and activate the next smaller format that supports multicam

let formats = videoDeviceInput.device.formats
for format in formats.reversed() {
    if format.isMultiCamSupported {
        dims = CMVideoFormatDescriptionGetDimensions(format.formatDescription)
        if dims.width < activeWidth || dims.height < activeHeight {
        do {
            try videoDeviceInput.device.lockForConfiguration()
            videoDeviceInput.device.activeFormat = format
            videoDeviceInput.device.unlockForConfiguration()
            return true
        } catch {
            return false
        }
    }
}
```

Supported Session / App Configurations

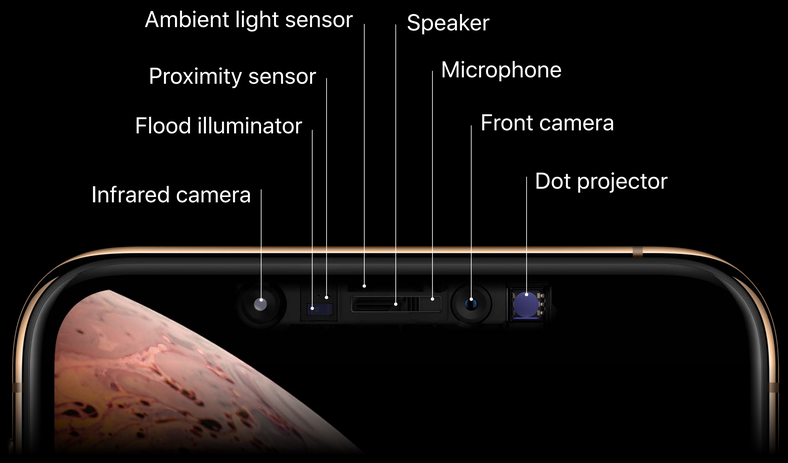
	macOS	iOS
One app, one capture session, multiple cameras		
One app, multiple sessions, one or more cameras		
Multiple apps, multiple sessions, one or more cameras		

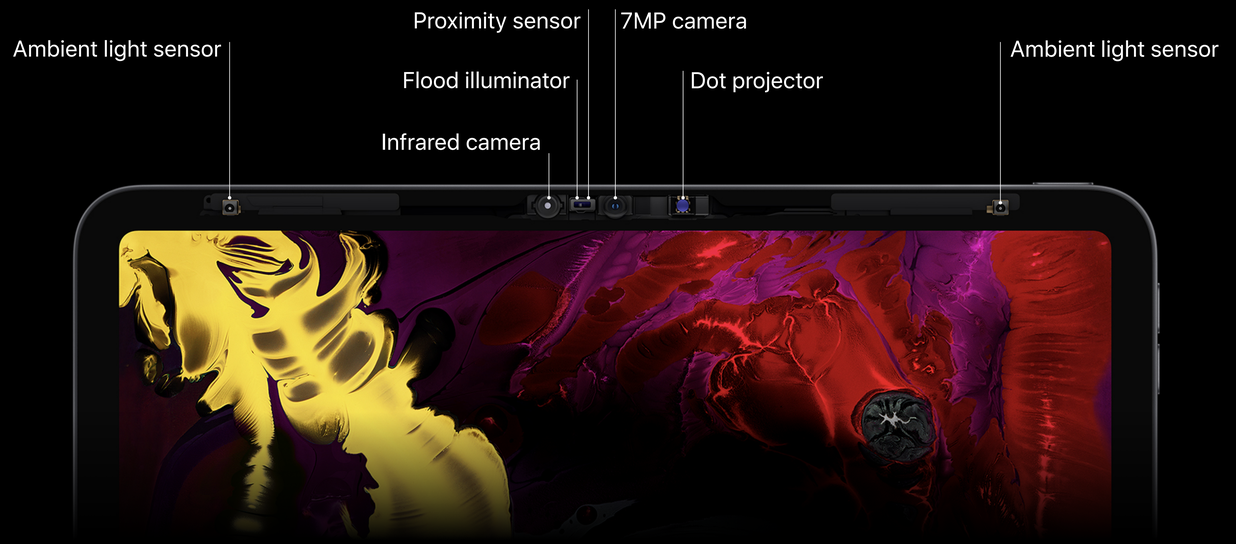
Be Responsible

Multi-Camera Capture

Synchronized Streaming

Virtual Cameras





Virtual Cameras

DualCam presents one video stream at a time*

Switches between cameras at different zoom levels

Generates disparity (depth) from wide and tele

*AVCapturePhotoOutput dualCameraDualPhotoDelivery is the exception

NEW

```
// Virtual devices are made up of constituent devices

if aCameraDevice.isVirtualDevice == true
{
    let subCameras = aCameraDevice.constituentDevices

    for let subCamera in subCameras {
        print("Sub cameras: \(subCamera.localizedName)")
    }
}
```

Synchronized Streaming

Synchronized Streaming

When running a virtual device, its constituent devices share the same

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- Active resolution

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When running a virtual device, its constituent devices share the same

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- Frame rate

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They are synchronized

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- Sensor read out matches frame centers

Synchronized Streaming

When running a virtual device, its constituent devices share the same

- Active resolution
- Frame rate

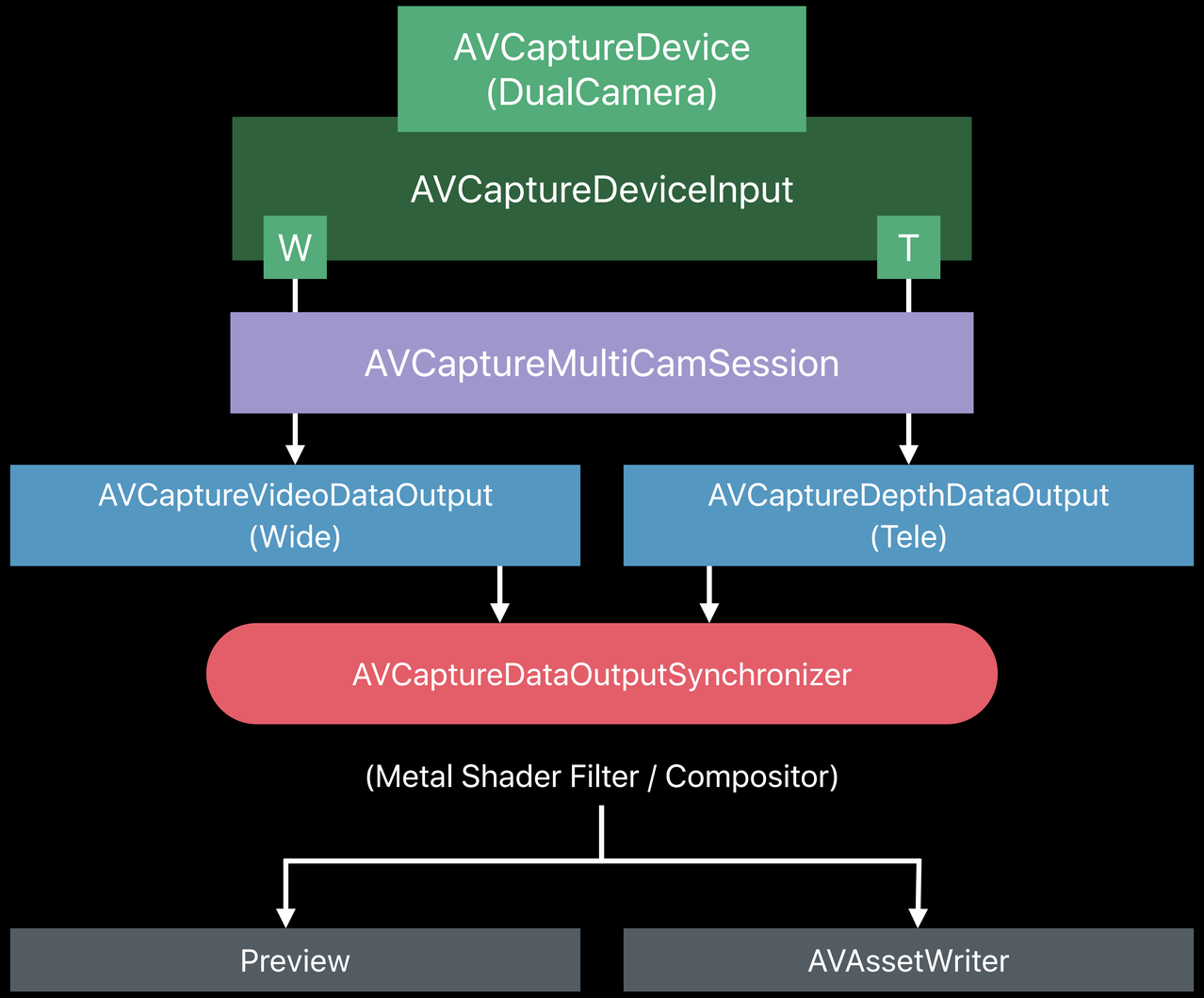
They are synchronized

- Sensor read out matches frame centers
- Exposure / White Balance / Focus

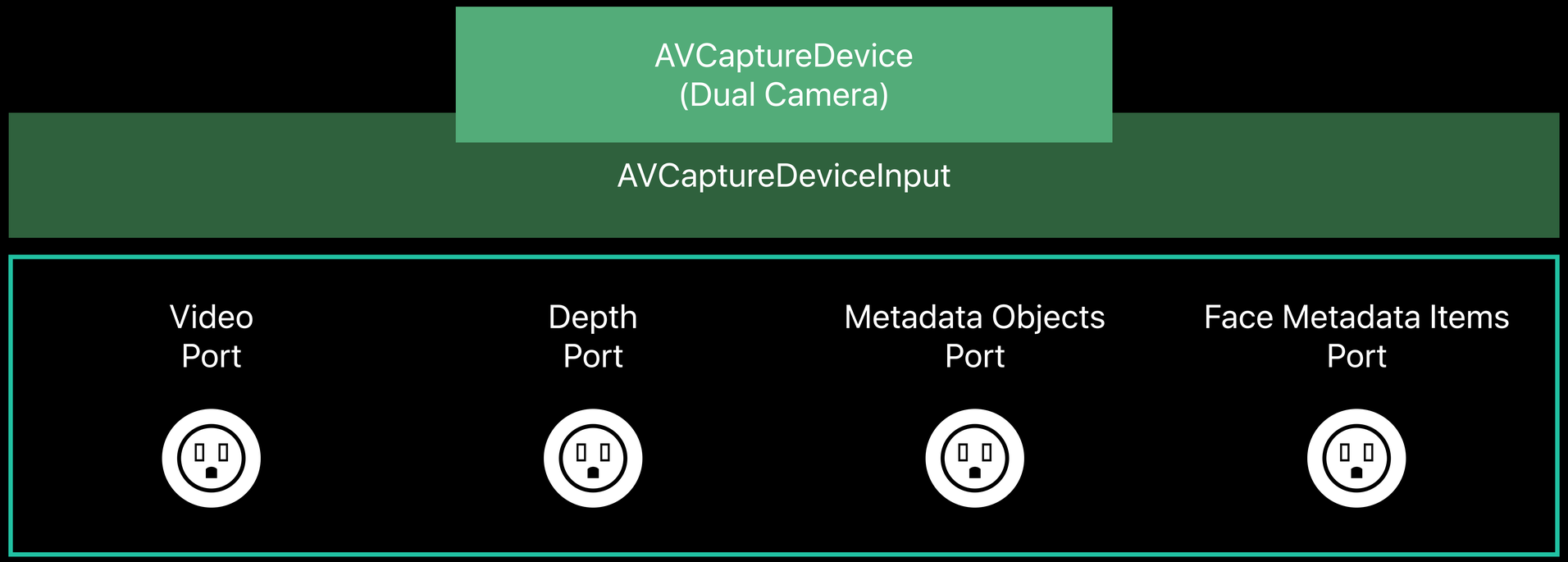
Demo

AVDualCam

AVDualCam Graph Topology



Any Port in a Storm?




```
let ports: [AVCaptureInput.Port] = dualCameraDeviceInput.ports
```

Virtual devices have secret ports.

```
// Constituent Device Port Discovery

  guard let widePort = dualCameraInput.ports(for: .video,
                                sourceDeviceType: .builtInWideAngleCamera,
                               sourceDevicePosition: dualCamera.position).first,
        let telePort = dualCameraInput.ports(for: .video,
                                sourceDeviceType: .builtInTelephotoCamera,
                               sourceDevicePosition: dualCamera.position).first
   else {
       print("Could not obtain wide and telephoto camera input ports")
       return false
  }
```

```
// Constituent Device Port Discovery

    guard let widePort = dualCameraInput.ports(for: .video,
                                               sourceDeviceType: .builtInWideAngleCamera,
                                              sourceDevicePosition: dualCamera.position).first,
          let telePort = dualCameraInput.ports(for: .video,
                                               sourceDeviceType: .builtInTelephotoCamera,
                                              sourceDevicePosition: dualCamera.position).first
    else {
        print("Could not obtain wide and telephoto camera input ports")
        return false
    }
```

```
// Constituent Device Port Connections

let wideAngleCameraConnection = AVCaptureConnection(inputPorts: [widePort],
                                                    output: wideVideoDataOutput)
guard session.canAddConnection(wideAngleCameraConnection) else {
    print("Could not connect wide-angle video input to output")
    return false
}
session.addConnection(wideAngleCameraConnection)
```

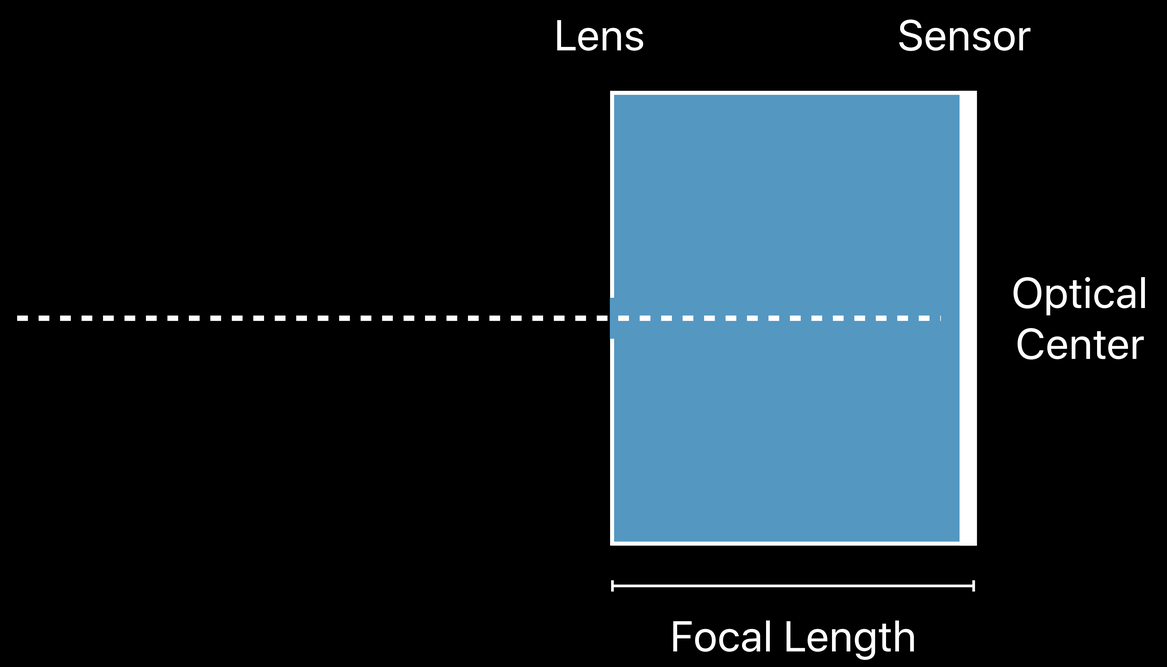
Dual Camera Homography Aids

Camera Intrinsics

Camera Extrinsics

Camera Intrinsics

$$K = \begin{bmatrix} f_x & s & x_0 \\ 0 & f_y & y_0 \\ 0 & 0 & 1 \end{bmatrix}$$




```
kCMSampleBufferAttachmentKey_CameraIntrinsicMatrix
```

Camera Extrinsics

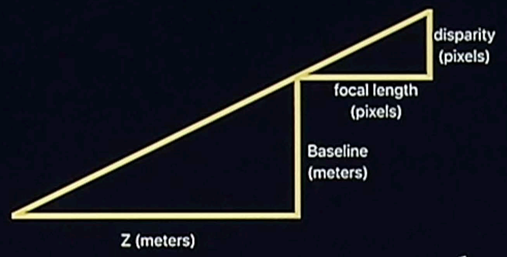
NEW

```
// Get extrinsics
if let wide = AVCaptureDevice.default(.builtInWideAngleCamera, for: nil, position: .back),
   let tele = AVCaptureDevice.default(.builtInTelephotoCamera, for: nil, position: .back) {
        self.extrinsics = AVCaptureDevice.extrinsicMatrix(from: tele, to: wide)
}
```

$$[\,R \mid t\,] = \left[\begin{array}{ccc|c} r_{1,1} & r_{1,2} & r_{1,3} & t_1 \\ r_{2,1} & r_{2,2} & r_{2,3} & t_2 \\ r_{3,1} & r_{3,2} & r_{3,3} & t_3 \end{array}\right]$$

Rotation Translation

Removing Despair from Disparity



$$\frac{b}{z} = \frac{d}{fl}$$

Multi-Camera Capture

Multi-Microphone Capture

Review: AVCaptureSession Mic Selection

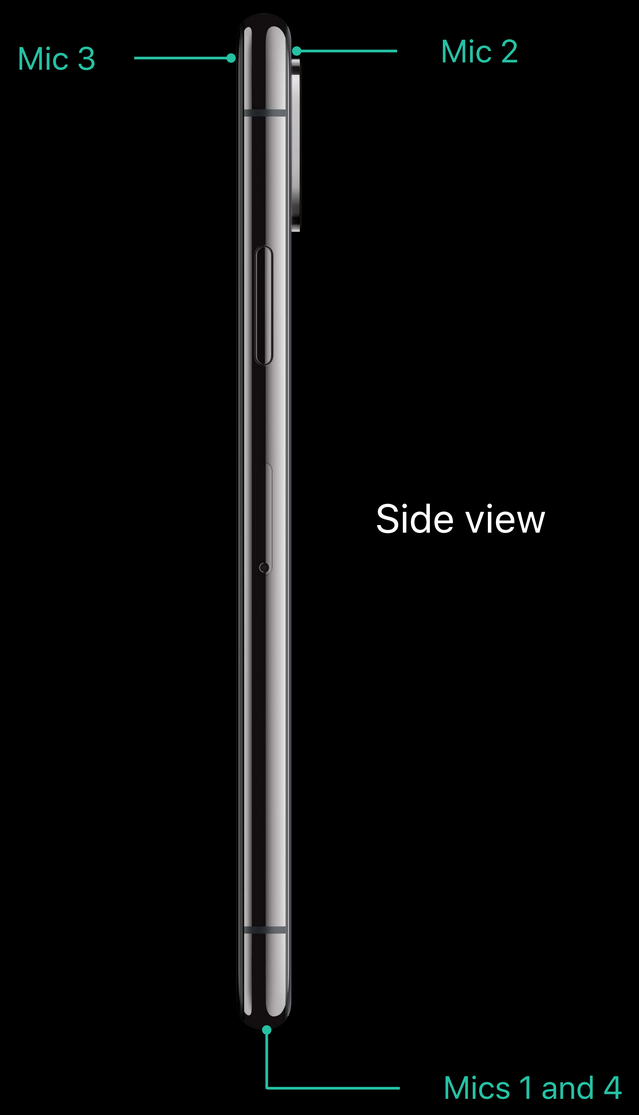
Default behaviors

- Front camera in use = selects front microphone
- Back camera in use = selects back microphone
- Audio only session = selects omnidirectional mic (usually at the bottom)

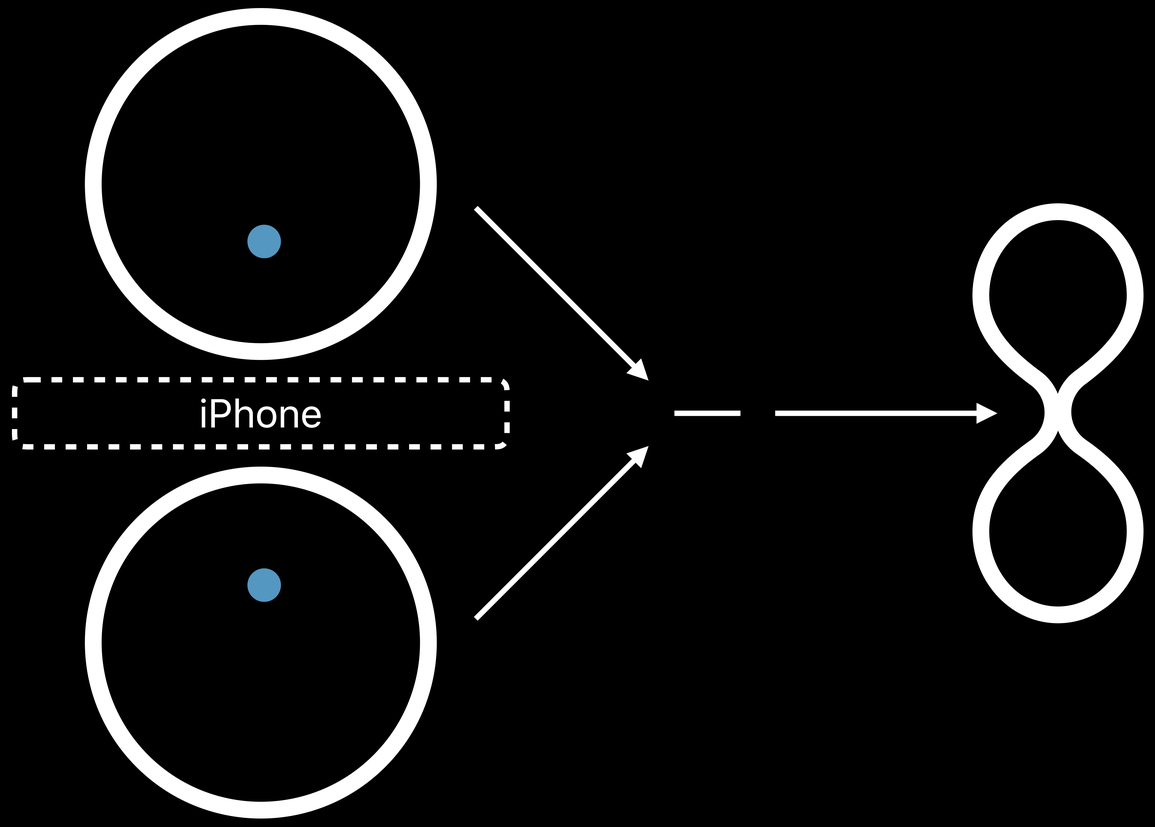
Power feature — app can use AVAudioSession to configure mics

There’s no such thing as a “front mic”.

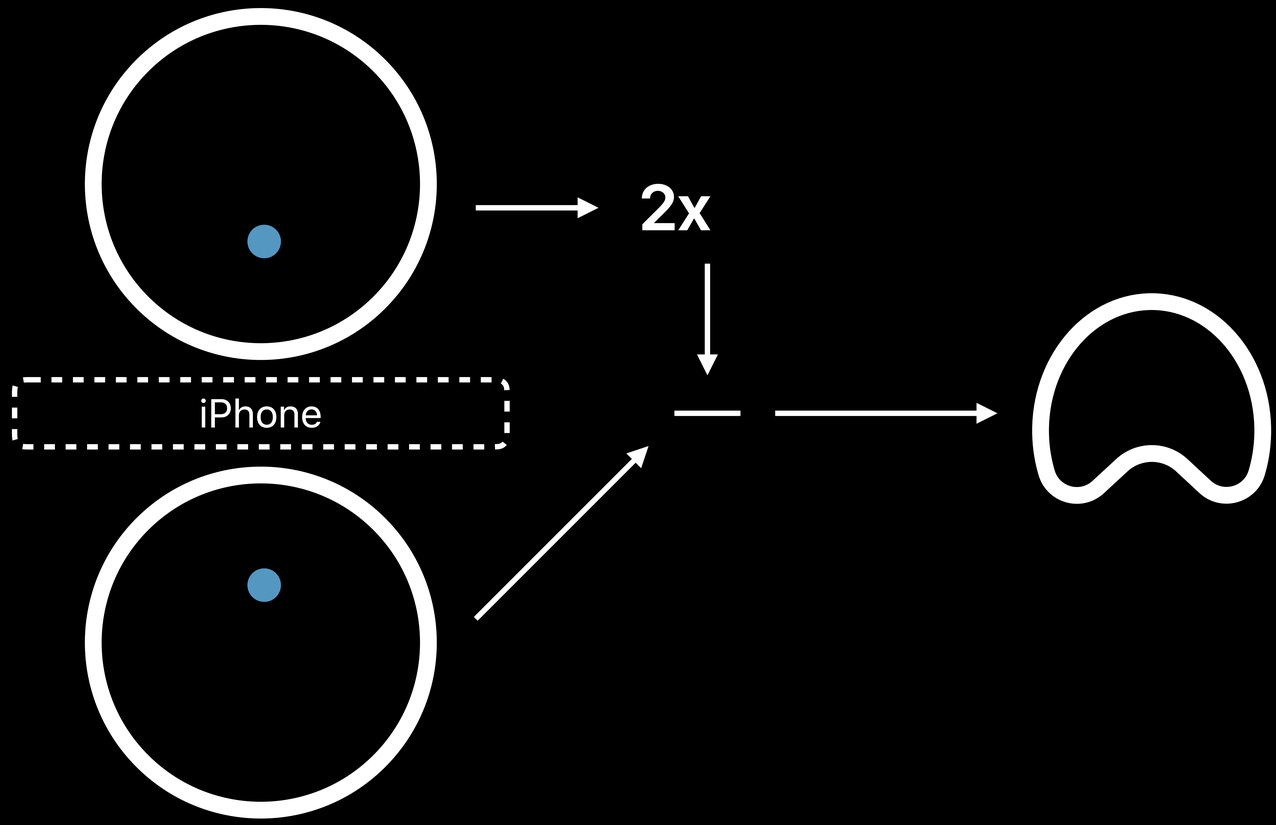
iPhone Microphone Arrays



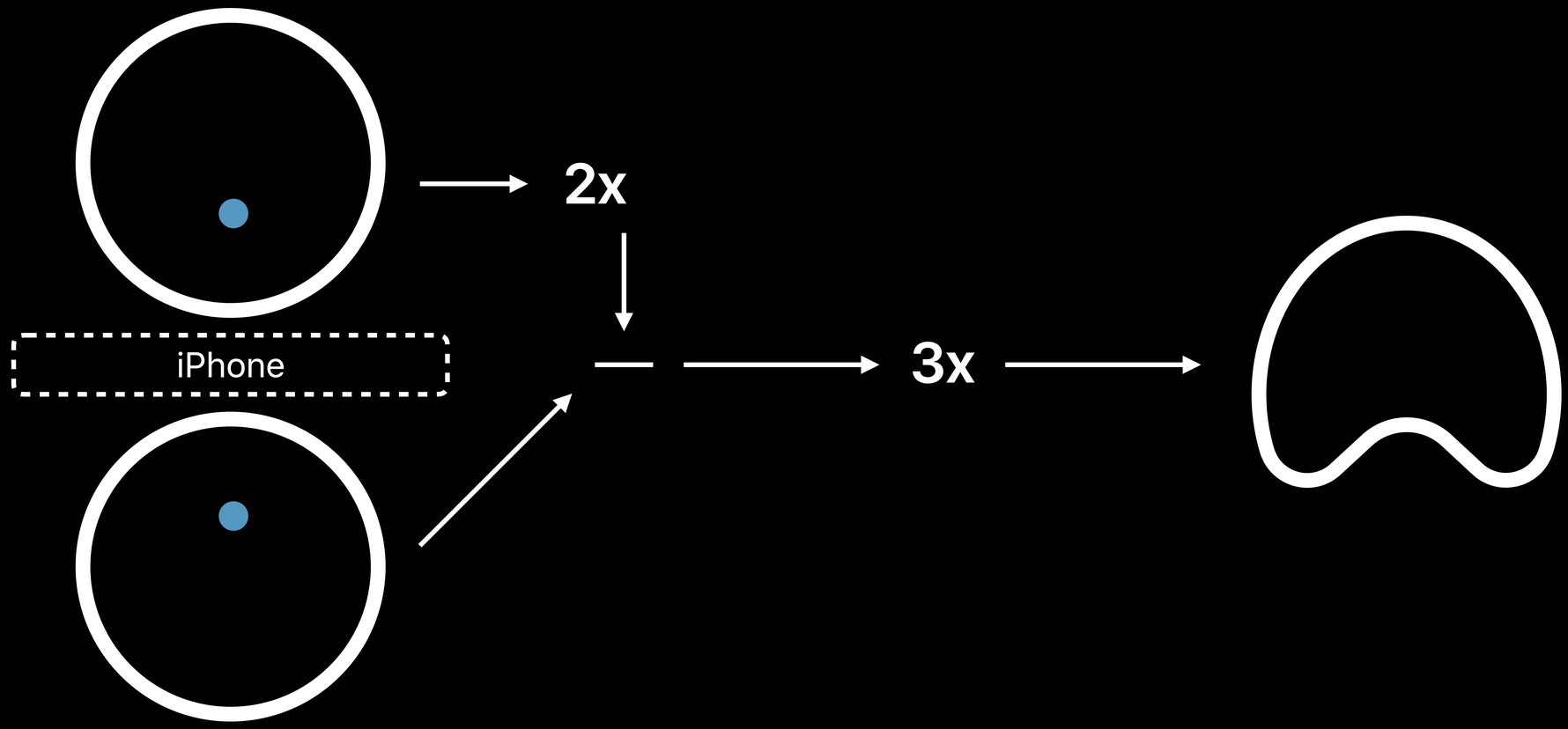
Microphone Beam Forming



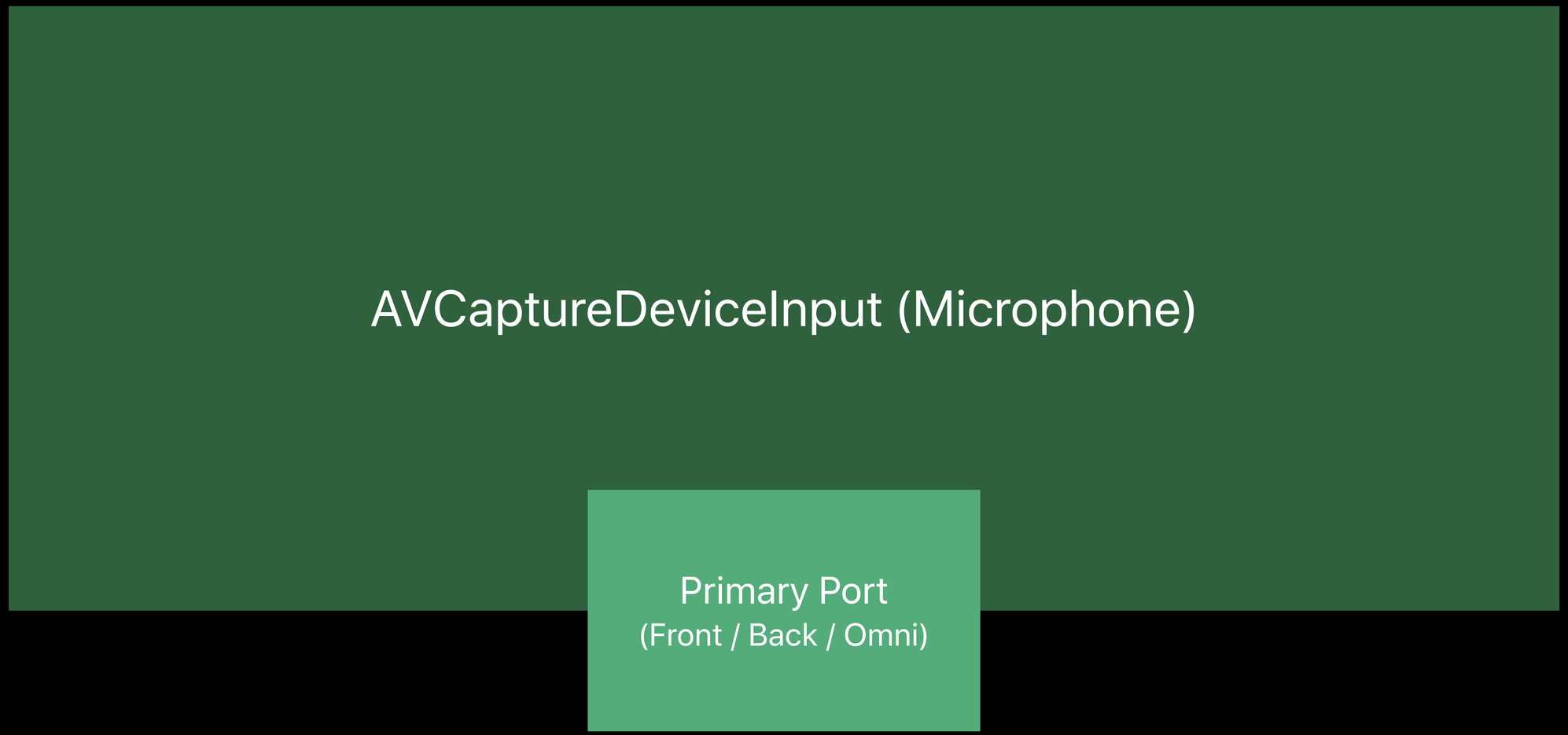
Microphone Beam Forming



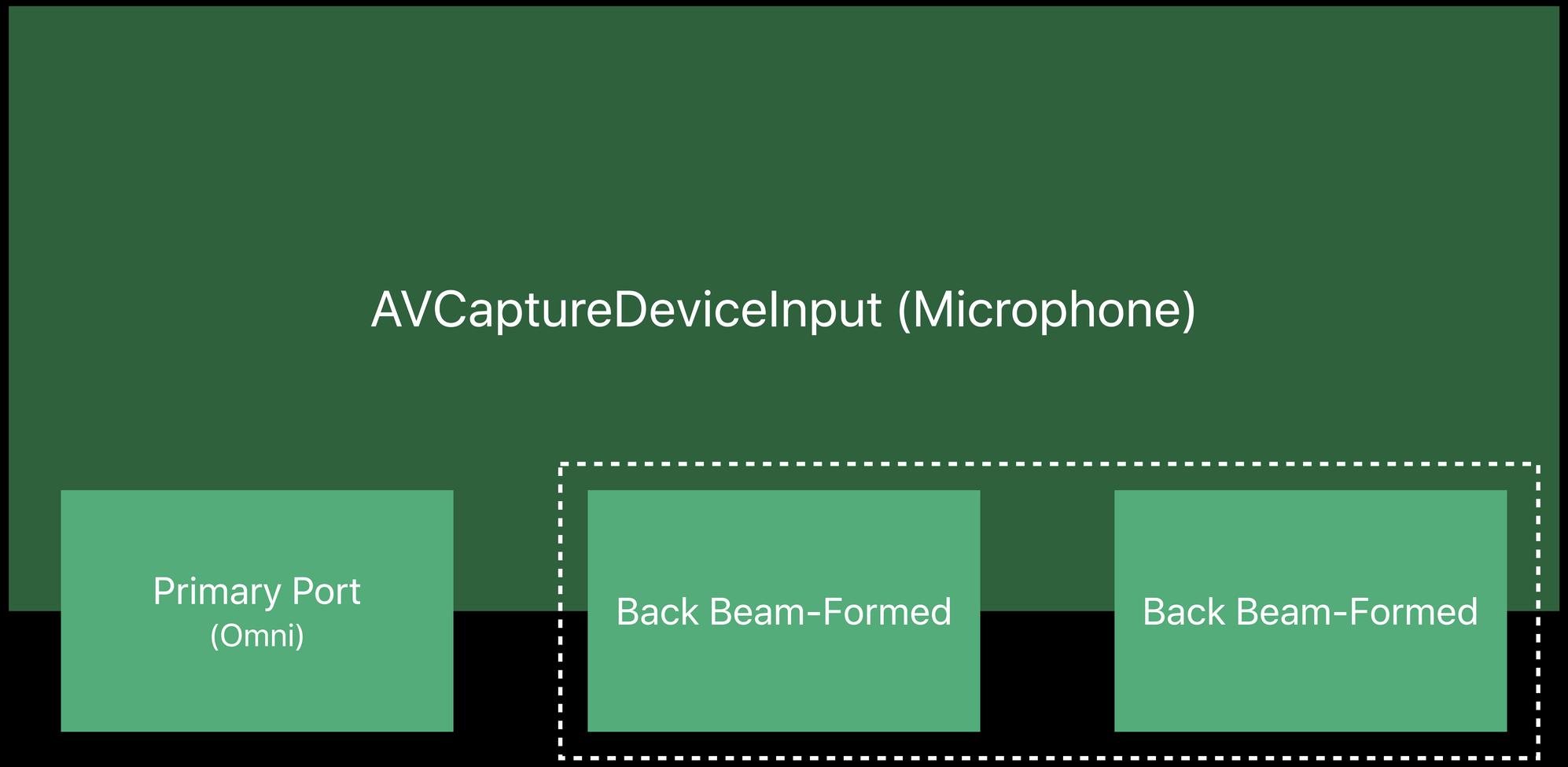
Microphone Beam Forming



AVCaptureSession Mic Input Port Behavior



MultiCam Behavior: The Return of the Secret Ports



Positional Audio Connections

```
let frontPort = micInput.ports(for: .audio,
                    sourceDeviceType: micDevice.deviceType,
                sourceDevicePosition: .front).first

let  backPort = micInput.ports(for: .audio,
                    sourceDeviceType: micDevice.deviceType,
                sourceDevicePosition: .back).first
```

Only supported in AVCaptureMultiCamSession

Positional Audio Connections

```
let frontPort = micInput.ports(for: .audio,
                    sourceDeviceType: micDevice.deviceType,
                sourceDevicePosition: .front).first

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                    sourceDeviceType: micDevice.deviceType,
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```

Only supported in AVCaptureMultiCamSession

Positional Audio Connections

```
let frontPort = micInput.ports(for: .audio,
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```
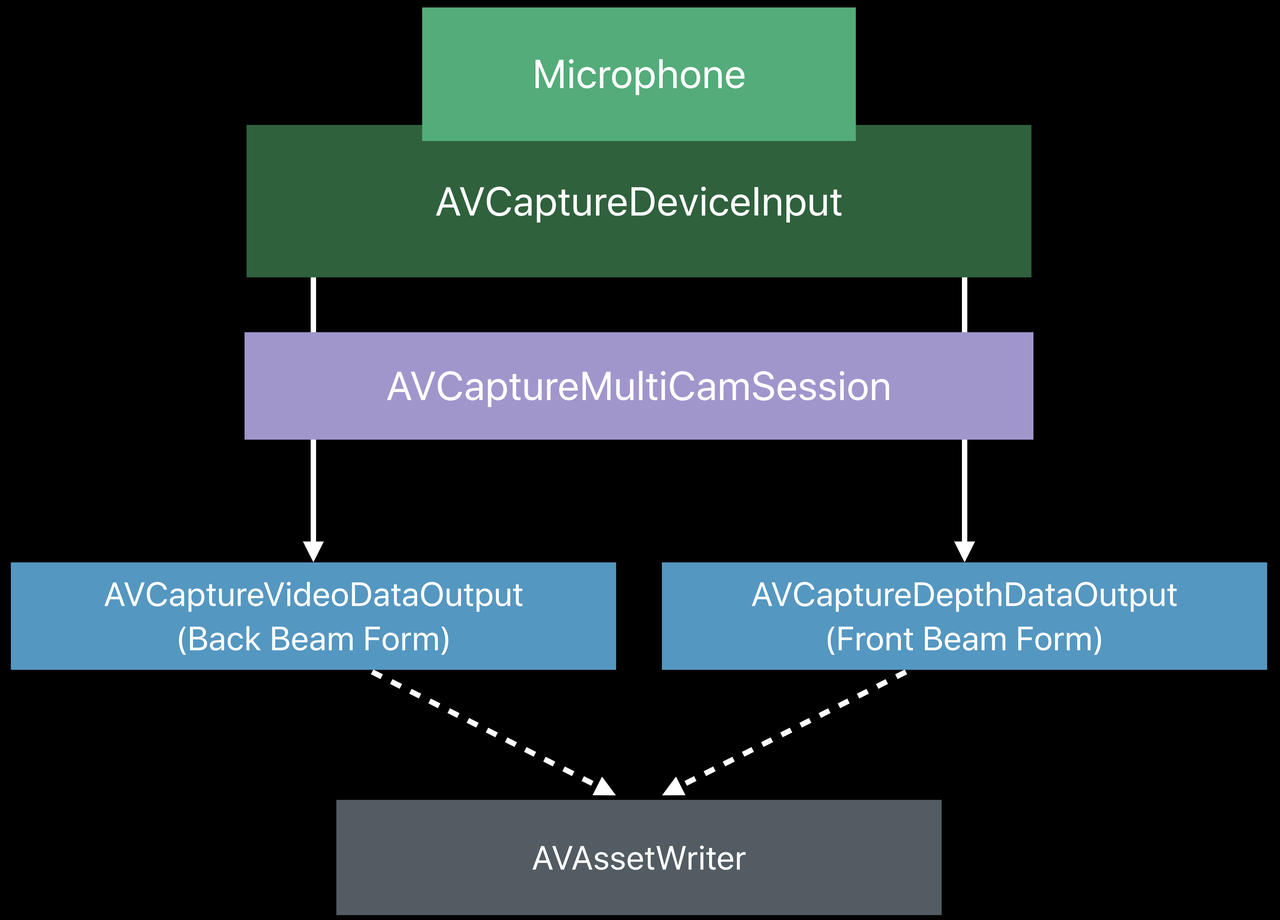

Only supported in AVCaptureMultiCamSession

Multi-Mic Beam Forming in AVMultiCamPiP



Non Built-In Mic Behaviors

Beam-forming only works with built-in mics

External audio signal is duplicated to all audio input ports (omni, front, and back)

Multi-Camera Capture Summary

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Use AVCaptureMultiCamSession

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Know its limitations

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Use constituent device ports for synchronized camera streaming

Multi-Camera Capture Summary

Use AVCaptureMultiCamSession

Know its limitations

Thoughtfully handle hardware and system pressure costs

Use constituent device ports for synchronized camera streaming

Use front, back, or omni mics simultaneously

And Now For Something Completely Different

Changes to AVCapturePhotoOutput

- Deprecation of auto still image stabilization
- Addition of photo quality versus speed hinting

Video coming soon to developer.apple.com

Semantic Segmentation Mattes

Jacob Schack Vestergaard, Camera Software
David Hayward, Core Image


PORTRAIT
DEPTH
ƒ4.5
Cancel
Done

iOS12: PortraitEffectsMatte

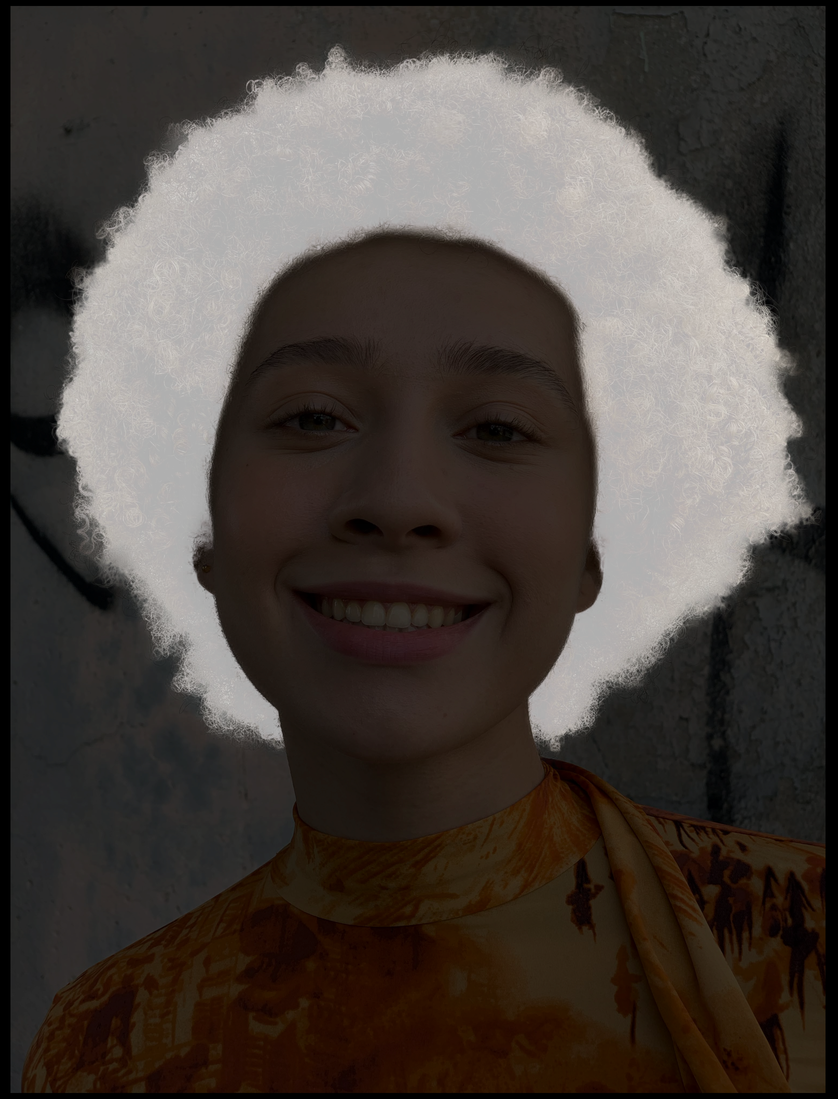
iOS12: PortraitEffectsMatte

Semantic Segmentation Mattes

NEW

Semantic Segmentation Mattes

NEW



Semantic Segmentation Mattes

NEW

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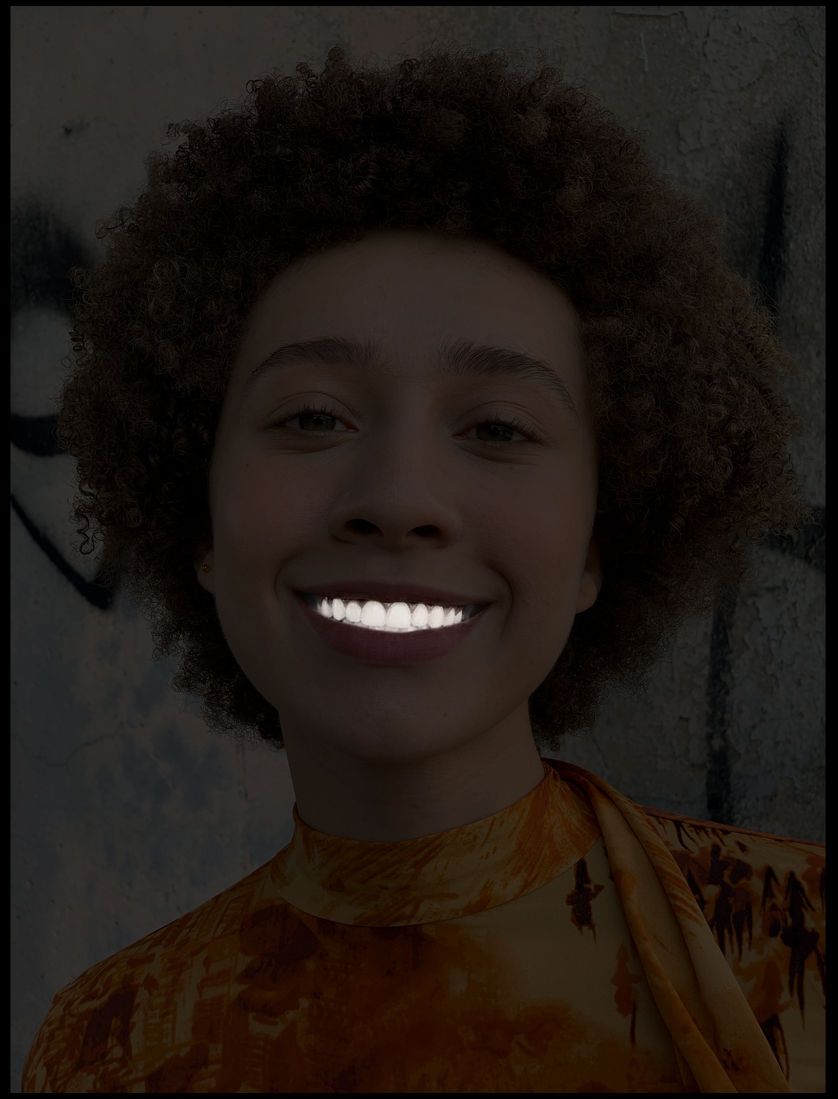
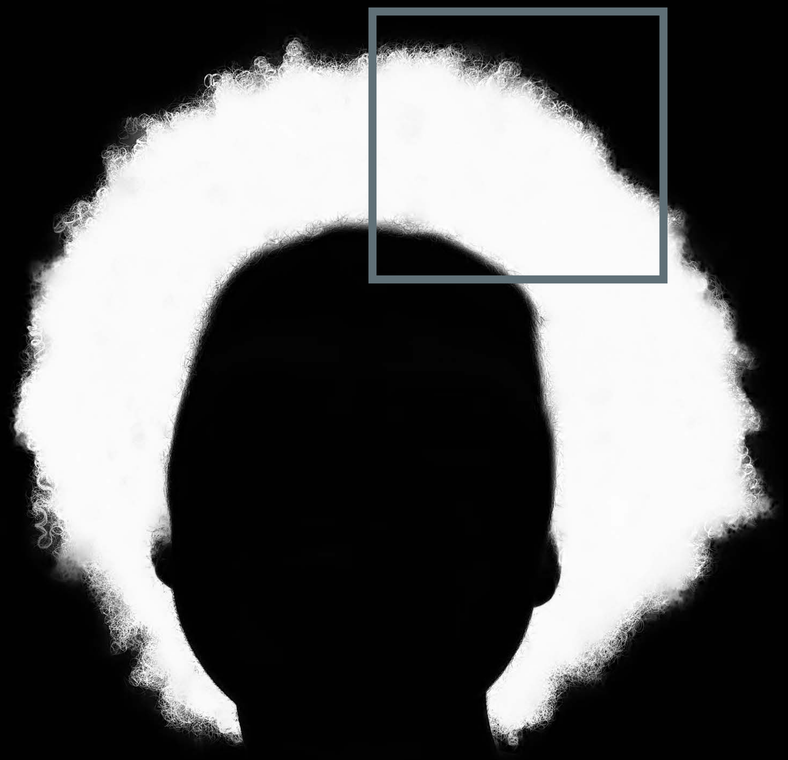
NEW



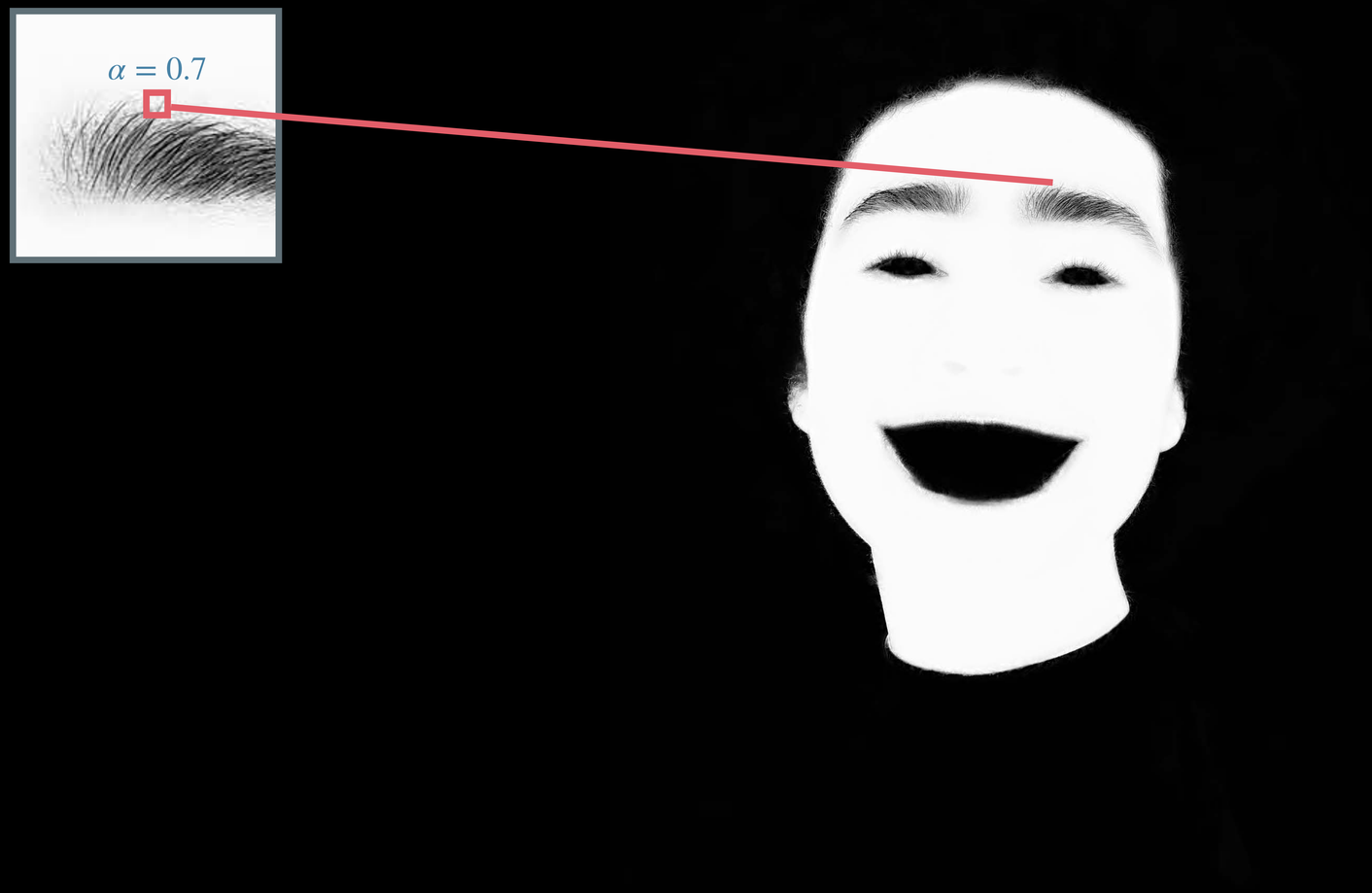
Semantic Segmentation Mattes

NEW

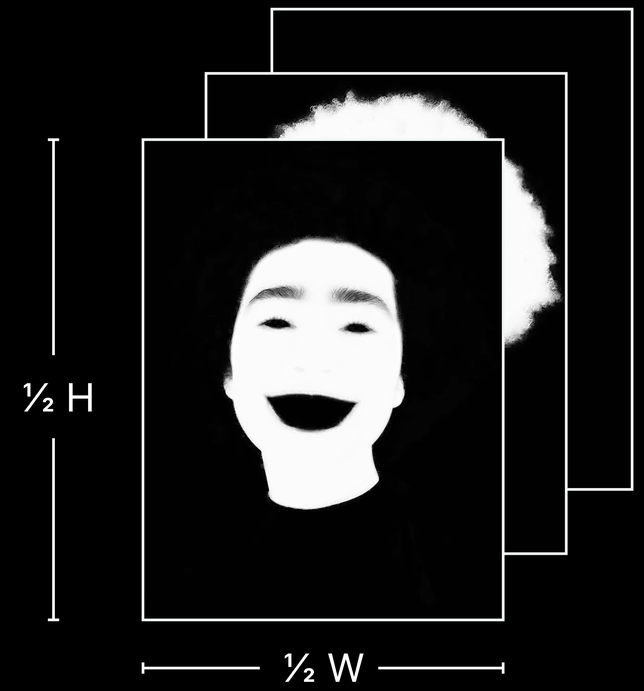


Semantic Segmentation Mattes

NEW

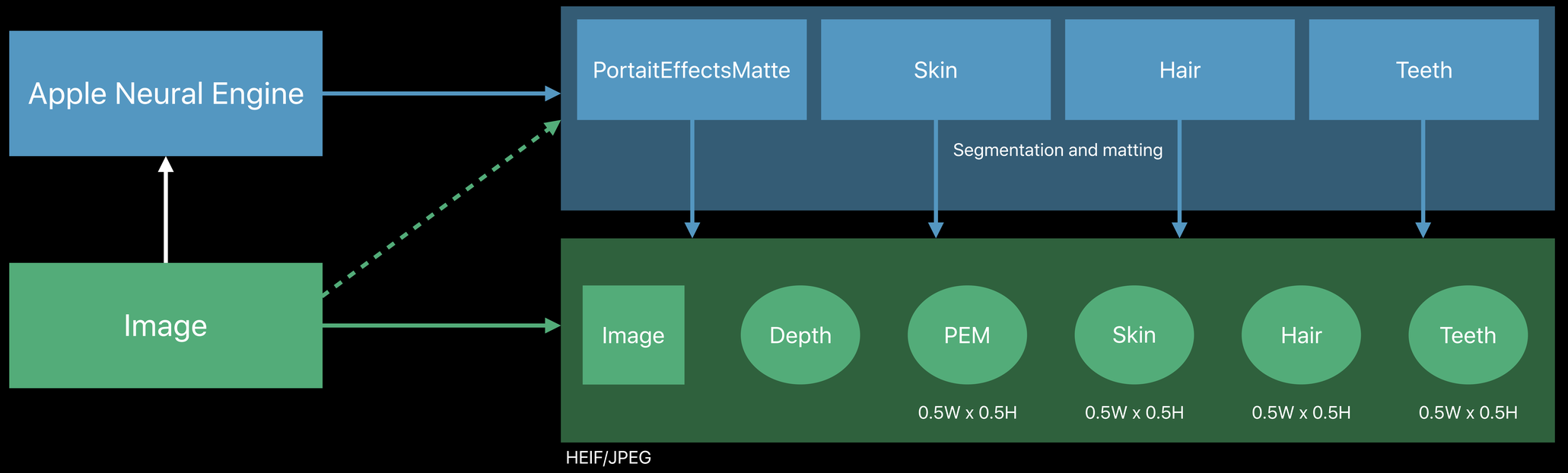


Mattes Are Half-Size




A12
BIONIC

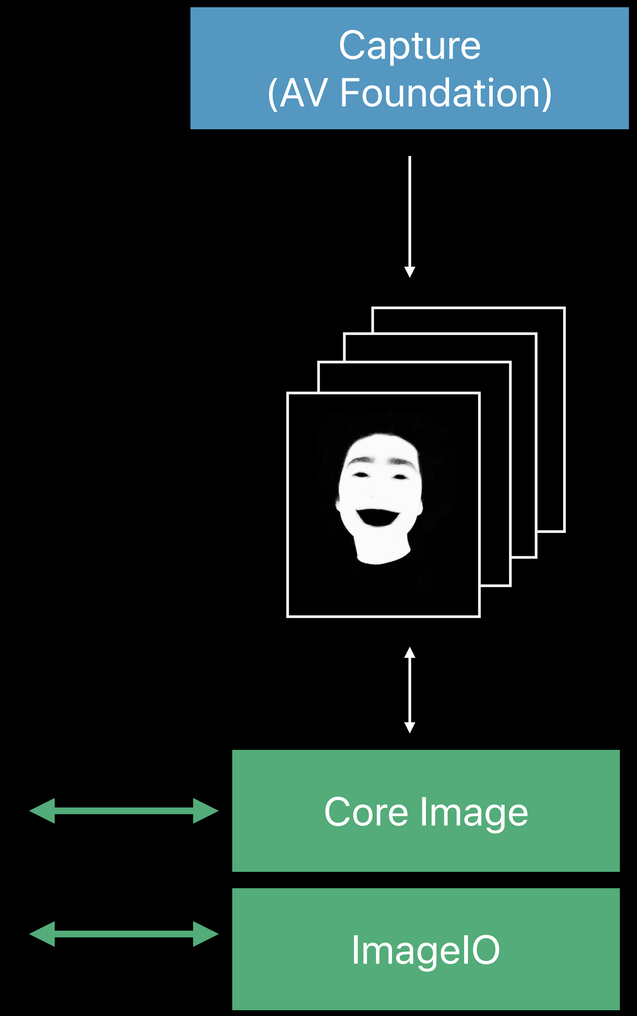
Under the Hood



Where Do the Mattes Come From?

Embedded in Portrait Mode captures

Write your own capture app and opt-in



More Information

developer.apple.com/wwdc19/249

Capturing Depth in iPhone Photography	WWDC 2017
Introducing the Photos Frameworks	WWDC 2014


WWDC19